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Electrophysiological study of action-affordance priming between object names.

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Electrophysiological study of action-affordance priming between object names

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A B S T R A C T

If our central representation of an object is defined through embodied experience, we might expect access to action affordances to be privileged over more abstract concepts. We used event-related potentials to examine the relative time course of access to affordances. Written object names were primed with the name of an object sharing the same affordance as the target (e.g. precision-grip: "grape" primed by "tweezers") or the same taxonomic category (e.g. fruit: "grape" primed by "apple"). N200 latencies, related to go/nogo semantic cate-   gory decisions on target words, revealed no difference in facilitation provided by affordance and semantic priming. However, separate analyses of ERPs for go and nogo trials showed that semantic priming led to earlier activation during go trials (around 430 ms), and affordance priming led to earlier activation during nogo trials (around 180 ms). While affordances appear to be peripheral to the conceptual representation of objects, they do lead to direct motor preparation.

1. Introduction

The majority of the embodied cognition literature has focused on the sensorimotor processes involved in processing action words and sentences. However, it is also thought that the name of an object will also recruit the sensorimotor brain activity associated with the referent's form and function, such as its action affordances (Bub & Masson, 2012). Affordances are the behavioural possibilities provided by the environment and are detected automatically by the visual system, regardless of the organism's intention to act (Garbarini & Adenzato, 2004; Gibson, 1979). For example a mug affords being grasped with the hand (Withagen, de Poel, Araújo, & Pepping, 2012). The Indexical Hypothesis proposes that nouns are indexed to mental representations (such as mental pictures) of the objects they refer to (Glenberg & Robertson, 1999). Subsequently, when a noun is processed the affordances of the referent object are made available. According to the Indexical Hypothesis accessing the affordances of referent objects is crucial for noun comprehension (Glenberg & Gallese, 2012; Glenberg & Robertson, 1999). A number of behavioural studies support the idea that affordances are retrieved during object name processing (Barbieri, Buonocore, Bernardis, Dalla Volta, & Gentilucci, 2007; Bub & Masson, 2012; Bub, Masson, & Cree, 2008; Gentilucci & Gangitano, 1998; Glover & Dixon, 2002; Glover, Rosenbaum, Graham, & Dixon, 2004; Marino, Gough, Gallese, Riggio, & Buccino, 2013; Myung, Blumstein, & Sedivy, 2006; Tucker & Ellis, 2004). Participants are quicker to make

categorical judgements when responding with a hand-grip that would be used to interact with the referent object (Tucker & Ellis, 2004; experiment 3). Furthermore, reading the name of a manipulable object activates areas of the premotor cortex which are also involved in action word processing (Grabowski, Damasio, & Damasio, 1998).

While the interaction between motor and language processing is well evidenced, the utility of this relationship is an area of considerable controversy. There seems to be little doubt that linguistic representations of actions and affordances can generate motor activity, but it is unclear what, if any, role this activity plays in language comprehension (Chatterjee, 2010; Dove, 2009, 2011; Mahon & Caramazza, 2008). Mahon and Caramazza (2008) argue that findings purported to support embodied cognition could just as easily be explained by a disembodied account. They propose that an initial retrieval of abstract concepts is followed by the spreading of activation to sensory and motor areas, with these activations reflecting a later epiphenomenal process, such as mental imagery. Language and situated simulation (LASS) theory proposes that two systems are involved in language comprehension (Barsalou, Santos, Simmons & Wilson, 2008). The Linguistic system identifies the word form and the simulation system activates perceptual and experiential information associated with the object, such as its affordances. The linguistic system is sufficient for resolving tasks that only require shallow processing, involving statistical relations between words in a semantic network (words associated through frequent co-occurrence). For deep and meaningful processing, simulations are

necessary and these are activated automatically, within 200 ms after word onset. It is important to understand when, and by implication what stage of processing, language perception makes use of embodied representations. If they are fundamental to the conceptual representations of objects it might be expected that they would be available in advance of more abstract information. This kind of temporal information can be difficult to ascertain with behavioural experiments, but is particularly well suited to the ERP technique. Amsel, Urbach and Kutas (2013) used this technique to determine the temporal order of access to abstract and motor related semantic information when presented with the names of objects. Using a go/nogo task they compared the temporal onset of the N200 component when participants were asked to make a judgment on whether objects were graspable or non-graspable, or whether they were living or non-living. The N200 is a negative going component resulting from the subtraction of go from nogo trials, and is thought to provide an indication about when sufficient information has become available to allow a participant to make or withhold their response (Augustin, Defranceschi, Fuchs, Carbon, & Hutzler, 2011). Amsel et al. (2013) found that the onset of the N200 related to a living/non-living judgment was at around 160 ms after stimulus presentation, compared to 300 ms for the graspable/non-graspable judgment. The relatively late access to grasp-related affordances prompted the authors to conclude that they did not play a crucial role in the conceptual representation of objects.

Although the results provided by Amsel et al. (2013) seem relatively clear, they are based upon the assumption that the participant has direct access to the information relevant to this explicit decision. However, affordances are generally considered to be processed automatically as a component of object representation that provides implicit facilitation of a wide range of responses (Barbieri et al., 2007; Glover et al., 2004; Marino et al., 2013; Myung et al., 2006; Pulvermüller, Shtyrov, & Ilmoniemi, 2005; Tucker & Ellis, 2004). For example, Glover et al. (2004) found that when participants went to grasp a wooden block, the aperture of their grip was larger when they read a word referring to a large object than a small object. Another study found that when participants heard the names of objects they spent longer looking toward pictures of objects that shared similar manipulation features with the named object than those that did not, with affordance-related looking occurring as early as 300 ms (Myung et al., 2006; experiment 2). As it has been established that affordance modulates behaviour without the awareness of the participant, it is possible that the earliest access to this property may not be revealed through explicit questioning.

In our study we wanted to capture the implicit effects of affordance in an ERP study similar to that of Amsel et al. (2013). However, instead of comparing the N200 related to different explicit judgment decisions, i.e. those based on semantic and affordance information, we examined how the N200 related to the same semantic decision would be modulated by priming. Semantic priming effects are well established in the literature (Lucas, 2000), with priming found to improve both the accuracy and reaction times in lexical decision tasks (Meyer & Schvaneveldt, 1971). This facilitation is also found when the prime is masked (e.g. Forster & Davis, 1984), that is when presented for a very short duration (50–60 ms), usually sandwiched between two visually obscuring forward and backward masks. This is designed to allow the investigation of the prime-target relationship without the awareness of the participant, so preventing the use of explicit response strategies. Studies using the ERP technique have shown that semantically related prime-target pairs elicit a smaller N400 than semantically unrelated prime-target pairs (Deacon, Hewitt, Yang, & Nagata, 2000; Kutas & Federmeier, 2011). This is thought to reflect the greater ease in which the target is integrated into the semantic context provided by the prime (Borovsky, Elman, & Kutas, 2012). In most studies, the semantic relatedness between prime and target is determined by semantic category norms, such as those of Battig and Montague (1969), which largely shared a taxonomic relationship (e.g. steel and iron being "types of

metal"). There are few studies that have examined the relationship between objects formed by a shared affordance. In one such study by Myung et al. (2006), auditory prime and target words either shared similar manipulation features (e.g. piano and typewriter) or not (e.g. piano and blanket). This study showed that shared affordances facilitated reaction times, but did not provide any direct comparison with the facilitation provided by taxonomic semantic priming.

Here we have used the masked priming paradigm to compare the relative differences in priming between written prime-target word pairs that are related either through taxonomy (e.g. "grape" and "banana" are both fruit) or affordance (e.g. "hammer" and carrot" are both manipulated using a power-grip). Both of these related priming conditions were also compared to a baseline condition, where the prime did not share the same taxonomy or affordance with the target (e.g. "mushroom" and "drill"). These word pairs were used in a go/nogo task to evoke an N200 component related to a speeded natural/manmade decision on the target words. An estimate of the temporal onset of affordance and general semantic information was provided through a comparison of the N200 between the three priming conditions. If the sensorimotor activity associated with affordances is fundamental to object representation, then we would hypothesise that the facilitation provided by the priming of affordances should occur earlier than that of semantic priming. Conversely, if affordances are produced as part of a post-lexical mental simulation of object use or accessed via an amodal process of spreading activation we would expect that the temporal onset of this information should occur after semantic processing.

2. Method

2.1. Participants

Sixty native monolingual English speakers gave informed, written consent to participate in the experiment and were paid £12 for their participation. The Data from 9 participants was discarded due to excessive EEG and electrooculography (EOG; eye movements) artefacts (less than 66% of recorded trials available for analysis). The remaining 51 participants (32 female) were aged between 18 and 32 (mean age = 21.76). All participants were right-handed (as assessed with the Edinburgh Handedness Inventory; Oldfield, 1971), reported having normal or corrected-to-normal vision and had no history of neurological impairment.

2.2. Stimuli

The critical stimuli consisted of 32 different concrete nouns (taken from the CELEX database; Baayan, Piepenbrock, & Gulikers, 1995) referring to manually manipulable objects. Sixteen of the nouns were used as prime words (3–10 letters in length) and 16 were used as the target words (3–6 letters in length). Half of the prime words referred to natural objects and half referred to manmade objects. Within each of those categories, half were the names of objects affording a power-grip (e.g. "hammer" or "carrot") and half were names of objects affording a precision-grip ("scalpel" or "grape"). The target words were a different set of 16 nouns that were also equally divided between these four categories (manmade power-grip; manmade precision-grip; natural power-grip; natural precision-grip).

Each prime word was paired with each target word so that there were 256 prime-target pairs. There were three conditions: *semantic* (when the prime and target referred to objects that were taxonomically related but did not afford the same grip e.g. 'strawberry-banana' or 'potato-pea'); *affordance* (when the prime and target referred to objects that afforded the same hand grip but were not taxonomically related e.g. 'tweezers-lentil' or 'orange-axe'); or *neutral* (when the prime and target referred to objects that were neither semantically related nor afforded the same grip e.g. 'fig-hammer' or 'scalpel-apple'; see Appendix for a full list of the stimuli). There were 64 different prime-
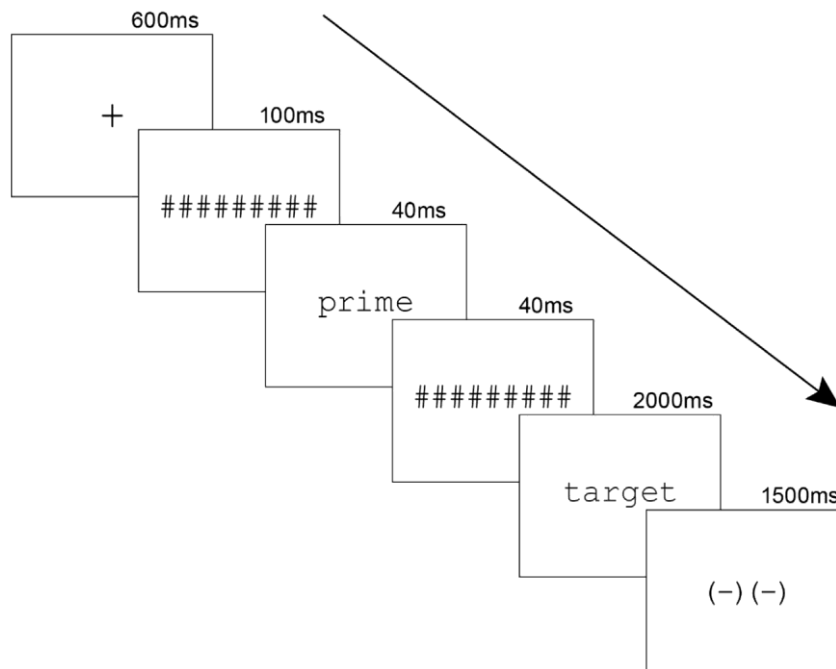
Fig. 1. Example of stimuli presented in the experiment (a) and an illustration of the experimental sequence (b).

target pairs in each condition. The remaining prime-target pairs were used as filler stimuli.

2.3. Procedure

Participants were presented the stimuli on a CRT monitor (30.5 cm height by 40.5 cm width; 100 Hz refresh rate) positioned at eye level one metre from the participant in a quiet dimly-lit booth. Stimuli were presented using E-Prime 2.0 (Schneider & Zuccoloto, 2007), with responses collected using an E-Prime button box.

The sequence of each trial was as follows. At the beginning of each trial, a fixation point, "+", appeared at the centre of the screen for 600–800 ms. The fixation point was followed by a forward mask (##########) for 100 ms. This was followed by a prime word presented for 40 ms and then a backward mask (##########) for

40 ms. The target was then presented for up to 2000 ms or until the participant responded. At the end of each trial a blink symbol, "(–) (–)", was displayed for 1500 ms, giving the participant the opportunity to blink if necessary (see Fig. 1 for example stimuli and an illustration of the experimental sequence). The participants were asked to avoid making eye movements or blinks until the blink symbol was displayed in order to reduce contamination of the EEG data. All text was displayed in the Courier New typeface in black on a white background. Participants responded to the target words using the index finger of their left hand. This was to make the response as unrelated to the object affordance as possible because the participants were all right-handed and would therefore usually pick up the objects with their right hand. A go/nogo paradigm in two between-participants response conditions was adopted whereby half of the participants were required to respond only to natural stimuli and to withhold responses to manmade stimuli.

The other half were required only to respond to manmade stimuli and to withhold a response when they saw natural stimuli. Participants were instructed to indicate as quickly and accurately as possible whether the word referred to the semantic category to which they had been assigned (i.e. natural or manmade).

A sequence of 18 practice trials (using separate stimuli that were not used in the main experiment) was completed by each participant and could be repeated if necessary. After this each of the 256 prime-target word pairs were presented three times in three seamless blocks, resulting in 576 critical trials and 192 filler trials. Trials with slow (> 1200 ms) or incorrect responses were excluded from further analysis (1% of trials). Trials were presented continuously with participants being provided with a 'rest period' after every 90 trials.

2.4. EEG recording

BrainVision Recorder (Version 1.10, Brain Products GmbH) was used to collect the scalp voltages from 61 Ag/AgCl active electrodes (actiCAP, Brain Products, Gilching, Germany). The sensors were ar-ranged in the International 10–20 configuration and secured in place on the participant's scalp by an elastic cap. An additional two sensors were positioned below and adjacent to the participant's right eye to monitor eye movements. Segments of EEG data containing eye movement or blink artefacts were not included in later analyses. All scalp electrode impedance measurements were kept below 20 kΩ. The EEG signals were amplified by a BrainAmp MR Plus amplifier (Brain Products).

2.5. EEG analyses

Vision Analyser (Version 2.0, Brain Products GmbH) was used to process the data. EEG was sampled at a rate of 250 Hz and filtered offline with a band-pass filter of 0.1–40 Hz (with a roll-off slope of 12 dB/oct) and subjected to a 50 Hz notch filter. The EEG recordings were segmented into 1000 ms epochs, spanning from 200 ms before the onset of the target word until 800 ms afterwards. Separate ERPs were generated for the same set of target word stimuli presented in three different priming conditions (semantic, affordance and neutral priming). Baseline correction was performed using the average EEG activity between −200 ms and 0 ms. The electrodes were referenced to the left mastoid electrode and then re-referenced offline to the average of the left and right mastoid data. The central anterior-frontal electrode (AFz) was used as the ground. Segments containing artefacts were re-jected from analyses and participants with less than two thirds of their segments intact after artefact removal were excluded from the analyses. Inaccurate responses were discarded, as were trials with reaction times 2.5 standard deviations above or below the mean, or outside the 200–1200 ms time window.

To calculate the N200, the go data was subtracted from the nogo data for each condition (Amsel et al., 2013; Schmitt, Münte, & Kutas, 2000). Comparisons between conditions were conducted across all electrodes and post zero-point sample points using pairwise analyses based upon the cluster randomisation technique of Maris and Oostenveld (2007), to avoid multiple comparisons. In this technique, two-sided *t*-tests were carried out comparing each electrode-time sample pair between two of the tested conditions (e.g. affordance and semantic priming). Those samples with a *t*-value above significance threshold (p < .05) were clustered together in terms of temporal and spatial adjacency. Only clusters of eight or more samples were con-sidered for analysis. For each of the remaining clusters a summed *t*-value was calculated as a total of all individual *t*-values from all of the individual comparisons. Analysis thereafter was based on these clusters rather than the individual data points. In the second step of this pro-cedure the interval occupied by the cluster with the largest cluster-level *t*-value was selected. Each of the original paired sample *t*-tests that were used to generate this cluster were repeated, but with the data items of each pair randomly assigned between the two conditions. This was

performed 1000 times to generate a Monte Carlo distribution of summed *t*-values corresponding to the null hypothesis. The final Monte Carlo *p*-value was calculated as the proportion of the 1000 summed *t*-values in the random distribution that exceeded the observed cluster-level *t* statistic.

3. Results

3.1. Behavioural results

Accuracy data. The average proportion of correct responses across all conditions was found to be 99.44%. An ANOVA was conducted comparing accuracy between the 3 conditions (semantic, affordance, neutral), 2 response types (go, nogo) and 2 categories (manmade, natural). There were no significant effects, $ps > .1$.

Reaction Times. An ANOVA was conducted comparing the 3 conditions (semantic, affordance, neutral) and 2 categories (manmade, natural). A significant main effect of condition was found, $F(3, 147) = 9.89$, $p < .0001$, with participants responding significantly quicker on the semantic primed trials ($M = 572.38$ ms, $SD = 90.78$) compared to the affordance trials ($M = 587.97$ ms, $SD = 90.78$; $F(1, 49) = 11.39$, $p < .01$), and the neutral trials ($M = 587.88$ ms, $SD = 90.84$; $F(1, 49) = 10.94$, $p < .01$). Reaction times for the affor-dance and neutral trials did not differ significantly from each other, $F(1, 49) = .031$, $p > .5$. A significant effect of category was also found $F(1, 49) = 4.22$, $p < .05$, with responses to natural object targets ($M = 552.76$ ms, $SD = 95.63$) being significantly faster than responses to manmade object targets ($M = 601.76$ ms, $SD = 77.08$). There was no significant interaction between condition and target category, $F(3, 147) = 1.50$, $p > .1$.

3.2. Electrophysiological results

N200 analyses: comparison to baseline. The N200 was calculated by subtracting ERPs for go trials from those of nogo trials for the three priming conditions. For each condition, independent *t*-tests were used to compare the voltage of the N200 to a baseline of 0 across all temporal samples and active electrodes. These multiple comparisons were then corrected using the previously described cluster randomisation procedure. Significant clusters are listed in Table 1 and scalp maps il-lustrating the location of activity are shown in Fig. 2. This indicates that the information contingent on the semantic decision task (natural vs. manmade categorisation) was available from 208 ms after target word onset when primed with a semantically related word, from 252 ms when primed with a word sharing a similar micro-affordance and from 280 ms when it was primed with a neutral word.

N200 analyses: comparison between conditions. Independent *t*-tests were also carried out to examine the difference between the N200s of the different conditions. Again, multiple comparisons were corrected using the cluster randomisation procedure. The resulting significant clusters are shown in Table 2 and displayed in Fig. 3.

When subtracting the neutral from the semantic priming condition the presence of an early negative cluster (cS-N1) shows that the onset of the N200 was significantly earlier for semantically primed compared to neutrally primed target words. The later positive cluster (cS-N2) also

Table 1
Summary of significant clusters for the N200 of the semantic, affordance, and neutral conditions compared to baseline.

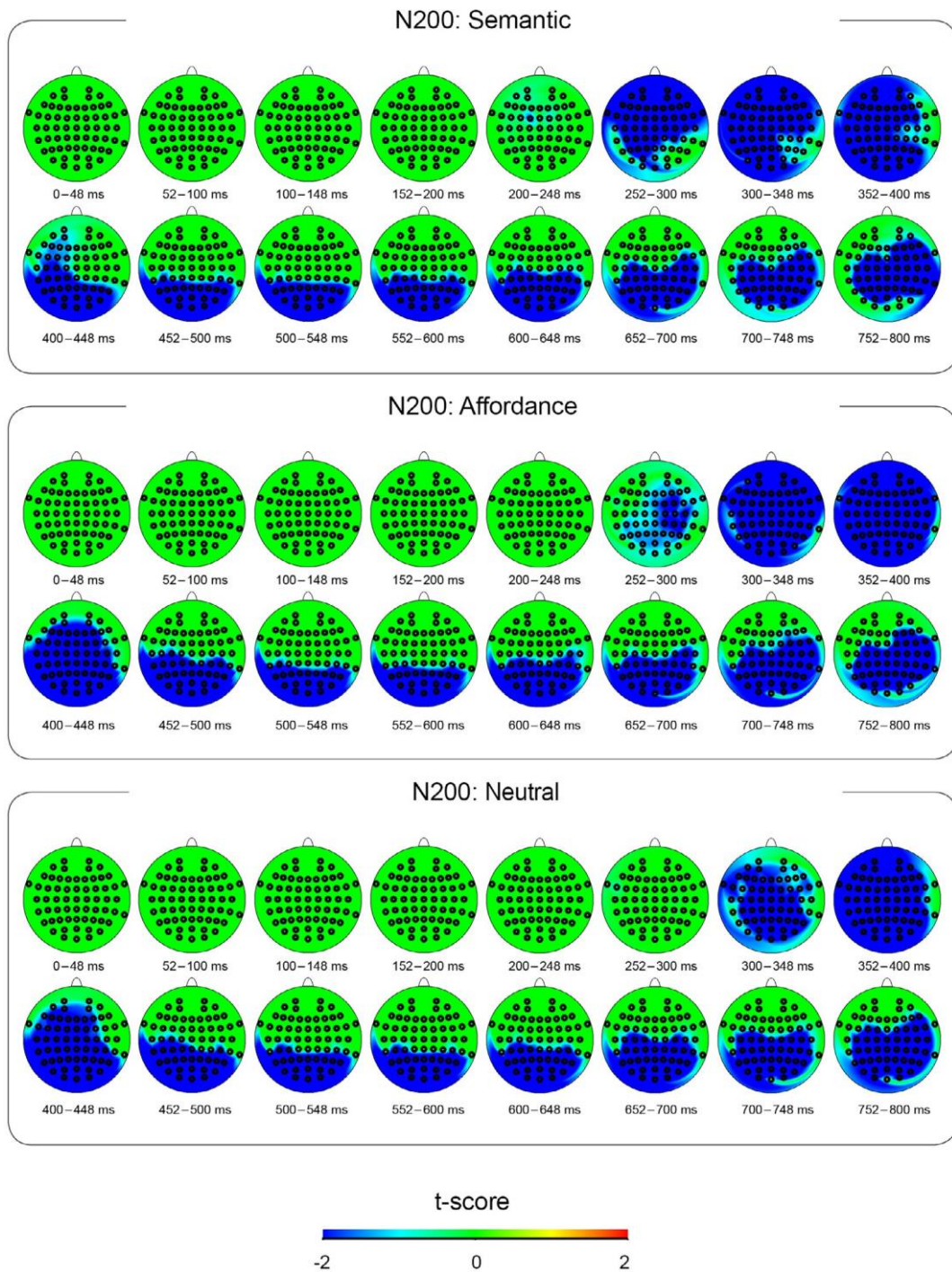| Condition	No. of clusters	Name of cluster	Polarity	Duration	P-value
Semantic	1	cS	Negative	208–800 ms	$p < .001$
Affordance	1	cA	Negative	252–800 ms	$p < .001$
Neutral	1	cN	Negative	280–800 ms	$p < .001$

Fig. 2. Scalp maps showing *t*-scores for significant clusters revealed by the cluster randomisation comparison between the N200 and baseline for semantic, affordance, and neutral priming conditions.

Table 2

Summary of significant clusters in the comparisons between the N200 of the semantic, affordance, and neutral conditions.

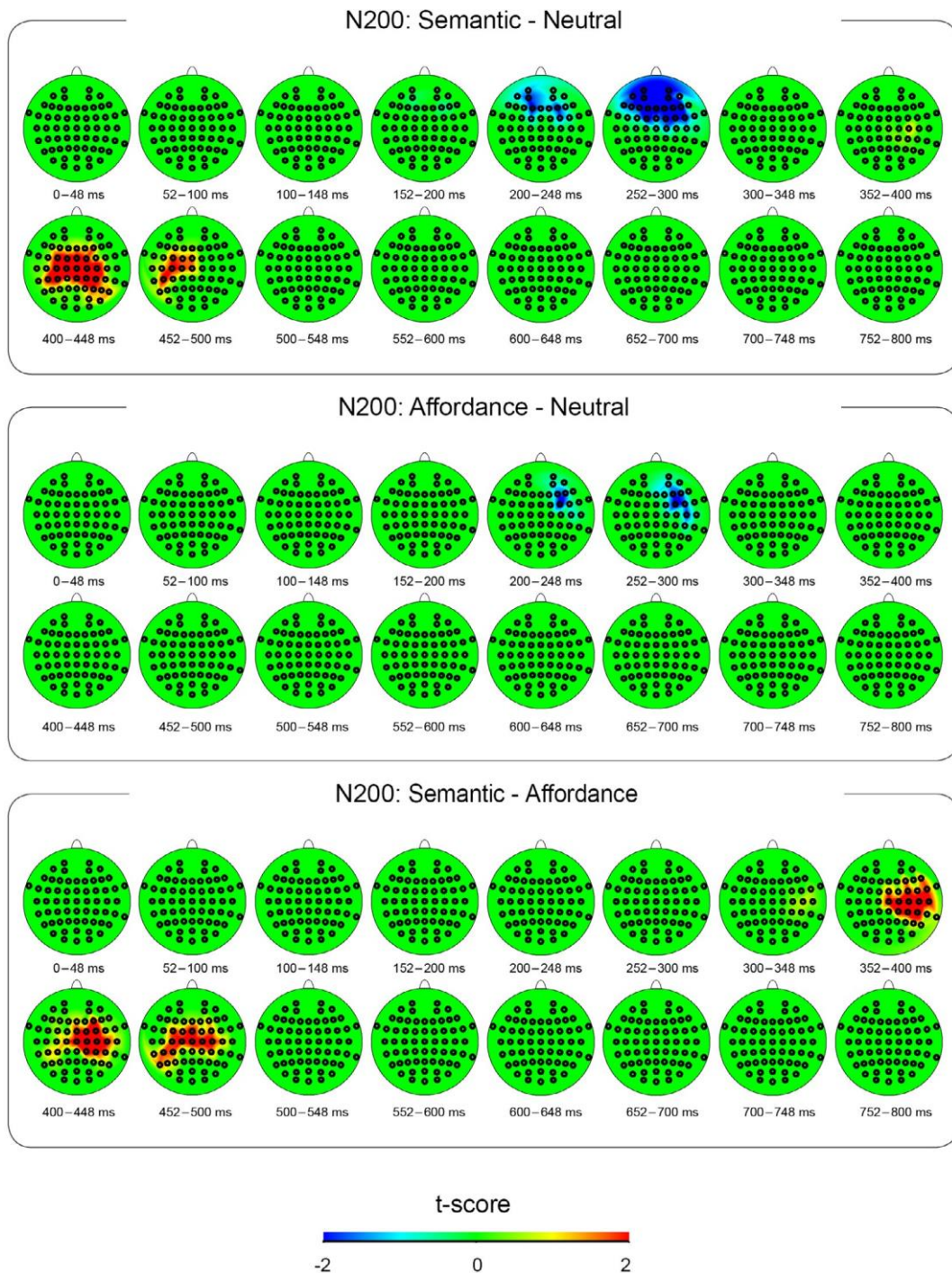| Conditions compared	No. of clusters	Name of cluster	Polarity	Duration	P-value
Semantic – Neutral	2	cS-N1	Negative	176–300 ms	$p = .002$
		cS-N2	Positive	368–500 ms	$p < .001$
Affordance – Neutral	1	cA-N	Negative	200–292 ms	$p < .001$
Semantic – Affordance	1	cS-A	Positive	320–500 ms	$p < .001$

Fig. 3. Scalp maps showing *t*-scores for the significant clusters revealed by the cluster randomisation comparing semantic, affordance, and neutral priming N200s.

indicates that the offset of the N200 is earlier in the semantic than the neutral priming condition. Similar comparisons also revealed that the N200 was earlier in the affordance priming condition than the neutral priming condition (cluster cA-N). However, there was no significant difference between the latency of the onset of the N200 between the semantic priming condition and the affordance priming condition, only that the offset of the N200 was earlier in the former condition (cluster cS-A).

Summary of N200 results. Given that the onset of the N200 is thought to reveal the earliest time a participant has access to information required to make their task-related judgement, it is normal to find that onset latencies for this component are highly correlated to

behavioural reaction times. This was indeed the case when comparing our semantic and neutral priming conditions, with the reaction times and N200 onset both being earlier in the semantic than the neutral priming condition. However, while reaction times were found to be significantly faster in the semantic priming condition than the affordance priming condition, we found no significant difference in the onset of the N200 between these conditions. A logical explanation for this disparity lies in the fact that reaction times are only garnered during go trials, while the N200 is the result of a subtraction of ERP between go and nogo trials. Thus, it is possible that the relatively early onset of the N200 for affordance priming is a result of greater activity during nogo trials, which would not be reflected in reaction times. Therefore, to test

Table 3
Summary of significant clusters in the comparisons between the go trial ERPs of the semantic, affordance, and neutral conditions.

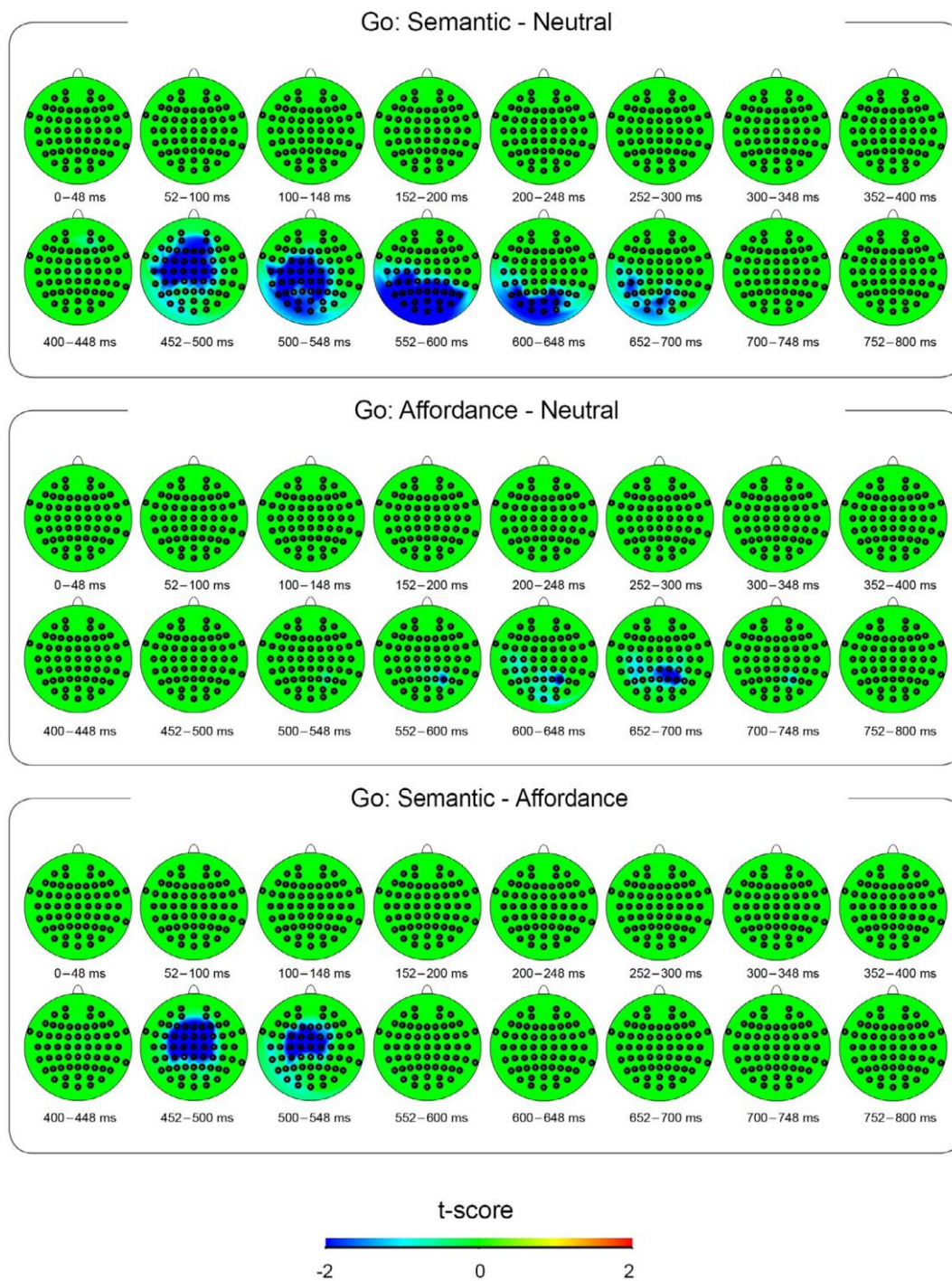| Condition	No. of clusters	Name of cluster	Polarity	Duration	P-value
Semantic – Neutral	1	cS-N-Go	Negative	428–708 ms	p < .001
Affordance – Neutral	1	cA-N-Go	Negative	520–728 ms	p = .001
Semantic – Affordance	1	cS-A-Go	Negative	440–556 ms	p < .001

Fig. 4. Scalp maps showing *t*-scores for significant clusters revealed by the cluster randomisation comparison between semantic, affordance, and neutral priming conditions in go trials.

Table 4
Summary of significant clusters in the comparisons between the nogo trial ERPs of the semantic, affordance, and neutral conditions.

Condition	No. of clusters	Name of cluster	Polarity	Duration	*p*-value
Semantic – Neutral	1	cS-N-Nogo	Negative	500–632 ms	$p = .001$
Affordance – Neutral	1	cA-N-Nogo	Negative	176–352 ms	$p = .001$
Semantic – Affordance	2	cS-A1-Nogo	Positive	296–472 ms	$p = .002$
		cS-A2-Nogo	Negative	492–628 ms	$p < .001$

this hypothesis we conducted separate analyses of ERP for go and nogo trials.

Analyses of go trials. Paired sample *t*-tests were used to compare the ERPs of the semantic and neutral priming conditions for go trials only. As before, individual *t*-tests were conducted for each sample recorded over each of the electrodes and multiple comparisons then corrected using the cluster randomisation procedure. The significant clusters are displayed in Table 3 and Fig. 4. Both semantic and affordance related priming evoked earlier activity in go-trial targets when compared with the neutral priming condition. However, activity for semantic primed targets occurred ~100 ms earlier than those primed with affordance, as indicated by the presence of the negative polarity cluster (cS-A-Go).

Analyses of nogo trials. The significant clusters resulting from the cluster randomisation procedure for nogo trials are displayed in Table 4 and Fig. 5. As in the go trials, both semantic and affordance priming of targets in nogo trials resulted in significantly earlier activity than in the neutral priming condition. However, in this case, a direct comparison of semantic and affordance priming showed that the onset of activity was significantly earlier in the affordance priming condition, as revealed by the positive polarity cluster (cS-A1-Nogo). The later cluster (cS-A2-Nogo) did reveal greater negative amplitudes due to semantic priming, but later, from 492 to 628 ms.

4. Discussion

In this study, we examined the relative time course of access to an object's semantic or action-affordance features when reading its name. The availability of these different types of information was ascertained through an examination of the N200 ERP component, which can be used to determine when specific task-related information becomes available to a participant in a go/nogo paradigm. In our study participants made a semantic decision related to a written object name, categorising the described object as either manmade or natural. These target object names were primed by written words that were related to the target through a shared affordance, semantic taxonomy or were unrelated to the target in a neutral priming condition.

Our results showed that the onset of the N200 was earlier when the target words were primed with either semantic or affordance related primes, at around 210–250 ms post target onset, than when they were preceded with an unrelated word, where the onset was at 280 ms. Importantly, there was no significant difference in N200 onset latency between affordance and semantic related primes. This would normally indicate that the two types of related priming conditions offer equivalent facilitation of the semantic decision made on the target words. However, this was found to be at odds with the behavioural reaction time data. Only semantic priming facilitated decision latencies, with latencies during the priming of affordances not differing significantly from the neutral priming condition. The explanation we pursued to explain for this disparity relates to the methodology used to calculate the N200 component, which is a difference wave of stimuli presented in go and nogo trials. This analysis draws upon all of the trials tested in the experiment, while reaction times are only provided for go trials. The disparity between reaction times and N200 latencies suggests that there is an asymmetric difference in ERPs between go and nogo trials that is modulated by the priming condition. From an embodied perspective

this would not be unexpected, as it is possible that the motor preparation afforded by the objects described in the prime words could interact with a later task-related manual response. To investigate this explanation, we conducted separate ERP analyses for go and nogo trials. In go trials we found that the onset of activity in the semantic priming condition was significantly earlier than the other two priming conditions, starting around 430 ms after target onset. While the onset of activity in the affordance priming condition was earlier than that of the neutral condition, this difference was relatively late, at around 520 ms. This could explain why affordance priming had no significant effect on reaction times, as the associated activity was proximal to the behavioural response times of around 560–580 ms and therefore too late to influence those responses. Thus, it would appear that the temporal aspect of go-response ERPs is in line with the behavioural latency differences. Conversely, in the ERPs from nogo trials the effect of affordance priming started at 180 ms, significantly earlier than semantic priming at around 500 ms. This comparison of go and nogo trials shows how the parity in the N200 onset in semantic and affordance priming conditions mask quite different underlying activities, with early activation of semantic representations in go trials, and early affordance related activity in nogo trials.

In part, these findings follow established semantic priming results, with activation from the prime word facilitating the activation of the proceeding semantically related targets. This is clearly evident in the semantic priming condition, where we find facilitation of behavioural semantic decision latencies, and early activity in the go trial ERPs. We also found activity related to affordance priming in go trials, but in a much later temporal window. Normally, these particular results would be indicative of a post-lexical mental simulation account of affordance (Mahon & Caramazza, 2008) but they are at odds with other studies that have found an affordance-related facilitation in lexical decision latency (Myung et al., 2006; Rueschemeyer, Lindemann, van Rooij, van Dam, & Bekkering, 2010).

One potential reason why we did not find a behavioural effect of affordance priming previously seen in lexical decisions is due to the task used in our study. This is not related particularly to the semantic decision task per se, but rather the relationship between the task and the two priming conditions. In the semantic priming condition, the taxonomic relation between prime and target ensured that they would share the semantic feature directly probed by the task i.e. prime and target would either both be natural or both be manmade. In contrast, the primes and targets in the affordance condition were selected such that their only shared feature should be the grip used to manipulate them. As such, natural primes would always be paired with artificial targets and vice versa. Thus, prime-target pairs in the affordance condition are always unrelated with respect to the attended semantic feature directed by the behavioural task (i.e. natural vs manmade). This means that the semantic priming condition has a direct relationship between prime, target, and task, whereas in the affordance condition the relationship between prime and target was orthogonal to the task. Therefore, it is possible that reaction times in affordance and semantic priming conditions may have been modulated by differences in the relationship between prime and task, rather than the relationship between prime and target. It must be noted, that this distinction cannot be applied to the temporal disparities shown in the study by Amsel et al. (2013), as they compared the temporal onset of distinct and explicit semantic
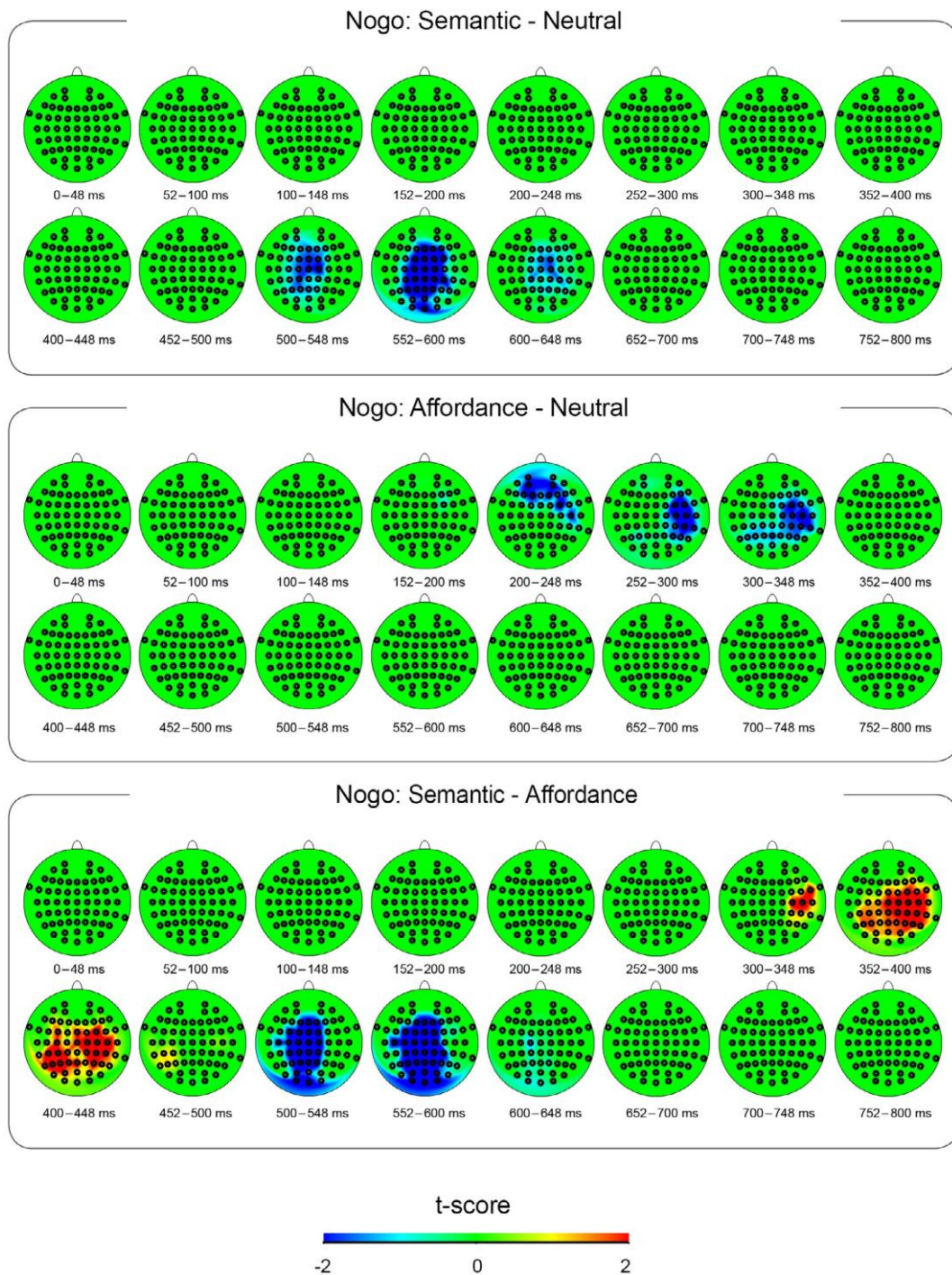
Fig. 5. Scalp maps showing *t*-scores for the significant clusters revealed by the cluster randomisation comparison between semantic, affordance, and neutral priming conditions in nogo trials.

decisions, rather than comparisons of priming in the same decision.

In Amsel et al. (2013) the onset of the N200 ERP component revealed that participants were able to differentiate between living and non-living entities from as early as 160 ms, whereas the graspability of the object was retrieved around 300 ms. It is concluded that this relatively late access to grasp-related affordances indicates that they do not play a crucial role in the conceptual representation of objects. In our own study, N200 latencies when priming affordance and semantic features of target words were equivalent, from around 210 ms. Although similar, there are some important methodological divergences between our two studies that could explain the differences between our

N200 latencies. Firstly, the affordances related to Amsel et al.'s stimuli appeared to be based on the object's geometry, rather than stored representation of use. For example, a "mouse" (the small rodent not the hand-held device) is categorised as graspable, but a "motorbike" is not. In terms of affordances, the experience one has with using or manipulating an object is an important aspect of the sensorimotor activity elicited (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Rueschemeyer et al., 2010; Siakaluk et al., 2008). Therefore, one could categorise a motorbike as a "graspable" object, as it is manipulated primarily through its handlebars. Conversely, a mouse is unlikely to have a stored affordance, generated through past interactions, but

would rely upon an intrinsic geometric affordance inferred from its size. Physical size provides a salient affordance in visual stimuli, with direct vision-to-action activation obviating the requirement for higher level knowledge (Rumiati & Humphreys, 1998). However, in a linguistic modality, geometric affordances have to be mediated through stereotyping of object properties. Therefore, in Amsel et al. the temporal onset of affordance seen in the N200 would have included any delay required to infer a geometric affordance. In contrast, our study used a combination of stored and geometric affordance for each prime/target pair. This could be particularly important given that Amsel et al. based their temporal estimates upon a manipulation of the question posed in an explicit decision task, i.e. between making a living/non-living or graspable/non-graspable judgment.

One of our central questions is whether the availability of implied geometric information to an explicit decision task, as tested in Amsel et al., can provide an ecologically valid estimate of the temporal onset of affordance. We suggest that this is challenged by our finding of early activity associated with affordance priming in nogo trials, a con-sequence of the manual motor preparation generated by the shared affordances between prime and target. In nogo trials this motor pre-paration is incompatible with the requirement of the participant to withhold a manual response, and the inhibition of the response be-comes evident in the ERP. The spatial distribution of this activity, evident in right pre-frontal electrodes, is similar to the activity found in previous research in the right inferior frontal gyrus during the inhibi-tion of motor responses (Chikazoe, Konishi, Asari, Jimura, & Miyashita, 2007; Hampshire, Chamberlain, Monti, Duncan, & Owen, 2010). Lesion studies also illustrate the involvement of the frontal lobe in inhibiting affordances that are automatically elicited by visual objects. One study found that some patients with frontal lobe lesions would grasp and use any objects in their field of vision without any real purpose for doing so (Lhermitte, 1983; Riddoch, Edwards, Humphreys, West, & Heafield, 1998). Lhermitte (1983) argued that this 'utilization behaviour', as he termed it, resulted from the inability of the frontal lobe to perform the usual inhibitory function on the parietal lobe's motor programs. Re-search shows how the parietal lobe is involved in the integration of visual and somatosensory information and converting this into motor commands (see Fogassi & Luppino, 2005, for a review). The temporal period of this affordance related activity, spanning P2 and N2 compo-nents, is also consistent with previous accounts of these components reflecting stimulus evaluation and response selection (Gajewski, Stoerig, & Falkenstein, 2008; Potts, 2004). Gajewski et al. (2008) ar-gued that this might be more effortful when an incorrect response is activated by misleading cues. We posit that there is a similar modula-tion of the P2/N2 complex in our study due to the effort required to inhibit a response once the motor system had been primed to respond. We suggest that this is the source of the early activity observed in our affordance primed nogo trials.

A particularly noteworthy aspect of this account of our affordance effects is that the task-related manual response was not directly related to the affordance of the object. While participants were asked to re-spond or withhold a manual response, the left index finger button press required was not directly related to the grip afforded by either the prime or target referent object. Similarly, generalised effects have been found in previous research (Postle, Ashton, McFarland, & De Zubicaray, 2013; Rueschemeyer et al., 2010; Siakaluk et al., 2008). Rueschemeyer et al. found that lexical decisions were quicker and more accurate for names of manipulable objects when participants simultaneously exe-cuted a motor action. In this case the action, requiring participants to run their finger along the edge of a desk, was not specific to the af-forded actions of the objects. Postle et al. also found that it didn't matter which body part was being described by their linguistic stimuli, the

right hand was affected indifferently. This shows that the motor pre-paration generated through affordance priming does not necessarily have to be related to a specific motor program, such as a particular grip, but can be broadly tuned to include other manual activity.

5. Conclusions

The main aim of this study was to investigate the deeply embodied claim that sensorimotor information related to the form or function of an object, is fundamental to its conceptual representation and plays a privileged role in the comprehension of their linguistic descriptors (Glenberg & Gallese, 2012; Glenberg & Robertson, 1999). Conversely, it has been suggested that access to action-affordances is not privileged above other semantic features that make up an object's conceptual re-presentation, and that their activation is a result of post-lexical mental simulation of referent object use (e.g. Amsel et al., 2013; Mahon & Caramazza, 2008). In support of the former theory, we established that the priming of affordance evokes the rapid activation of motor re-presentation during the reading of object names. This is indicative of somatotopic activity in the motor system associated with the affordance of the named object, similar to that shown across a range of studies during the reading of action words (Hauk, Shtyrov, & Pulvermüller, 2008; Pulvermüller, Härle, & Hummel, 2001; Pulvermüller, Lutzenberger, & Preissl, 1999; Shtyrov, Hauk, & Pulvermüller, 2004). However, while listeners do seem able to extract embodied information from linguistic representations, this information does not appear to play a fundamental role in the semantic integration processes related to our task. The early activity related to affordance priming, seen from around 180 ms, was strictly limited to nogo trials. This indicates that this ac-tivity is related to the inhibition of the afforded motor preparation, as participants seek to withhold the manual response related to the task. While taxonomically related primes facilitated semantic decisions, af-fordance related primes did not. In go trials the onset of activity related to affordance priming was relatively late, starting at around 520 ms, compared to an onset of 430 ms for semantic priming. This set of findings is perhaps most consistent with theories that posit multiple processing routes in comprehension, such as the language and situated simulation (LASS) theory (Barsalou et al., 2008). This would allow for a distinction between the early activation of the motor representation afforded by the described object and the route used to access abstract conceptual information during comprehension. Whereas semantic-priming can occur by recruiting the linguistic system's method of ac-tivating associated words in a distributional semantic network, affor-dance-priming involves the situated simulation route. Our research suggests that the early motor simulation activity is activated auto-matically and in a similar time frame to categorical knowledge. Later affordance related activation could either be the result of another si-mulation cycle or integration of information across the two routes.

Statement of significance

From examining the event-related potentials of participants reading object names, we found early activation of object affordances from 176 ms. This suggests affordances are activated during an earlier stage of linguistic processing than previously thought. In the article, we ex-plain why current research methodologies may have failed to find si-milar results.

Appendix. Stimuli

Semantic		Affordance		Neutral	
Prime	*Target*	*Prime*	*Target*	*Prime*	*Target*
Marker	Axe	Potato	Axe	Strawberry	Axe
Eraser	Axe	Cucumber	Axe	Fig	Axe
Tweezers	Axe	Orange	Axe	Bean	Axe
Scalpel	Axe	Pear	Axe	Mushroom	Axe
Marker	Hammer	Potato	Hammer	Strawberry	Hammer
Eraser	Hammer	Cucumber	Hammer	Fig	Hammer
Tweezers	Hammer	Orange	Hammer	Bean	Hammer
Scalpel	Hammer	Pear	Hammer	Mushroom	Hammer
Marker	Drill	Potato	Drill	Strawberry	Drill
Eraser	Drill	Cucumber	Drill	Fig	Drill
Tweezers	Drill	Orange	Drill	Bean	Drill
Scalpel	Drill	Pear	Drill	Mushroom	Drill
Marker	Saw	Potato	Saw	Strawberry	Saw
Eraser	Saw	Cucumber	Saw	Fig	Saw
Tweezers	Saw	Orange	Saw	Bean	Saw
Scalpel	Saw	Pear	Saw	Mushroom	Saw
Spanner	Pin	Strawberry	Pin	Potato	Pin
Spade	Pin	Fig	Pin	Cucumber	Pin
Stapler	Pin	Bean	Pin	Orange	Pin
Trowel	Pin	Mushroom	Pin	Pear	Pin
Spanner	Needle	Strawberry	Needle	Potato	Needle
Spade	Needle	Fig	Needle	Cucumber	Needle
Stapler	Needle	Bean	Needle	Orange	Needle
Trowel	Needle	Mushroom	Needle	Pear	Needle
Spanner	Biro	Strawberry	Biro	Potato	Biro
Spade	Biro	Fig	Biro	Cucumber	Biro
Stapler	Biro	Bean	Biro	Orange	Biro
Trowel	Biro	Mushroom	Biro	Pear	Biro
Spanner	Pencil	Strawberry	Pencil	Potato	Pencil
Spade	Pencil	Fig	Pencil	Cucumber	Pencil
Stapler	Pencil	Bean	Pencil	Orange	Pencil
Trowel	Pencil	Mushroom	Pencil	Pear	Pencil
Strawberry	Apple	Spanner	Apple	Marker	Apple
Fig	Apple	Spade	Apple	Eraser	Apple
Bean	Apple	Stapler	Apple	Tweezers	Apple
Mushroom	Apple	Trowel	Apple	Scalpel	Apple
Strawberry	Banana	Spanner	Banana	Marker	Banana
Fig	Banana	Spade	Banana	Eraser	Banana
Bean	Banana	Stapler	Banana	Tweezers	Banana
Mushroom	Banana	Trowel	Banana	Scalpel	Banana
Strawberry	Carrot	Spanner	Carrot	Marker	Carrot
Fig	Carrot	Spade	Carrot	Eraser	Carrot
Bean	Carrot	Stapler	Carrot	Tweezers	Carrot
Mushroom	Carrot	Trowel	Carrot	Scalpel	Carrot
Strawberry	Onion	Spanner	Onion	Marker	Onion
Fig	Onion	Spade	Onion	Eraser	Onion
Bean	Onion	Stapler	Onion	Tweezers	Onion
Mushroom	Onion	Trowel	Onion	Scalpel	Onion
Potato	Lentil	Marker	Lentil	Spanner	Lentil
Cucumber	Lentil	Eraser	Lentil	Spade	Lentil
Orange	Lentil	Tweezers	Lentil	Stapler	Lentil
Pear	Lentil	Scalpel	Lentil	Trowel	Lentil
Potato	Pea	Marker	Pea	Spanner	Pea
Cucumber	Pea	Eraser	Pea	Spade	Pea
Orange	Pea	Tweezers	Pea	Stapler	Pea
Pear	Pea	Scalpel	Pea	Trowel	Pea
Potato	Grape	Marker	Grape	Spanner	Grape
Cucumber	Grape	Eraser	Grape	Spade	Grape
Orange	Grape	Tweezers	Grape	Stapler	Grape

Pear	Grape	Scalpel	Grape	Trowel	Grape
Potato	Cherry	Marker	Cherry	Spanner	Cherry
Cucumber	Cherry	Eraser	Cherry	Spade	Cherry
Orange	Cherry	Tweezers	Cherry	Stapler	Cherry
Pear	Cherry	Scalpel	Cherry	Trowel	Cherry

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