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Imagine that! ERPs provide evidence for distinct hemispheric contributions to the processing of concrete and abstract concepts

Hsu-Wen Huang[1], **Chia-Lin Lee**[2], and **Kara D. Federmeier**[2],[3],[4]

[1] Institute of Neuroscience, National Yang-Ming University

[2] Department of Psychology, University of Illinois

[3] Program in Neuroscience, University of Illinois

[4] the Beckman Institute for Advanced Science and Technology, University of Illinois

Abstract

Although abstract and concrete concepts are processed and remembered differently, the underlying nature of those differences remains in dispute. The current study used visual half-field (VF) presentation methods and event-related potential (ERP) measures to examine how the left (LH) and right (RH) cerebral hemispheres process concrete and abstract meanings of polysemous nouns (e.g., "green book," referring to the concrete, physical object that is a book, versus "engaging book," referring to the abstract information that a book conveys). With presentation to the right VF, nouns preceded by concrete modifiers were associated with more positivity on the P2 and N400, suggesting that concrete concepts were easier for the LH to process perceptually and semantically. In contrast, with presentation to the left VF (RH), nouns used in a concrete sense elicited a sustained frontal negativity (500-900 ms) that has been previously linked to imagery. The results thus reveal multiple, distinct neural and cognitive sources for concreteness effects and point to a critical role for the RH in linking language input to sensory imagery.

In the prologue to Shakespeare's Hamlet, the chorus encourages the audience to:

> Think when we talk of horses, that you see them
>
> Printing their proud hoofs i' the receiving earth;
>
> For 'tis your thoughts that now must deck our kings.

The power of language to evoke vivid sensory imagery remembered or newly created has long been celebrated by authors, harnessed by advertisers and politicians, and recognized by language users of all types. Research over several decades has shown that the processing of *concrete* expressions – i.e., those that denote a concept that can easily be experienced by the senses – is facilitated relative to that for more abstract expressions in a wide range of language, memory, and other higher cognitive tasks. Concrete words are easier to identify (Schwanenflugel et al, 1988), read aloud (Gerhand and Barry, 2000) and remember (Paivio, 1991). Similarly, concrete sentences are easier to comprehend (Schwanenflugel and Shoben,

Address correspondence to: Kara D. Federmeier Department of Psychology University of Illinois 603 E. Daniel Champaign, IL, 61820 Phone: 217.333.8303 kfederme@uiuc.edu.

1983) and to judge for meaningfulness and truthfulness (Belmore et al., 1982). Yet the underlying nature of the processing differences between concrete and abstract expressions remains poorly understood.

One view, known as “context availability theory” (Schwanenflugel, 1991), hypothesizes that concreteness effects arise through differences in the extent and strength of the associative connections between these word types and information stored in a single, amodal semantic system (e.g., Pylyshyn, 1984). On this account, then, concreteness effects reflect quantitative processing differences within a single neurocognitive system, which should be reduced or eliminated by contextual information that provides more semantic support for abstract expressions.

Studies examining the basis for concreteness effects using visual half-field (VF) presentation (to induce asymmetric processing biases) or hemodynamic brain imaging methods, however, have suggested instead that concrete and abstract expressions may be processed by at least partially non-overlapping neural systems distributed across the two cerebral hemispheres (e.g., Binder et al., 2005; Eviatar et al., 1990; Sabsevitz et al., 2005). These patterns provide support for views emphasizing that language comprehension involves the simulation of embodied experience, including modality-specific perceptual and motor processes (e.g., Glenberg and Robertson, 2000; Lakoff & Johnson, 1999).

For example, Paivio's (2007) “dual coding theory,” says that concrete words manifest processing advantages because they are encoded both verbally, in a left-hemisphere (LH) language system, and nonverbally, using sensory imagery that arises from bilateral processing mechanisms. Although many studies provide support for the general hypothesis that the left and right (RH) cerebral hemispheres differ in their processing of concrete and abstract words, the precise pattern of laterality is less clear. Some studies have reported patterns that match the predictions of dual coding, showing bilateral processing of concrete words but LH-dominant processing of abstract words (Binder et al., 2005; Eviatar et al., 1990; Sabsevitz et al., 2005). Other studies, however, observed increased LH activity (Fiebach and Friederici, 2003) and LH processing advantages (see review in Chiarello et al., 2001) for concrete words, or enhanced activations for abstract words bilaterally (Pexman et al. 2007) or selective to the LH (Noppeney and Price, 2004) or RH (Kiehl et al., 1999).

The disparity across studies suggests that concreteness effects may involve multiple mechanisms, which are differentially engaged by different types of stimuli and/or under different task conditions (e.g., Chiarello et al., 2001). This view receives additional support from event-related potential (ERP) studies. Holcomb and colleagues (Holcomb et al., 1999; Kounios and Holcomb, 1994; West and Holcomb, 2000) have shown that concrete words elicit more negative-going potentials beginning in the time window of the N400, a component that has been closely linked to semantic processing (Federmeier and Laszlo, in press). Consistent with aspects of context availability theory, these differences are attenuated when concrete and abstract words are put into predictive sentence contexts (Holcomb et al., 1999) or are repeated (Kounios and Holcomb, 1994). However, whereas the typical N400 has a centro-posterior scalp distribution, the potentials elicited by concrete words between 250 and 500 ms are also more negative over the front of the head, and this frontal negative effect is sustained beyond the N400 time window. These distributional and timecourse differences suggest non-identical neural sources involved in the processing of concrete and abstract words, in line with dual coding.

There are other indications that the electrophysiological pattern reflects dissociable mechanisms. The more posterior (N400) part of the concreteness effect is consistent across word types (appearing similarly for nouns, verbs, and class-ambiguous words; Lee and

Federmeier, 2008) and, consistent with the larger literature on N400 effects (for a review, see Kutas et al., 2007), is sensitive to context (Holcomb et al., 1999; Swaab et al., 2002). In contrast, the sustained frontal effect is sensitive to word type (appearing for nouns and unambiguous, but not ambiguous, verbs; Lee and Federmeier, 2008) and task (larger for semantic and imagery tasks than for lexical decision; West and Holcomb, 2000), but less sensitive to the availability of context information (Swaab et al., 2002). Frontally-distributed N400 potentials are also seen to pictures (e.g., Ganis et al, 1996) and effects with a similar distribution (taking into account differences in reference site) have been observed in ERP studies of mental imagery (Farah et al., 1989).

If the frontal concreteness effect is due to mental imagery, then both dual coding theory (Paivio, 2007) and the more general literature on imagery (e.g., Ehrlichman and Barrett, 1983; Kosslyn, 1987) would posit links between this effect and right hemisphere (RH) processing. Thus, a primary goal of the present study is to further elucidate the neural mechanisms involved in the processing of concrete expressions by combining ERP measures with VF methods in order to look at hemispheric processing biases. We predict important RH contributions to the frontal concreteness effect, pointing to a unique role for the RH in mediating the access of perceptually rich meaning information during language comprehension.

At the same time, we further examine the N400 concreteness effect, which seems likely to arise from general mechanisms of semantic access (Federmeier & Laszlo, in press). A difficulty with interpreting the extant data is that effects have been assessed across different sets of lexical items, which, in addition to differing in concreteness, potentially differ along other dimensions known to affect N400 amplitude (e.g., orthographic neighborhood size and semantic ambiguity). In the present study, therefore, we adopt the novel approach of manipulating concreteness *on the same lexical items* by taking advantage of polysemy. We use (lateralized) nouns that have both a concrete and an abstract meaning (e.g., “book”, which can refer to a physical object or to the information conveyed by that object) and highlight one of these senses through modification by a centrally-presented adjective – for example, “green book” versus “engaging book”. Whereas the RH may be more involved in sensory imagery, as indexed by frontally-distributed potentials, we predict that the LH may be more likely to use information provided by the adjective context to adjust its linguistic (N400) and even perceptual (P2) processing of the polysemous noun (as suggested by the PARLO hypothesis; Federmeier, 2007).

Methods

Thirty-two University of Illinois undergraduates (16 females, mean age 20, range 18-25) participated for cash or course credit. All were monolingual English speakers with no early second language exposure and no history of neurological or psychiatric disorders. Participants were right-handed, as determined by the Edinburgh inventory (Oldfield, 1971); 12 reported left-handed family members.

Stimuli consisted of 112 nouns with multiple, related meaning senses (i.e., polysemous nouns), which varied in their baseline concreteness (Toglia and Battig, 1978) from fairly abstract (e.g., “atmosphere” and “vision”) to concrete (“nose” and “lamb”). Adjectives were then used to pick out concrete and abstract senses of each of these polysemous nouns, making use of well-studied polysemous alternations such as product/producer, building/institution, and animal/meat, among others (e.g., Pustejovsky, 1995). An adjective referring to physical aspects of the noun (e.g., “hilly farm”) was used to induce a concrete reading, whereas an adjective referring to features less available to the senses (e.g., “productive farm”) was used to induce an abstract reading. Each noun was paired with four adjectives, two concrete and two abstract, resulting in a final set of 448 adjective-noun pairs.

The perceived concreteness of the adjective-noun pairs was assessed in a norming study. Forty-four monolingual English-speaking University of Illinois students (19 females, mean age 19, range 18-25) participated for course credit. No participant was run in both the norming and ERP studies. Word pairs were divided into two lists; within each, nouns were repeated once, paired with different adjectives and separated by at least 50 pairs. Participants used a 1-7 concreteness rating scale, with "1" indicating a concept that "is difficult to experience with one's senses" (i.e., is abstract). The final set of concrete adjective-noun pairs had a mean rating of 6.01 (SE = .04) and the final set of abstract pairs had a mean rating of 2.96 (SE = .06).

Critical items were divided into two sets, containing 112 each of concrete and abstract adjective-noun pairs followed by probe adjectives (drawn from the same normed set, half concrete and half abstract), which were used for the modification appropriateness judgment task. Within a set, nouns were repeated once across VF (at least 100 trials apart), appearing once in a concrete and once in an abstract pairing. Two additional lists, identical except that presentation VF was reversed, were created from each set. These four lists were then used to create another four in which the critical and probe adjectives were swapped. To each of the lists, 168 filler triplets were added, in which one (56 items) or both (112 items) of the adjectives were anomalous as a modifier of the noun; two-thirds of these nouns were repeated across VF, always with different adjectives. Stimuli were randomized once for each list and presented to participants in the same order. In total, each participant saw 392 triplets: 56 concrete pairs, 56 abstract pairs and 84 filler trials in each VF. Table 1 shows an example of the stimuli and list structure.

Participants viewed the stimuli sitting one meter in front of a computer screen in a dimly lit room. Their task was to read each three-word series (adjective, lateralized noun, adjective) without moving their eyes from central fixation (a 3 by 3 pixel square presented a few pixels below the center of the screen) and to indicate, via a button press, which adjective seemed a better modifier for the noun. Hand used to indicate "first" or "second" was counterbalanced. A 20-trial practice familiarized subjects with the task. At the start of each trial, four plus signs appeared (500 ms). After a random (800-1300 ms) stimulus onset asynchrony (SOA), the initial adjective was presented centrally (500 ms), followed by 500 ms of blank screen. The noun (subtending 2.5-5.5, mean 4, degrees of visual angle) was then presented (200 ms) with its inner edge two degrees to the left or right of fixation, followed by 1000 ms of blank screen and presentation of the second adjective (500 ms). One second after the offset of the second adjective a question mark appeared, indicating that participants should respond. There were eight blocks of trials, with 49 trials per block. Between blocks, participants took a short break.

The electroencephalogram (EEG) was recorded from 26 silver/silver-chloride electrodes evenly spaced over the scalp. Eye movements were monitored via a bipolar montage of electrodes on the outer canthus of each eye. Blinks were detected by an electrode below the left eye. Signals were amplified with a 0.02-100 Hz bandpass and digitized at 250 Hz. Data were referenced online to the left mastoid and rereferenced offline to the average of the left and right mastoids. Each trial consisted of a 920 ms epoch preceded by a 100 ms prestimulus baseline. Trials contaminated by eye movements, blinks or other recording artifacts were rejected offline. Average trial loss was 4% for the adjectives and 5% for the lateralized nouns. A digital bandpass filter of 0.2 to 20 Hz was employed prior to statistical analyses. Main effects of electrode and interactions with electrode site are reported only when of theoretical significance.

Results

Behavior

Response accuracy was computed for fillers with one anomalous adjective. In general, responses were quite accurate (mean 84%; range 70-100%), showing that participants were attending to the stimuli and able to apprehend the lateralized nouns. Responses were more accurate in the RVF (88%) than in the LVF (82%) [$F(1,31)=8.2$, $p < .01$], consistent with findings of more efficacious word apprehension by the LH (Jordan, 2003).

For critical trials, because both adjectives are related to the noun, both responses are equally correct. Table 2 shows the endorsement rates for the first and second adjectives across conditions and VF. An ANOVA with factors VF (RVF, LVF), Condition Type (Concrete/Concrete, Abstract/Abstract, Concrete/Abstract, Abstract/Concrete), and Adjective Position (first, second) conducted on the endorsement rates revealed no significant effects or interactions. Participants chose concrete and abstract adjectives (LVF/RH: 49%, 51%, RVF/LH: 50%, 50% respectively) and those before and after the critical nouns (LVF/RH: 49%, 51%, RVF/LH: 48%, 52% respectively) in approximately equal proportions.

Adjectives

Previous ERP studies have described out of context concreteness effects for nouns (Holcomb et al., 1999; Kounios and Holcomb, 1994; West and Holcomb, 2000) and verbs (Lee and Federmeier, 2008) but not other word classes. Therefore, it was of interest to examine responses to the initial, centrally-presented adjectives (Figure 1). Mean amplitude of the N400 was measured between 300-500 ms over posterior electrodes (marked in Figure 1) and subjected to a repeated measures analysis of variance (ANOVA) with concreteness and electrode as factors. There was a main effect of concreteness [$F(1,31)=39.23$, $p < .001$, $\eta_p^2 = .56$], with more negative responses to concrete than abstract adjectives. Effects over frontal sites were evident between 300-500 ms [$F(1,31)=34.05$, $p < .001$, $\eta_p^2 = .52$] and 500-900 ms [$F(1,31)=18.07$, $p < .001$, $\eta_p^2 = .37$], again in the form of enhanced negativity to more concrete words. Thus, similar to effects seen for nouns and verbs out of context, concrete adjectives elicit larger N400s and a sustained frontal negativity.

Lateralized Nouns

Concreteness effects on the lateralized nouns were analyzed for the N400 (posterior channels, 300-500 ms) and frontal negativity (frontal channels, 300-500 ms and 500-900 ms), using ANOVAs with VF (RVF versus LVF), concreteness (concretely versus abstractly modified) and electrode site (11 frontal or 15 posterior) as factors. In addition, analyses were conducted on the frontal P2 (180-240 ms), an ERP component related to high-level visual processing and visuospatial attention, which has proven sensitive to language context effects in a number of VF ERP studies (Federmeier et al., 2005; Wlotko and Federmeier, 2007).

There was a main effect of VF on the P2 [$F(1,31)=4.2$, $p < .05$, $\eta_p^2 = .12$], as RVF presentation yielded larger P2 responses. A main effect of concreteness was evident on the frontal negativity (500-900 ms) [$F(1,31)=5.9$, $p < .05$, $\eta_p^2 = .16$], with more negative responses to concretely than to abstractly modified nouns. Importantly, there was an interaction of concreteness and VF on the frontal P2, the N400, and the frontal negativity (500-900 ms): $F(1,31)=6.59$, $p < .05$, $\eta_p^2 = .18$; $F(1,31)=6.06$, $p < .05$, $\eta_p^2 = .16$; and $F(1,31)=5.59$, $p < .05$, $\eta_p^2 = .15$, respectively. Follow-up analyses were thus conducted separately in each VF.

Figure 2 shows the ERP responses to concretely and abstractly modified nouns in each VF; for both VFs, the waveforms, timelocked at the noun, immediately follow those to the centrally-presented adjectives shown in Figure 1. Lateralization affected waveform morphology as is

typical for VF ERP studies (c.f., Federmeier & Kutas, 1999), such that visual components are larger and peak earlier over contralateral occipital electrode sites and are followed by a long-lasting selection negativity contralateral to presentation VF.

For RVF/LH presentation, concreteness effects were found on the frontal P2 [$F(1,31)=6.48$; $p < .05$, $\eta_p^2 = .17$] and the N400 [$F(1,31)=7.64$; $p < .01$, $\eta_p^2 = .2$], with more positive responses to concretely than to abstractly modified nouns on both components. The increased positivity over posterior sites to concretely modified nouns continued into the 500-900 ms time window [$F(1,31)=8.93$; $p < .01$, $\eta_p^2 = .22$], modulating the amplitude of the late positive complex (LPC), a component that often follows the N400 and has been linked to more explicit aspects of semantic processing (e.g., Swaab et al., 2003). However, no effects were observed on the frontal negativity (F's □ 1). In contrast, with LVF/RH presentation, concreteness effects were significant on the frontal negativity between 500-900 ms [$F(1,31)=13.56$; $p < .001$, $\eta_p^2 = .3$], with more negative responses to concretely modified nouns, but not on the frontal P2 or N400 components (F's □ 1). Processing biased to the left and right hemispheres is thus associated with completely distinct types of ERP concreteness effects.

To determine whether the observed effects arise from the concreteness of the unified concept referred to by the adjective-noun pairing, we looked to see whether similar patterns obtained in the unrelated condition, when the concrete or abstract adjective cannot be meaningfully integrated with the noun (e.g., *watery glove* vs. *loyal glove*)[1]. In the RVF/LH, concreteness-related P2 effects were significant even for these meaningless pairs [$F(1,31)=7.05$; $p < .05$, $\eta_p^2 = .19$], suggesting that the P2 differences reflect a state induced by a concrete or abstract modifier, irrespective of contextual fit (c.f., Wlotko and Federmeier, 2007). However, N400 and LPC effects in the RVF/LH and the frontal negativity in the LVF/RH were both absent for meaningless adjective-noun pairings (F's □ 1), suggesting that these effects reflect the concreteness of an integrated conceptual representation (Figure 3).

Discussion

Replicating concreteness effects that have been documented for both nouns (Holcomb et al., 1999; Kounios and Holcomb, 1994; West and Holcomb, 2000) and verbs (Lee and Federmeier, 2008) that are presented out of context, we found that concrete adjectives, presented in sequence-initial positions, elicit more negative ERP responses than do abstract adjectives. Thus, posterior brain responses between 300 and 500 ms (N400) and frontal brain responses between about 300 and 900 ms are consistently different for semantic content picked out by nouns, verbs, and adjectives (e.g. things, actions, and properties) that are more or less associated with sensory features.

Still in dispute, however, are the number and nature of the mechanisms involved in concreteness effects (e.g., whether they are due to differences in the amount of semantic information associated with these words or expressions, to the differential use of mental imagery, or some combination of these) and how these are mediated by lateralized processing resources. Part of the challenge in answering these questions has come from the fact that concreteness effects are normally assessed across different lexical items, which may vary at multiple levels. In this study, therefore, we used adjectives to induce concrete and abstract readings of the same polysemous nouns, thereby holding bottom-up perceptual and lexico-semantic features constant across the concreteness comparison. In order to specifically test the dual coding account of concreteness effects (e.g., Paivio 2007) and, more generally, to examine the

[1]Concreteness values for the adjectives alone were collected in a norming study (N=46) using the same procedures as for the adjective-noun pairs. Mean concreteness ratings were 5.0 for concrete adjectives and 2.6 for abstract adjectives.

dissociability of the processes underlying the electrophysiological signature of these effects, we also lateralized the target nouns to assess hemispheric asymmetries.

Using adjectives to pick out different senses of polysemous nouns was successful in inducing processing differences, which, given that they occurred on exactly same lexical items, can thus be more definitively linked to the concreteness of the evoked concept. Strikingly, these concreteness effects are quite different – indeed, nonoverlapping – in the two hemispheres. With initial presentation to the LH, concreteness effects manifest on the frontal P2 and the N400, two components that have been linked to effects of contextual constraint and target expectancy in language processing (e.g., Wlotko and Federmeier, 2007). In contrast, when processing is biased to the RH, concrete modification leads to a sustained frontal negativity – the part of the ERP concreteness effect that has been associated with mental imagery (West and Holcomb, 2000).

With RVF/LH presentation, concretely modified nouns elicit an enhanced frontal P2 response and a smaller N400. The P2 is part of the normal visual evoked response and has typically been linked to the detection and analysis of higher-level visual features, guided by attention (Luck and Hillyard, 1994; for an alternative perspective see Bles, Alink, & Jansma, 2007). In sentence processing paradigms, the amplitude of the frontal part of the P2 has been found to be modulated by contextual constraint with RVF/LH – but not LVF/RH – processing: targets in strongly constrained sentence contexts (i.e., contexts that elicit strong, consistent predictions for particular endings) elicit more positive P2 responses than those in weakly constrained contexts (Federmeier et al., 2005; Wlotko and Federmeier, 2007). Thus, being able to form strong context-based expectations for upcoming words seems to change how the perceptual processing system allocates attention and analyzes subsequent stimuli. Strikingly, however, these constraint-related P2 enhancements occur not only for the expected lexical item but also for unexpected ones, suggesting that this effect arises at a point in processing prior to the actual identification of the target word (Wlotko and Federmeier, 2007). Similar to the pattern seen in sentences, in the present study the P2 was enhanced for nouns preceded by a concrete modifier irrespective of whether the adjective-noun pair was congruent or anomalous. Thus, for the LH, it seems that concrete adjectives may establish a more constraining context for upcoming nouns than do abstract adjectives.

If, as suggested by the P2 results, concrete adjectives establish more constraining semantic contexts for upcoming nouns, then the large literature on the N400 component (as reviewed in Kutas et al., 2007) would predict reduced N400 amplitudes to nouns following concrete than abstract adjectives, given that increased level of expectancy. Consistent with that prediction, we found that concretely (as opposed to abstractly) modified nouns that are presented initially to the LH facilitate N400 responses, but – distinct from the pattern seen for the P2 – only for congruent pairs. Thus, congruent nouns following a concrete adjective seem to be more expected and thus easier to process semantically. The fact that these expectancy-related effects arise only after presentation to the LH is consistent with theories that posit a specialized role for the LH in using language context information to predict features of upcoming words (the PARLO framework; Federmeier, 2007).

The effect of concrete and abstract modification on the N400 elicited after RVF/LH presentation of the critical noun is different from the pattern seen for concrete and abstract lexical items presented out of context, in which larger N400s have typically been reported for concrete as opposed to abstract words (as was found for the adjectives in the present study). However, the pattern is consistent with prior work suggesting that N400 concreteness effects are sensitive to context (e.g., Holcomb et al., 1999). Across the literature, the pattern of effects suggests that concrete lexical items engender more activity during semantic access when encountered out of context, perhaps because concrete words tend to have more associated

feature information (e.g., Kounios & Holcomb 1994), which might be expected to increase baseline N400 amplitudes (see review in Federmeier and Laszlo, in press). However, placing concrete and abstract words into supportive contexts that tend to preactivate many of the target words' features should reduce the magnitude of this difference, as Holcomb et al. (1999) have shown. Furthermore, when concrete and abstract words are themselves used as *context* for upcoming words, the richer semantic feature information elicited by concrete words (as for the adjectives in the present study) can actually provide a more constraining context for accessing related features of upcoming words. The increased expectancy created by these more constraining contexts would then be expected to lead to N400 amplitude reductions, as seen in the present data for the same target nouns preceded by concrete and abstract adjectives.

The LH, then, seems to treat concrete and abstract words in a qualitatively similar fashion, with differences arising only on the amplitude of components that are obligatorily elicited by all visually-presented content words. A very different pattern, however, is seen when processing of the same stimuli is biased to the RH. In that case, nouns used in a concrete sense elicit a sustained frontal negativity. As discussed, similar sustained frontal negativities have been observed in prior studies of concreteness, as well as studies of mental imagery (Farah et al., 1989)[2]. In past studies, concreteness effects over frontal sites have often been found to onset earlier (~300 ms) than those in the present study, which were observed between 500 and 900 ms. However, in those studies overlap with the frontal part of the concurrent N400 concreteness effect made the true onset of the sustained frontal negativity difficult to assess. The present results support West and Holcomb's (2000) findings that the frontal effect specifically related to imagery (which they term the “N700”) onsets later.

Importantly, in the present study, this effect arose without instructions or task demands that would bias participants to image, thus suggesting that this process is naturally elicited by the RH when language stimuli are read for meaning, as long as the words can be linked to a coherent conceptual representation. In support of the dual coding hypothesis (Paivio, 2007), the current findings provide a critical link between data suggesting that sensory imagery processes play a role in concreteness effects (Paivio, 1991) and data pointing to RH contributions to the processing of concrete words (Day, 1977; Jones-Gotman and Milner, 1978; Schack et al., 2003; Shallice and Warrington, 1975). Our data are consistent with those of a recent magnetoencephalographic (MEG) study, which found concreteness-related activations between 550 and 700 ms in RH occipital and parietal areas, which the authors linked to imagery (Dhond et al., 2007). The findings of the present study not only support a link between concreteness effects and RH brain areas and processes involved in imagery, but further suggest that the involvement of the RH in language processing is critical for *initiating* such imagery, as the frontal negativity was not observed when processing was biased toward the LH.

The present data thus provide strong evidence that concreteness effects arise at multiple processing stages mediated by distinct cognitive and neural mechanisms. The LH, well-known to be critical for language processing, clearly derives meaning from both concrete and abstract words and seems to do so in qualitatively similar ways that are nonetheless sensitive to factors that render these word types more or less constrained, expected, or otherwise easy or difficult to process in different contexts. Concrete words and concepts, however, also seem to elicit qualitatively different processing, in the form of mental imagery that creates the rich sensory experience that often accompanies language comprehension. And, strikingly, it is the RH that appears to be critical for mediating this uniquely human ability to mentally recreate kings and horses from words created several centuries in the past.

[2]Farah et al. found a slow sustained positivity with a focus over occipital and posterior temporal regions associated with imagery. However, they used Fpz as their reference rather than the more traditional mastoid reference employed in the current study. When the present data are rereferenced to Fpz, the effect observed with LVF/RH presentation shows the distributional pattern of Farah et al.

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Appendix

NOUNS	CONCRETE ADJECTIVE	CONCRETE ADJECTIVE	ABSTRACT ADJECTIVE	ABSTRACT ADJECTIVE
arms	bare	muscular	loving	clumsy
atmosphere	foggy	damp	tense	depressing
badge	embroidered	hexagonal	scouting	merit
banner	ragged	cloth	distracting	triumphant
baseball	stitched	round	exciting	professional
basketball	orange	bouncing	competitive	amateur
bath	porcelain	raised	evening	leisurely
beans	salted	stringy	cultivated	profitable
beer	frothy	cool	intoxicating	relaxing
belt	tan	braided	safety	seat
bible	leather	old	sacred	consoling
block	colored	stackable	city	residential
blood	red	congealed	royal	young
bolt	lead	rusted	unexpected	tremendous
book	green	thick	interesting	engaging
box	tin	hinged	penalty	batting
brain	slimy	bloody	intelligent	shrewd
breakfast	sticky	sweet	early	hurried
brunch	cheesy	burnt	weekly	family
brush	bristly	plastic	tentative	suggestive
certificate	cardboard	printed	validated	valuable
chain	aluminum	clanking	restaurant	supermarket
chicken	fried	breaded	juvenile	pet
church	wooden	painted	traditional	orthodox
class	crowded	large	boring	easy
coat	fur	zippered	protective	first
coffee	dark	bitter	energizing	invigorating
company	nearby	busy	welcome	respectable
cotton	off-white	fluffy	breathable	absorbent
country	grassy	fragrant	civilized	invaded
crown	weighty	jeweled	reigning	powerful
diary	flowered	closed	secret	personal
dictionary	dusty	blue	authoritative	updated
disc	thin	circular	confidential	missing
dish	styrofoam	chipped	tempting	seafood
display	long	multicolored	entertaining	engineering
drain	steel	clogged	serious	unyielding
dress	purple	flowered	native	ceremonial
duck	chopped	seasoned	wild	inbred
ears	bumpy	protrudung	critical	musical
earth	sandy	black	orbiting	fragile
encyclopedia	hardback	heavy	informative	exhaustive
eyes	bloodshot	almond	accusing	wise
factory	clean	unfinished	unionized	uncaring
farm	hilly	fenced	productive	organic
feast	warm	meaty	joyful	holiday
fingers	slim	crooked	artistic	skillful
floor	carpeted	squeaky	dance	upper
flyer	yellow	crumpled	simplistic	religious
foot	slender	tapering	restless	dominant
football	brown	oblong	violent	youth
goal	rectangular	striped	realistic	ultimate
hall	dim	narrow	banquet	community
hand	chubby	soft	agile	helping
head	oval	bald	capable	clear
heart	pounding	enlarged	kind	broken
hospital	two-story	brick	teaching	rural
hotel	shabby	bright	accommodating	friendly
iron	hot	steaming	magnetic	oxidized
jungle	humid	dense	confusing	disorganized
lamb	skewered	charbroiled	newborn	naïve
laundry	dirty	smelly	tedious	simple
leg	skinny	hairy	flexible	frail
letter	capital	cursive	anonymous	classified
library	glass	spacious	extensive	organized

NOUNS	CONCRETE ADJECTIVE	CONCRETE ADJECTIVE	ABSTRACT ADJECTIVE	ABSTRACT ADJECTIVE
lunch	greasy	cold	free	late
magazine	glossy	torn	humorous	news
medal	polished	bronze	prestigious	service
medicine	liquid	flavored	required	helpful
mouth	wide	wet	cruel	foul
museum	quiet	huge	fascinating	history
music	noisy	shrill	popular	memorable
newspaper	inky	tattered	liberal	daily
nose	pimply	pudgy	sensitive	expert
oak	sanded	carved	deciduous	majestic
oil	gooey	slippery	lucrative	crude
painting	framed	pastel	classical	famous
path	winding	rocky	true	unknown
picture	creased	symmetrical	hilarious	treasured
pill	tiny	powdery	beneficial	prescription
pin	metallic	shiny	honorific	military
plaque	maple	engraved	official	awarded
plate	ceramic	decorated	salad	healthy
poster	colorful	laminated	complicated	scientific
prize	wrapped	silver	academic	common
rattle	lavender	rubber	ominous	warning
record	grooved	scratched	unbeatable	world
rice	puffy	clumped	growing	planted
school	one-room	dingy	specialized	art
shelter	underground	chilly	insufficient	necessary
show	loud	gaudy	educational	funny
shower	marble	roomy	quick	refreshing
sign	triangular	bent	encouraging	supernatural
slide	muddy	twisting	winning	gutsy
snack	salty	crunchy	hasty	cheap
speech	nasal	lisping	stirring	emotional
spot	oily	light	secluded	peaceful
step	steep	concrete	important	final
stone	smooth	mossy	quarried	landscaping
supper	bland	soupy	cheerful	casual
tape	adhesive	transparent	revealing	security
television	flat	square	repetitive	dramatic
thesaurus	paperback	worn	comprehensive	scholarly
thread	scratchy	frayed	aimless	typical
tongue	pink	rough	strange	foreign
track	dirt	stony	correct	fast
trophy	ornate	brass	coveted	sports
turkey	baked	marinated	aggressive	domesticated
university	ugly	sprawling	pricey	private
vision	blurred	cloudy	disturbing	eerie
volleyball	white	patterned	beach	active
wood	splintered	cut	spooky	enchanted

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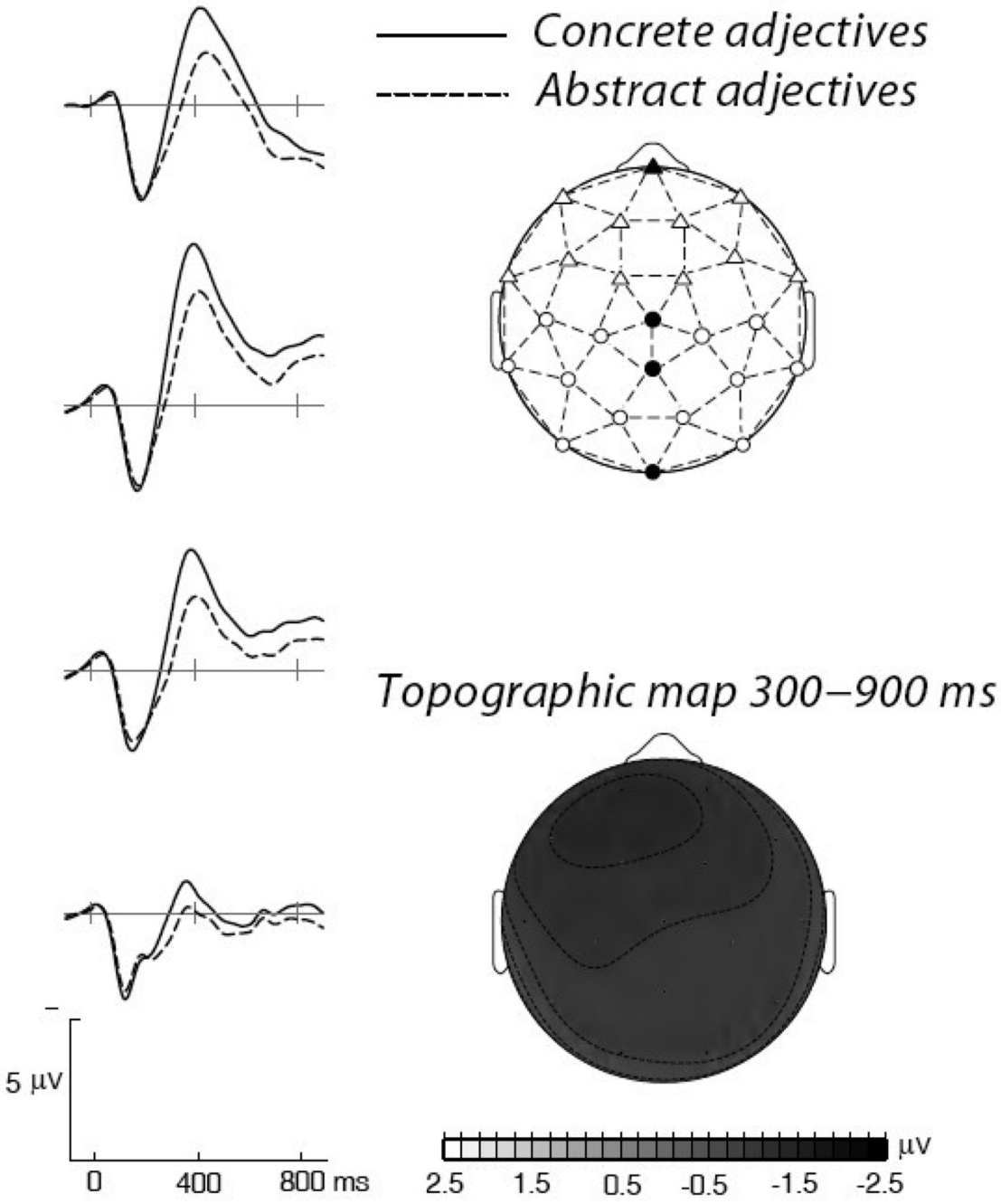

Figure 1.
Grand average ERPs to concrete (e.g., “green”) and abstract (e.g., “interesting”) adjectives are shown at four electrode sites (left side of the figure). The distribution of the concreteness effect (response difference between concrete and abstract adjectives) between 300 and 900 ms is shown on the topographic plot (lower right).

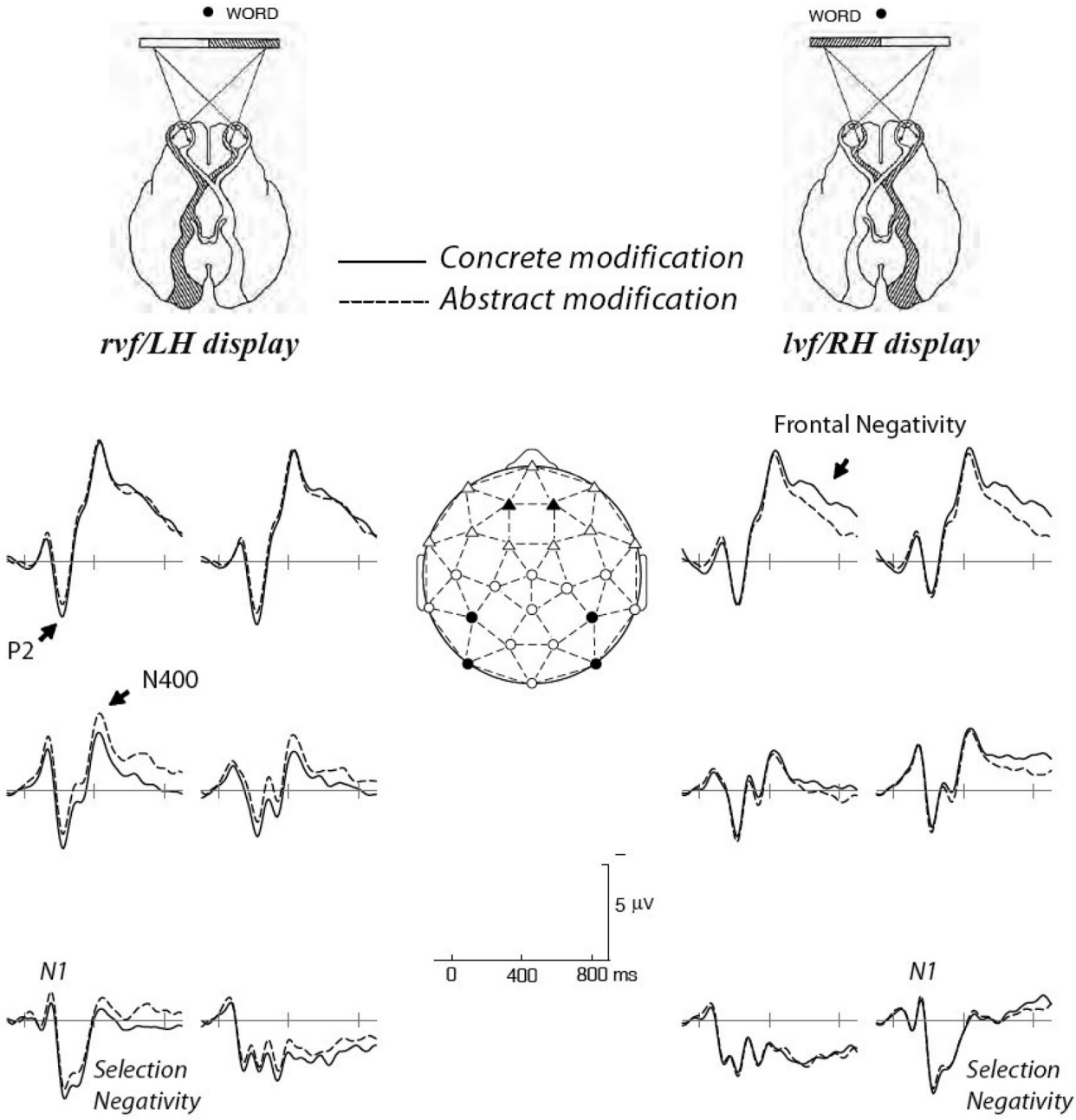

Figure 2.

Grand average ERPs to concretely and abstractly modified nouns presented in the RVF/LH (at left) and LVF/RH (at right) are shown at six representative electrode sites (positions indicated by darkened shapes on the head diagram). Arrows highlight the experimental effects. With RVF/LH presentation, concretely modified nouns elicited enhanced P2 and reduced (more positive) N400 responses. In contrast, with LVF/RH presentation, concrete modification was associated with a sustained frontal negativity. Over occipital sites (at bottom) basic effects of stimulus lateralization are apparent (labels in italics). In particular, sensory components such as the N1 are larger and earlier contralateral to presentation VF, and are followed by a contralateral selection negativity that continues throughout the recording epoch.

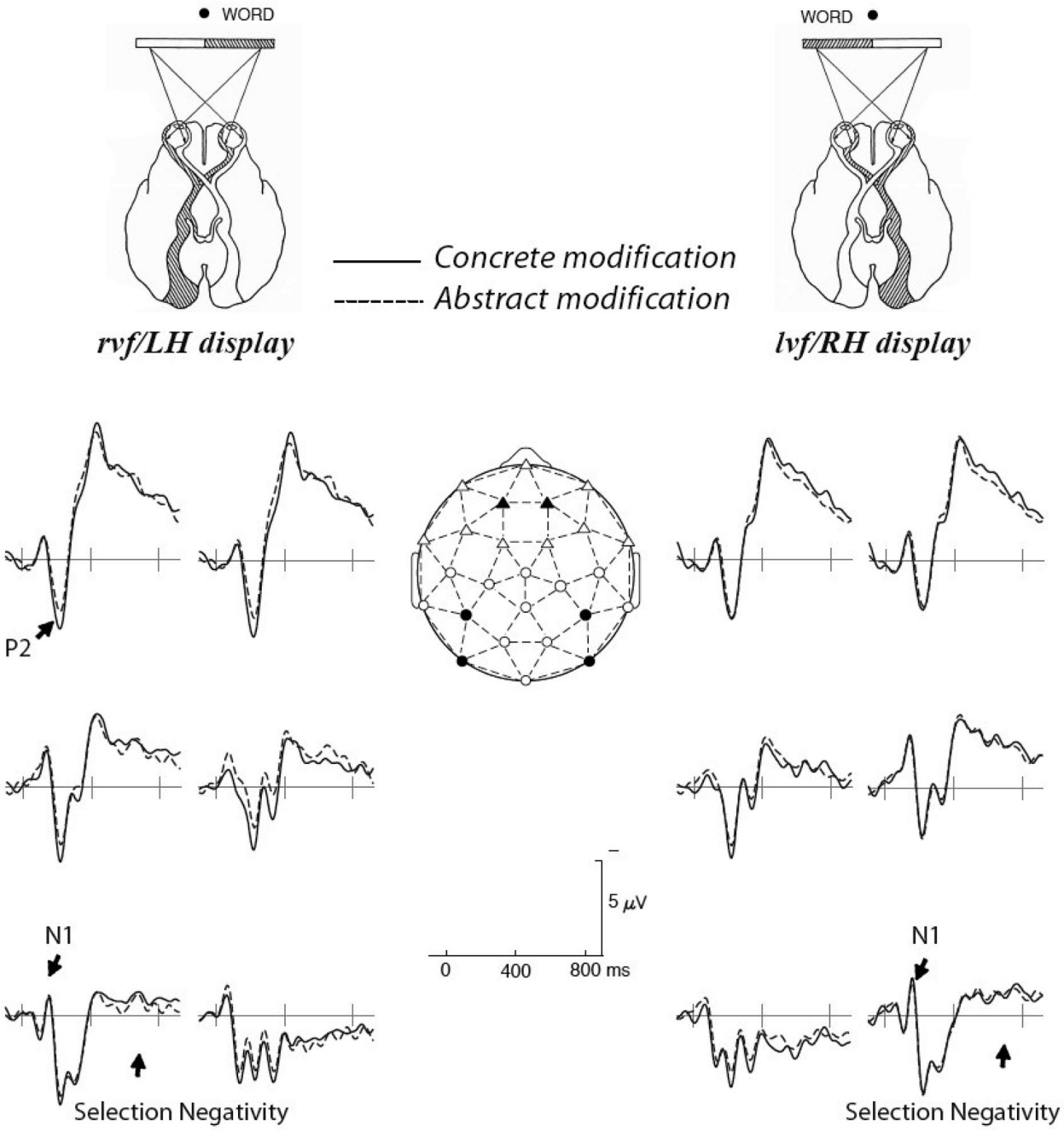

Figure 3.

Table 1

Example stimuli and list structure

List 1					
Adjective type	***Adjective***	***Noun***	***Probe Adjective***	***Probe Adjective type***	***VF of the noun***
concrete	green	book	thick	*concrete*	
concrete	pimply	nose	expert	*abstract*	LVF
abstract	productive	farm	organic	*abstract*	(RVF in List 3)
abstract	native	dress	purple	*concrete*	
concrete	hilly	farm	fenced	*concrete*	RVF
concrete	flowered	dress	ceremonial	*abstract*	(LVF in List 3)
abstract	interesting	book	engaging	*abstract*	
abstract	sensitive	nose	pudgy	*concrete*	
List 2					
Adjective type	*Adjective*	*Noun*	*Probe Adjective*	*Probe Adjective type*	*VF of the noun*
concrete	pimply	nose	pudgy	*concrete*	
concrete	green	book	engaging	*abstract*	LVF
abstract	native	dress	ceremonial	*abstract*	(RVF in List 4)
abstract	productive	farm	hilly	*concrete*	
concrete	purple	dress	flowered	*concrete*	RVF
concrete	fenced	farm	organic	*abstract*	(LVF in List 4)
abstract	sensitive	nose	expert	*abstract*	
abstract	interesting	book	thick	*concrete*	

Table 2

Endorsement rates for the first and second adjectives across conditions and visual fields (C=concrete, A=abstract, U=unrelated, and R=related).

	Critical trials								Filler trials			
Conditions	**CC**		**CA**		**AA**		**AC**		**RU**		**UR**	
Endorsed ADJ	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
LVF/RH nouns (%)	48	52	48	52	48	52	53	47	83	17	19	81
RVF/LH nouns (%)	47	53	50	50	47	53	50	50	89	11	14	86