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Comprehension of lexical ambiguity in healthy aging, mild cognitive impairment, and mild Alzheimer's disease

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ABSTRACT

Two experiments examined processing of lexical ambiguity in healthy older control (HC), mild cognitive impairment (MCI) and Alzheimer's disease (AD) participants. In Experiment 1, groups of HC, MCI and AD participants took part in an ERP study in which they read lexically ambiguous items presented in a subordinate context and primed by the same item presented in a dominant context. Ambiguous items were homonyms (e.g., *bank*), metaphorical polysemes (e.g., *star*), or metonyms (e.g., *rabbit*). All participants exhibited smaller N400s for items preceded by a related prime. In addition, HC participants exhibited a smaller N400 for metonyms than for metaphorical polysemes or homonyms; this effect was diminished in MCI and AD participants. In Experiment 2, HC and MCI participants completed a primed lexical decision task where targets related to the subordinate meaning/sense of ambiguous items were preceded by primes biasing the dominant meaning/sense (e.g., financial–bank–*river*). In contrast to the results of Experiment 1, both HC and MCI participants showed priming for metonymic items, but not homonyms or metaphorical polysemes. These results suggest that basic knowledge of multiple senses of metonyms is preserved in MCI, but the processing advantage conveyed by this semantic richness is diminished in MCI and AD.

1. Introduction

Alzheimer's disease (AD) is a devastating, progressive neurodegenerative disorder that affects several cognitive systems. In addition to the hallmark deficit in memory, impairments are observed in various aspects of language processing, notably lexical-semantic processing (e.g., Caramelli, Mansur, & Nitrini, 1998; Nebes, 1989; Nebes & Brady, 1991). Mild cognitive impairment (MCI, Petersen et al., 1999; Petersen, Stevens, et al., 2001) has recently been identified as an important risk factor for AD. MCI presents as an objective memory impairment in the absence of dementia, and patients with MCI have an elevated risk of developing AD: around 15% per annum, versus 1–2% in the healthy elderly population (Petersen, Stevens, et al., 2001). This suggests that MCI constitutes a preclinical stage of AD in many or most cases (see, e.g., Chertkow, 2002).

Alterations in language abilities, and particularly in lexical-semantic processing, are also observed in MCI (for a review, see Taler & Phillips, 2008). However, the majority of studies to date have relied upon standardized clinical tests such as naming and word fluency tasks. Little research to date has examined more subtle aspects of performance alteration. The present study focuses on the phenomenon of lexical ambiguity, where the same letter string has more than one meaning (e.g., *bank*). Lexical ambiguity is ubiquitous in language and includes several subtypes. In the case of *homonymy*, two words have identical forms but possess two unrelated meanings. For example, the word *bank* may refer to the side of a river or a financial institution. *Polysemy*, in contrast, refers to the case where a word has two related senses, one of which is literal and one which may be either literal (metonymy) or metaphorical (metaphorical polysemy). For example, the word *rabbit* has two literal senses: it may refer either to the animal or to the meat. In contrast, the word *star* has one literal sense, a celestial body, and one metaphorical sense, a famous individual.

A considerable body of research has focused on the representation of homonymy and polysemy in the mental lexicon. Some authors claim that the two meanings or senses of homonymous and polysemous words are represented separately (e.g., Klein & Murphy, 2001; but cf. Klepousniotou, Titone, & Romero, 2008).

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Others suggest that the two meanings of homonyms are represented separately, whereas polysemes possess one central sense, and sense extensions are computed on-line (Frazier & Rayner, 1990), or that both senses are accessed immediately, possibly via a single underspecified representation (Frisson & Pickering, 1999). In a recent MEG study, Pylkkanen, Llinas, and Murphy (2006) examined whether priming between senses and meanings of ambiguous words was driven by identity (i.e., the fact that the two items are the same) or simply by similarity in form and meaning. They found that polysemy priming (e.g., lined paper–liberal paper) could not be accounted for in terms of a combination of form priming, where a lexical item is primed by a formally identical but semantically distinct item (i.e., a homonym), and semantic priming (e.g., lined paper–monthly magazine). These results suggest that, in healthy adults, the senses of polysemous items are connected to the same representation, but that each sense is listed within the representation. Recent research examining processing of homonymy, metaphor, and metonymy suggests that these items in fact fall on a continuum, where homonymous meanings are most separated and metonyms least separated, while metaphor falls in between (Klepousniotou, 2002). Processing of multiple meanings is assumed to proceed through two stages, including activation of multiple representations and subsequent inhibition of irrelevant or contextually inappropriate meanings (Onifer & Swinney, 1981; Seidenberg et al., 1982; Swinney, 1979; Tanenhaus et al., 1979). However, activation of the different meanings is influenced both by context and by the relative frequency of each meaning (Duffy, Morris & Rayner, 1988; Pacht & Rayner, 1993; Rayner, Binder & Duffy, 1999; Rayner & Duffy, 1986; Rayner & Frazier, 1989; Rayner, Pacht & Duffy, 1994).

Very little research examining lexical ambiguity processing in AD has been reported to date, and the studies that have been conducted focus on homonymy processing. Chenery, Ingram, and Murdoch (1998) report a study of homonym processing in which AD and control participants listened to two-sentence paragraphs and then responded to visually presented targets presented at either 330 or 1000 ms after a homonym. Targets were either associates of the contextually appropriate meaning of the homonym or of its contextually inappropriate meaning. Targets that were associates of either meaning of the homonym showed priming in both participant groups at 330 ms; at 1000 ms, associates of the contextually appropriate meaning were primed in both participant groups, but AD participants showed inhibition for the inappropriate associate, suggesting spared automatic activation of both meanings of the homonym, but alterations in integration of lexical material into a discourse context. Faust, Balota, Duchek, Gernsbacher, and Smith (1997) examined the extent to which AD individuals were able to activate appropriate meanings of homonymous words and inhibit inappropriate meanings. In this study, AD and control participants read sentences ending in a homonymous lexical item and then judged whether a test word was congruent with the sentence context. Contextually inappropriate meanings remained activated longer in the AD group than in the healthy control group, suggesting that AD participants showed alterations in selective activation of the contextually appropriate meaning and/or inhibition of the contextually inappropriate meaning.

In recent work, we examined AD and MCI patients' processing of different noun classes, including metonymic nouns such as *rabbit* (Taler & Jarema, 2004, 2006). In one study, both AD and MCI participants showed deficits in selecting the subordinate sense of metonymic nouns in a sentence–picture matching task, suggesting difficulty in either inhibiting the dominant sense or accessing the subordinate sense (Taler & Jarema, 2004). A follow-up study found that healthy elderly adults, but not AD and MCI participants, showed a reaction time (RT) advantage for metonymic nouns, although faster processing of count than mass nouns was preserved in MCI and AD (Taler & Jarema, 2006).

In sum, the findings reported in the literature are suggestive of alterations in processing of ambiguous words of various classes in AD and MCI. However, although differences are known to exist in processing of different ambiguity subtypes in healthy young adults (e.g., Klepousniotou, 2002; Klepousniotou & Baum, 2007; Klepousniotou et al., 2008; Pylkkanen et al., 2006), to date no study has examined processing of these subtypes in AD and MCI. A better understanding of how lexical ambiguity processing is affected in AD and MCI may lead to important insights with respect to alterations in lexical access and/or representation in these populations.

The present study aims to assess the extent to which the multiple senses/meanings of ambiguous words are activated when they are seen in context. We examine a wider variety of ambiguous items than have been included in previous studies of lexical ambiguity processing in AD (homonyms, metonyms, and metaphorical polysemes). Experiment 1 uses an event-related (ERP) methodology; the component of interest is the N400, a negative-going peak in the waveform that occurs approximately 400 ms following stimulus onset (Kutas & Hillyard, 1980, 1983). The N400 reflects processing of semantic information, with semantically anomalous words eliciting a larger N400 than semantically congruent words (e.g., Osterhout, McLaughlin, & Bersick, 1997). Semantic priming is reflected in a reduction in the N400 (Holcomb, 1988). Abnormalities in the N400 component are observed in MCI and AD (e.g., Olichney et al., 2002).

Similar to Pylkkanen et al. (2006), in Experiment 1 we examined the degree of priming seen for the subordinate sense or meaning of an ambiguous lexical item when primed by a word pair biasing the dominant sense or meaning. Given that healthy older adults are typically reported to possess intact, or even superior, lexical-semantic skills relative to younger adults (e.g., Bowles, Williams, & Poon, 1983; Burke & Peters, 1986; Howard, 1980) we predicted a similar performance to that reported for younger adults in behavioral studies: a greater degree of priming (i.e., a reduced N400) for items that share a central representation, namely polysemous items, than those that do not, namely homonyms.

In the case of AD participants, previous research suggests two possible patterns of alteration in performance. The first follows from Faust et al.'s (1997) suggestion that alterations in processing of lexical ambiguity in AD are driven by breakdowns in inhibitory control processes. If this is the case, then AD participants would be expected to show a greater degree of priming in the homonymy condition than healthy control (HC) participants, who would be expected to inhibit the contextually inappropriate meaning, resulting in diminished priming when it is presented. Metonyms and metaphorical polysemes should be relatively unaffected, because the two senses are closely linked in the lexicon, and thus would remain activated in HC as well as AD participants (consistent with the findings of Pylkkanen et al., 2006, for healthy young adults). The second possible pattern of results follows from the possibility that AD patients may exhibit deficits in activation of the subordinate sense of polysemous items (Taler & Jarema, 2004, 2006). If this is the case, then AD participants would be expected to exhibit diminished priming in the metonymy and metaphor conditions relative to HC participants, because HC but not AD participants would activate the subordinate sense. Furthermore, similar priming patterns should be observed in AD and HC groups in the homonymy condition, because HCs are expected to inhibit the subordinate meaning of homonyms when they are seen in a context biasing the dominant meaning, and AD participants would not activate the subordinate meaning at all.

Given that lexical semantic difficulties are also present in MCI (for a review, see Taler & Phillips, 2008), MCI and AD participants are predicted to manifest similar patterns of performance: either increased priming in the homonymy condition relative to HC participants, if inhibitory deficits underlie the performance alterations

Table 1
Participant demographic information.

Group	HC participants	MCI participants	AD participants
N	19	20	10
Age[a]	74.68 ± 7.58	75.80 ± 7.62	82.4 ± 5.38
Education[b]	14.22 ± 3.12	12.45 ± 2.72	11.00 ± 3.33
Sex	8 men, 11 women	10 men, 10 women	3 men, 7 women
MMSE (/30)	n/a	27.36 ± 2.27[c]	24.18 ± 4.58
MoCA (/30)	26.33 ± 1.68		

AD = Alzheimer's disease; HC = healthy controls; MCI = mild cognitive impairment; MMSE = Mini Mental State Examination; MoCA = Montreal Cognitive Assessment.
[a] AD > HC, $p < 0.05$
[b] AD < HC, $p < 0.05$
[c] MMSE scores were unavailable for six MCI participants. These participants scored an average of 23.33 ± 2.50 on the MoCA.

in AD, or decreased priming in the metaphor and metonymy conditions, if deficits in activation of the subordinate sense of polysemous items underlie their performance alterations.

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

Three participant groups took part in Experiment 1: HC, MCI, and AD participants. The procedure was explained to all participants, who signed an Informed Consent form approved by the Jewish General Hospital Ethics Review Board. All participants were remunerated for their participation. Demographic information for all participants, as well as their scores on screening tests, are reported in Table 1.

2.1.1.1. HC participants. Nineteen HC participants took part in the study. All were native speakers of English with no neurological or psychiatric history and had normal or corrected-to-normal vision, and all but one were right-handed. They were recruited through newspaper advertisements or from the Herzl Family Clinic at the Jewish General Hospital. To exclude dementia and MCI, they completed the Montreal Cognitive Assessment (Nasreddine et al., 2005); scores are reported in Table 1.

2.1.1.2. MCI participants. Twenty MCI patients participated in the study; 17 were native English speakers and the remaining three spoke English very fluently and used it on a daily basis. All were right-handed and had normal or corrected-to-normal vision. MCI participants were recruited from the Memory Clinic at the Jewish General Hospital, a tertiary referral centre. They met clinical and neuropsychological criteria for MCI (Petersen et al., 1999; Petersen, Stevens, et al., 2001) as follows: objective memory impairment, operationalized as performance at least 1 standard deviation and usually 1.5 standard deviations below age-adjusted norms on Logical Memory 2 of the Wechsler Memory Scale-Revised (Wechsler, 1987) and/or the delayed recall score of the Rey Auditory Verbal Learning Test (Schmidt, 1996); subjective memory impairment as reported by either the patient or family members, preserved general intellectual function, and absence of significant functional impairment or dementia. Diagnosis was made by the assessment physician and by a geriatrician. A diagnosis of MCI corresponds to amnestic or multi-domain MCI according to Petersen criteria (Petersen, Doody, et al., 2001).

2.1.1.3. AD participants. Ten AD participants took part in Experiment 1; all were native English speakers and had normal or corrected-to-normal vision, and all but one were right-handed. AD participants were recruited from the Memory Clinic at the Jewish General Hospital. The clinical diagnosis of probable AD was established by a neurologist or neuropsychologist on the basis of diagnostic criteria for dementia (American Psychiatric Association, 1994) and were diagnosed as having probable AD (mild or moderate stage) on the basis of standard clinical criteria (McKhann et al., 1984). Assessment included standard blood work and neuroimaging (CT or MRI). Dementia severity was ascertained using the MMSE (Folstein, Folstein, & McHugh, 1975).

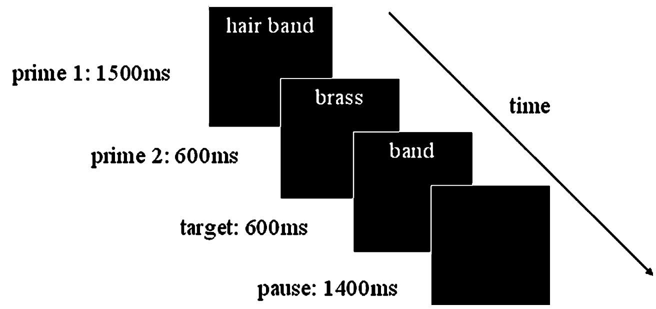

Fig. 1. Procedure, Experiment 1.

2.1.2. Stimuli and procedure

Critical stimuli comprised ambiguous items from three categories: unbalanced homonymy, metaphorical polysemy, and metonymic polysemy ($n = 45$ per category). Stimuli were balanced across categories for length, frequency according to published norms (Baayen, Piepenbrock, & van Rijn, 1993; Kučera & Francis, 1967), neighborhood density and neighbor frequency, mean bigram frequency, and bigram frequency by position according to data from the English Lexicon Project (Balota et al., 2002), and for concreteness, familiarity and imageability according to data from the MRC psycholinguistic database (Coltheart, 1981).

Unbalanced homonymous words were chosen from standardized lists of ambiguous words (e.g., Nelson, McEvoy, & Schreiber, 1998; Nelson, McEvoy, Walling, & Wheeler, 1980; Twilley, Dixon, Taylor, & Clark, 1994). The frequency of occurrence of the dominant meaning was never less than 70% and the frequency of occurrence of the subordinate meaning was never greater than 30%.

Standardized lists of metonymic and metaphorical words do not exist; therefore, these words were chosen so as to exhibit specific relations between their two senses as documented in the theoretical linguistics literature (e.g., Nunberg, 1979; Pustejovsky, 1995). In order to control for repetition effects and semantic facilitation effects from one experimental stimulus to another, as well as to investigate the effects of a broader range of words with metonymic and metaphorical meaning extensions, multiple types of metonymic and metaphorical words were included. In particular, metonymic words exhibited the following three types of metonymic relations: words with the count/mass relation (e.g., "rabbit" → "the animal" and "the meat of that animal"); words with the container/containee relation (e.g., "bath" → "the container" and "its contents", e.g., "porcelain bath" vs. "soapy bath"); and words with the figure/ground reversals relation (e.g., "cage" → "the actual object" and "the space that is enclosed within it"). Similarly, metaphorical words exhibited three types of metaphorical relations, namely body part/object words (e.g., "mouth" → "an aperture on the face" and "where a river meets the ocean"), animal/human characteristic words (e.g., "fox" → "a wild animal of the forest" and "a sly and cunning individual"), and physical object/human characteristic words (e.g., "star" → "a bright object in the night sky" and "a famous individual").

Standard dictionaries (e.g., "The Oxford English Dictionary. 2nd ed.," 1989; the on-line Wordsmyth English Dictionary-Thesaurus, Parks, Ray, & Bland, 1998) were consulted to verify the classification of all stimuli as homonymous, metonymic or metaphorical (see also Klepousniotou & Baum, 2007). All such dictionaries respect the distinction between homonymy and polysemy by listing the different meanings of homonymous words as separate entries, whereas the different senses of metonymic and metaphorical words are listed within a single entry. In addition, all standard dictionaries respect sense dominance by listing the central or dominant sense of metonymic and metaphorical words first and then providing the extended or subordinate senses.

Each critical stimulus was preceded by two primes. Prime 1 was a word pair biasing the dominant meaning of the ambiguous word; it comprised an adjective or noun and the critical word (e.g., *hair band*). Prime 2 was an adjective or noun biasing the subordinate meaning of the ambiguous item (e.g., *brass*). The target word (e.g., *band*) was then presented. Priming was compared to a neutral control condition (unrelated lexical items as prime 1; prime 2 was the same as in the experimental condition). Sample stimuli are provided in Table 2, and the procedure is illustrated in Fig. 1.

Each prime and target was presented for 600 ms and the interstimulus interval (ISI) between primes and between prime and target was set to 0 ms. The ISI between

Table 2
Sample stimuli, Experiment 1.

	Related condition			Unrelated condition		
	Prime 1	Prime 2	Target	Prime 1	Prime 2	Target
Homonymy	Brass band	Hair	Band	Sea salt	Hair	Band
Metaphorical polysemy	Iron anchor	Television	Anchor	Blue carpet	Television	Anchor
Metonymy	Dying pine	Sanded	Pine	Bestselling author	Sanded	Pine

Table 3
Average epochs accepted by condition and group, Experiment 1.

Group	Homonymy-related	Homonymy-unrelated	Metaphor-related	Metaphor-unrelated	Metonymy-related	Metonymy-unrelated
HC	43.16	41.63	42.32	42.37	42.42	42.21
MCI	43.00	42.60	42.60	41.75	43.20	42.40
AD	41.80	41.10	41.80	40.90	41.40	41.10

trials was set to 1400 ms. Stimuli were presented in yellow 36-point Arial font on a black background. Participants were given a break every 45 trials, for a total of two breaks per block of testing. To ensure attentiveness, participants were required to verbally provide the last word seen on 46 trials (17% of trials), randomly distributed throughout the experimental session. The instruction to provide the last word seen appeared in white 24-point Arial font, and remained on the screen until the participant responded.

Testing took place in a single session of approximately 2 h. Stimuli were divided into two lists, such that each critical stimulus appeared only once in each list. Participants saw the two lists in the same experimental session, in counterbalanced order and separated by another unrelated list of stimuli that lasted approximately 35 min.[1]

2.1.3. EEG recording and data analysis

EEG was recorded continuously from 32 Ag/AgCl electrodes fitted into a commercially available nylon cap (EZ Cap, Herrsching-Breitbunn, Germany); impedances were kept below 5 kΩ. Electrodes were positioned following the 10–20 international convention. EEG responses were recorded from five midline sites (Fz, FCz, Cz, CPz, Pz) and 20 lateral sites (FP1/2, F3/4, F7/8, FT7/8, FC3/4, P3/4, P7/8, CP3/4, TP7/8, O1/2). EEG activity was recorded relative to a left ear reference, and recomputed offline to a linked ear reference. Electrodes were placed at the outer canthi of each eye (horizontal EOG) and above and below the left eye (vertical EOG) to record electrooculogram activity (EOG). Ground was a cephalic (forehead) location. Critical EEG epochs were time-locked to the onset of presentation of each target word. They were amplified using Neuroscan Synamps in a DC-30 Hz bandwidth, and sampled at 100 Hz for 1100 ms (100 ms pre-stimulus).

Off-line processing was conducted using Neuroscan Edit 4.3 software as follows. The file was first re-referenced and a DC drift correction applied. VEOG artefacts were identified and corrected; the file was then epoched into discrete EEG trials on the basis of stimulus onset. Trials contaminated by horizontal EOG (HEOG) activity (±50 μV) were rejected, as were trials in which the EEG epoch was contaminated due to clipping, movement artifact, etc. (±100 μV). The remaining EEG trials were then used to calculate average ERP waveforms for each participant and condition.

2.2. Results

Repeated-measures analyses of variance (ANOVAs) were conducted using SPSS (Version 10.0) statistical software, and the Greenhouse–Geisser (Greenhouse & Geisser, 1959) non-sphericity correction was applied when appropriate. Significant interactions ($p < 0.05$) were further assessed using least significant difference (LSD) post hoc tests. We report unadjusted degrees of freedom, the Greenhouse–Geisser epsilon value (e) and adjusted p value.

Based on visual inspection, we chose to analyze activity from 300 to 650 ms post-stimulus onset. This captures the traditional N400 window, but is slightly longer due to delayed N400s in AD participants (e.g., Schwartz, Federmeier, Van Petten, Salmon, & Kutas, 2003). We calculated mean amplitude in 50 ms slices (i.e., 300–350, 350–400 ms, etc.). This yielded a factor of Time that was entered into the ANOVAs. In separate analyses, we examined early activity (0–350 ms), also in 50 ms slices. Two separate ANOVAs were conducted for each time period, one for midline and one for lateral electrode sites. In the midline analyses, each site was treated separately (Fz, FCz, Cz, CPz, Pz), yielding a factor of Site. In the lateral region of interest analyses, average amplitude was calculated for each scalp region (left anterior: F7, F3, FT7, FC3, right anterior: F8, F4, FT8, FC4, left posterior: TP7, CP3, P7, P3; right posterior: TP8, CP4, P8, P4), yielding factors of Anteriority and Hemisphere. Group was included as a between-subjects factor in all ANOVAs. Thus, four separate ANOVAs were conducted in total: two analyzing activity in midline sites (one in each time window) and two analyzing activity in lateral sites, one in each time window. Average number of epochs accepted by condition and group is presented in Table 3. Number of epochs accepted did not differ between groups ($F(2,46) = 0.518$, $p > 0.60$) and no differences were observed for any experimental variable except relatedness, where more related than unrelated epochs were accepted.

ERP grand average waveforms for each condition are shown for HC, MCI and AD participants in Figs. 2–4 respectively. In both Figs. 2 and 4, stimuli preceded by a related prime (solid lines) can be seen to elicit a smaller N400 than those preceded by an unrelated prime (control condition—dashed lines). Smaller N400 s to metonymic items (light grey lines) than homonymic or metaphoric items can be observed in midline sites for HC but not MCI or AD participants (i.e., in Fig. 2 but not Figs. 3 and 4). In order to further visualize differences between metonymic and homonymous items, difference waveforms illustrating the waveform for the unrelated metonymy condition subtracted from the unrelated homonymy condition for the three participant groups is provided in Fig. 5. A larger difference between the two conditions (i.e., a larger peak) can be observed for HC participants (light grey lines) but not MCI or AD participants (black dashed and solid lines), particularly in posterior midline electrodes.

2.2.1. Early activity (0–350 ms)

In this early time window, the only significant effect of the experimental variables was a significant interaction between ambiguity type, relatedness and time ($F(8,368) = 2.42$, $p < 0.04$). LSD post hoc analyses revealed that this was due to more negative-going activity in the unrelated homonymy condition than in the unrelated metonymy and metaphor conditions between 250 and 300 ms post-stimulus onset ($p < 0.05$), likely reflecting early N400 effects. No effect of group or interaction between group and the experimental variables was observed.

2.2.2. N400 window

2.2.2.1. Effects of relatedness and ambiguity type. A main effect of relatedness was observed in midline sites ($F(1,46) = 7.30$, $p < 0.01$) and anterior lateral sites (relatedness × anteriority interaction, $F(1,46) = 5.89$, $p < 0.02$), whereby more negative-going activity was seen in the unrelated condition across all participant groups. In midline sites, the relatedness effect was strongest in the Fz, FCz and Cz electrodes (relatedness × electrode interaction, $F(4,184) = 5.90$, $p < 0.007$) between 400 and 650 ms post-stimulus onset (relatedness × time interaction, $F(6,276) = 9.81$, $p < 0.001$).

With respect to ambiguity type, an ambiguity type × anteriority × time interaction ($F(12,552) = 2.66$, $p < 0.03$) was observed in lateral sites. This was due to more negative-going activity in anterior sites to homonymous than metaphorical items between 300 and 350 ms post-stimulus onset, and than metonymic items from 500 to 650 ms post-stimulus onset; more negative-going activity was also observed to homonymous than metaphorical items in posterior sites from 550 to 650 ms post-stimulus onset. An ambiguity type × relatedness × time interaction in midline sites ($F(12,552) = 2.21$, $p < 0.045$) was due to later onset and shorter duration of relatedness effects in the homonymy condition (relatedness

[1] The second experiment examined neighborhood density effects. Participants were required to read sentences presented one word at a time on the computer screen and respond to periodic comprehension questions. Critical stimuli did not overlap between the two experiments. The 2-h testing time included both studies.

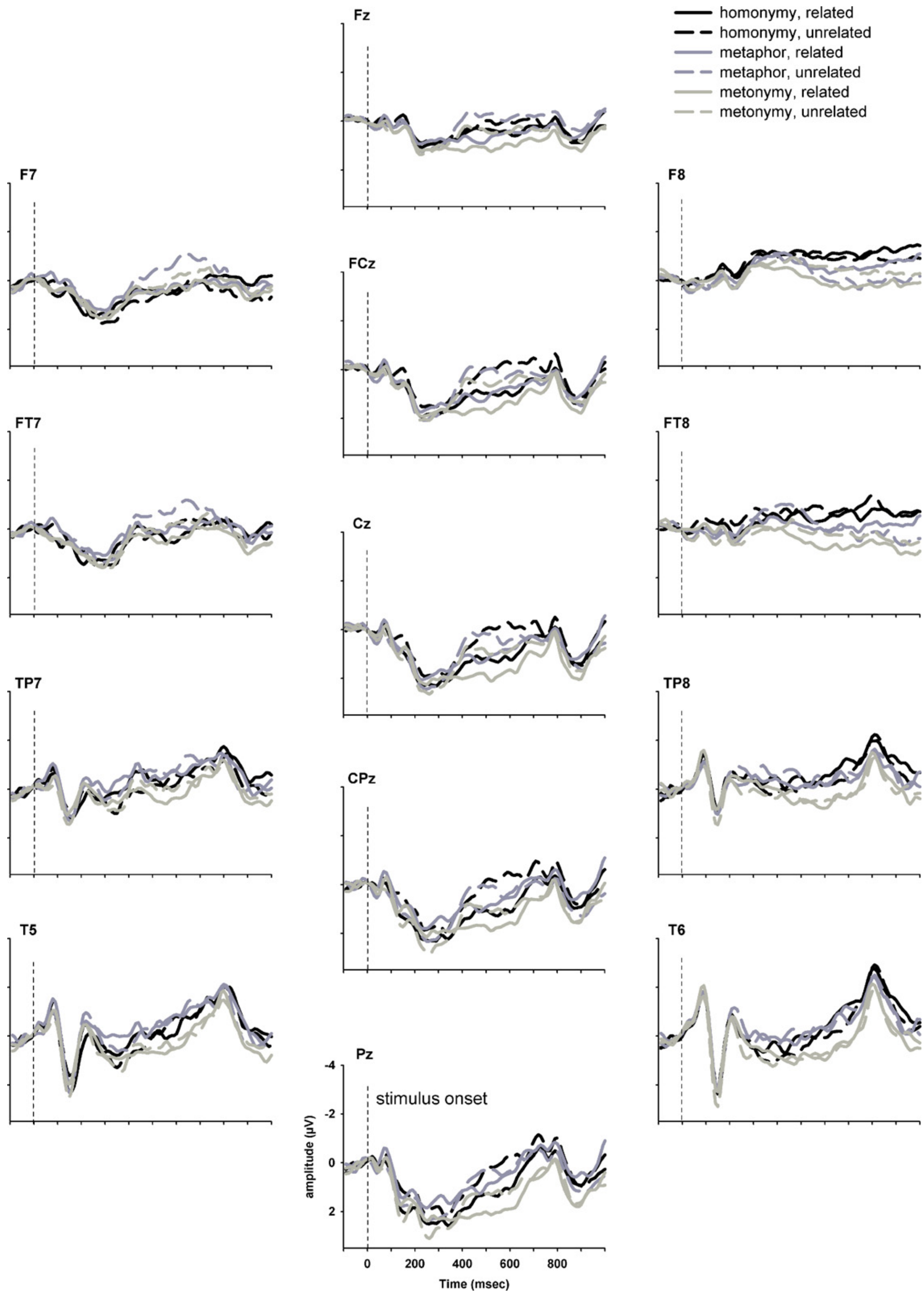

Fig. 2. Grand average waveforms for healthy older control participants, showing homonymous, metaphorical and metonymic items in related and unrelated conditions. Time is plotted on the *x*-axis and amplitude in microvolts on the *y*-axis; following convention, negative amplitudes are plotted upwards.

effect from 550 to 600 ms) than in the metonymy condition (relatedness effect from 500 to 600 ms) and the metaphor condition (relatedness effect from 450 to 650 ms).

2.2.2.2. Group effects. Some overall differences in activation were observed between participant groups, reflecting more negative-going activity in posterior and left hemisphere sites with increasing impairment. The AD group showed more negative-going activity than the HC group in posterior midline electrodes (CPz and Pz; electrode × group interaction, $F(8,184) = 3.87$, $p < 0.004$); a borderline effect in the same direction was observed between HCs and MCIs in electrode Pz ($p < 0.06$). In addition, AD participants showed more negative-going activity than MCI participants in the left hemisphere between 500 and 650 ms (hemisphere × time × group interaction,

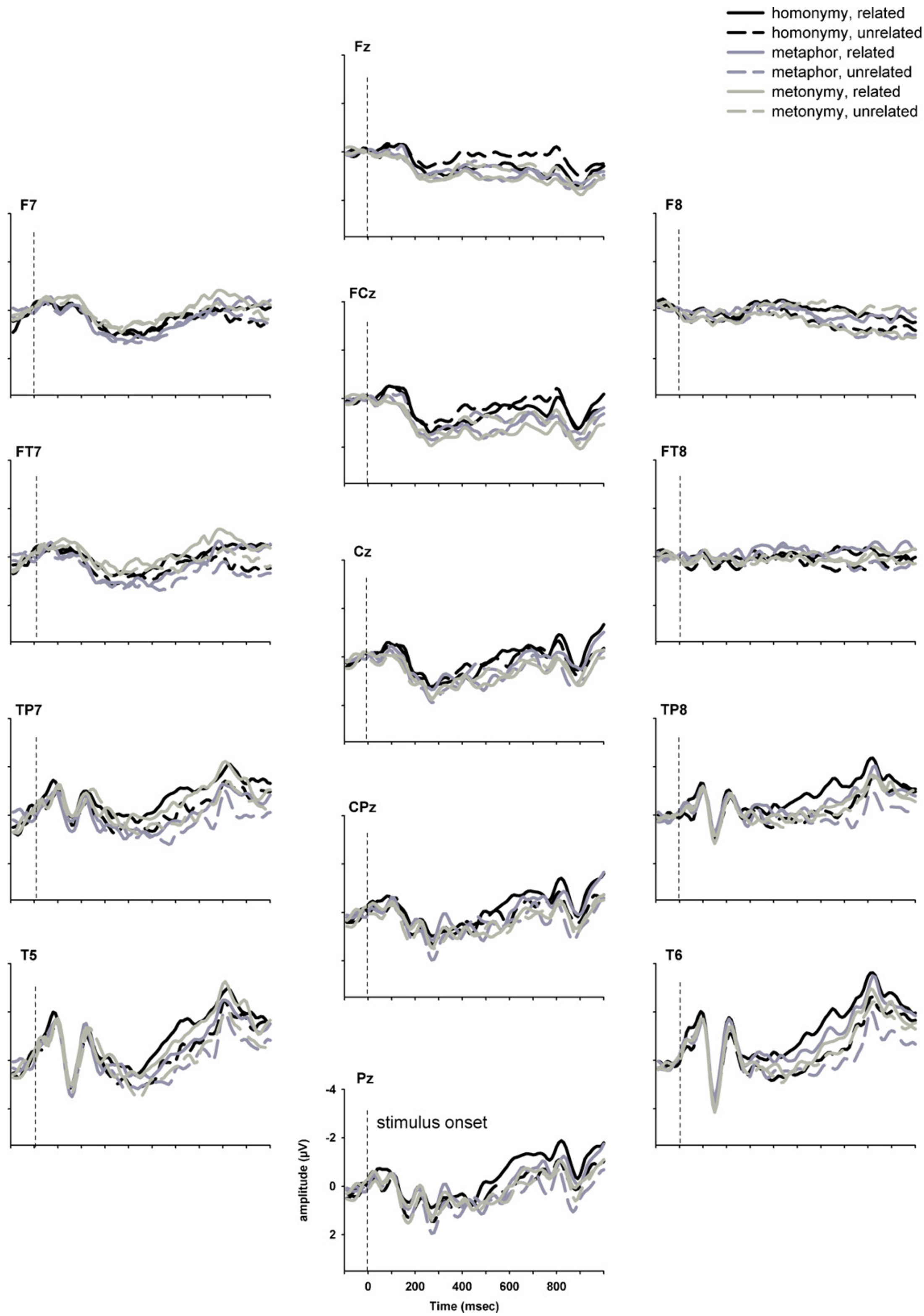

Fig. 3. Grand average waveforms for MCI participants, showing homonymous, metaphorical and metonymic items in related and unrelated conditions. Time is plotted on the *x*-axis and amplitude in microvolts on the *y*-axis; following convention, negative amplitudes are plotted upwards.

$F(12,276) = 2.48$, $p < 0.044$); a trend in the same direction was seen between AD and HC groups from 600 to 650 ms post-stimulus onset ($p < 0.06$).

With respect to the experimental manipulations, a relatedness × time × group interaction ($F(12,276) = 2.31$, $p < 0.05$) was observed in lateral sites; LSD post hoc tests revealed that HC participants showed a stronger relatedness effect between 500 and 650 ms post-stimulus onset, while MCI participants showed a more temporally circumscribed effect, between 600 and 650 ms post-stimulus onset. No significant effects were observed for the AD group. Finally, an ambiguity × group interaction in lateral sites ($F(4,92) = 2.50$, $p < 0.05$) was due to more

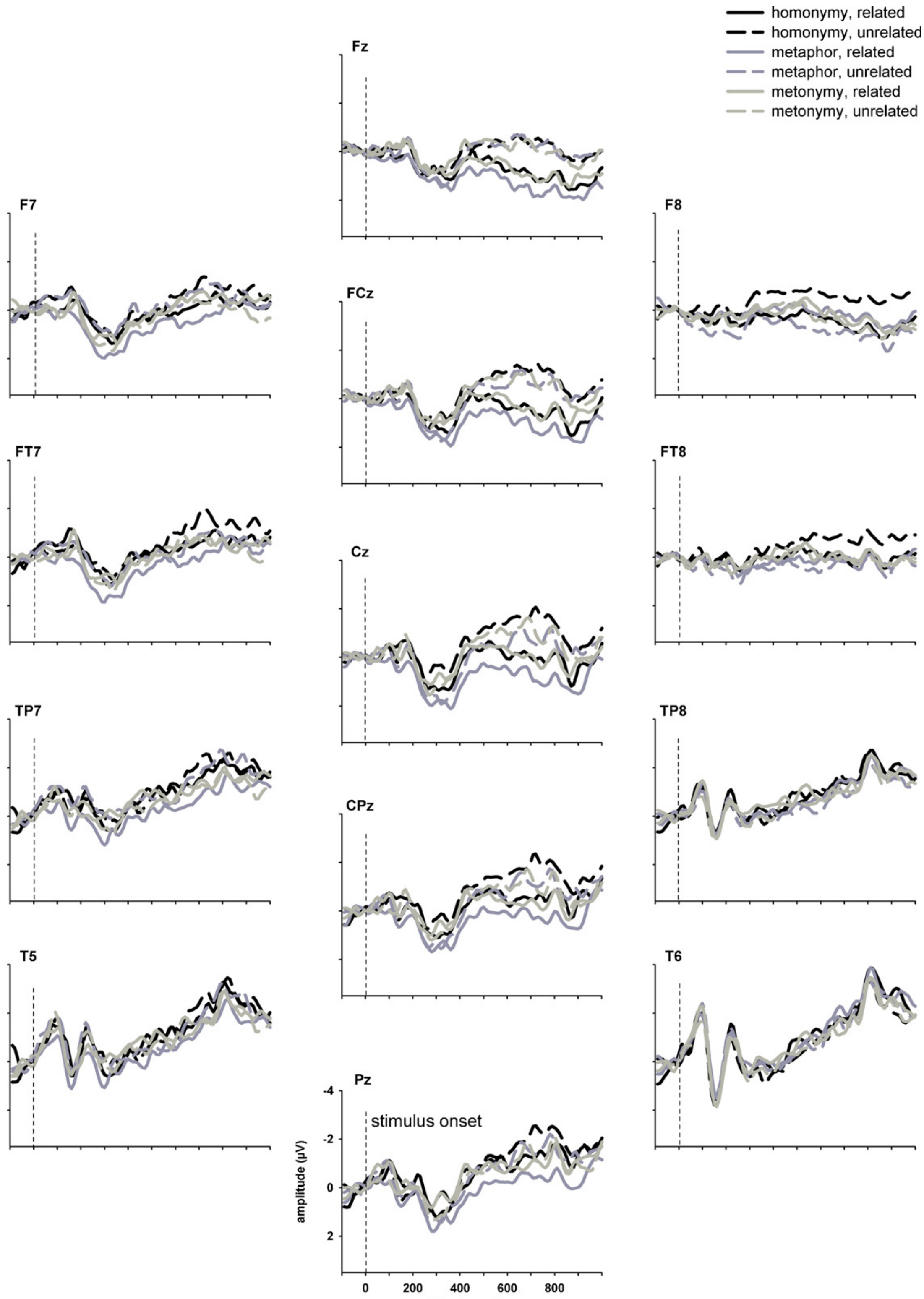

Fig. 4. Grand average waveforms for AD participants, showing homonymous, metaphorical and metonymic items in related and unrelated conditions. Time is plotted on the *x*-axis and amplitude in microvolts on the *y*-axis; following convention, negative amplitudes are plotted upwards.

negative-going activity in the HC group to metaphorical and homonymous than metonymic stimuli; no such effect was observed in the MCI and AD groups (MCI participants, homonymy vs. metonymy, $p > 0.25$, metaphor vs. metonymy, $p > 0.51$; AD participants, homonymy vs. metonymy, $p > 0.86$, metaphor vs. metonymy, $p > 0.26$).

2.2.2.3. Re-analysis excluding non-native speakers. Three of the MCI participants were not native speakers of English. We conducted the same analyses without these subjects and the results were virtually identical. In midline sites, unrelated items elicited a more negative-going waveform than related items (main effect of relatedness, $F(1,43) = 6.59$, $p < 0.01$). This effect was strongest in Fz,

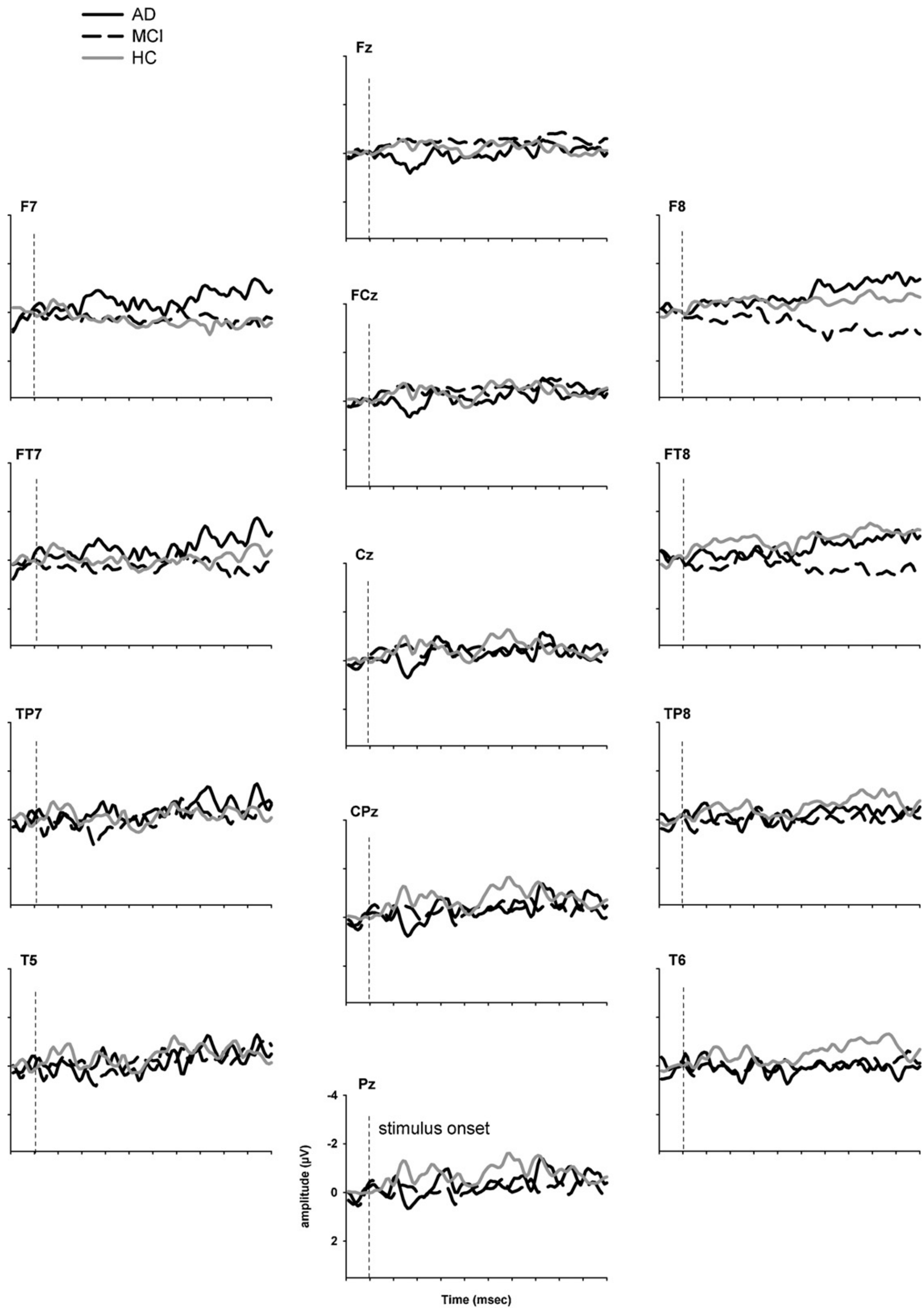

Fig. 5. Difference waveforms for unrelated homonymy condition–unrelated metonymy condition. Time is plotted on the *x*-axis and amplitude in microvolts on the *y*-axis; following convention, negative amplitudes are plotted upwards.

FCz and Cz (relatedness × electrode, $F(4,172) = 5.02$, $p < 0.01$) and between 400 and 650 ms post-stimulus onset (relatedness × time, $F(6,258) = 8.91$, $p < 0.001$). In lateral sites, there was a more negative-going waveform in the unrelated than the related condition (main effect of relatedness, $F(1,43) = 4.83$, $p < 0.03$). Homonymous items elicited a more negative-going response than metaphorical or metonymic items in anterior sites from 300 to 350 ms and 500 to 650 ms (ambiguity × anteriority × time, $F(12,258) = 2.34$, $p < 0.05$). Relatedness effects were more temporally circumscribed in MCI than HC participants (relatedness × time × group, $F(4,86) = 2.61$, $p < 0.05$); the strongest relatedness effects in HC participants were observed between 500 and 650 ms, and in MCI participants between 600 and 650 ms. Finally, an interaction between ambiguity and group ($F(12,258) = 2.61$, $p < 0.05$) was due to a smaller

Table 4
Sample stimuli, Experiment 2.

	Related condition			Unrelated condition		
	Prime 1	Prime 2	Target	Prime 1	Prime 2	Target
Homonymy	Badminton	Racket	Noise	Green	Fern	Noise
Metaphorical polysemy	Latch	Key	Solution	Bread	Knife	Solution
Metonymy	Fluffy	Rabbit	Stew	Sushi	Rice	Stew

N400 to metonymic than homonymous or metaphorical items in HC ($p < 0.05$) but not MCI or AD participants ($p > 0.2$ in all cases). A borderline difference between metaphor and homonymy in MCI ($p > 0.06$) was in fact in the other direction, with greater negativity to metaphorical than homonymous items.

2.3. Discussion

While some differences in overall patterns of activity were observed between groups, all groups showed an effect of relatedness, with more negative-going activity in the unrelated than the related condition in midline and anterior lateral sites. Relatedness effects had an earlier onset and were longer lasting in HC than MCI participants. More negative-going activity was seen across groups to homonymous than metaphorical and metonymic items; an ambiguity type × group interaction was due to more negative-going activity to homonymous and metaphorical than metonymic items in the HC group, but not the MCI or AD groups. We note that the results reported here are unlikely to be due to generalized cortical atrophy in the MCI and AD groups, because the differences between groups result from differential patterns of activity in different experimental conditions, rather than a generalized reduction in activity in the patient groups.

The finding that HC participants manifest more negative-going activity to homonymous and metaphorical than metonymic items suggests that for these participants, processing demands are reduced for metonymic items relative to metaphorically ambiguous or homonymous items. This likely reflects the "sense relatedness advantage" (Klepousniotou & Baum, 2007) whereby lexical processing is facilitated by multiple related senses, specifically when the senses are literal as opposed to metaphorical. MCI and AD participants, in contrast, show diminished effects of ambiguity type that suggest a reduction in the processing advantage experienced by these participants. This finding is also consistent with prior behavioral research demonstrating a processing advantage for mass/count ambiguous items (a subtype of metonymic item) relative to pure mass and count items, in healthy elderly but not MCI or AD participants (Taler & Jarema, 2006). It should be noted, however, that the small number of AD patients included in this experiment precludes extensive interpretation of the null effect in this group.

The fact that relatedness effects are seen in both MCI and AD participants, regardless of ambiguity type – homonymy, metaphor, or metonymy – is interpretable in two ways. One possibility is that this simply reflects repetition priming, since in the related condition the same lexical item was seen within the same trial. However, this interpretation is unlikely for two reasons. First, repetition priming has been demonstrated to evoke an early positive shift, with onset at approximately 200 ms post-stimulus onset (Doyle, Rugg, & Wells, 1996). In the present results, more negative-going activity was seen in the unrelated homonymy condition between 250 and 300 ms across the three groups, but no effects were observed in this time window in the metaphor and metonymy conditions. This suggests that this finding does not reflect repetition priming, but rather early N400 effects. Second, repetition priming effects are significantly diminished in patients with mild AD (Olichney et al., 2006), suggesting that the diminished N400 observed in the MCI and AD participants in the present study when a stimulus is repeated cannot be attributed to repetition priming alone.

A second possibility is that these individuals activate all senses and/or meanings of ambiguous lexical items, thus showing priming across all ambiguity types. Such an interpretation would be consistent with previous research showing that AD individuals fail to efficiently inhibit contextually inappropriate meanings of ambiguous words in on-line processing and/or to selectively activate the appropriate representations (Balota & Duchek, 1991; Faust et al., 1997).

In order to tease apart these possibilities, we conducted a second experiment assessing priming of lexical items related to subordinate meanings/senses of ambiguous items by the ambiguous item itself, presented in a context biasing the dominant sense. We used a behavioral task, lexical decision, to determine whether facilitation is observed. Associates of the subordinate sense or meaning of ambiguous items were primed by the ambiguous item, presented in a single-word context biasing the dominant meaning (e.g., badminton–racket–*noise*). Our hypotheses are as follows: HC participants should show priming for metonymic but not metaphorical or homonymous items, as demonstrated in previous research with healthy young adults at a long stimulus-onset asynchrony (Klepousniotou et al., 2008). If MCI participants activate both meanings/senses of the ambiguous item, and subsequent inhibition of the irrelevant sense/meaning is weakened or non-existent, then priming of the item related to the subordinate meaning/sense would be predicted for all ambiguity types for these participants. If, in contrast, the relatedness priming observed in Experiment 1 is due to pure repetition priming (because the orthographic forms of the prime and target are identical), then no priming is predicted for MCI participants in any of the three conditions. This is because semantic information about the subordinate sense/meaning is not activated and hence items related to this sense/meaning will not be facilitated. An AD group was not included in Experiment 2 for two reasons. First, it was judged that the priming task would be difficult for this population to complete. Second, AD and MCI participants manifested a similar pattern of results in the ERP experiment as well as in our previous studies of ambiguity processing (Taler & Jarema, 2004, 2006), suggesting that similar performance is observed in MCI and AD in lexical ambiguity processing.

3. Experiment 2

3.1. Materials and methods

3.1.1. Participants

Two participant groups took part in Experiment 2: HC and MCI participants. All were native speakers of English with no neurological or psychiatric history (other than MCI), and all had normal or corrected-to-normal vision. All but one MCI participant were right-handed. The two participant groups did not differ in age ($p > 0.1$) or education level ($p > 0.9$).

3.1.1.1. HC participants. Ten HC participants (8 women and 2 men, average age = 74.3 years ± 5.2; average education = 13.5 years ± 2.7) took part in the study. Control participants were recruited from the Herzl Family Clinic at the Jewish General Hospital, and underwent a complete neuropsychological battery to exclude dementia and mild cognitive impairment.

3.1.1.2. MCI participants. Ten individuals diagnosed with MCI participated in the study (3 women and 7 men; average age = 78.1 years ± 5.1; average education = 13.4 years ± 3.0). MCI participants were recruited from the Memory Clinic at the Jewish

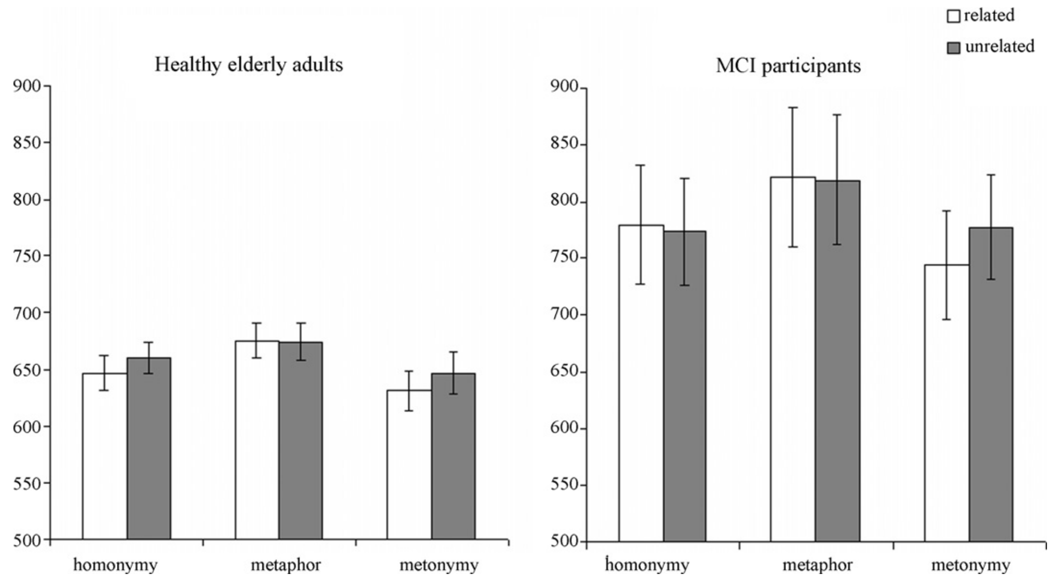

Fig. 6. Mean reaction time by category for healthy elderly and MCI participants.

General Hospital, a tertiary referral centre. The clinical diagnosis of MCI was made in the same way as described in Experiment 1.

3.1.2. Stimuli

A total of 180 triplets, distributed as illustrated in Table 4 (30 per cell), served as critical stimuli in Experiment 2. The first two items in the triplets were the primes, and the third was the target. Primes were ambiguous words, which, as in Experiment 1, were unbalanced homonyms, metaphorical polysemes or metonyms (Prime 2), preceded by a lexical item biasing the dominant sense/meaning of the ambiguous item (Prime 1) (e.g., badminton racket). Targets were lexical items associatively related to the subordinate meaning of the ambiguous word (e.g., *noise*). An additional 180 triplets in which the target item was a pseudoword were also included. Critical stimuli were nouns or adjectives and were balanced across categories for length, frequency (Baayen, Piepenbrock, & van Rijn, 1993; Kučera & Francis, 1967), neighborhood density and neighbor frequency, and mean bigram frequency according to data from the English Lexicon Project (Balota et al., 2002), and for familiarity according to data from the MRC psycholinguistic database (Coltheart, 1981).[2]

Stimuli were divided into two lists such that the same target word did not appear more than once in each list. Stimuli were pseudorandomized within each list with no more than three stimuli from the same category appearing in a row. Order of list presentation was counterbalanced across subjects.

3.1.3. Procedure

The procedure was explained to all participants prior to testing, and they signed an Informed Consent form approved by the Jewish General Hospital Ethics Review Board. All participants were remunerated for their participation.

Each prime was presented sequentially in white 32-point Arial font on a black background and remained on the screen for 600 ms. The target then appeared on the screen in yellow 32-point Arial font and remained until the participant responded or for 2000 ms, whichever was shorter. ISI between each item was set to 50 ms. Participants were instructed to press the spacebar if the third (yellow) word was a real word in English, and to wait for it to disappear from the screen if it was not a real word. The experiment was preceded by a practice session of 12 trials, including 6 word targets and 6 pseudoword targets. The participant was then given the opportunity to ask the experimenter any questions he/she might have. A break was given between list one and list two. In total, the experiment lasted approximately 20 min.

3.2. Results

Errors and outliers (defined as reaction times that were >±2.5 SD from the mean, by subject and category, and comprising 4.08% of responses) were excluded from analyses. Accuracy rates were very high overall (see Table 5). Statistical analyses were conducted on mean overall reaction times (RTs). Fig. 6 shows mean RTs by participant group and condition.

MCI participants responded more slowly than HC participants overall (main effect of group, $F(1,18) = 5.91$, $p < 0.03$). A main effect of prime type ($F(2,36) = 17.65$, $p < 0.01$) was due to longer RTs to targets related to the subordinate meaning/sense of metaphorical than homonymous items, and to targets related to the subordinate meaning/sense of homonymous than metonymic items. In addition, an interaction between relatedness and prime type was observed ($F(2,36) = 3.49$, $p < 0.05$), whereby priming was seen for targets related to the subordinate senses of metonymic but not metaphorical or homonymous items for both the HC and MCI groups. No effect of group or interaction between group and any other variable was observed.

3.3. Discussion

The goal of Experiment 2 was to determine whether HC and MCI participants were able to access on-line the multiple meanings of homonymous, metaphorical and metonymic lexical items. All participants showed priming for targets related to the subordinate sense of metonymic but not homonymous or metaphorical items. These results indicate that, in both groups, representation of and access to the secondary sense of metonymic lexical items are intact. This result is unexpected, because the results of Experiment 1 suggest that MCI individuals do not benefit from the sense relatedness advantage, consistent with previous research (Taler & Jarema, 2004, 2006). The reconciliation of the results of Experiments 1 and 2 is discussed in the following section.

4. General discussion

In Experiment 1, healthy elderly adults showed both a relatedness priming effect, indexed by a reduction in the N400 to related items relative to unrelated items, and a sense relatedness advan-

Table 5
Accuracy, Experiment 2.

	HC participants		MCI participants	
	Related	Unrelated	Related	Unrelated
Homonymy	99.67%	99.67%	98.33%	98.00%
Metaphorical polysemy	99.67%	98.33%	97.67%	98.00%
Metonymy	100%	100%	99.33%	98.33%
Pseudowords	95.26%		93.50%	

[2] 73% of the stimuli were present in this database.

tage, indexed by a reduction in the N400 to metonymic lexical items regardless of context. The sense relatedness advantage is due to a reduction in processing demands that occurs when a lexical item possesses multiple related, literal senses (the metonymic condition, e.g., *rabbit*), relative to items that do not possess multiple literal senses.

MCI and AD individuals showed a diminished sense relatedness advantage, indexed by the absence of an N400 reduction in the metonymy condition relative to the metaphor and homonymy conditions. However, a priming effect was seen in these populations, where a smaller N400 was seen to all classes of ambiguous items (homonymous, metaphorical or metonymic) presented in a context biasing the subordinate sense/meaning, when preceded by the same item presented in a context biasing the dominant sense/meaning (e.g., financial bank–river–bank, where "financial bank" is the dominant meaning and "river bank" is the subordinate meaning). This effect likely represents the activation of information about the subordinate meaning/sense of the ambiguous item.

Experiment 2 demonstrated that, in a lexical decision task, both HC and MCI participants activate the subordinate sense of metonymic items when these items are presented in a context biasing the dominant sense. No such activation was observed for the subordinate meaning/sense of homonymous and metaphorically polysemous items.

Given the results of Experiment 2, MCI patients' lexical entries contain information about both the dominant and the subordinate senses of metonymic lexical items. However, in Experiment 1, whereas HC participants showed an N400 reduction for metonymy versus other ambiguity types, the MCI and AD participants did not. These results suggest that, while the subordinate sense of metonymic items is still present and accessible in the lexicon in MCI, this additional information does not appear to facilitate processing of these items. This contention is supported by previous research indicating no sense relatedness advantage in MCI and AD individuals (Taler & Jarema, 2006).

The differing results from these RT and ERP studies may reflect differing underlying processes that are tapped by the two methodologies. It has been suggested that RT methodologies measure controlled processing while ERP measures more automatic processing (for a discussion, see Kotz, 2001). Under this view, the results described here suggest that MCI patients can use semantic information in a controlled or strategic way, hence showing priming in the behavioral experiment, but do not show the automatic reduction in neural processing that is observed in healthy controls when processing a metonymic lexical item. It should also be noted that the differing patterns of ERP activity in the context of similar behavioral findings in HC and MCI subjects could reflect neuroplastic processes in the MCI group, where different regions and/or strategies are used to complete the task in the two groups.[3]

Another possibility is that the diminished sense relatedness advantage observed in MCI and AD is due to a reduction in the general richness of semantic representations, while basic knowledge about senses is preserved. Martin and Fedio (1983) argue that specific semantic knowledge is lost first in AD, and that more general knowledge is lost later. The impairment in semantic processing observed in MCI, which is relatively minimal, thus likely preserves basic knowledge with respect to the different senses of metonymic items (e.g., that *chicken* can be either a meat or an animal), while more specific semantic knowledge is lost or inaccessible. If this is the case, then the sense relatedness advantage reported in a number of studies (e.g., Klepousniotou, 2002; Klepousniotou, 2007; Klepousniotou & Baum, 2007) would in fact constitute a subtype of processing advantage conferred by semantic richness rather than uniquely by multiple senses. This contention is supported by the finding that RTs are shorter in naming and lexical decision tasks to lexical items whose referents have many semantic features than those whose referents have few semantic features (Pexman, Lupker, & Hino, 2002). In the case of healthy elderly participants, this "semantic richness advantage" is maintained, given that semantic deficits are not typically seen in this population (e.g., Bowles et al., 1983; Burke & Peters, 1986; Howard, 1980). In MCI and AD, however, semantic processing is impaired, resulting in a diminished semantic richness advantage.

The studies reported here are a necessary first step in the exploration of ambiguity processing in MCI and AD; further research will be needed to explore the possibilities raised here. Specifically, it is of interest to examine the time course of ambiguity processing in these populations through manipulation of the stimulus onset asynchrony between prime and target, in order to identify the contributions of impairments in activation and inhibition to alterations in processing of ambiguous items. Additionally, the possibility that the processing advantages conferred by multiple related senses may be attributable to semantic richness should be further explored.

In sum, the results reported here suggest that, while knowledge of the multiple senses of metonymic lexical items is preserved at least in MCI, the processing advantage conferred by the semantic richness of these lexical items is diminished in MCI and AD. The present results have important implications in terms of understanding the nature of the alterations in semantic processing that are observed in MCI and AD. Consistent with a growing body of research, they indicate that subtle semantic deficits occur very early in the course of AD, prior to clinical diagnosis, while basic semantic knowledge is substantially preserved. Understanding of subtle aspects of impairments in lexical-semantic processing in MCI may point the way toward a tool for early diagnosis of AD, one of the major goals of research in MCI.

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[3] Thanks go to an anonymous reviewer for this suggestion.

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