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A "concrete view" of aging: Event related potentials reveal age-related changes in basic integrative processes in language

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Abstract

Normal aging is accompanied by changes in both structural and functional cerebral organization. Although verbal knowledge seems to be relatively stable across the lifespan, there are age-related changes in the rapid use of that knowledge during on-line language processing. In particular, aging has been linked to reduce effectiveness in preparing for upcoming words and building an integrated sentence-level representation. The current study assessed whether such age-related changes extend even to much simpler language units, such as modification relations between a centrally presented adjective and a lateralized noun. Adjectives were used to elicit concrete and abstract meanings of the same, polysemous lexical items (e.g., "green book" vs. "interesting book"). Consistent with findings that lexical information is preserved with age, older adults, like younger adults, exhibited concreteness effects at the adjectives, with more negative responses to concrete adjectives over posterior (300–500 ms; N400) and frontal (300–900 ms) channels. However, at the noun, younger adults exhibited concreteness-based predictability effects linked to left hemisphere processing and imagery effects linked to right hemisphere processing, contingent on whether the adjectives and nouns formed a cohesive conceptual unit. In contrast, older adults showed neither effect, suggesting that they were less able to rapidly link the adjective–noun meaning to form an integrated conceptual representation. Age-related changes in language processing may thus be more pervasive than previously realized.

Keywords

Aging; Language processing; Laterality; Concreteness effects; Event-related potentials; N400; Frontal imagery effects

1. Introduction

The processing of expressions denoting concrete concepts – i.e., those 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. For example, in young adults, concreteness has been shown to facilitate the identification and naming of words (Gerhand & Barry, 2000; Schwanenflugel, Harnishfeger, & Stowe, 1988), the comprehension of sentences (Belmore, Yates, Bellack, Jones, & Rosenquist, 1982; Holmes

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& Langford, 1976; Schwanenflugel & Shoben, 1983), and memory for linguistic material (Paivio, 1991; Paivio, Walsh, & Bons, 1994; Walker & Hulme, 1999). These advantages have been argued to arise because of the richer information provided by concrete expressions (Schwanenflugel, 1991; Schwanenflugel et al., 1988), the activation of sensory imagery processes (Paivio, 1991, 2007), or both (Schwanenflugel, 1991; Schwanenflugel et al., 1988).

Given the kinds of structural and functional changes that accompany normal aging (Hedden & Gabrieli, 2004), it might be supposed that concreteness affects processing differently across the lifespan. Age-related structural changes include volume reductions of prefrontal cortex and the hippocampus (Raz et al., 2005), and associated functional changes involve reductions in processing speed (Salthouse, 1996), impairments of executive function (West, 1996) and episodic memory (Small, 2001), and changes in the availability of certain language processing mechanisms (Wlotko, Lee, & Federmeier, 2010). As language and memory tasks get harder, then, do older adults rely on concreteness more? Or are they less able to make use of the processing mechanisms that underlie concreteness effects?

Although a good deal of behavioral research has addressed the question of how concreteness affects older adults' processing, the tasks that have been used in these studies are largely limited to the domain of explicit memory (and thus do not include the kind of language processing tasks that have been used with younger adults), and the results are mixed. Some studies report a memory advantage for concrete items that is similar across age groups (Rowe & Schnore, 1971; Whitbourne & Slevin, 1978), whereas others report an attenuation of this effect with age (Bruce, Coyne, & Botwinick, 1982; Rissenberg & Glanzer, 1987). One explanation offered for the disparity across studies is differences in task demands and, hence, the underlying neural circuits that need to be recruited. For example, those studies finding more of an effect of aging on concreteness effects have tended to use recollection-based tasks, which tap hippocampal functions, as opposed to more familiarity-based tasks (Peters & Daum, 2008). Another possible explanation involves the cognitive processing resources that participants allocate at the encoding stage (Dirkx & Craik, 1992). When the use of rote rehearsal or verbal strategies is stressed, concreteness effects have been found to be similar across age groups (Dirkx & Craik, 1992). However, when participants are encouraged to use imagery during encoding, concreteness effects – although present in both age groups – are smaller for older than younger adults (Dirkx & Craik, 1992; Rissenberg & Glanzer, 1987). Such dissociations might suggest that concreteness effects are multifaceted in nature.

Indeed, studies with young adults provide strong evidence that concreteness effects involve multiple mechanisms, which are differentially engaged by different types of stimuli and under different task conditions (e.g., Chiarello, Liu, & Shears, 2001). Event-related potential data have played a particularly important role in delineating these neurally and functionally dissociable effects. Holcomb and colleagues (Holcomb, Kounios, Anderson, & West, 1999; Kounios & Holcomb, 1994; West & Holcomb, 2000) have shown that concrete words elicit more negative-going potentials in the time window of the N400 (300–500 ms) over posterior electrode sites and a sustained frontal negativity from 300 ms up to 900 ms. The differing time courses and scalp distributions of these subcomponents of the ERP concreteness effect point to nonidentical neural generators, and, in fact, the two subeffects are functionally dissociable as well.

The more posterior (N400) part of the concreteness effect is consistent across word types, appearing similarly for nouns, adjectives, verbs, and class-ambiguous words (Huang, Lee, & Federmeier, 2010; Lee & Federmeier, 2008). This part of the ERP concreteness effect is also sensitive to context: when concrete and abstract words are placed into constraining sentence contexts (Holcomb et al., 1999; Swaab, Baynes, & Knight, 2002) or are repeated (Kounios & Holcomb, 1994), the baseline N400 amplitude differences between these word types are attenuated or eradicated. Given that the N400 is part of the normal response to words of all types and has been linked to semantic access processes (e.g., Federmeier & Laszlo, 2009), concreteness effects on this component seem consistent with suggestions that, out of context, concrete words elicit richer semantic associations (Schwanenflugel, 1991; Schwanenflugel et al., 1988), and, hence, larger N400s. Constraining context information, however, activates many of the features of these words prior to their encounter (e.g., Federmeier & Kutas, 1999), rendering them similarly facilitated.[1]

In contrast, the sustained frontal effect is sensitive to word type, appearing for nouns, adjectives, and unambiguous verbs, but not ambiguous words used as verbs (Lee & Federmeier, 2008). It is less sensitive to the availability of context information (Swaab et al., 2002) but is modulated by task demands, being larger for semantic and imagery tasks than for lexical decision (West & Holcomb, 2000). The sensitivity of the frontal effect to imagery-related manipulations, and the similarity of the distribution of the effect (when differences in choice of reference electrode across studies are taken into account) to effects seen during explicit visual imagery (Farah, Weisberg, Monheit, & Peronnet, 1989) jointly suggest that some aspects of concreteness effects arise from differences in the use of sensory imagery processes. This is consistent with the claims of dual-coding theory (Paivio, 1991, 2007), which attributes concreteness-based processing differences to qualitative differences in the availability of imagery-based representations for concrete and abstract expressions.

Further evidence for the multifaceted nature of concreteness effects comes from work looking at hemispheric differences in sensitivity to concreteness. Huang et al. (2010) used adjectives to induce concrete and abstract readings of the same polysemous nouns (e.g. “green book” vs. “engaging book”), which were lateralized to the left or right visual field (LVF, RVF) in order to bias processing to the contralateral hemisphere. Concreteness effects on the initially presented adjective replicated prior studies using concrete and abstract nouns or verbs out of context (Holcomb et al., 1999; Kounios & Holcomb, 1994; Lee & Federmeier, 2008; West & Holcomb, 2000), with larger amplitude N400 responses and a sustained frontal negativity to concrete as compared with abstract adjectives. Effects at the lateralized noun then differed as a function of presentation visual field (VF). Consistent with the hypothesis that concrete words elicit richer semantic feature information, concrete adjectives served as more constraining contexts for the polysemous nouns, resulting in increased facilitation on the N400, as well as more positive frontal P2 responses, which have also been linked to contextual constraint effects (e.g., Wlotko & Federmeier, 2007). And, consistent with claims that the left hemisphere (LH) is better able to use predictive context information to prepare for the processing of upcoming words (see reviews by Federmeier, 2007 and Federmeier, Wlotko & Meyer, 2008), these concreteness effects were seen only with presentation to the RVF/LH. No frontal negative concreteness effect was observed with RVF/LH presentation. In contrast, when processing was initially biased to the right hemisphere (RH), there was no effect of concreteness on the N400 (or P2), but nouns preceded by concrete adjectives did elicit a sustained frontal negativity between 500 and 900 ms. The RH therefore seems to play a important role in mediating the part of the ERP concreteness effect that has been associated with mental imagery (e.g., West & Holcomb, 2000, who refer to this effect as the “N700”), consistent both with claims from dual coding

[1]Note that the attenuation of the N400 concreteness effect in the presence of context information is, on the surface, consistent with the predictions of the context availability hypothesis (Schwanenflugel, 1991; Schwanenflugel et al., 1988). However, whereas context availability posits that this attenuation occurs because context augments the relatively impoverished semantic representations of abstract words, thereby rendering them more like concrete words, the N400 pattern instead suggests that context facilitates the semantic processing of both word types, but causes relatively more facilitation (N400 amplitude reduction compared to the out of context baseline) for concrete words.

(Paivio, 2007) and with findings from the more general literature on imagery (e.g., Ehrlichman & Barrett, 1983; Kosslyn, 1987).

Thus, the Huang et al. (2010) study provides further evidence that concreteness effects arise at multiple processing stages mediated by distinct cognitive and neural mechanisms. Moreover, this study shows that the kind of concreteness effects that have been seen at the single word level, assessed across different lexical items, can also be found at the compositional level, on the same lexical items as a function of whether modifying contextual information calls up more concrete or abstract features of that word. Both the LH N400 effect and the RH frontal negativity effect were clearly driven by the concreteness of the unified conceptual representation, as evidenced by the fact that both effects were absent when the concrete or abstract adjective could not be meaningfully integrated with the noun (e.g., *watery glove* vs. *loyal glove*). In revealing multiple kinds of concreteness effects (i.e., some associated with general semantic processing and others with sensory imagery) that manifest at different levels (lexical and compositional), the Huang et al. (2010) design provides a good starting point for examining whether the inconsistent effects of aging on concreteness effects found across prior studies using behavioral measures might have arisen because the multiple processing differences associated with concreteness are differentially affected by normal aging.

For example, it has been shown that word-level knowledge and processing remains relatively stable with age, as assessed off-line by word associations (Burke & Peters, 1986; Howard, 1980; Lovelace & Cooley, 1982) and online by semantic priming, measured either behaviorally or via electrophysiological measures (Burke, White, & Diaz, 1987; Federmeier, Schwartz, Van Petten, & Kutas, 2003; Laver & Burke, 1993). In contrast to this relative preservation of lexical level processing, however, the ability to rapidly integrate information to form a coherent sentence-level representation has been found to be substantially delayed and altered in mechanism in older adults (e.g., Cameli & Phillips, 2000; Federmeier & Kutas, 2005; Federmeier et al., 2003; see review by Wlotko et al., 2010). This suggests that word level concreteness effects are likely to remain relatively preserved with age, whereas concreteness effects arising at a compositional level, based on information integrated across more than one word, may be more affected.

With respect to imagery, studies of aging have shown in general that the ability to generate and manipulate even simple mental images (e.g., of single letters or simple geometric patterns) declines somewhat with age (Dror & Kosslyn, 1994; Johnson & Rybash, 1993). However, aging does not have uniform effects on imagery. Specifically, processes used to add simple segments to an image and those used to scan an imaged object do not degrade as much over age as other processes, such as those used to activate stored representation during image generation and to rotate imaged objects (Dror & Kosslyn, 1994), which have also been linked to the availability of working memory resources (Briggs, Raz, & Marks, 1999; Raz, Briggs, Marks, & Acker, 1999). Perhaps most important in the context of the present study is that, when verbal stimuli are used, older adults seem less likely to spontaneously engage imagery (e.g., when learning concrete nouns: Hulicka & Grossman, 1967), consistent with more general findings of age-related decline in self-initiated processing (Craik, 1983). These age-related differences decrease when older adults are explicitly instructed to image (Robertson-Tchabo, Hausman, & Arenberg, 1976; Treat & Reese, 1976), but, given that even under these conditions age-related differences are often still apparent (Dirkx & Craik, 1992), it remains an open question whether older adults are simply less likely to image or are also less able to image or less able to use imagery to affect other aspects of cognitive processing.

Therefore, to examine how concreteness effects change with age across both the lexical and compositional levels, in the current study we used the materials and procedure from Huang et al. (2010) with neurologically normal older adult participants. Given the typical finding that word-level processing remains relatively intact with age, we predict that older adults will show the canonical pattern of lexical-level ERP concreteness effects on the initial adjective (including larger N400 responses and a sustained frontal negativity to concrete as compared with abstract words); to our knowledge, these basic word-level ERP concreteness effects have never been assessed in older adults. However, we expect to see more dramatic age-related differences in concreteness effects at the compositional level. Assuming that older adults' diminished ability to use context information to anticipate and prepare to process likely upcoming words applies even at the level of an adjective–noun pair, we expect RVF P2 and N400 concreteness effects at the lateralized noun to be diminished or absent in the older adult sample. Finally, if older adults are less likely or less able to generate complex images in response to verbal information – and, in particular, if imagery effects at the compositional level require a stable, message-level semantic representation that older adults are slower to obtain – then we also expect the frontal negativity concreteness effect associated with LVF processing to be reduced or eliminated.

2. Methods

2.1. Participants

Twenty older adults (12 females and 8 males, mean age 65 years, range 60–81 years) participated in the study and were compensated with cash. Participants provided written, informed consent, and all procedures were approved by the University of Illinois at Urbana-Champaign Institutional Review Board. All participants were healthy, monolingual English speakers, with normal or corrected-to normal vision and no history of neurological or psychiatric disorders. They were all right-handed, as determined by the Edinburgh inventory (Oldfield, 1971); 11 reported having left-handed family members. Participants were educated for 17.8 years on average. They scored in the normal range on screening for cognitive impairment (average Mini Mental State Exam score: 29, range 26–30; Folstein, Folstein, & McHugh, 1975) as well as on verbal fluency and reading span measures (described below).

2.2. Materials

The stimuli were the same as those used in Huang et al. (2010), and consisted of 112 polysemous nouns paired with adjectives that modulated the concreteness of the referent concept. 32% of the critical nouns also had a verb usage; however, for those items, the frequency of use as a noun (mean 50) was greater than the frequency of use as a verb (mean 18) (Fellbaum, 1998). An adjective referring to physical aspects of the noun (e.g., *thick book*) was used to induce a concrete reading, whereas an adjective referring to features that are less available to the senses (e.g., *engaging book*) was used to induce an abstract reading. Each noun was paired with four adjectives, two of which created a concrete reading and two of which created an abstract reading, resulting in a final set of 448 adjective–noun pairs. The perceived concreteness of the adjective–noun pairs was determined by a norming study. For a more detailed description of the concreteness norming, please refer to Huang et al. (2010).

Critical items were divided evenly into two sets, each of which contained 112 concrete adjective–noun pairs and 112 abstract adjective–noun pairs. Adjective–noun pairs were followed by probe adjectives (drawn from the same normed set, half concrete and half abstract), which were used for a modification appropriateness judgment task. Within a set, nouns were repeated once across visual field (separated by at least 100 intervening trials), appearing once in a concrete pairing and once in an abstract pairing. Two lists were created from each set; these lists were identical except that the visual field of presentation of each item was reversed. These four lists were then used to create another four lists in which the critical and probe adjectives were swapped. To each of the lists, an additional 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 visual field, always with different modifying adjectives. Stimuli were randomized once for each list and presented to participants in the same order. In total, then, each participant saw 392 triplets, which included 56 concrete adjective–noun pairs, 56 abstract adjective–noun pairs and 84 filler trials in each visual field. Table 1 provides examples of stimuli and list structure.

2.3. Procedure

Participants viewed the stimuli while seated 1 m in front of a computer screen in a dimly lit room. They were told that a series of three words would appear on each trial; the first and third words were centrally presented adjectives and the second word was a lateralized noun. Participants were instructed to read each word without moving their eyes from central fixation. Their task was to decide which adjective seemed more appropriate as a description of the noun. They registered their response with a button press; the hand used to indicate “first” or “second” was counterbalanced across participants.

The experiment began with a 20-trial practice session to familiarize participants with the task and the experimental environment. A small fixation square (3 by 3 pixels) was presented a few pixels below the center of the screen throughout the experiment to help participants maintain central fixation. At the start of each trial, four horizontally adjacent plus signs appeared slightly above the fixation square for 500 ms. After a stimulus onset asynchrony (SOA) ranging randomly between 800 and 1300 ms (a random SOA was used in order to decrease the contribution of slow, anticipatory activity to the ERP), the adjective was presented centrally for 500 ms, followed by 500 ms of blank screen. The noun was then presented for 200 ms, with its inner edge 2° to either the left or right of the fixation and subtending 4° (range: 2.69–5.44°) of visual angle. Noun presentation was followed by a blank screen for 1000 ms, and the second adjective was then presented centrally for 500 ms. One second after the offset of the second adjective a question mark appeared on the screen, indicating that participants should register their response. There were eight blocks of trials, with 49 trials per block. Between blocks, participants took a short break.

At the conclusion of the testing session, participants were administered a short battery of neuropsychological tests that measured verbal fluency (letter and category; Benton & Hamsher, 1978), and reading span (Daneman & Carpenter, 1980). On average, the participants generated 49.9 words (range: 28–77) on the letter fluency portion and 64.8 words (range: 47–88) on the category fluency portion. Mean verbal fluency (letter and category combined) was 115 (range: 78–159). This score is comparable to the performance of age and education matched samples (Tombaugh, Kozak, & Rees, 1999). The average reading span score was 2.9 (range: 2–4.5), comparable to the performance of educated older adults previously reported in studies using the same test (e.g., Federmeier & Kutas, 2005).

2.4. EEG recording and data analysis

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 placed on the outer canthus of each eye. Blinks were detected by an electrode placed below the left eye. Signals were amplified with a 0.02–100 Hz bandpass filter and digitized at a rate of 250 Hz. Data were referenced online to the left mastoid and rereferenced offline to the average of the left and right mastoids. For averaging, 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, using thresholds set for individual subjects based on visual inspection of the data. Particular care was taken to reject all trials with any eye movement activity during the 200 ms presentation of the lateralized noun, in order to ensure the validity of the visual field manipulation. Average trial loss was 7% for the adjectives and 13% for the lateralized nouns. A digital band-pass filter of 0.2–20 Hz was employed before statistical analyses were performed. For all analyses, the main effects of electrode and interactions with electrode site are reported only when of theoretical significance.

3. Results

3.1. Behavior

Response accuracy was computed for fillers with one anomalous adjective (in which, unlike for the experimental stimuli, one answer is clearly more correct). In general, responses were quite accurate (mean 81%; range 60–100%), showing that participants were attending to the stimuli and able to apprehend the lateralized nouns. Responses were more accurate in the RVF (85%) than in the LVF (78%) [$F(1,19) = 7.9$, $p < .01$], consistent with findings of more efficacious word apprehension by the LH (e.g., Jordan, Patching, & Thomas, 2003).

Older adults' behavioral performance was numerically slightly lower than the performance of young adults in our prior study (Huang et al., 2010). For young adults, the mean accuracy was 84% (their responses were also more accurate in the RVF [88%] than in the LVF [82%]). However, an ANOVA with the between-subject factor of age (younger adults, older adults) and two within-subject factors of VF (RVF, LVF) and filler type (related/unrelated, unrelated/related) showed only a significant main effect of VF [$F(1,50) = 15.92$, $p < .001$], but no reliable main effect of age [$F = 2$] or filler type [$F = 1$]. The effect of age also did not interact with VF or filler type [Fs < 1].

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, and abstract/concrete), and adjective position (first, second) conducted on the endorsement rates revealed no significant effects or interactions. As was also true for young adults in Huang et al. (2010), older adult participants chose concrete and abstract adjectives (LVF/RH: 51%, 49%, RVF/LH: 51%, 49%, respectively) and those before and after the critical nouns (LVF/RH: 50%, 50%, RVF/LH: 49%, 51%, respectively) in approximately equal proportions.

3.2. ERP effects on centrally presented adjectives

Our prior study showed that younger adults elicited more negative N400s and a sustained frontal negativity to concrete adjectives in comparison to abstract adjectives. Therefore, we compared ERP responses to the initial adjectives (Fig. 1). Following early sensory components typical of visual word presentation, a negativity (N400) peaking at 415 ms post-stimulus-onset (not significantly different from the 410 ms latency of the N400 in young adults in Huang et al., 2010) is evident and is more negative for concrete than abstract adjectives. Over frontal sites, an enhanced negativity to concrete adjectives can be seen between 300 and 900 ms.

Effects were analyzed separately over the 15 posterior sites and the 11 frontal sites (marked in Fig. 1). Mean amplitude of the N400 was measured between 300 and 500 ms over posterior electrodes and subjected to a repeated measures analysis of variance (ANOVA) with concreteness and electrode as factors. There was a main effect of concreteness [$F(1,19)$

= 17.49; $p < .001$], with more negative responses to concrete as compared with abstract adjectives. Effects over frontal sites were evident between 300 and 500 ms [$F(1,19) = 30.66$; $p < .001$] and 500 and 900 ms [$F(1,19) = 16.65$; $p < .001$], again in the form of enhanced negativity to more concrete words. Thus, similar to effects seen for younger adults, concrete adjectives are associated with larger N400s and a sustained frontal negativity.

To compare the concreteness effects from the older adults and younger adults reported in our previous study (Huang et al., 2010), difference waves were calculated by taking a point by point subtraction of the ERP response to abstract adjectives from the ERP response to concrete adjectives. Mean amplitudes between 300 and 500 ms (15 posterior sites and 11 frontal sites) and 500 and 900 ms (11 frontal sites) were measured and then subjected to *t*-tests with age as a between-subject factor. Results revealed significant age effects limited to responses in the N400 time window [posterior: $t(1,50) = -2.4$; $p < .05$, frontal: $t(1,50) = -2.2$; $p < 05$]. Concreteness effects were reduced between 300 and 500 ms but not 500 and 900 ms [$t(1,50) = -0.22$; $p = .8$] for older adults.

3.3. ERP effects on lateralized nouns

3.3.1. Visual N1 and selection negativity—To assess whether the lateralized presentation of the words was effective in stimulating the contralateral hemisphere, ERPs to all words presented to the LVF vs. the RVF were measured at 8 electrode sites (LLTe, LDPa, LLOc, LMOc, RLTe, RDPa, RLOc and RMOc) during the time window of the visual N1 (100–200 ms), and were subjected to an ANOVA with factors of VF (LVF vs. RVF), hemisphere (right vs. left recording sites) and electrode site (4 lateral and posterior sites in each hemisphere). The results revealed the expected interaction between VF and hemisphere [$F(1,19) = 89.4$, $p < .001$]. The N1 was larger over right than left recording sites (−1.7 μV vs. −0.3 μV) when words appeared in the LVF, and showed the reverse asymmetry (0.2 μV vs. −1.6 μV) when words appeared in the RVF (Fig. 2). To compare older adults' N1 responses with those of younger adults (Huang et al., 2010), an ANOVA with age as a between-group factor and VF, hemisphere, and electrode site as within-subject factors was conducted. The results showed an interaction between VF and hemisphere [$F(1,50) = 113.4$, $p < .001$], but no reliable main effect of age, and no interaction of age with other factors [*F*s ≤ 2].

In addition to the N1, previous studies measuring ERPs to lateralized visual stimuli have reported a sustained late negative-going effect over lateral and posterior scalp sites contralateral to the VF of stimulus presentation in young adults (Coulson & Van Petten, 2007; Coulson, Van Petten, Federmeier, & Kutas, 2005), and we also observed a similar effect in this study. To characterize this negative-going process, mean amplitude measures from 300 to 900 ms were taken from the same 8 electrode sites and were subjected to an omnibus ANOVA with factors of VF (RVF vs. LVF), hemisphere (right vs. left recording sites) and electrode site. As expected, VF and hemisphere interacted [$F(1,19) = 49.9$, $p < .001$]. Stimuli presented to the LVF elicited more negative ERPs over right lateral posterior sites, and stimuli presented to the RVF elicited a mirror image pattern of responses. An ANOVA with age as a between-group factor and VF, hemisphere, and electrode site as within-subject factors revealed an interaction between VF and hemisphere [$F(1,50) = 59.5$, $p < .001$]. The main effect of age was also significant [$F(1,50) = 6.8$, $p < .05$], as older adults' responses were less negative than younger adults', but age did not interact with other factors [*F*s ≤ 2].

3.3.2. Concreteness effects at the compositional level—Concreteness effects were again analyzed on the N400 (posterior channels, 300–500 ms) and frontal negativity (frontal channels, 500–900 ms), using ANOVAs with concreteness (concretely vs. abstractly modified) and electrode site (11 frontal or 15 posterior) as factors in each VF. In addition, analyses were conducted on the frontal P2 (170–300 ms), an ERP component related to high-level visual processing and visuospatial attention, which has been shown to be sensitive to context effects in a number of VF ERP studies from younger adults (Federmeier, Mai, & Kutas, 2005; Huang et al., 2010; Wlotko & Federmeier, 2007).

Fig. 3 shows the ERP responses to concretely and abstractly modified nouns in each VF from older adults. No concreteness effect reached significance on any components in either hemisphere. (With RVF/LH presentation: frontal P2 [$F(1,19) = 1.6$]; N400 [$F(1,19) = 1.4$]; and frontal negativity [$F(1,19) = 1.6$]. With LVF/RH presentation: frontal P2 [$F(1,19) = 0.6$]; N400 [$F(1,19) = 1$]; and frontal negativity [$F(1,19) = 0.2$]). Our prior study showed that younger adults exhibited concreteness-based predictability effects linked to left hemisphere processing and imagery effects linked to right hemisphere processing at the lateralized nouns. In striking contrast, older adults showed neither effect pattern in the current study.

To again directly compare the responses of older adults in this study with those of younger adults in Huang et al. (2010), mean amplitude differences between abstractly modified nouns and concretely modified nouns during the time windows of interest were analyzed in each visual field (RVF/LH: frontal P2 and N400; LVF/RH: frontal negativity) and were subjected to t-tests with age as a between-subjects factor. There was no main effect of age on the RVF P2 effect [$t(1,50) = 0.8$], although this effect was numerically smaller in the older adult sample (younger adults: 0.6 μV; older adults: 0.32 μV). However, there was a main effect of age on the (RVF) N400 [$t(1,50) = 2.7$, $p < .01$]. Whereas young adults showed a pattern suggesting that concrete adjectives provided a more predictive context for the lateralized noun (reducing N400 amplitudes), older adults showed a numerically reversed pattern (and thus more like an out-of-context concreteness effect). There was also a significant effect of age on the (LVF) frontal negativity [$t(1,50) = -2.2$, $p < .05$], which patterned numerically in the same direction for older adults as younger adults, but was considerably reduced in amplitude in the older sample (younger adults: −0.95 μV, older adults: −0.12 μV).

3.3.3. N400 congruity effect—Although no concreteness effects were significant on the lateralized nouns, it was not the case that older adults simply failed to show any effects at the lateralized noun position.[2] As can be seen in Fig. 4, older adults showed clear N400 congruity effects on the lateralized nouns in the fillers, when comparing cases in which the noun could or could not be meaningfully integrated with the preceding adjective (e.g., volcanic mountain vs. limpid mountain). Mean amplitude measures were taken from 300 to 500 ms at all 26 electrode sites and were subjected to an ANOVA with factors of VF, congruence, and electrode site. There was a significant main effect of congruence [$F(1,19) = 4.7$, $p < .05$] with less negative responses to congruous pairs, showing that participants were comprehending and integrating the adjective–noun pairings. This was true for presentation to both hemispheres, as there was no main effect of VF [$F = 2$], and VF did not interact with congruity [$F < 1$].

[2]In order to make sure that the absence of a concreteness effect at the compositional level is not due simply to difficulties processing lateralized nouns, we examined word-level concreteness effects for abstract and concrete lateralized nouns in data from another study (Meyer & Federmeier, 2010) that used some ($N = 9$) of the same participants (as the nouns in the present study were homogenously concrete). Mean amplitudes from 300 to 500 ms were subjected to an ANOVA with factors VF (LVF vs. RVF), concreteness (concrete vs. abstract), and electrode site, revealing a main effect of concreteness, significant even in this smaller sample [$F(1,8) = 9.93$, $p < .05$]. The pattern was identical to the lexical level concreteness effects seen on the adjectives in the present study, such that concrete lateralized nouns elicited more negative responses than abstract lateralized nouns. Thus, older adults manifest concreteness effects even for lateralized nouns, when concreteness arises at the lexical rather than at the compositional level.

Older and younger adults' N400 congruity effects were compared using an ANOVA with age as a between-subjects factor and VF and electrode site as within-subjects factors. There was no main effect of age [$F < 1$], showing that older adults elicited congruity effects of similar magnitude to those seen in younger adults. Peak latency of the N400 congruity effect was compared across groups at electrode MiPa. N400 peak latency was 407 ms for the young and 444 ms for the elderly participants [$F(1,50) = 4.3$, $p < .05$].

4. Discussion

In this study, we examined how neural mechanisms involved in the processing of concrete and abstract expressions at lexical (single word) and compositional (multiple word) levels change with age. At the sequence-initial adjective, older adults showed the pattern of ERP concreteness effects that has been well-replicated in younger adults across word types (Holcomb et al., 1999; Kounios & Holcomb, 1994; Lee & Federmeier, 2008; West & Holcomb, 2000), including the materials used in the present study (Huang et al., 2010). To our knowledge, this is the first study showing that older adults' lexical-level ERP concreteness effects are qualitatively similar to those from younger adults. Concrete adjectives elicited larger, posterior N400s and a sustained, frontally distributed negativity relative to abstract adjectives. This effect pattern has been interpreted as suggesting that concrete words elicit richer semantic feature information (N400) and engender more sensory imagery (frontal negativity) than do abstract words (West & Holcomb, 2000). The N400 part of the concreteness effect was reduced in amplitude in older adults as compared with younger adults, consistent with prior work showing that N400 effects become progressively smaller with advancing age (e.g., Kutas & Iragui, 1998). In contrast, the frontal negativity effect was not reduced with age, indicating that older adults, like younger ones, spontaneously elicit some sensory imagery in response to words. Because the images evoked from adjectives are relatively simple (i.e., often a single sensory property, such as color or volume), and aging effects on imagery have been found to depend on image complexity (Dror & Kosslyn, 1994), it is unclear whether larger age-related differences might be seen at the lexical level for more complex imagery, such as in response to nouns. Overall, however, lexical-level concreteness effects on the initial adjective are consistent with the body of evidence suggesting that word-level knowledge and processing are relatively well-maintained across age (e.g., Federmeier et al., 2003; Wlotko et al., 2010).

At the lateralized noun, we observed the typical effects of stimulus lateralization, showing that VF presentation was effective in stimulating the contralateral hemisphere. Furthermore, the behavioral patterns and the basic N400 congruity effects obtained in the filler trials attest that older adults could read the lateralized nouns, integrate them with the preceding adjectives, and judge their plausibility. The N400 congruity effect in older adults was, however, delayed in latency compared to the same effect in younger adults. N400 effect delays in older adults are commonly reported in sentence comprehension tasks (e.g., Federmeier et al., 2003; Gunter, Jackson, & Mulder, 1995) and have been linked to reduced working memory capacity or slowed processing. The current study shows that such delays manifest even for integration across pairs of words.

Strikingly, despite the fact that older adults elicited basic congruency effects at the noun with presentation to both VFs, no significant effects of concreteness were observed at the combinatorial level in the older adult sample. With RVF presentation, young adults showed a pattern suggesting that they used the adjectives to prepare for likely upcoming nouns and that the concrete adjectives provided a more constraining predictive context than did the abstract ones (Huang et al., 2010). Older adults, however, did not show this pattern, replicating prior sentence processing work, which has consistently found that older adults as a group are less likely to use contextual information to prepare for upcoming words in time for their arrival (Federmeier & Kutas, 2005; Wlotko et al., 2010). Thus, the findings are consistent with claims that older adults are less able or less likely to make use of predictive processing mechanisms during comprehension even when, as in the present study, working memory demands are relatively minimized (Federmeier, Kutas, & Schul, 2010). Age-related changes in the use of predictive processing mechanisms therefore seem to be quite pervasive, extending even to processing across a simple two-word phrase.

Older adults also failed to manifest the frontal negativity that was associated with RH-initiated processing in young adults. This failure to show imagery-related concreteness effects on the noun is notable given that these same older adults did manifest imagery effects on the adjectives. This may indicate that older adults are disproportionately impaired by increases in stimulus complexity (Dror & Kosslyn, 1994). That is, older adults may be able to form the kind of simple images that most adjectives would elicit (e.g., a color) but be impaired relative to younger adults at the more complex imagery required for a noun. Alternatively – or additionally – it may be that older adults have difficulty initiating imagery based on compositional level language information. In particular, eliciting an image likely requires a stable semantic representation (cf., Lee & Federmeier, 2008). The fact that older adults seem to build message-level meaning representations more slowly and less effectively, as evidenced by prior work looking at sentence processing and aging (Cameli & Phillips, 2000; Federmeier & Kutas, 2005; Federmeier et al., 2003; see review by Wlotko et al., 2010) and corroborated by the delays in the N400 congruency effects observed in the present study, may therefore result in imagery effects being significantly delayed or bypassed altogether. Further, if semantic integration is more resource-intensive for older than younger adults, then older adults may have a reduced capacity or tendency to engage additional processes, including imagery (Federmeier et al., 2010; Meyer & Federmeier, 2010). It would be interesting to examine whether these age-related differences are reduced if task demands or instructions explicitly encourage imagery (cf., Robertson-Tchabo et al., 1976; Treat & Reese, 1976).

In sum, we uncovered striking differences in the effect of aging on concreteness effects arising during language processing at the lexical as compared with the compositional level. At the lexical level, both semantic and imagery-based contributions to concreteness effects were qualitatively similar for older adults and younger adults, and, in fact, imagery-related effects were also quantitatively similar. In contrast, however, older adults failed to show any concreteness effects at the compositional level. This pattern is consistent with findings from sentence processing studies suggesting that older adults are less able to or less likely to (1) engage LH-dominant predictive processing mechanisms and (2) use message-level meaning information to initiate controlled processing, including RH-initiated processes associated with imagery. Taken together, this set of findings suggests that whether or not older adults will manifest the kind of behavioral concreteness-related benefits typically observed in the young will depend on task circumstances. Concreteness effects might be robust for concepts evoked through single words, especially those that are relatively easy to image. However, for concepts evoked at the message level, the fact that older adults are less able or less likely to spontaneously evoke images means that they may not experience the enhanced memory or other processing benefits that younger adults attain from the richer information available in concrete language.

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Appendix A

Nouns	Adj/concrete	Adj/concrete	Adj/abstract	Adj/abstract
Atmosphere	Foggy	Damp	Tense	Depressing
Basketball	Orange	Bouncing	Competitive	Amateur
Beer	Frothy	Cool	Intoxicating	Relaxing
Block	Colored	Stackable	City	Residential
Book	Green	Thick	Interesting	Engaging
Breakfast	Sticky	Sweet	Early	Hurried
Certificate	Cardboard	Printed	Validated	Valuable
Church	Wooden	Painted	Traditional	Orthodox
Coffee	Dark	Bitter	Energizing	Invigorating
Country	Grassy	Fragrant	Civilized	Invaded
Dictionary	Dusty	Blue	Authoritative	Updated
Display	Long	Multicolored	Entertaining	Engineering
Duck	Chopped	Seasoned	Wild	Inbred
Encyclopedia	Hardback	Heavy	Informative	Exhaustive
Farm	Hilly	Fenced	Productive	Organic
Floor	Carpeted	Squeaky	Dance	Upper
Goal	Rectangular	Striped	Realistic	Ultimate
Hall	Dim	Narrow	Banquet	Community
Hospital	Two-story	Brick	Teaching	Rural
Jungle	Humid	Dense	Confusing	Disorganized
Leg	Skinny	Hairy	Flexible	Frail
Lunch	Greasy	Cold	Free	Late
Medicine	Liquid	Flavored	Required	Helpful
Music	Noisy	Shrill	Popular	Memorable
Newspaper	Inky	Tattered	Liberal	Daily
Nose	Pimply	Pudgy	Sensitive	Expert
Painting	Framed	Pastel	Classical	Famous
Pill	Tiny	Powdery	Beneficial	Prescription
Plate	Ceramic	Decorated	Salad	Healthy
Record	Grooved	Scratched	Unbeatable	World
School	One-room	Dingy	Specialized	Art
Shower	Marble	Roomy	Quick	Refreshing
Speech	Nasal	Lisping	Stirring	Emotional
Stone	Smooth	Mossy	Quarried	Landscaping
Supper	Bland	Soupy	Cheerful	Casual
Television	Flat	Square	Repetitive	Dramatic
Tongue	Pink	Rough	Strange	Foreign
Trophy	Ornate	Brass	Coveted	Sports
University	Ugly	Sprawling	Pricey	Private
Wood	Splintered	Cut	Spooky	Enchanted

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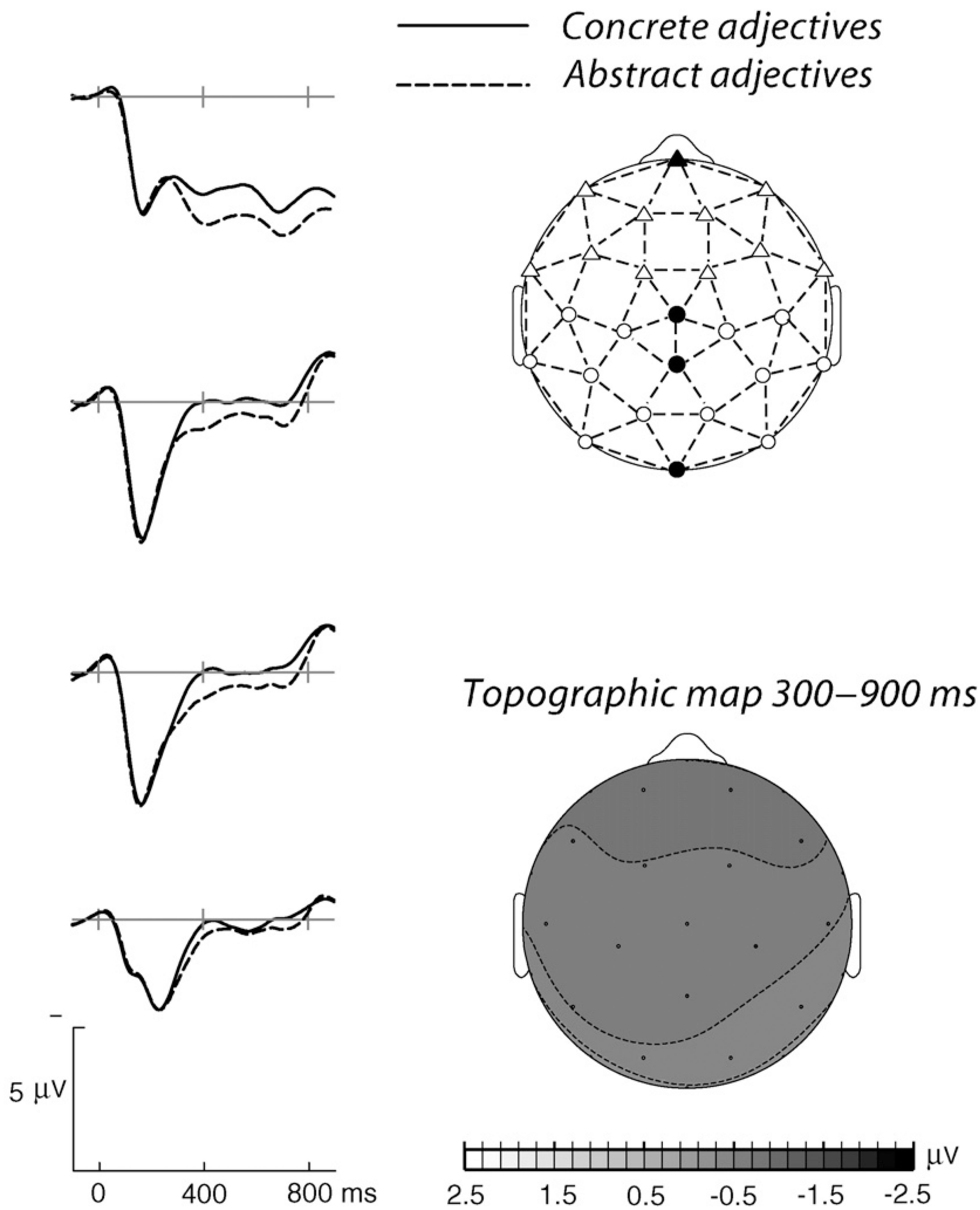

Fig. 1.

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).

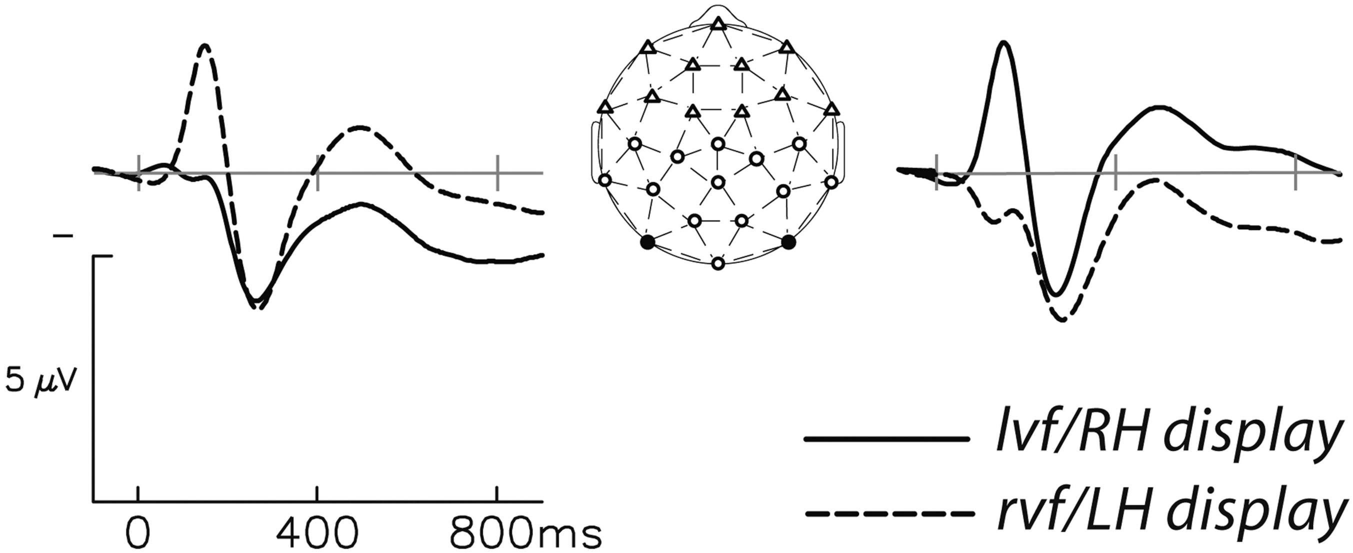

Fig. 2.

To show the general ERP effect of stimulus lateralization, responses to target words presented to the RVF and LVF are overplotted at left and right occipital sites indicated by darkened circles where such effects were largest. N1 responses (100–200 ms) are largest contralateral to VF of presentation and are followed from about 300 ms by an extended negative-going effect that is also largest contralaterally.

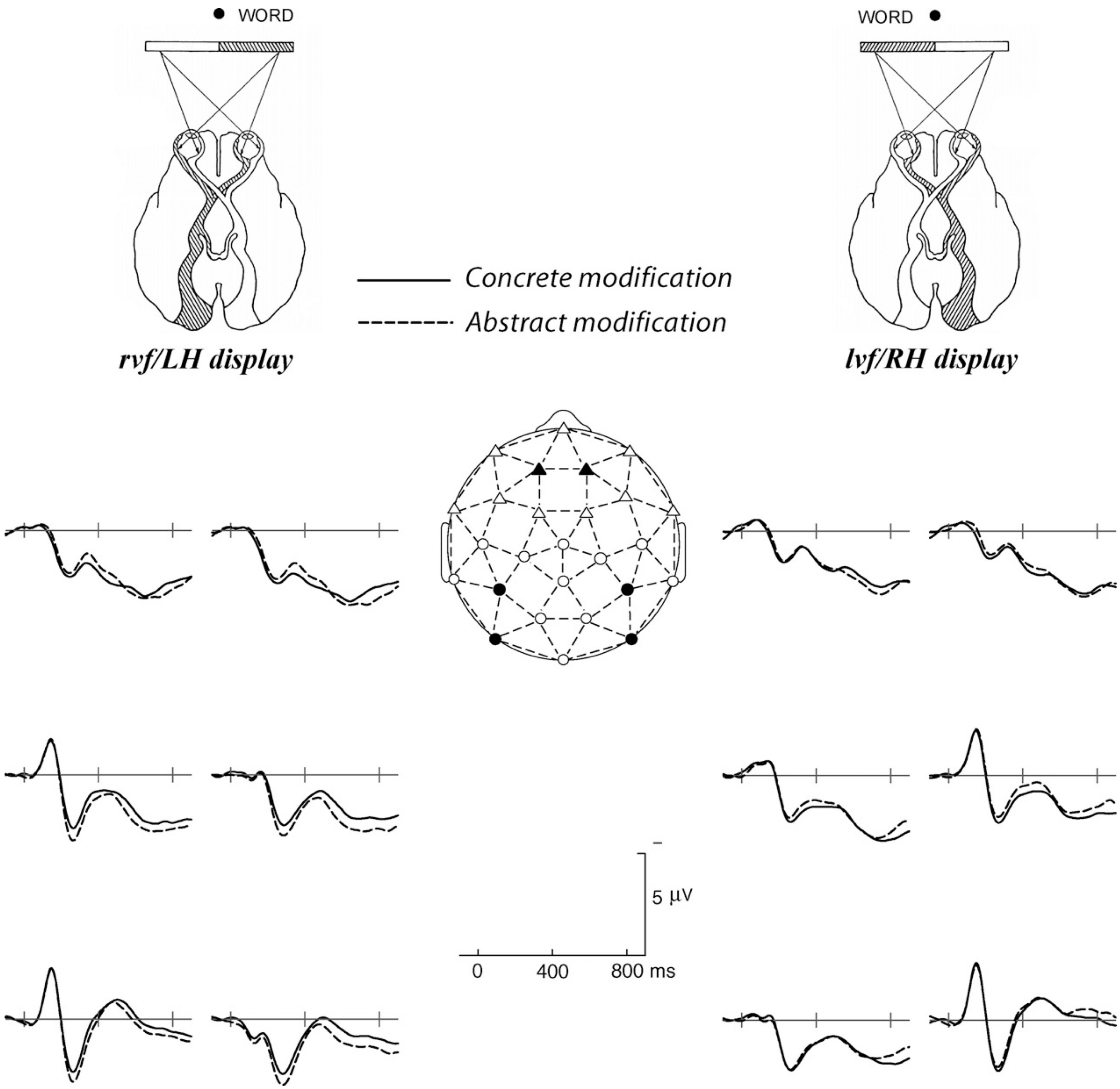

Fig. 3.
Grand average ERPs to concretely and abstractly modified nouns presented in the RVF/LH (at left) and LVF/RH (at right) are shown at six representative electrode sites (positions indicated by darkened shapes on the head diagram). With RVF/LH presentation, frontal P2 and posterior N400 effects are diminished. With LV/RH presentation, frontal negativity (500–900 ms) is also absent.

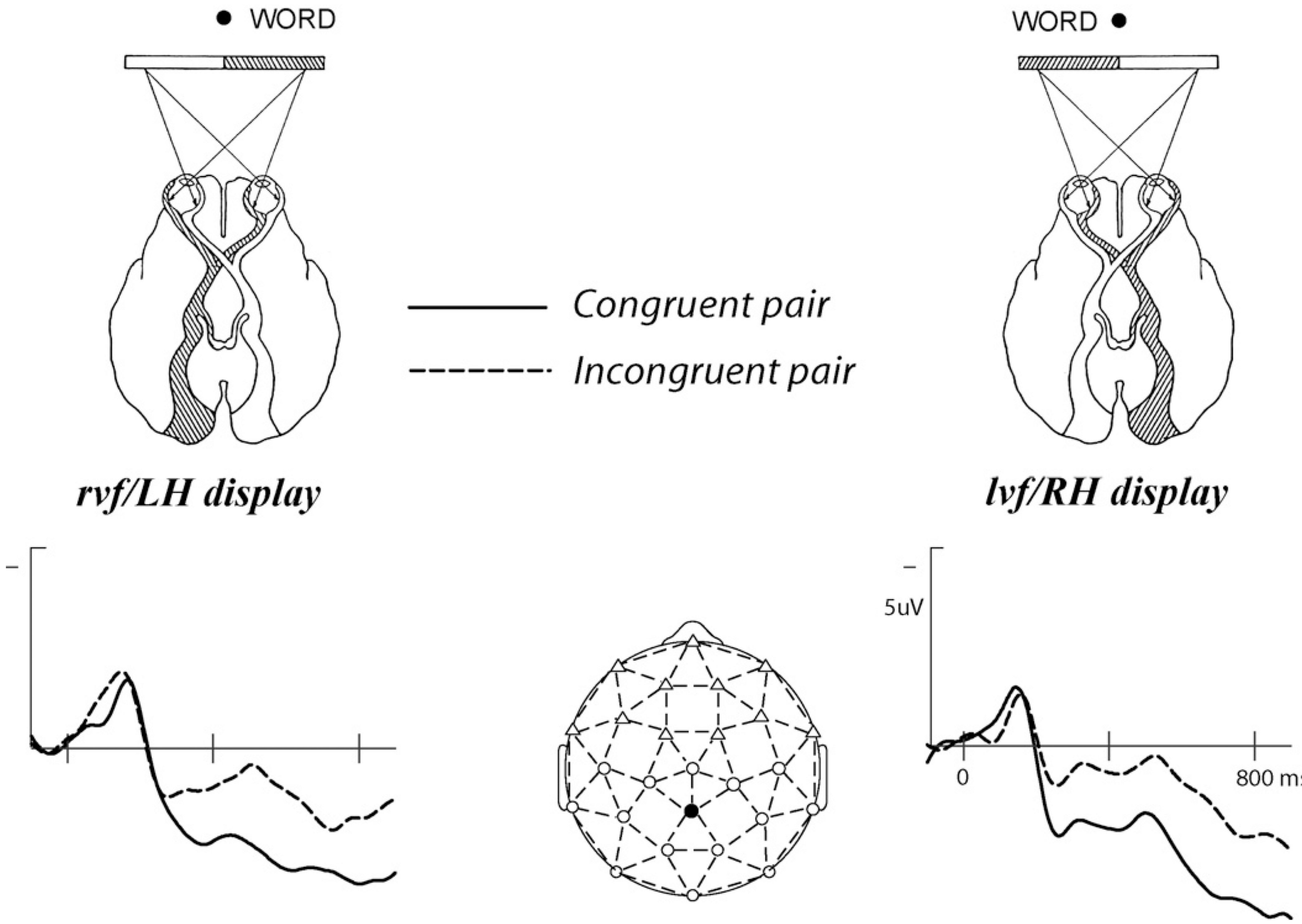

Fig. 4.
The congruity effect on the lateralized nouns presented in the RVF/LH (at left) and LVF/RH (at right) is plotted at a representative electrode site. In both visual fields, N400 responses are reduced (less negative) to congruous pairs (e.g. volcanic mountain) than to incongruous pairs (e.g. limpid mountain).

Table 1

Example stimuli and list structure.

Adjective type	Adjective	Noun	Probe adjective	Probe adjective type	VF of the noun
List 1					
Concrete	Green	Book	Thick	Concrete	LVF
Concrete	Pimply	Nose	Expert	Abstract	(RVF in List 3)
Abstract	Productive	Farm	Organic	Abstract	
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					
Concrete	Pimply	Nose	Pudgy	Concrete	LVF
Concrete	Green	Book	Engaging	Abstract	(RVF in List 4)
Abstract	Native	Dress	Ceremonial	Abstract	
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	

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Table 2

Endorsement rates for the first and second adjectives across conditions and visual fields.

	Critical trials								Filler trials			
Conditions	**CC**		**CA**		**AA**		**AC**		**RU**		**UR**	
Endorsed ADJ	**1st ADJ**	**2nd ADJ**	**1st ADJ**	**2nd ADJ**	**1st ADJ**	**2nd ADJ**	**1st ADJ**	**2nd ADJ**	**1st ADJ**	**2nd ADJ**	**1st ADJ**	**2nd ADJ**
LVF/RH nouns (%)	47	53	55	45	46	54	53	47	78	22	22	78
RVF/LH nouns (%)	48	52	54	46	45	55	51	49	87	13	17	83