Age-Related Differences in Semantic Priming: Evidence from Event-Related Brain Potentials

Luisa Cameli

A Thesis

in

The Department

of

Psychclogy

Presented in Partial Fulfilment of the Requirements
for the Degree of Master of Arts at
Concordia University
Montreal, Quebec, Canada

July 1999

0-612-43618-7

ABSTRACT

Age-Related Differences in Semantic Priming: Evidence from Event-Related Brain Potentials

Luisa Cameli

The goal of this study was to test whether semantic priming in response to a word that immediately follows a related sentence or single-word is age-invariant. This was done using the N400 event-related brain potential (ERP). N400 amplitude varies inversely with semantic priming (Kutas, 1980), and this effect is larger for sentence primes than for word primes (Kutas, 1993). ERPs were recorded while 20 older ($\underline{M}$ = 71.5, $\underline{SD}$ = 6.4) and 20 young ($\underline{M}$ = 23.0, $\underline{SD}$ = 2.3) subjects read word-pairs and highly constrained sentences. Each final word varied on the degree of relatedness to the preceding context, with some being highly related (BC), moderately related (R), or unrelated (U). An Age X Context X Relatedness repeated-measures analysis of variance (ANOVA) was conducted on N400 amplitude at the .05 level of significance. Significant results were further analyzed with Tukey A post-hocs also conducted at the .05 level of significance. In young subjects, N400 amplitude showed the expected N400 effect gradient (U > R > BC) in both the sentence and word-pair contexts. N400 responses in older subjects showed no discrimination between the conditions (U = R = BC) for the word-pairs and limited discrimination (U > BC) for the sentence endings, indicating that older subjects were able to benefit from the constraints of a sentence context. These results provide electrophysiological evidence of age-related changes in semantic priming, and are interpreted in the context of the inhibition-deficit hypothesis (Hasher & Zacks, 1988) whereby older adults fail to inhibit related but irrelevant items in working memory.

Acknowledgments

This project was supported in part by research grants awarded to Dr. Natalie A. Phillips by Le Fonds pour la Formation des Chercheurs et l' Aide à la Recherche (FCAR) and Fonds de la Recherche en Sante du Québec (FRSQ).

I am forever grateful to Dr. Phillips for giving me the opportunity to work in her lab and for sponsoring my admission into the Graduate Program in Psychology at Concordia. Dr. Phillips has been a mentor and role model to me. Her unfailing support throughout the completion of this project has been invaluable.

I am grateful to all members of the laboratory for contributing in various ways to this study: in particular to Dayle L' Espérance and Vivian Akerib for scoring some of the behavioral data, to Sarah Auchterlonie for administering subtests of the Wechsler Adult Intelligence Scale-Revised (WAIS-R) to subjects, and to Manon Leblanc and Nesrine Awad for their help in preparing the electrophysiological data for analysis.

I am thankful to all subjects who so kindly volunteered their time and effort. I wish to thank Drs. Phillips, Overbury and Turnbull for letting me recruit young subjects from their classrooms, and Mr.Whittaker for letting me use some space and equipment at the Jewish General Hospital of which he had charge.

I also wish to thank the members of my thesis review committee, Dr. David G. Mumby and Dr. Tannis Y. Arbuckle-Maag for their helpful comments.

Finally, I wish to thank my parents, Bernardino and Thérèse Cameli for their love and support, and my partner of 10 years Michael Sarman for his constant encouragement. His thirst for knowledge and his curiosity have instilled in me the love of research, and his patience and devotion continue to embellish my life.

Table of Contents

List of Figures

List of Tables

Age-Related Differences in Semantic Priming: Evidence from Event-Related Brain Potentials.

The ultimate goal of this study was to test whether semantic priming effects are age-invariant. In the following literature review, semantic priming effects in young adults are reviewed first. The effect of aging on semantic priming is reviewed second, along with pertinent hypotheses in the literature. Thirdly, an electrophysiological index of semantic priming is introduced, and research findings on the effect of aging on this physiological index are discussed. Finally, goals and predictions of the present study are specified.

As the proportion of older persons in society continues to increase, it is imperative that we gain more knowledge about the effects of aging on cognitive functioning. Since the processes of semantic memory are assumed to underlie higher levels of cognitive functioning, the effect of aging on semantic memory is of genuine interest (Bowles, 1994). For instance, word finding ability, assumed to depend on processes of semantic memory, is known to decline with age (e.g., Burke, MacKay, Worthley & Wade, 1991). Age-related changes in the processes of semantic memory would also have broad implications for episodic processing since the two are interrelated (Craik, Anderson, Kerr, & Li, 1995). The spreading of activation paradigm offers a promising tool to identify age differences in the processes of semantic memory.

In the typical semantic priming paradigm, a prime is followed by a target (e.g., "dog") that is either semantically related (e.g., "cat") or unrelated (e.g., "clock") to the prime. A neutral prime (e.g., the word "blank") is also often used to provide a baseline. A response to a target that is semantically related to the prime is typically faster and more accurate than a response to a target that follows a neutral or unrelated prime. A response to a target that is semantically unrelated to the prime is typically slower and less accurate than a response to a target that follows a neutral prime (e.g., Neely, 1977). It is generally assumed that the prime activates its own representation in memory and that this activation spreads to partially activate the representations of related items. This partial activation is assumed to reduce the time required to reach some threshold level of activation necessary to initiate a behavioral response (e.g., naming or making a lexical decision). At longer SOAs, the prime activates its own representation in memory and simultaneously inhibits the activation of unrelated representations. The benefit component of semantic priming resulting from both spreading activation and expectancy is inferred from the difference in RT to targets related to the prime and to targets that follow the neutral prime. The cost component resulting from the inhibition of semantically unrelated primes is inferred from the difference in RT to targets unrelated to the prime and to targets that follow the neutral prime. Semantic priming can also be inferred from the difference in RT to targets related and unrelated to the prime. This approach is limited in that at longer SOAs it becomes difficult, if not impossible to tease apart increased activation of related nodes and inhibition of unrelated ones. However, because of the difficulty in finding a truly neutral prime (see Neely, 1991), the approach of directly comparing RT in related and unrelated conditions may be advantageous. There are other measures of semantic priming, for instance, stem-completion, which will be discussed later.

Current accounts of semantic priming effects (Neely, 1991) rely on three concepts: spreading activation, expectancy, and post-lexical decisional strategy. It is assumed that information is represented in memory by distinct but interconnected nodes and that the activation of one node (by presentation of a priming context) leads to the spread of activation among related nodes (e.g., "bread-butter"). Expectancy is the process by which subjects consciously predict a set of targets that are the most likely to follow a priming context. Expectancy, in addition to increasing activation at semantically related nodes, has been shown to inhibit the activation of unrelated nodes. Spreading activation is defined as operating essentially without attentional control, a characteristic that allows priming benefits to appear when the stimulus onset asynchrony (SOA) between the prime and the target is relatively brief (e.g., 200 ms). Expectancy, in contrast, does require attention and as a result requires more time to develop. Expectancy-based priming effects are often not evident until the prime-target SOA is 400 ms or greater (Favreau & Segalowitz, 1983). Finally, there are post-lexical decision processes related to making the decision leading to the behavioral response. For instance, these can operate when deciding whether a string of letters is a word (e.g., "book") or a nonword (e.g., "vook") in a lexical decision task (LDT). Post-lexical decision processes of semantic priming are task-dependent since they can be observed only when a task requires a behavioral response.

Notwithstanding that semantic priming effects have been known for about 100 years (e.g., Cattell, 1985/1947), only recently has their relation to aging been systematically investigated. Different predictions about changes in the amount or rate of semantic priming arise from three dominant hypotheses. The inhibition-deficit hypothesis predicts an age-related decrease in semantic priming, whereas the general slowing hypothesis and interactive-compensatory hypothesis both predict an age-related increase in semantic priming (hyperpriming). The two latter hypotheses differ in their specific accounts of the mechanisms responsible for hyperpriming. Each will be discussed in further detail.

The inhibition-deficit hypothesis

Hasher and Zacks (1988) proposed an inhibition deficit hypothesis (IDH) in normal aging. According to the IDH, an age-related decrease in inhibition efficiency permits the entry of irrelevant information into working memory and fails to clear working memory of no longer relevant information. In the short term, irrelevant information may prevent access to relevant information thereby compromising text or discourse comprehension. For instance, if, when presented with the referent of a pronoun, the subject has an irrelevant thought, the failure to retrieve the referent in a timely manner because of competition from the irrelevant thought will jeopardize text comprehension. In the long term, the increase of irrelevant information in working memory creates circumstances ideal for forgetting: The initial encoding may be weaker (since in the short term irrelevant information may interfere with comprehension), and there may be strong competition among related ideas (Hasher & Zacks, 1988). The IDH would predict an age-related decrease in semantic priming due to a decrease in the inhibition of unrelated targets. Semantic priming can be operationally defined as the difference in the RT (or other dependent measure) in response to a target related to the prime and that in response to a target unrelated to the prime. A decrease in the inhibition of unrelated targets would lead to a decrease in the difference in RT (or other dependent measure of semantic priming) between responses to targets related and unrelated to the prime because there would be less slowing in the responses to unrelated targets. For the same reason, the IDH would in addition predict an age-related decrease in the ratio of semantic priming of highly related to moderately related targets. This would reflect reduced efficiency in the inhibition of endings related to the best completion, but not as appropriate as the best completion. For example, the IDH would predict more priming of the target "coffee" following the prime "He puts lemon and sugar in his ___" for older than for young adults, whereas priming of the target "tea" would not differ between the two groups. Finally, a third prediction of the IDH, based on the work of Craik (see chapter nine in Craik et al., 1995), is that when contextual support is great (e.g., a highly constrained sentence), age-related differences in semantic priming will be minimal. One consistent finding in the literature has been that age-related differences are reduced substantially when supportive cues are presented with the target items at encoding and at the time of retrieval (see Craik et al., 1995). In the context of the IDH, it can be hypothesized that greater contextual support may help older adults inhibit unrelated or weakly related items. This could compensate for the proposed inhibition deficits of older adults and result in an increase in semantic priming as measured by the difference in RT (or other measure) to targets related and unrelated to a preceding prime.

Much of the research on semantic priming in aging has been conducted in the framework of the IDH. Hartman and Hasher (1991) had young and older subjects read highly constrained sentence fragments for which the final word had a high cloze probability (e.g., "She ladled the soup into her ___"). For each sentence, subjects had to predict the ending (e.g., "bowl"). Following the prediction, the ending of the sentence was shown. For some sentences, the ending presented confirmed the predicted ending (e.g., "bowl"), while for other sentences the ending presented differed from the predicted ending (e.g., disconfirmed ending "lap"). Subjects were instructed to remember the ending that was actually presented for a later memory test, one of which was a sentence fragment completion task. After the study sentences were presented, subjects were told that several unrelated tests would be given before the memory test. Of interest was whether there would be an age difference in the likely use of confirmed and disconfirmed endings when subjects were instructed to complete with the first word that came to mind for medium cloze sentence fragments. In other words, for the sentence fragment "Scotty licked the bottom of the ___", for instance, would older subjects be more likely than young subjects to produce the disconfirmed ending "bowl"? This, in comparison to sentence fragments lending themselves to be ended with a confirmed ending such as "lap": "The kitten slept peacefully on her owner's ___"). Subjects were lead to believe that the purpose of this task was to help the experimenters develop stimuli for future experiments. Older subjects produced both types of endings (confirmed and disconfirmed) equally as completions, while young subjects tended to produce only confirmed endings. These results were interpreted as evidence supporting the IDH. The assumption was that older subjects, in contrast to young subjects, had not inhibited the expected but disconfirmed endings during reading. Limitations to this study are twofold. First, many young subjects and few older ones were aware of the relationship between the sentences presented during reading and at test (i.e., that the sentences could be completed with the same endings). The young adults, therefore, may have adopted a strategy of completing the sentences at test with the confirmed endings. Secondly, remembering which endings were read and which were expected was necessary for learning the correct completion. Older adults have been shown in various studies to have deficits in source memory relative to young adults (e.g., Spencer & Raz, 1995). As a consequence, the differences observed between the young and old adults in Hartman and Hasher (1991) may have been due to age-related differences in episodic memory rather than to age-related differences in inhibition efficiency while reading.

In an attempt to test the IDH *during* reading, Hamm and Hasher (1992) presented subjects with 24 passages, half of which ended as expected (e.g., "The artist had three months... to finish his painting") or changed unexpectedly mid-way through (e.g., "The artist had three months... to live"). Mid-way (before confirmation or invalidation of the expectations) and at the end of each paragraph, a series of 14 words appeared on the screen that included the two critical words related to the two possible outcomes (e.g., "finish, live") and words related or unrelated to those. Subjects had to decide as fast as possible whether each word was consistent with their current understanding of the passage, had been previously presented or was inconsistent with their current understanding of the passage and to signal their response with one of two possible button presses. After reading six of the 24 passages, an inference question was asked for each paragraph (e.g., "The artist had three months left for what?"). Young and older subjects performed equally well on the inference questions. For passages that ended as expected, the performance of young and older subjects on the speeded decision task (consistent or not?) did not differ. For passages that ended unexpectedly, older subjects misjudged no-longer-consistent words as consistent to a significantly greater extent than did younger adults, while correctly judging consistent words as consistent to the same extent as did younger subjects. The results were taken as an indication that older adults had failed to inhibit the inconsistent inference made during reading for passages that changed unexpectedly even though subjects had arrived at a more appropriate inference following the new information which was demonstrated by the fact that they did as well as young subjects on the inference questions. However, group differences in Hamm and Hasher (1992), as in Hartman and Hasher (1991), may have been due to deficits in episodic memory rather than to inhibition deficits while reading. To perform the task, subjects had to remember which words had been presented. Correct "yes" responses to a new interpretation required knowledge that it was the current interpretation, whereas correct "no" responses to the original implicit competing interpretation required knowledge that it was not the current interpretation *and* that it had not been presented earlier in the passage. Older adults' episodic memory decline would reduce their retention of what had been explicitly stated earlier in the paragraph, inflating "yes" responses because they incorrectly remembered that they appeared in the passage (Burke, 1997). A further limitation of the study was the reliance on manual responses which can act as a confound in two ways. First, manual responses have been shown to be highly susceptible to decision processes not related to language processing (Balota at al., 1992). Secondly, manual responses increase working memory load (e.g., remembering that the left button means inconsistent). Increases in working memory load has been shown to impair the performance of older subjects on linguistic tasks to a greater extent than that of younger subjects (e.g., Gunter, Jackson & Mulder, 1995).

To avoid the limitations associated with manual responses, while testing the IDH "on-line", Hopkins, Kellas, and Paul (1995) used a naming task priming paradigm in which young and older subjects read contextually biasing sentences, ending with a homograph (e.g., "After the accident they shut down the *plant*"). After a delay of either 0, 500, or 1000 ms following each homograph, subjects named a target word related to either the contextually appropriate (e.g., "building") or the contextually inappropriate (e.g., "green") meaning of the homograph. Naming latencies were compared with those to the same target words when preceded by a neutral sentence prime. Based on the IDH, young adults should inhibit the contextually inappropriate meaning of the homograph, while older adults should fail to do so. Thus, according to the IDH, older subjects were expected to show more facilitation to target words related to the contextually inappropriate meaning of the homograph relative to young adults. Contrary to these predictions, there was no evidence of facilitation for either age group to target words related to the contextually inappropriate meaning. Only responses to target words related to the contextually appropriate meaning of the homograph were facilitated, equally so for the two age groups. This was the case regardless of the delay occurring between prime-sentence and target word (0, 500, or 1000 ms). The failure to find age-related differences in the priming of contextually inappropriate meanings of homographs was interpreted as evidence against the IDH. However, the sentence primes may have provided such contextual constraint as to not lead to the activation of the alternate meaning of the homographs in any of the subjects. For instance, there is no a-priori reason why the "green plant" meaning of "plant" should become activated after reading "After the accident they shut down the plant".

Paul (1996) presented older and younger adults with sentences in which the homograph occurred *prior to* the disambiguating context (e.g., "I waited at the *bank* until the *boat* returned for me."). Subjects named a target word presented 0, 500, or 1000 ms after each sentence which was related to the contextually appropriate (e.g., "fish') or inappropriate (e.g., "money") meaning of the homograph. Naming latencies were compared with those to the same target words when preceded by a neutral sentence prime. Responses to target words related to the contextually appropriate and inappropriate meanings of the homograph were equally facilitated, and this for both age groups. These results diverge from Hopkins et al. (1995) where only contextually appropriate meanings of the homographs were facilitated. This may be due to the use of a strategy by young subjects in Paul (1996). When presented initially with a sentence like "I waited at the bank until the boat returned for me", young subjects may not have activated the word "boat" because it is related to the less frequent meaning of the word "bank". With repeated trials, young subjects may have learned that the experimental sentences were just as likely to include the less frequent or more frequent meaning of the homographs. In response, they may have adopted an "open-mind" strategy whereby they did not inhibit the less frequent meaning of the homographs. Older subjects in contrast, may not have inhibited the less frequent meaning of the homographs because of deficits preventing them from doing so.

In a separate experimental condition, Paul (1996) presented older and younger adults with sentences such as "It hung from the *beam*". After a delay (0 ms, 500 ms, or

1000 ms) subjects named a target word high salient to the sentence context (e.g., "support") or low salient to the sentence context (e.g., "above"). Naming latencies were compared with those to the same target words when preceded by a neutral sentence prime. Responses to high salient target words were facilitated across all delays for both age groups. Responses to low salient target words were facilitated across all delays for older adults only. By contrast, younger adults showed facilitation to low salient targets at the 0 ms delay only. Paul (1996) interpreted the results as support for the IDH. Based on results from both experiments, the author suggested that older adults may develop a more semantically elaborated representation of sentences than young adults, because although they exclude clearly irrelevant information (Experiment 1), they are less likely to exclude relevant information (Experiment 2).

Results from a meta-analytic review of studies on semantic priming in older adults (Laver & Burke, 1993) suggest an age-related increase in semantic priming effects. The IDH cannot account for this finding. Two hypotheses, the general slowing hypothesis and the interactive-compensatory hypothesis, have been proposed to account for the finding of hyperpriming with increasing age. These will be reviewed next and evidence for each will be presented.

<u>The general slowing hypothesis</u>

The finding that older adults perform more slowly than do young adults on a wide range of cognitive tasks (e.g., Salthouse, 1985) had led some investigators to suggest that a single slowing factor may account for cognitive aging in general (e.g., Myerson, Hale, Wagstaff, Poon, & Smith, 1990). This hypothesis is typically tested in a plot of older adults' mean latency as a function of younger adults' mean latency. The general slowing factor is supported when a linear function with a slope greater than 1, or a positively accelerated function is obtained, indicating a multiplicative (not additive) relation (Meyerson et al., 1990). Both functions predict that any factor that increases RT should have a greater impact on older than on younger adults. In semantic priming, primes unrelated to the target increase RT to the target. Consequently, the general slowing hypothesis predicts hyperpriming in older adults, due to an increase in the inhibition of unrelated targets. This prediction is the opposite of that from the IDH. The general slowing hypothesis does not specify whether age-related changes are limited to the time required to activate unrelated nodes or whether they may extend to the strength of activation of unrelated nodes.

Evidence supporting the general slowing hypothesis as an explanation for hyperpriming in aging is limited. Lima, Hale, and Meyerson (1991) plotted older adults' RT as a function of young adults' RT using data from 10 lexical decision studies and 9 other studies involving various lexical tasks. The best-fitting linear function had a slope of 1.5. Lima et al. (1991) suggested that a single slowing factor of 1.5 describes older adults' performance on all lexical tasks. Madden (1989) also provided evidence for a single slowing factor of 1.5 on a LDT. However, as Laver and Burke (1993) note, the literature shows considerable variations in the quantitative estimates of a slowing factor. For example, the slope of the young-old RT function has been reported as varying between 1.08 and 1.70 (Cerella et al., 1980) and between 1.2 and 2.0 (Salthouse, 1985). As Baron and Mattila (1989), also cited in Laver and Burke (1993), have pointed out:

"This wide range of possible deficits, 20% to 100%, is difficult to reconcile with a fundamental aspect of the general slowing hypothesis; that a single value (or at least a circumscribed range of values) can be used to characterize slowing independently of the experiment or task" (p. 71).

The interactive-compensatory hypothesis

Spreading of activation is assumed to reduce the amount of sensory processing needed for word recognition (Madden, 1988). Within the framework of the interactive-compensatory hypothesis, factors that slow word recognition will increase the size of the semantic priming effect since semantic context is a complementary source of activation which reduces the amount of sensory analysis required for recognition (Madden, 1988). Laver and Burke (1993) presented a horse race analogy: "A slow horse will save more time than a fast horse when the distance of the race track is reduced by a constant amount." There are various sources of evidence for interactive-compensatory mechanisms. For instance, semantic priming effects are larger for long, low-frequency words than for short, high frequency words (e.g., Madden, 1986), for degraded than for intact words (e.g., Madden, 1988), for poor readers than for good readers (e.g., West & Stanovich, 1978), and for younger than for older children (e.g., Stanovich, Nathan, West, & Vala-Rossi, 1985). The interactive-compensatory hypothesis leads to the clear expectation that older adults would show larger semantic priming effects, given the evidence that visual perceptual analysis slows with age (e.g., Fozard, 1990). More specifically, the interactive-compensatory hypothesis predicts increased activation of highly and moderately related targets in older adults relative to young adults. In addition, according to the interactive-compensatory hypothesis, older adults may be expected to benefit more from contextual support (e.g., a highly constraining sentence) than young adults because of their perceptual and/or cognitive deficits.

Thus, whereas the general slowing hypothesis predicts hyperpriming because of an increase in the inhibition of unrelated targets, the interactive-compensatory hypothesis predicts hyperpriming because of an increase in the activation of related targets. In a recent meta-analysis of 13 LDT and two naming studies with 49 conditions in total, Laver and Burke (1993) found evidence of hyperpriming in aging. When each study was taken separately, however, the size of the semantic priming effect did not differ statistically even though older adults often showed a larger difference between reaction time to related and unrelated targets. Laver and Burke (1993) interpreted the results as support for the interactive-compensatory hypothesis. The results failed to support the general slowing hypothesis because a plot of the priming in the old as a function of priming in the young yielded a slope of 1 with a positive intercept indicating an additive (as opposed to multiplicative) relation.

The architecture of the semantic network in aging

Salthouse (1988) has proposed that the semantic network of older adults may be larger than that of young adults. In most studies of aging, the older group has processed language stimuli for at least two to three times longer than the younger group. This age-related expertise with language may result in a more elaborate semantic network. If this elaboration of the network results in more interconnections, then a given node may be activated by a higher number of nodes than would be the case in younger adults. All things being equal, older adults would then show hyperpriming because of this increase in the sources of activation for each node. This hypothesis has been supported by Laver and Burke (1993). On the other hand, if the semantic network is larger, then activation may be more diffuse. An analogy would be vessels receiving blood from a larger artery: the more numerous the vessels, the less blood each vessel will need to carry to the tissue it irrigates. This diffusion of spreading activation would result in attenuated semantic priming in the old. This result would be similar to that predicted by the IDH, although the mechanism would be somewhat different.

Conclusions

Evidence supporting the IDH comes from a variety of studies and methodologies: sentence fragment completion (Hartman & Hasher, 1991), text comprehension (Hamm & Hasher, 1992), homograph reading (Paul, 1996), and naming (Balota et al., 1992). The limitations of each were discussed. These included the lack of on-line measures of semantic priming (especially in Hartman & Hasher, 1991) and methodological problems specific to each study (e.g., an episodic memory confound in Hamm & Hasher, 1992; a possible strategy in Paul, 1996).

Evidence for the general slowing hypothesis in semantic priming comes mainly from the meta-analysis by Lima et al. (1991), and while evidence for the interactive-compensatory hypothesis derives from the meta-analysis by Laver and Burke (1993). Evidence for the general slowing and the interactive-compensatory hypotheses is limited by the fact that only LDT studies were included in each of the two meta-analyses. Laver and Burke (1993) state, "The conclusion that temporal properties of spreading semantic activation are age constant is difficult to accept because of the pervasive slowing of other cognitive processes. Nonetheless, this conclusion has been reached in virtually every study of aging and speed of spreading activation." The suggestion that age-related constancy in semantic priming should be accepted may be premature for the following reasons. First, the evidence is largely based on a task (LDT) known to reflect not only automatic spreading activation and expectancy, but also a post-access backward search from the target to the prime for a semantic relation (Neely, 1991). This is because, while words can be related to the prime, non words are always unrelated to the prime. Therefore, subjects can use the detection of a prime-target relation to bias their "word' response, thereby facilitating responses to related in comparison to unrelated targets (Neely, 1991).

Secondly, there are limitations specific to using RT measures to study the effect of aging on semantic priming. The most important one is the inability to clearly separate the strength of the process from its timing. As stated in Van Petten (1993): "A 30 ms reaction time advantage looks like any other 30 ms reaction time advantage whatever the underlying mechanism." When priming is measured as a difference in RT, one can not distinguish between differences due to the effect of semantic relatedness on the *speed* of priming (e.g., how long it takes for "dog" to become activated following "cat") and those due the effect of semantic relatedness on the *strength* of activation of a related node (e.g., how strongly "dog" becomes activated following "cat"). Because of this, one cannot tell whether age-related RT differences reflect changes in the speed or strength of the process. Distinguishing between the two is important. Age-associated deficits related to speed may not be as detrimental as deficits related to the strength of a process. Attempts to differentiate speed from strength have been made by varying the SOA (e.g., Balota et al., 1992; Hopkins et al., 1995; Paul, 1996). However, rarely are more than 3 SOAs used, for obvious practical reasons. This is a far cry from a genuine "on-line" measurement of semantic priming. In addition, the ecological validity of this approach can be questioned.

Reaction time measures reflect an agglomeration of processes, some of which may interact. For instance, decision processes in older subjects could interact with relatedness such that decisions would be slowed in the unrelated condition. Older adults may require greater certainty before making a response, and consequently could take longer to respond when unsure. This would act to maximize age-related differences in the unrelated condition.

A final concern is with regards to the use of difference scores (RT unrelated - RT related) in research on semantic priming. Difference scores tend to be less reliable than the original scores from which they were derived. This is because the difference score absorbs the measurement error from both scores, whereas the variability in each score that is truly due to the effect of relatedness is canceled out by the subtraction (Kaplan & Saccuzzo, 1993).

Despite these limitations, it is possible that semantic priming effects increase (Laver & Burke, 1993) or do not change with aging. Several investigators (e.g., Burke et al., 1987; Madden, 1989; Balota & Duchnek, 1988; as well as the individual studies in Laver & Burke, 1993) have failed to find age-related differences in semantic priming in LDT or naming tasks. Whereas the lack of evidence of age-related hyperpriming in those studies could be due to a lack of statistical power, as suggested by Laver and Burke (1993), it could also be due to the lack of age-related differences. The fact that the most studies on the effects of aging on semantic priming do not find age-related deficits support the later view.

Comparison of sentence and word context effects

The majority of studies that have found evidence supporting the IDH have used a sentence-priming paradigm (e.g., Hartman & Hasher, 1991; and Paul, 1996); whereas the two meta-analyses that have found evidence supporting the general slowing (Lima et al., 1991) and interactive-compensatory (Laver & Burke, 1993) hypotheses have included mostly word-priming studies. To this author's knowledge, no study has yet directly compared sentence-priming and word-priming in older adults. This may be partly due to problems associated with RT measures that do not make them amenable or particularly well suited for such comparisons.

The direct comparison of sentential (sentence-priming) and lexical (word-priming) effects in aging is important for a number of reasons. First, age-related changes in bottom-up processing can be contrasted with changes in top-down processing. "Bottom-up" refers to lexical priming, whereby the prime directly activates the target (e.g., "bread-butter"). In contrast, sentences involve novel combinations of words that cannot be pre-stored (e.g., "The game was called off when it started to rain"). Therefore, an integration of the prime is necessary before the sentence context can have a "top-down" effect on the target. It is as yet unknown whether the same or different mechanisms underlie bottom-up and top-down processes. However recent evidence (e.g., Kutas, 1993; Van Petten, 1993) suggests a common underlying mechanism.

In addition to providing greater insight into the nature of changes in semantic processing that occur with aging, the comparison of sentential and lexical context effects in young and older subjects could inform us about the mechanism(s) underlying context effects. Evidence of age-related differences restricted to one of the two types of processing (top-down or bottom-up) would provide evidence suggesting different underlying mechanisms, whereas age-related changes in both, or age invariance, would support the hypothesis of a common underlying mechanism.

There are clear predictions from each of the main hypotheses previously reviewed for the effect of context on semantic priming in aging. The IDH and the interactive-compensatory hypotheses predict that older adults should benefit more than younger adults from contextual support. A sentence context provides much more support (assuming that it is highly constrained) than does a word context, and therefore, older adults should benefit more from the former. The rationale behind this prediction is similar for the IDH and the interactive-compensatory hypotheses. In the framework of the IDH, older adults have difficulty inhibiting related but irrelevant targets, such that when presented for example with "flower," they may activate the representation of a wide variety of flowers, colors, fertilizers, and so on from semantic memory. However, if presented with "Roses are red, violets are...", they may be able to better inhibit the activation of those items (flowers, fertilizers) and more specifically activate the representation of "blue."

In the framework of the interactive-compensatory hypothesis, older adults benefit more than young adults from any factor that increases the speed of word identification. This is to compensate for a slowing in perceptual processing. If we assume that a sentence prime can speed up word identification more than a word-prime because it leads to greater expectancy (as in "Roses are red, violet are..."), then age-related differences in semantic priming are expected to be greatest with even more hyperpriming in the old in the sentence context relative to the word context.

Predictions from the general slowing hypothesis are less obvious. On the one hand, the general slowing factor (e.g., the 1.5 factor proposed by Lima et al., 1991) should be equal for words and sentences since it is assumed to be task or condition-independent. However, if the amount of slowing is to accumulate, a sentence context would have a more detrimental effect on semantic priming in the old than would a word context. In either case, the general slowing hypothesis would fail to account for older adults benefitting from the added contextual support of a sentence prime if such an effect were observed.

Event-related potentials (ERPs)

Event-related potentials (ERPs) are complementary to behavioral measures of semantic priming. It is generally accepted that ERPs reflect activity originating within the brain (Coles & Rugg, 1995). Although the relationship between this activity and what is observed at the scalp is not completely understood, the following points are clear. First, ERPs recorded from the scalp represent net electrical fields associated with the activity of sizeable populations of neurons. Secondly, and relatedly, the individual neurons that comprise such a population must be synchronously active and have a certain geometric configuration if they are to induce fields that can be measured at the scalp (Coles & Rugg, 1995). In particular, the neurons must be configured in such a way that their individual electrical fields summate to yield a dipolar field (a field with positive and negative charges between which current flows). Such configurations are known as "open fields" and usually involve the alignment of neurons in a parallel orientation (Coles & Rugg, 1995). Although the neural generators of a given ERP component may not be easily localized (e.g., a field recorded at a parietal site could reflect neural activity in frontal cortex, although significant advances in source localization are being made), the scalp distribution of an ERP component can nonetheless be informative. For instance if the distribution of an ERP component in the same task is different for two groups of subjects, it is highly likely that the neural generator(s) are also different. Finally, biophysical and neurophysiological considerations strongly suggest that scalp-recorded ERP waveforms are principally a reflection of post-synaptic (dendritic) potentials, rather than of axonal action potentials (Coles & Rugg, 1995).

Event-related potential components are typically examined with respect to their amplitude, timing, polarity, and scalp distribution. The advantages of using ERP measures are at least twofold. First, they are multidimensional and can illuminate the relative strength (amplitude in μV) and timing (latency measured on the order of milliseconds) of stages of cognitive processing (Brandeis & Lehmann, 1986). Second, ERPs can reveal internal states which may not be revealed by behavioral observation or methods (e.g., RT or error rate measures) and are not contingent upon making a behavioral response.

Thirdly, ERPs are an on-line measure. Event-related potentials are labeled after their alleged polarity and occurrence time after the stimulus. For example, the N400 is a negative-going waveform deflection which peaks at approximately 400 ms post-stimulus.

Event-related potentials are particularly relevant to studies of cognitive processes that compare different subject populations. Event-related potentials can specify whether a difference in overall performance between young and older subjects reflects a slowing of the underlying cognitive processes through the latency of an ERP component or a dampening of the same processes through the amplitude of an ERP component. This is in contrast to reaction time measures. Event-related potentials can specify whether older subjects process information differently during the course of reading (ERPs are on-line) and whether this difference occurs in the subject's natural environment (ERPs do not require the subject to make a behavioral response). In addition, ERPs can specify whether any difference in processing (either a slowing or a dampening) between young and older adults arises from the same cognitive operations (e.g., the scalp distribution and morphology of the ERP component is the same) or whether older adults may perform different, perhaps compensatory cognitive operations (the scalp distribution and/or morphology of the ERP component is different).

The N400 ERP component is a sensitive index of semantic relatedness and expectancy. The N400 is typically found to be largest over centro-parietal scalp sites. When hemispheric differences are examined, the N400 is found to be larger over the right hemisphere (see Kutas, Van Petten, & Besson, 1988 for an overview of the scalp distribution of the N400).

The amplitude of the N400 varies inversely with the amount of semantic priming (Kutas & Hillyard, 1980 a, b, c). For instance, the word "cry" following the sentence prime, "The pizza was too hot to ____" would result in a large N400; the word "eat" would result in a small or nonexistent N400; while the word "drink" would result in a N400 of intermediate amplitude. The amplitude of the N400 also varies inversely with expectancy defined as cloze probability (Kutas, Lindamood & Hillyard, 1984; Kutas & Hillyard, 1984). A word's cloze probability is defined as the proportion of subjects using that word to complete a particular sentence. Kutas and Hillyard (1984) presented subjects with sentence fragments that were completed in a meaningful way, but varied in the cloze probability of their terminal words. One third of the sentences were highly constrained: half of these ended with the highest cloze probability word (e.g., "He mailed the letter without a *stamp*"), and the other half with a low cloze probability word (e.g., "The bill was due at the end of the *hour*"). One third of the sentences were of intermediate constraint: half of these ended with the highest cloze probability word (e.g., "She locked the valuables in the *safe*"), and the other half with a low probability word (e.g., "The dog chased our cat up the *ladder*"). The last third of the sentences were of low constraint: half ended with the highest cloze probability word (e.g., "There was nothing wrong with the *car*"), and half with a low probability word (e.g., "He was soothed by the gentle *wind*"). The N400 effect was reflected in the difference in N400 amplitude to high and low cloze probability endings (the later being more negative) and was largest for highly constrained sentences. This study was important in showing that the N400 was an index of how intensely the previous context prepared the way for the final word (priming), and not of cognitive reprocessing following a nonsense ending as in "The pizza was too hot to *cry*". In fact, if the N400 is to be an index of semantic priming, it must reflect both spreading of activation (indexed by the effect of semantic relatedness) and expectancy (indexed by the effect of cloze probability). The fact that the two mechanisms can be observed at the same SOA (700 milliseconds in Kutas & Hillyard, 1984) is consistent with findings in the behavioral literature (Balota et al., 1992). Further evidence indicating that the N400 is strictly an index of semantic priming comes from studies that have demonstrated the N400 to be insensitive to grammatical violations (e.g., incorrect verb tense), to nonlinguistic deviations (e.g., word in a surprisingly large font) or to manipulations of the probability of occurrence (e.g., 75% versus 25%of semantic anomalies; Kutas & Hillyard, 1980 a, b, c.; Kutas & Hillyard, 1984). Because of these properties, the N400 ERP component is a useful measure of semantic processing and has been widely used in studies of language. The N400 amplitude effect is not limited to written language, and can be observed for instance in picture priming paradigms (e.g., Barrett & Rugg, 1991; Holcomb & McPherson, 1994; Ostrosky-Solis, Castaneda, Perez, Castillo, & Bobes, 1998).

N400 responses are elicited by word pair contexts as well. Kutas and Hillyard (1989) presented subjects with word pairs which were either highly related (e.g., "wet-dry"), moderately related (e.g., "bank-teller"), or unrelated (e.g., "wallet-vest"). They found the same relatedness effect on N400 amplitude elicited by the target word (Unrelated > Moderately related > Highly related) as for sentences. (The N400 effect was reported as statistically significant, although the difference in amplitude between the Moderately related and Unrelated word pairs yielded a p-value of .067). The N400 effect for word pairs was reported as smaller and of shorter duration than that which is typically reported for sentences.

Kutas (1993) was the first to directly compare single-word and sentence context effects on the N400. In the first phase of the study, young subjects read sentence primes (e.g., "He shouted at the top of his ____") followed by a target word that best completed the sentence prime (e.g., “lungs”), or a target word related (e.g., “vocal cords”) or unrelated (e.g., “stairs”) to the best completion. In the second phase, subjects were presented with word pairs derived from the sentences, and had to perform a letter search task (decide whether the letter “p” was present in one of the words). High relation word pairs consisted of the word most highly related to the best completion followed by the best completion (e.g., “heart-lungs”), medium relation word pairs consisted of the best completion followed by the related completion (e.g., “lungs-vocal cords”) and low relation word pairs consisted of the best completion followed by the unrelated completion (e.g., “lungs-stairs”). For both sentence and word contexts, a gradient of increasing N400 amplitude was found with responses to the best completions being the smallest, responses to the unrelated completions being the largest, and responses to the related completions being of intermediate amplitude. This gradient was smaller for the word context than for the sentence context. Together with the similarity of N400 scalp distribution for sentence and word contexts, these results led to the conclusion that sentence context effects and word context effects on N400 amplitude differ quantitatively and not qualitatively. A limitation to the study was that while the goal was to directly compare the effect of a word and sentence context, a different task was used for each. While subjects read the sentences for meaning, they were instructed to look for a letter ("p") in the word-pairs. As a result, subjects may have processed the sentences at a deeper level allowing context to have a stronger effect on N400 amplitude. Another possibility is that because the order of presentation of the sentences and word pairs was not counterbalanced, fatigue may have contributed to the attenuation of the N400 effect in the word context (presented last). Finally, because at least 25% of the sentences contained lexical associates (e.g., "The *parking* lot was full of foreign expensive *autos*"), there is great difficulty in teasing apart sentential from lexical effects.

In contrast to the extensive research on semantic priming using the N400 in young adults, relatively little research has been done on the effect of aging on semantic priming using the N400. Aging effects on the N400 were first noted by Harbin, Marsh, and Harvey (1984) in a study on late positive ERP components. In their study, young ($\underline{M}$ = 21 years) and older ($\underline{M}$ = 71 years) subjects read a series of words and had to decide whether the fifth word matched the preceding four, which were drawn from the same semantic category. In the case of a mismatch, an N400 was elicited. The N400 response to mismatched final words was attenuated and delayed in the older subjects, relative to younger subjects. However, the N400 was not the focus of the study, and age-related differences on the N400 were reported but not discussed.

The first direct investigation of age-related changes in semantic priming using the N400 was conducted by Gunter et al. (1992). In their study, middle-aged academics ($\underline{M}$ = 56 years) and young subjects ($\underline{M}$ = 22 years) read 120 sentences, each containing seven or eight words. Half of the sentences ended with a word that was congruent with the sentence context, whereas the other half ended with a word that was incongruent. Each word remained on the screen for 280 or 700 ms. The N400 to incongruent endings was attenuated and delayed in older subjects, relative to younger subjects. The effect of presentation rate did not interact with relatedness (congruent versus incongruent ending), and N400 was more negative for both groups in the 280 ms condition. The two presentation rates used were not optimal for a study of aging. The 280 ms may have lead to shallower processing in older subjects, while the 700 ms interval may have capitalized on the distractibility of older subjects; both could have resulted in less priming in older subjects. This is in contrast to most studies of aging in which presentation rate is calibrated for each subject (e.g., Paul, 1996; Hamberger, Friedman, Ritter, & Rosen, 1995). Gunter et al. (1992) interpreted the age-related reduction in N400 amplitude to incongruent endings as evidence supporting the IDH. The authors also suggested an alternative explanation for the results, whereby older adults showed more activation of incongruent endings because of a larger semantic network. Assuming multiple paths of activation, incongruent endings could take longer to become activated in the old (which would explain the age-related delay in N400), but would ultimately be activated more strongly than in the young, explaining the age-related N400 attenuation. Finally, because the N400 was significantly more pronounced in the right hemisphere for both groups, the authors concluded that the age-related difference in semantic priming was quantitative and not qualitative in nature.

Gunter et al. (1992) discussed their results in terms of spreading of activation, ignoring expectancy effects. This is because they collected norms on the words most likely to be used to complete each sentence (cloze probability) in a group of young and older adults. Sentences for which over 70% of subjects used the same word as an ending were selected for their study. The authors concluded that expectancy could not have played a role in the age-related differences, because cloze probability was the same for the two groups. However, the age-related differences were not for the congruent endings, but for the incongruent ones. Thus, there was no direct evidence to support the notion that incongruent endings were equally unexpected by both age groups.

Gunter, Jackson, and Mulder (1995) had middle-aged academics (M = 58 years) and young subjects (M = 21 years) read memory demanding sentences of about 20 words that imposed a high (e.g., translation from Dutch: "The small drowning person was by the hero, while a large crowd stood towards to look, saved.") or low (e.g., "While a large crowd stood towards to look, was the small drowning person by the hero saved.") load on working memory. In addition, sentences ended in a congruent or incongruent manner. In the low working memory load condition, results indicated attenuated and delayed N400 responses to incongruent endings in older subjects, relative to young subjects. In the high memory load condition and in contrast to young subjects, older subjects did not show the N400 incongruity effect. The authors discussed these results as they apply to working memory capacity. A thorough review of working memory is beyond the scope of this project; however, the results are relevant inasmuch as they revealed age-related changes in semantic priming as measured with the N400.

N400 studies of aging in the visual modality are limited to Gunter et al. (1992, 1995). (Linnville [1995] in a short abstract described a study of sentential priming in aging using the N400. No age differences were found. However, flaws were reported by the author which prevented meaningful interpretations). Woodward, Ford and Hammett (1993) auditorily presented young (M = 22 years) and older (M = 70 years) subjects with spoken sentences that ended with semantically typical or atypical words. Results indicated an attenuated and delayed N400 in response to atypical endings in older subjects, relative to young subjects. These results provided converging evidence, from a different modality, that semantic priming of unrelated items increases with aging. Taken together, results from the three ERP studies provide support for the IDH. However, the results can alternatively be explained by an enrichment of the semantic network with aging.

Hamberger et al. (1995), in the first N400 investigation of semantic memory in Alzheimer's disease, incidentally looked at the effects of aging on semantic priming. Young adults (M = 26 years), older adults (M = 67 years), and patients with Alzheimer's disease (M = 67 years) read short sentences (e.g., "The guard sounded the ___") that ended either with the best completion (e.g., "alarm"), a word related to the best completion and contextually appropriate (e.g., "bell"), a word related to the best completion but contextually inappropriate (e.g., "lock") or a word unrelated to the best completion and contextually inappropriate (e.g., "molars"). Subjects made decisions as to whether the completions made sense or not. The rate of presentation of the words was calibrated for each subject. For the young adults and Alzheimer's patients, the expected gradient of N400 amplitude was observed, with N400 amplitude from most negative to most positive: unrelated and inappropriate > unrelated but appropriate > related and appropriate > best completions. In contrast to these results, older adults failed to exhibit a gradient of N400 amplitude, showing a small N400 response to best completions but equally large N400 responses to completions in the other three conditions. This unexpected pattern of results was interpreted as reflecting the perseverance of older adults in using a strategy which consisted of classifying all unexpected endings as nonsensical. This strategy would result in correct responses to best completions, to unrelated and inappropriate completions as well as to related and appropriate completions while resulting in erroneous responses to unrelated and appropriate completions. The use of this strategy by older adults was supported by their accuracy data and by subjective accounts.

Conclusions and rationale for this study

Limitations to the use of RT measures to study the effect of aging on semantic priming were reviewed. Because of these limitations, the need for converging evidence with different methodologies is great. As summarized by Tabossi (1991), cited in Kutas (1993): "Methodological problems are rather serious in the study of lexical processing, and are not restricted to one experimental paradigm only; hence, it is very important that comparable results can be obtained with different techniques," (p. 6). ERP measures are complementary to behavioral measures and offer the significant advantage of being on-line. They do not require a behavioral response and provide separate estimates of the time course and strength of cognitive processes. The N400 varies inversely with *degree* of relatedness: it therefore allows a finer-grained analysis of semantic priming. Finally, the N400 can specify whether group differences in semantic priming are attributable to changes in the unrelated or in the related condition, independently of other processes such as decision-making.

To date, there are only three N400 studies of semantic priming in aging. In all three studies, the manipulation of relatedness was limited to two levels, namely Unrelated and Best Completion. The N400 amplitude gradient (Unrelated > Related > Best Completion) well documented in the young remains unexplored in older adults. Testing the N400 amplitude gradient in older adults would give indications of how subtle age-related differences in semantic priming are; that is, whether they are restricted to extremely unrelated targets or whether they extend to moderately related ones.

According to the IDH, the N400 amplitude gradient should be significantly reduced in older adults because they would fail to inhibit unrelated and moderately related targets to the same extent as young subjects. In contrast, the interactive-compensatory hypothesis would predict an increase in the N400 amplitude gradient (i.e., hyperpriming) with aging because of age-related deficits in perceptual identification. These both are in contrast to the general slowing hypothesis which would only predict delayed N400 responses in older adults.

Finally, word and sentence context effects have not yet been directly compared in a single study in older adults. An important question is whether older adults are able to benefit from context. For instance, whereas a word context may not provide enough support for the processes involved in priming, a sentence context may. According to the IDH and to the interactive-compensatory hypothesis, older adults should benefit more than young adults from the support of a sentence context. Such a prediction would not be consistent with the general slowing hypothesis.

This study focused on the following questions. First, do older adults benefit from a related context, and, if so, to what extent relative to young adults? An age-related difference in the use of context would be reflected in an Age X Relatedness X Context interaction effect on N400 amplitude. Second, is the effect of aging on semantic priming, measured with the N400, consistent with the IDH (decreased inhibition of unrelated targets reflected in an age-related decrease in N400 amplitude in response to unrelated items) or with the interactive-compensatory hypothesis (increased activation of related targets reflected in an age-related increase in N400 amplitude in response to unrelated targets)? Alternatively, is the effect of aging on semantic priming limited to a decrease in processing speed; that is, the general slowing hypothesis which would be reflected in an age-related delay of the N400)? Thirdly, assuming age-related differences in semantic priming, do these reflect changes in the top-down or bottom up processes underlying semantic priming? Evidence for this would be found in age-related changes in N400 amplitude limited to responses in the sentence context or in the word context, respectively.

To address these questions, young and older subjects were presented with word and sentence primes. Single word targets varied in the degree of relatedness to the preceding context (sentence or single-word prime). Findings are discussed in relation to three dominant hypotheses in the field of cognitive aging (IDH, interactive-compensatory and general slowing hypotheses), and in relation to suggestions from the ERP and behavioral literature.

Method

Subjects

Twenty young (M = 23.0 years, range 19 to 29) and twenty older (M = 72.3, range 62 to 88) adults participated in this study. Older adults were recruited through pamphlets distributed at the 50 Plus conference for seniors held at Place Bonaventure (Montreal) and through ads posted throughout the Jewish General Hospital where the study took place. Young adults were recruited mainly through classroom advertisement in the Department of Psychology at Concordia University.

All potential subjects were given a health screening questionnaire over the telephone. Exclusion criteria included a history of neurological or cardiac disease, and any chronic illness which may impair cognitive function (e.g., liver disease). Subjects who reported suffering from cognitive deficits (e.g., memory impairments) or from a psychiatric disorder (e.g., depression) were excluded. Finally, given the linguistic nature of the stimuli, only native English speakers were recruited, with few exceptions. For all exceptions, subjects learned English before 5 years of age and considered English to be the language with which they were most familiar (see Appendix A for the screening questionnaire). Except for two young and two older subjects, all subjects were right-handed.

Those satisfying the requirements for participation completed the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale Revised (WAIS-R; Wechsler, 1981) in the laboratory (see Table 1 for the average demographic and WAIS-R data for the young and older groups and Appendix B for the raw data). Subjects

Table 1. <u>Average demographic and WAIS-R data for the young and older groups.</u>

	Young M (SD)	Old M (SD)	t[1, 38] = , p =
Age	23.0 (2.3)	71.5 (6.4)	N/A
Gender	8 males: 12 females	8 males: 12 females	N/A
Handedness	18 right: 2 left	18 right: 2 left	N/A
Education	15.8 (1.8)	12.4 (1.7)	t = 6.36, p = .0001
Vocabulary	11.1 (2.3)	11.2 (1.5)	t = -.08, p = .94
Block Design	12.1 (3.2)	10.3 (1.5)	t = 2.23, p = .03
FSIQ	107.6 (13.9)	102.9 (6.8)	t = 1.36, p = .18

participated on a volunteer basis. However, travel fees were paid for older subjects, who were also given a small gift for coming to the laboratory. Young and older subjects were matched on verbal ability as measured by age-scaled scores on the Vocabulary subtest of the WAIS-R ($t[1, 38] = -0.08$, $p = .94$) and on Full Scale IQ (FSIQ) as estimated from the combination of each subject's scaled scores on two subtests of the WAIS-R: the Vocabulary and Block Design subtests ($t[1, 38] = 1.36$, $p = .18$). This estimate has been shown to be a reliable (Silverstein, 1980, 1982) and valid measure of global intelligence (Kaufman, 1990). Young adults in this study had significantly more years of education than older adults ($t[1, 38] = 6.36$, $p < .0001$). However, in light of the two groups being matched on verbal ability and overall intelligence, the effect of years of education on subjects' task performance is likely to be minimal.

This study received ethical approval from Concordia University and from the Jewish General Hospital, Montreal. Informed consent was obtained from all participants. A copy of the consent form can be found in Appendix C.

Stimuli

The stimuli were sentence primes and word primes followed by a target word which differed in degree of relatedness to the priming context. The stimuli were selected mainly from Kutas (1993) with a few exceptions. Not chosen were 85 of the 320 sentence primes in Kutas (1993) that contained a word lexically associated with the target word (e.g., "Every Monday the gardener *mows* the *lawn*."). Since one of the purposes of examining N400 amplitudes following a sentence versus word context was to compare sentential and lexical context effects, sentences containing a lexical associate of the target word were excluded. Had those sentences not been excluded, N400 amplitude could have reflected lexical rather than sentential context effects. These sentences were replaced with sentences from Hamberger et al. (1995) and Bloom and Fishler (1980). All sentences are shown according to their degree of relatedness in Table 1 of Appendix D and as presented to subjects in Table 2 of the same appendix. All stimuli were presented in 4 centimeter high yellow letters against a black background on a 15 inch SVGA computer monitor. The screen was approximately 1 meter from the subject, but was moved closer on one occasion upon a subject's request.

Sentences: The 240 sentences employed were of medium to high contextual constraint leading to completions with cloze probabilities of 0.75 or greater. All sentences were semantically meaningful. Eighty sentences (Best Completion: BC) ended with the highest cloze probability word (0.75 or greater); 80 sentences ended with a low cloze probability word (0.05 or less) semantically related to the highest cloze probability word (related completion: R), and 80 sentences ended with a low cloze probability word (0.05 or less) which was semantically unrelated to the highest cloze probability word (unrelated completion: U). The following are examples: BC: "Abby brushes her teeth after every *meal*"; R: "The game was called when it started to *lightning*" [best completion would be "rain"]; U: "The children went outside to *shower*" [best completion would be "play"]. These 240 sentences were divided into two lists of 120 sentences (40 BC, 40 R, and 40 U) which were presented to fifty percent of the subjects respectively. For each list, sentences from the three conditions (BC, R, U) were matched on the number of words using repeated-measures analyses of variance (ANOVAs) . Terminal words in the three conditions within each list were matched on the following variables: word length, word frequency (Kucera & Francis, 1967), and word concreteness and imagery (Pavio, Yuille &

Madigan, 1968). The two lists of sentences did not differ across condition (BC, R, U) on those same variables. Means, standard deviations, and range of the data are presented for each condition and each list in Appendix E.

Word pairs: Two hundred and forty word pairs were derived from the sentences. High relation word pairs (BC) consisted of the word most highly related to the Best Completion followed by the Best Completion (e.g., "eat-meal" derived from the BC sentence above). Medium relation word pairs (R) consisted of the Best Completion followed by the related completion (e.g., "rain-lightning" derived from the R sentence above). Unrelated word pairs (U) consisted of the Best Completion followed by the unrelated completion (e.g., "play-shower" derived from the U sentence above). The majority of the related word pairs were related by virtue of a categorical relationship including near synonymity and antonymity (e.g., "tablet-pill", "black-white", respectively). The remainder were situational (e.g., "quarterback-football") or featural (e.g., "month-year"), including primarily compound nouns (e.g., "bunk-bed"), and a few substrate-superstrate relations (e.g., "window-glass"). For each list, the first words of the pairs were matched on number of letters, word frequency (Kucera & Francis, 1967), and word concreteness and imagery (Pavio, et al. 1968) such that these did not significantly differ across the three relatedness conditions. The same was true of the second words of the word-pairs (see Appendix E).

Testing procedure

Subjects were tested individually in one session that lasted approximately 3 hours. Subjects sat in a comfortable chair. Prior to the start of the experimental trials, the rate of presentation of the individual sentence words was calibrated for each subject to ensure that all subjects had sufficient time to read the sentences. To calibrate the rate of presentation, each subject was asked to read silently a set of 25 sentences similar to the experimental stimuli. The words were presented one at a time and each remained on the screen for 250 milliseconds (ms). After each sentence, the subject indicated whether the rate of presentation was too fast, too slow, or comfortable. The presentation rate was then adjusted based on the subject's report until it was judged comfortable on at least 5 consecutive trials. Following the calibration trials, the presentation rate for the subject was fixed for the remainder of the experiment. The range of rates available to subjects was of 200 to 400 ms, and the resulting range varied between 250 and 400 ms. A t-test revealed no significant difference for rate of presentation between young and old subjects ($\underline{M}$ = 275.00, $\underline{SD}$ = 25.65 for the young, and $\underline{M}$ = 290.00, $\underline{SD}$ = 44.72 for the old; $\underline{t}[1, 38] = -1.30$, $\underline{p} = .20$).

As previously described, the total set of stimuli were 240 sentences and 240 word pairs derived from the sentences. To avoid repetition effects, each subject read one set of 120 sentences and one set of 120 word pairs derived from the alternative set of 120 sentences (i.e., sentences 1 to 120 were presented with word pairs derived from sentences 121 to 240 for 50% of subjects, and sentences 121 to 240 were presented with word pairs derived from sentences 1 to 120 for the remaining 50%). Within each set of sentences and word pairs, a single order of presentation was pseudo-randomly determined with the constraint that no more than 3 stimuli of each condition (BC, R, U) occurred sequentially. Half the subjects in each age group were presented first with sentences and then with word pairs, while the other half were presented first with word pairs and then with sentences. Subjects within each age group were assigned a stimulus presentation block in a semi-random fashion. For both sentences and word pairs, individual words were presented one at a time with an inter-word interval of 700 ms. Each sentence word remained on the screen for the period of time calibrated for each individual, while each word of the word pairs remained on the screen for 250 ms. The inter-sentence and inter-word pair interval was self-paced. At the end of each sentence or word pair, a yellow cross appeared on the screen after which the subject pressed a hand-held button to initiate the next trial. There were three advantages to self-pacing. First, it ensured that subjects were paying attention. Secondly, it made the task as natural as possible. Thirdly, it allowed subjects to blink without contaminating the EEG epoch of interest. The first word of each sentence began with a capital letter, and the last word ended with a period. Word-pairs started with a lower cap letter and did not end with a period. Subjects were instructed to read the sentences for meaning and to understand how the two words of the pair were related to each other.

After presentation of the first block of stimuli, a memory test was administered. If the subject had read the sentences in the first block, (s)he was presented with a sentence stem from each of the sentences (e.g., "The game was called off when it started to ____") in booklet format with a single sentence stem on each page. The subject was told that the sentence had all been presented and was instructed to try to remember the word that completed each sentence. Sentence stem presentation was controlled by the experimenter turning the sheets, and the subject was asked to say the first word that came to mind only when (s)he could not recall the actual ending presented. After the subject had responded (e.g., "lightning"), the page was turned and a word forced choice alternative was presented (e.g., "rain lightning"). The subject was told that the sentence had ended with one of the two words, and that s(he) was to indicate the one s(he) remembered reading. During the forced choice recognition, subjects were allowed to select a word different from that which was recalled on the preceding sentence stem. The instructions for the word pair condition were the same ("sentence" was replaced with "word"). After each experimental block (sentences or word pairs), the appropriate memory test was administered.

EEG recording

EEG was recorded from 5 frontal sites (Fz, F3, F4, F7, F8), 4 temporal sites (T3, T4, T5, T6), 3 parietal sites (PZ, P3, P4), and 3 central sites (Cz, C3, C4) based on the International 10-20 System (Jasper, 1958) using tin recording electrodes embedded in a commercially available cap (ElectroCap, Inc). Linked ears were used as the reference. Vertical electrooculogram (EOG; indexing eye movement artifact) was recorded with electrodes placed above and below the left eye; horizontal EOG was recorded with electrodes placed at the outer canthi of both eyes. An electrode attached to the forehead served as the ground. Electrode impedance was kept at or below 5 kilo-ohms (kΩ). The EEG epoch began 100 ms before the onset of each stimulus and continued for 1000 ms after onset. EEG was recorded in a bandpass of DC-30 Hz and sampled at 500 Hz.

Two continuous EEG files were recorded from each subject: one while reading sentences, and the other while reading word pairs. EEG epochs time-locked to the final word of the sentence or word pair were extracted. The EEG epochs were then assessed for eye movements, which may contaminate EEG recording especially at frontal sites. Voltage fluctuations due to eye movement are much larger (about 70 μV) than EEG voltage fluctuations tied to sensory or cognitive processing (e.g., about 4 μV for the N400 response to unexpected final words). Consequently, trials involving eye movement artifact defined as a deflection of ± 70 μV at either vertical or horizontal EOG channel were identified and rejected. In order to ensure adequate signal-to-noise ratio, a limit was set on the number of trials that were rejected.

EEG trials were sorted for each subject (120 for the sentence context and 120 for the word context) according to relatedness such that within each context there was a possible maximum of 40 BC, 40 R, and 40 U trials. Trials contaminated by eye blinks were assessed within each of the six conditions. When the number of trials contaminated in a given condition exceeded 15/40 (37.5%), a regression algorithm was employed that corrects the continuous waveform for eye blinks without having to reject trials (Semlitsch et al., 1987). This procedure was used for three young and six older subjects. The mean number of trials in each condition was of 34.9 BC, 34.3 R, 34.8 U in the sentence context, and 35.9 BC, 35.6 R and 35.9 U in the word context.

Finally, an average of the waveforms within each of the six conditions (Context [sentence, word] X Relatedness [BC, R, U]) was computed for each subject. It was on these ERP averages that the N400 effect was identified and quantified. The peak identification method was applied to each average waveform, which quantifies amplitude in μV relative to the average voltage of the pre-stimulus baseline. Latency in ms was calculated relative to stimulus onset.

Early sensory-related components (N1 and P2) were also scored. The N1 was scored as the most negative point in the average waveform in the 70-150 ms latency range. The P2 was scored as the most positive point in the average waveform in the 100-250 ms latency range. The Late Positive Component (LPC) was scored as the most positive point in the average waveform in the latency range following the N400 to the end of the recording epoch (1000 ms). For each subject, 90 data points were generated through these steps (2 Contexts X 3 Relatedness conditions X 15 Sites) for each ERP component (N400, N1, P2, LPC) for latency and for amplitude. It is on these data that statistical analyses were performed.

Results

Due to technical problems during testing, one older subject did not participate in the sentence condition of the study. The missing data for this subject were estimated and replaced with the mean of data from older subjects in the sentence condition (see Fidell & Tabachnick, 1996). These non-biased estimates were used for analyses which included context as a factor, but not for analyses restricted to the sentence condition. Thus, for the latter analyses, only data from the 19 remaining older subjects were used. Also due to technical problems during testing, data missing at Pz for one young and one older subjects were estimated and replaced with the mean of data from young and older subjects respectively; this was done separately for the sentence and word conditions. Given that data for these two subjects were replaced for one electrode site (Pz) only, these non-biased estimates were used for all analyses.

Strategy for statistical analyses of the ERPs

Repeated-measures analyses of variance (ANOVAs) were conducted separately on amplitude and latency measures for each component using the BMDP 4V program (Dixon et al., 1993). For each ANOVA, Age (young, old) was the between factor, with Context (sentence, word pair), Relatedness (U, R, BC), and Site (Midline) as within factors. Although the N400 was scored at all 15 scalp locations, results from analyses limited to the midline sites (Fz, Cz, Pz) are first reported for two reasons: First, the N400 is most pronounced at midline centro-parietal scalp locations (e.g., Kutas et al., 1988; Connolly & Phillips, 1994). Second, it allows for a meaningful comparison of the scalp distribution of the N400. A larger N400 amplitude effect at Pz than at Fz for instance is important in demonstrating that the N400 was most pronounced posteriorly than frontally as reported in the literature.

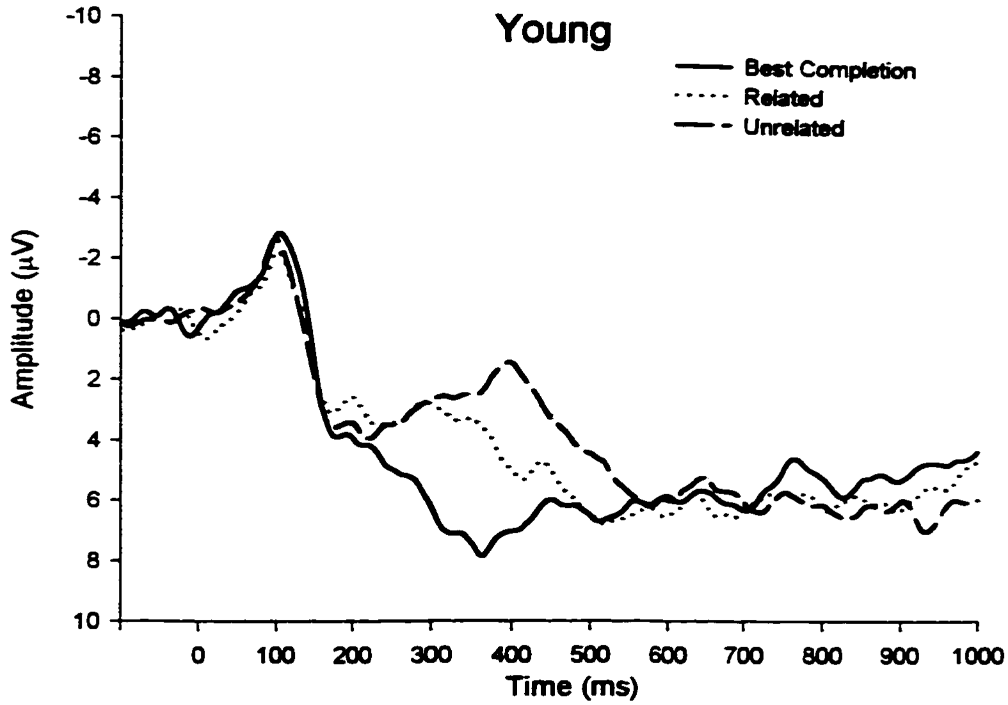
Given the evidence that the processing of sentences and words may be qualitatively different (e.g., Van Petten, 1993), additional analyses were performed separately on data from each age group within each context. In those instances, a repeated-measures ANOVA was conducted with Relatedness and Site as within factors. Main effects are reported first, and interaction effects second. For all analyses, significant effects ($p < .05$) were further explored using Tukey A post-hoc tests. Comparisons where $p < .05$ were considered statistically significant.

Given the increase in the likelihood of violating the assumption of sphericity with a repeated-measures design (Vasey & Thayer, 1987), the Greenhouse-Geisser (1959) correction was applied to all within-subjects analyses. Following convention, unadjusted degrees of freedom and the epsilon value (ϵ) are reported for each ANOVA. Only results reaching significance are reported.

N400 amplitude

Grand average waveforms at the central midline site (Cz) recorded in the sentence and word contexts are presented in Figures 1 and 2, respectively. In each Figure, mean amplitude is plotted for each age group as a function of relatedness and time. While the N400 amplitude gradient (U > R > BC from most negative to positive) is clear for the young subjects within each context (Figures 1 and 2, upper panels), it is less evident for the old subjects. An N400 amplitude gradient does not appear to be elicited by sentence terminal words for the old (Figure 1, lower panel). It appears present in the word context (Figure 2, lower panel in the old group) but appears attenuated relative to the young.

Figure 1. Grand average waveforms at the central midline site (Cz) for the Sentence condition. Mean amplitude in microvolts (μV) is shown for each Age group as a function of Time in milliseconds (ms) and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated).


Young
Best Completion
Related
Unrelated
Amplitude (μV)
-10
-8
-6
-4
-2
0
2
4
6
8
10
0
100
200
300
400
500
600
700
800
900
1000
Time (ms)

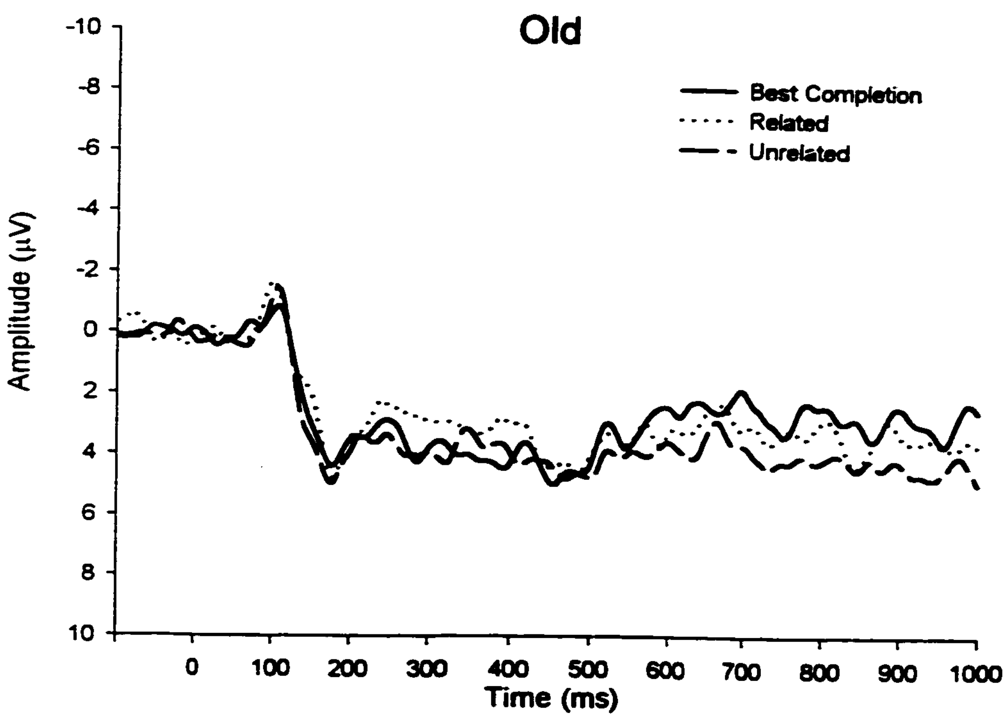
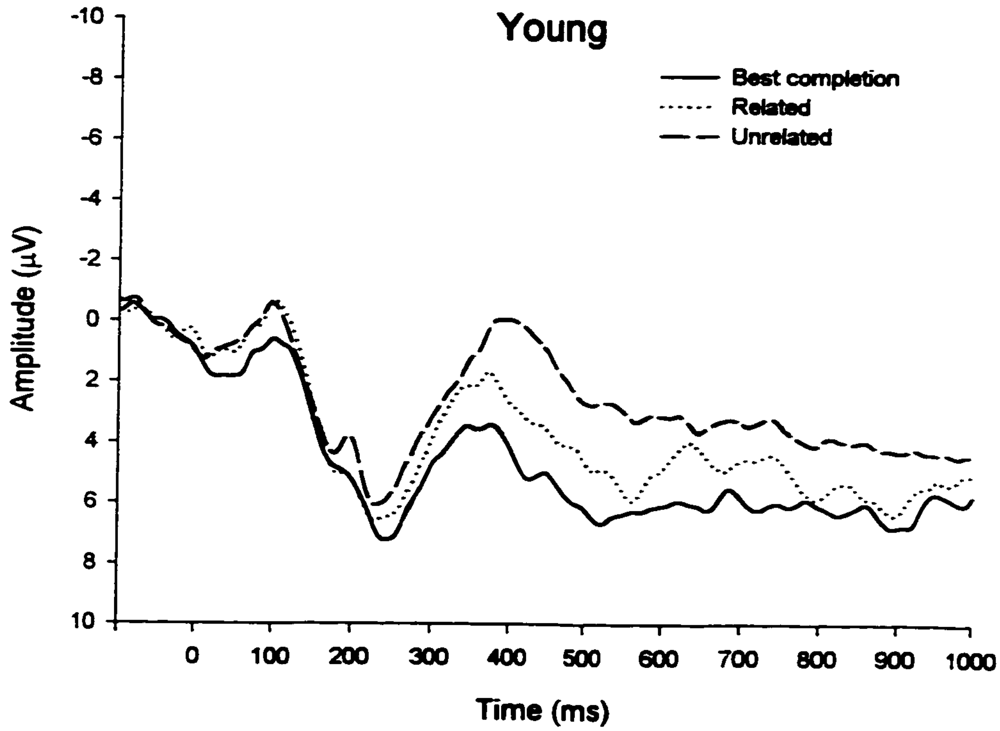
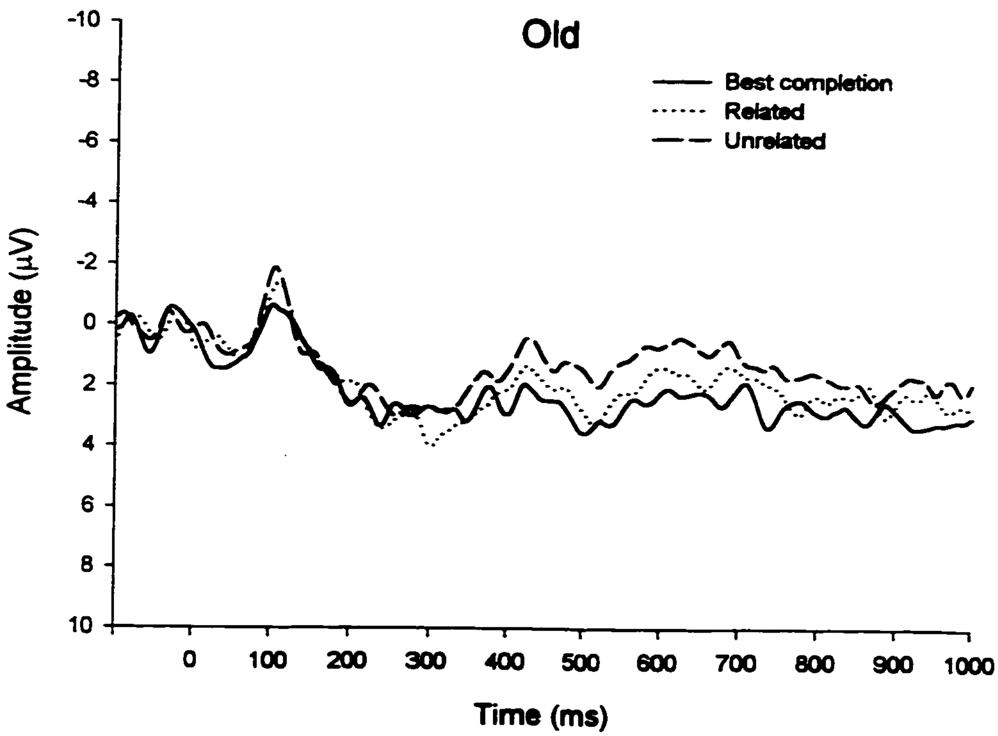

Old
Best Completion
Related
Unrelated
Amplitude (μV)
-10
-8
-6
-4
-2
0
2
4
6
8
10
0
100
200
300
400
500
600
700
800
900
1000
Time (ms)

Figure 2. Grand average waveforms at the central midline site (Cz) for the Word condition . Mean amplitude in microvolts (μV) is shown for each Age group as a function of Time in milliseconds (ms) and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated).


Young
Best completion
Related
Unrelated
Amplitude (μV)
-10
-8
-6
-4
-2
0
2
4
6
8
10
0
100
200
300
400
500
600
700
800
900
1000
Time (ms)

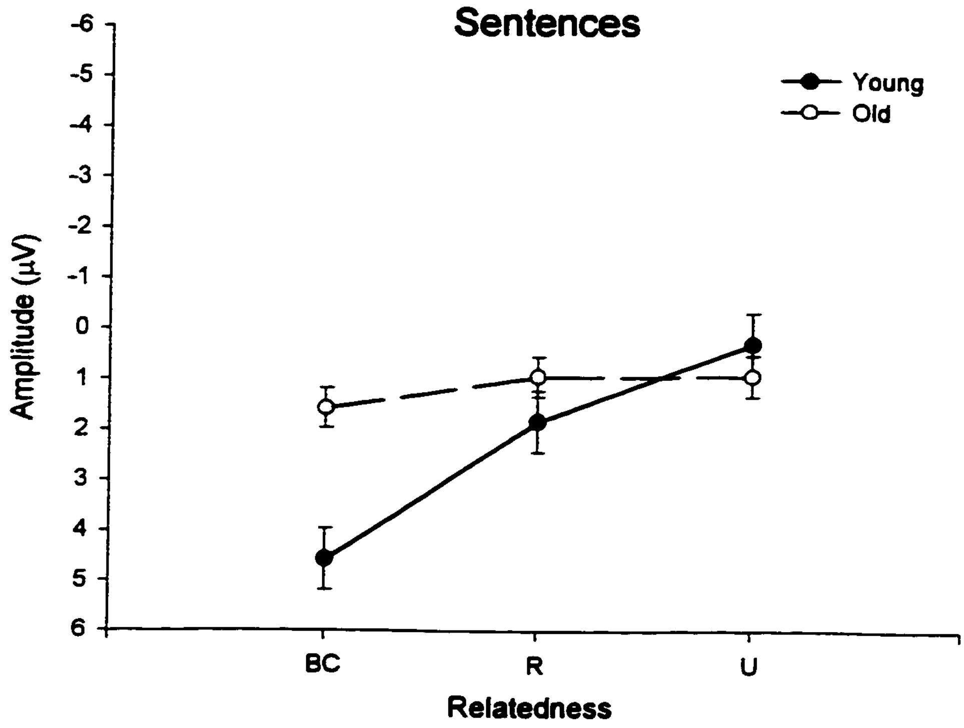

Old
Best completion
Related
Unrelated
Amplitude (μV)
-10
-8
-6
-4
-2
0
2
4
6
8
10
0
100
200
300
400
500
600
700
800
900
1000
Time (ms)

A repeated-measures ANOVA was performed on N400 amplitude with Age as the between factor, and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). Mean N400 amplitudes and standard errors are illustrated as a function of age and level of relatedness for each context in Figure 3. The ANOVA revealed a significant main effect of Context ($F[1, 38] = 11.16$, $p = .002$). As can be seen in Figures 1 thru 3, N400 amplitude was significantly more negative in the word context ($M = -.32$, $SE = .28$) than in the sentence context ($M = 1.15$, $SE = .23$). Given overall differences in amplitude between the two context conditions, further ANOVAs were conducted within each context to better evaluate the effect of relatedness on N400 amplitude. There was a significant main effect of Relatedness ($F[2, 76] = 26.50$, $p < .0001$, $\epsilon = 1.00$), and of Site ($F[2, 76] = 7.57$, $p = .001$, $\epsilon = .80$), but not of Age ($F[1, 38] = .90$, $p = .350$). There was a significant interaction of Age X Relatedness ($F[2, 76] = 10.00$, $p < .0001$, $\epsilon = 1.00$). However, this interaction was modified by Site. The interaction of Age X Relatedness X Site ($F[4, 152] = 3.52$, $p = .020$, $\epsilon = .69$) is clarified in the context-specific ANOVAs below. N400 amplitude for each midline site is presented as a function of age group and relatedness for the sentence and word contexts in Figures 4 and 5, respectively.

<u>Within Context Analyses</u>

For young subjects within the sentence context (Figure 4, solid line), there was a significant main effect of Relatedness ($F[2, 38] = 12.63$, $p < .0001$, $\epsilon = .93$), but not of Site ($F[2, 38] = .01$, $p = .99$, $\epsilon = .68$). These effects were modified by a significant interaction effect of Relatedness X Site ($F[4, 76] = 8.98$, $p < .0001$, $\epsilon = .59$). N400 amplitude differed significantly at all levels of relatedness (U > R > BC) at Cz and Pz (ps < .05). At Fz, N400 amplitude was significantly more negative in the Unrelated condition than in the Best Completion condition ($p < .05$); however, neither differed from the Related condition (ps > .05).

Figure 3. Mean N400 amplitude in microvolts (μV) averaged over midline site (Fz, Cz, Pz) as a function of Age group and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated) for each Context (Sentences, Words). Standard errors are shown by vertical bars.


Sentences
Young
Old
Amplitude (µV)
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
BC
R
U
Relatedness

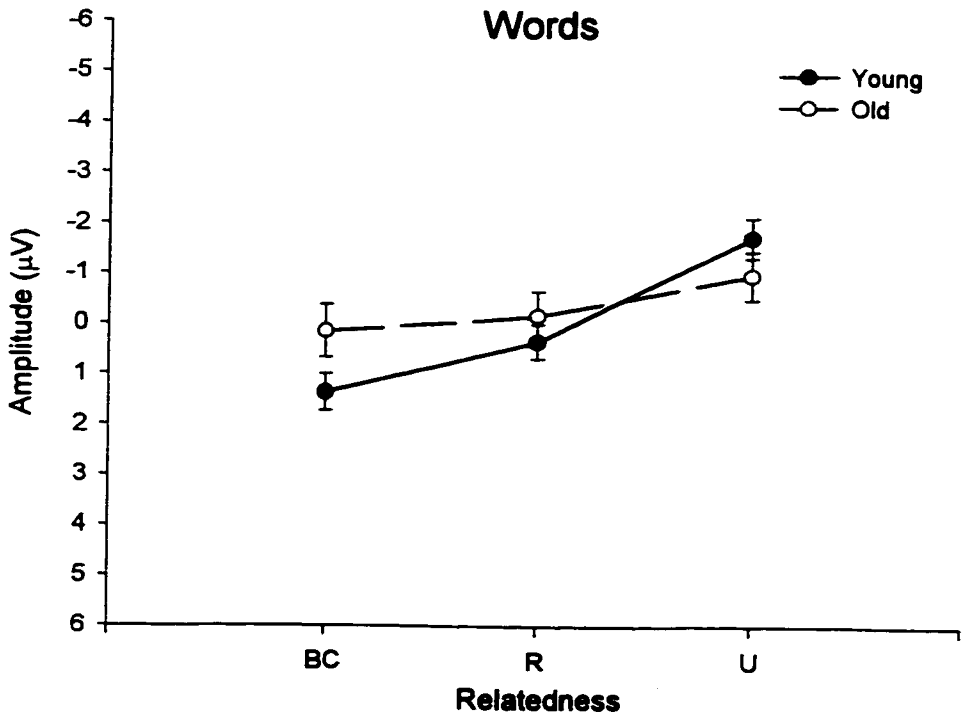

Words
Young
Old
Amplitude (µV)
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
BC
R
U
Relatedness

Figure 4. Mean amplitude in microvolts (μV) for each midline Site (Fz, Cz, Pz) as a function of Age group and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated) in the Sentence context. Standard errors are shown by vertical bars.

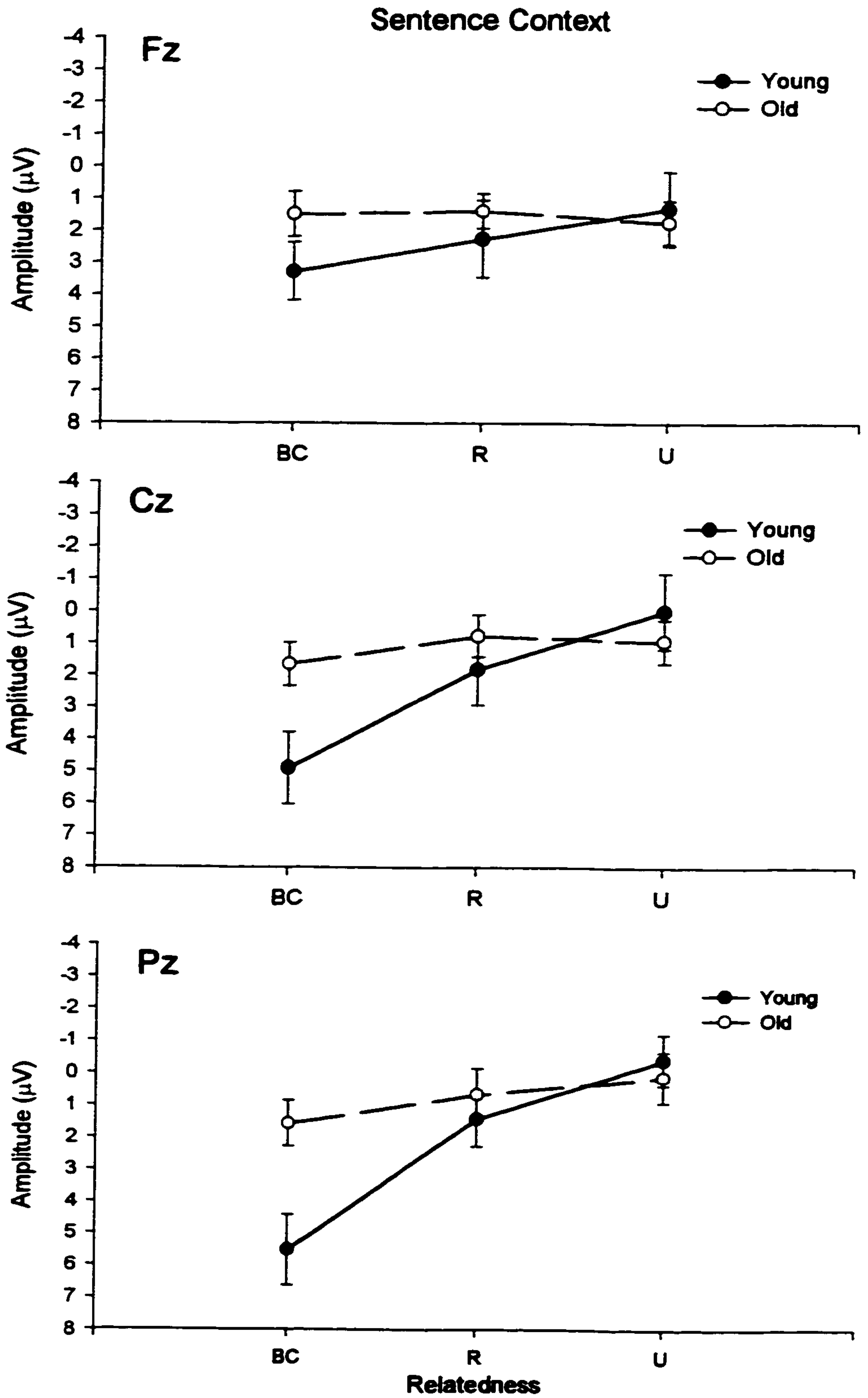
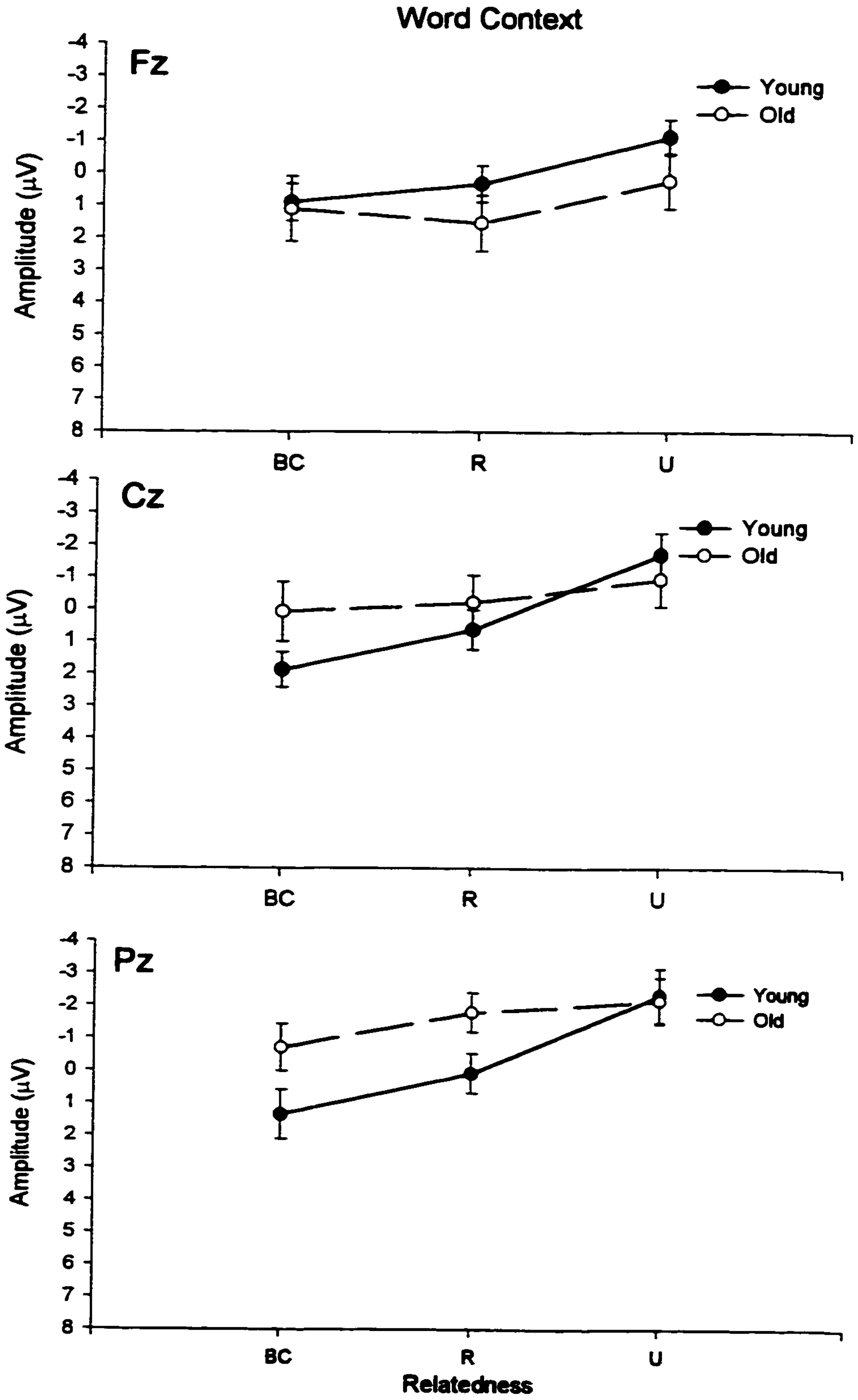

Sentence Context
Fz
Young
Old
Amplitude (µV)
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
BC
R
U
Cz
Young
Old
Amplitude (µV)
BC
R
U
Pz
Young
Old
Amplitude (µV)
BC
R
U
Relatedness

Figure 5. Mean amplitude in microvolts (μV) for each midline Site (Fz, Cz, Pz) as a function of Age group and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated) in the Word context. Standard errors are shown by vertical bars.


Word Context
Fz
Cz
Pz
Young
Old
Amplitude (µV)
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
BC
R
U
Relatedness

For older subjects within the sentence context (Figure 4, dashed line), there was no significant main effect of Relatedness ($F[2, 36] = .98$, $p = .386$, $\epsilon = .87$), nor of Site ($F[2, 36] = 1.10$, $p = .34$, $\epsilon = .57$). There was, however, a significant interaction effect of Relatedness X Site ($F[4, 76] = 4.43$, $p = .011$, $\epsilon = .64$). In contrast to the young however, the stepwise N400 amplitude gradient (U > R > BC) was not found at any of the midline sites. There was no effect of relatedness at either Fz or Cz (ps > .05). At Pz, N400 amplitude was significantly more negative in the Unrelated condition than in the Best Completion condition ($p < .05$); however, neither differed from the Related condition ($p > .05$). Thus, for older subjects, N400 amplitude elicited by sentence terminal words differed only at the two extreme levels of relatedness (U > BC) and only at the midline parietal site (Pz).

For young subjects within the word context (Figure 5, solid line), there was a significant main effect of Relatedness ($F[2, 38] = 14.33$, $p < .0001$, $\epsilon = .71$), but not of Site ($F[2, 38] = .66$, $p = .52$, $\epsilon = .73$). The effect of Relatedness was modified by a significant interaction effect of Relatedness X Site ($F[4, 76] = 8.98$, $p < .0001$, $\epsilon = .59$). N400 amplitude differed significantly at all levels of relatedness (U > R > BC) at Cz and Pz (ps < .05). At Fz, N400 amplitude was significantly more negative in the Unrelated condition than in the Best Completion condition ($p < .05$); however, neither differed from the Related condition (ps > .05). As in the sentence context, this confirms the centro-parietal distribution observed in young adults.

For older subjects within the word context (Figure 5, dashed line), reliable effects were limited to a main effect of Site (F[2, 38] = 18.26, $p < .0001$, $\epsilon = .80$). Results indicated a significant gradient of N400 amplitude of Pz > Cz > Fz (ps < .05). There was a trend towards a main effect of Relatedness (F[2, 38] = 2.93, $p = .066$, $\epsilon = .99$) suggesting that N400 amplitude was more negative in the Unrelated condition ($M = -.96$, $SE = .48$) than in either the Related ($M = -.16$, $SE = .48$) and Best Completion ($M = .16$, $SE = .52$) conditions. There was a trend towards a Relatedness X Site interaction (F[4, 76] = 2.74, $p = .059$, $\epsilon = .67$) suggesting that N400 amplitude was most negative in the Unrelated condition than in the other two conditions at Pz (see figure 5, dashed line lower panel).

Region-Specific Analyses

The finding of a significant N400 amplitude gradient (U > R > BC) at central-posterior sites (Cz and Pz), but not at the frontal site (Fz) in the young is consistent with studies that have looked at the scalp distribution of the N400 effect (e.g., Kutas et al., 1988). Moreover, the only significant effect of relatedness in the old (U > BC) was found at Pz for the sentence context (with a similar trend for the word context). For these reasons, a second set of analyses were conducted to determine if an effect of relatedness in the old was obscured in the midline analyses. In addition to being more pronounced at posterior sites, the N400 effect has been shown to be larger over the right hemisphere (e.g., Kutas et al., 1988). These possibilities were explored in a secondary series of analyses.

First, a repeated-measures ANOVA was performed on N400 amplitude with Age as the between factor, and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Scalp location (Anterior; i.e., mean N400 amplitude at Fz, F3, F4, F7, F8, versus Posterior; i.e., mean N400 amplitude at T3, T4, T5, T6, Pz, P3, P4) to ascertain that the N400 amplitude effect was more likely to be detected at posterior locations. Results indicated a significant main effect of Context ($F[1, 38] = 12.82$, $\underline{p} = .001$). As before, N400 was more negative in the word context ($\underline{M} = -.66$, $\underline{SE} = .17$) than in the sentence context ($\underline{M} = .18$, $\underline{SE} = 2.85$). Given overall differences in amplitude between the two context conditions, further ANOVAs were conducted within each context to better evaluate the effect of relatedness on N400 amplitude. There was a significant main effect of Relatedness ($F[2, 76] = 20.13$, $\underline{p} < .0001$, $\underline{\epsilon} = .99$) and of Location ($F[1, 38] = 16.31$, $\underline{p} = .0003$), but not of Age ($F[1, 38] = .76$, $\underline{p} = .388$). However, the former two interacted together and were further modified by Age. Consistent with previous results, the interaction of Age X Relatedness was also significant ($F[2, 76] = 7.05$, $\underline{p} = .002$, $\underline{\epsilon} = .99$). The interaction of Age X Relatedness X Location ($F[2, 76] = 5.50$, $\underline{p} = .008$, $\underline{\epsilon} = .87$) was clarified in the group-specific ANOVAs below and is illustrated in Figure 6.

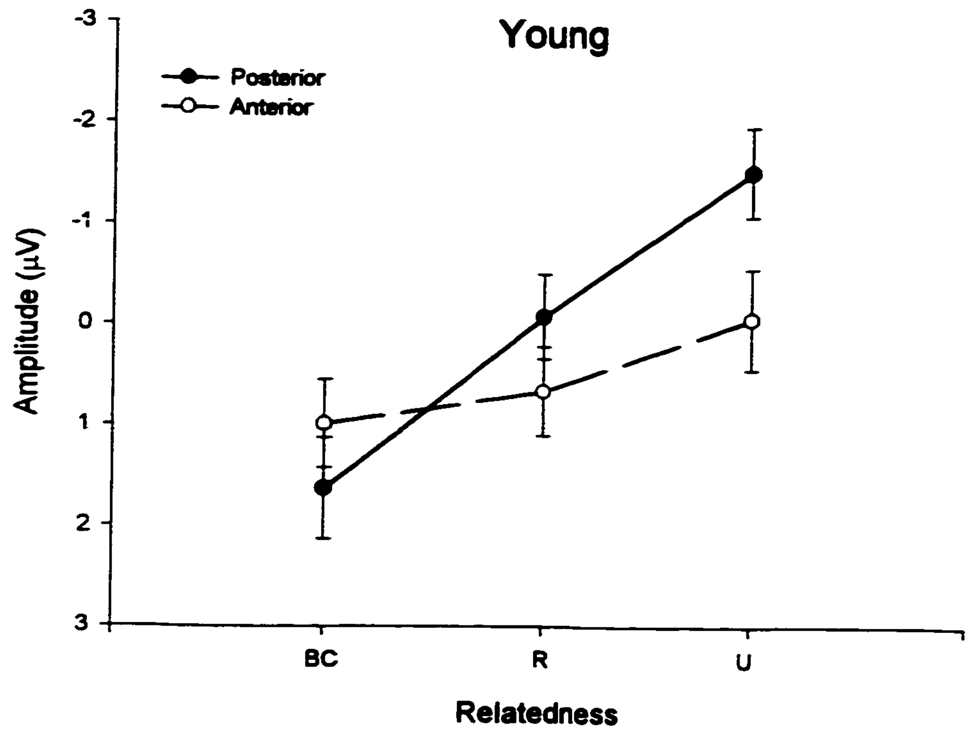
<u>Within Group Analyses</u>

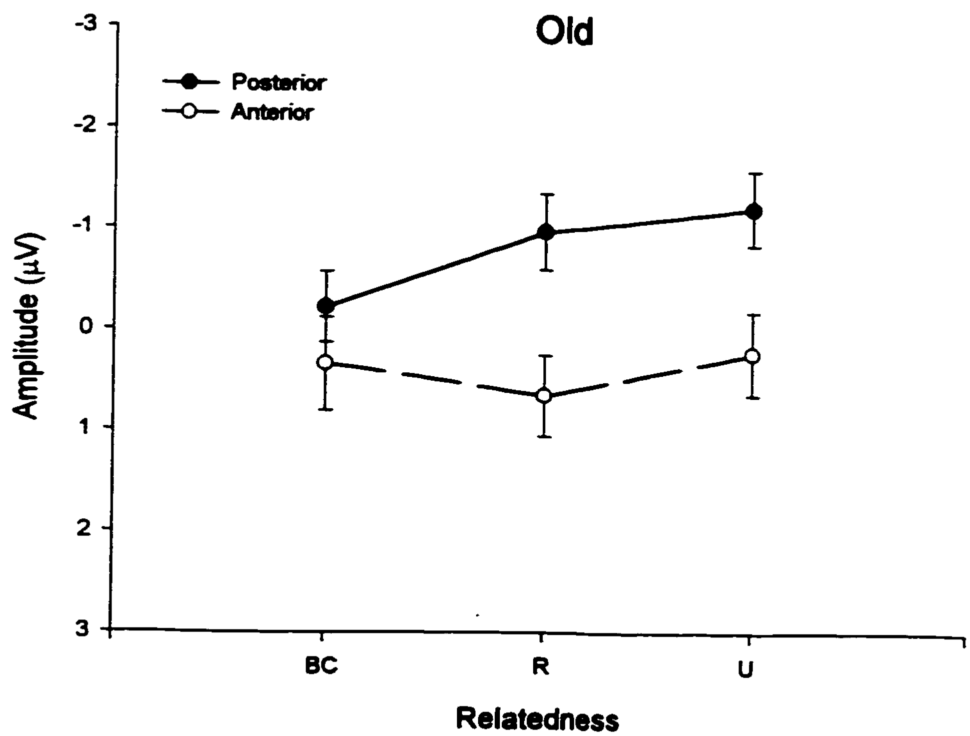
Within the young subjects, there was a significant main effect of Relatedness ($F[2, 38] = 18.51$, $\underline{p} < .0001$, $\underline{\epsilon} = .98$), and a trend toward a significant main effect of Location ($F[1, 19] = 3.68$, $\underline{p} = .07$). These effects were modified by a significant Relatedness X Location interaction effect ($F[2, 38] = 26.56$, $\underline{p} < .0001$, $\underline{\epsilon} = .88$). The stepwise N400 amplitude gradient (U > R > BC) was significant at the posterior location only ($\underline{p}$s < .05). At the anterior location, N400 amplitude was significantly more negative in the Unrelated condition than in the Best Completion and Related conditions ($\underline{p}$s < 05); however, the later two conditions did not significantly differ ($\underline{p} > .05$). This is consistent with the context-specific effects reported earlier.

Within the old group, there was a trend toward a significant main effect of Relatedness ($F[2, 38] = 2.72$, $p = .079$, $\epsilon = .83$), and a significant main effect of Location ($F[1, 19] = 13.28$, $p = .002$). These effects were modified by a significant interaction effect of Relatedness X Location ($F[2, 38] = 11.50$, $p = .0001$, $\epsilon = .86$). N400 amplitude was more negative in the Unrelated and Related conditions than in the Best Completion condition ($ps < .05$) at the posterior location only; however, the former two conditions did not significantly differ ($ps > .05$) At the anterior location, there was no significant effect of Relatedness ($ps > .05$). Taken together, these results indicate that both groups were more likely to show the N400 amplitude gradient at posterior locations.

Next, a repeated-measures ANOVA was performed on N400 amplitude with Age as the between factor, and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Hemisphere (Right, Left) to ascertain whether the N400 amplitude effect was more pronounced at posterior right hemisphere sites (the mean of C4, T4, T6, P4) than at posterior left hemisphere sites (the mean of C3, T3, T5, P3). Figure 7 illustrates mean N400 amplitude for both age groups at posterior sites as a function of hemisphere and level of relatedness collapsed across context. Mean N400 amplitude and standard errors at right posterior sites are reported for both age groups by level of relatedness for the sentence and word contexts in Tables 2 and 3, respectively. Results indicated significant main effects of Relatedness ($F[2, 76] = 42.76$, $p < .0001$, $\epsilon = .98$), Context ($F[1, 38] = 15.61$, $p = .0003$), and Hemisphere ($F[1, 38] = 5.00$, $p = .03$), but not of Age ($F[1, 38] = 3.05$, $p = .089$). The interaction of Age X Relatedness ($F[2, 76] = 13.29$, $p < .0001$, $\epsilon = .98$) was significant. This is illustrated in Figure 7, and is consistent with all previous analyses. There were also significant interactions of Relatedness X Hemisphere ($F[2, 76] = 9.37$, $p < .0001$, $\epsilon = .93$), and of Context X Hemisphere ($F[1, 38] = 8.81$, $p = .005$).

Figure 6. Mean amplitude in microvolts (μV) for each Age group as a function of Site (Anterior = Fz, F3, F4, F7, F8; and Posterior = T3, T4, T5, T6, Pz, P3, P4) and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated) collapsing across Context. Standard errors are shown by vertical bars.


Young
Posterior
Anterior
Amplitude (µV)
-3
-2
-1
0
1
2
3
BC
R
U
Relatedness


Old
Posterior
Anterior
Amplitude (µV)
-3
-2
-1
0
1
2
3
BC
R
U
Relatedness

Tukey A post-hoc analyses conducted on the Relatedness X Hemisphere interaction indicated that the N400 amplitude gradient (U > R > BC) was significant in both hemispheres (ps < .05). However, it can be noted in Figure 7 that the slope of the N400 effect (particularly between R and U) is steeper over the right hemisphere, and this is true for both age groups.

Tukey A post-hoc analyses conducted on the Context X Hemisphere interaction indicated that N400 amplitude varied as a function of Hemisphere in the word context only, with N400 amplitude being more negative over the left (M = -1.53, SE = .22) than right hemisphere (M = -.63, SE = .24; ps < .05). In both hemispheres, N400 amplitude was more negative within the word context (M and SE above) than within the sentence context (M = .63, SE = .27 over the left, and M = .55, SE = .28 over the right; ps < .05).

Grand average waveforms at P4, the right parietal site, are illustrated in Figures 8 and 9 for the sentence and word contexts, respectively. In each case, mean N400 amplitude is shown for each age group as a function of relatedness and time. In comparison to Figures 1 and 2, in which the same waveforms are presented but at Cz (the central midline site), the N400 effects are clearer for the old in Figures 8 and 9 at P4.

Given these results, analyses similar to those reported for the midline were conducted for the right posterior sites only (T4, T6, and P4). Mean N400 amplitudes and standard errors at the right posterior sites are presented in Figure 10 as a function of age and level of relatedness for each context. This Figure can be compared to Figure 3 which represents the same information but at the vertex (Cz). Note that although the two figures appear identical within the word context (lower panels), they differ notably within the sentence context (upper panels). In the sentence context (upper panel, dashed line), older subjects appear to now (at right posterior sites) show an N400 relatedness effect. This is consistent with observations of the grand averages at P4.

Figure 7. Mean amplitude in microvolts (μV) at Posterior sites (T3, T4, T5, T6, Pz, P3, P4) for each Age group as a function of Hemisphere (Right, Left) and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated) collapsing across context. Standard errors are shown by vertical bars.

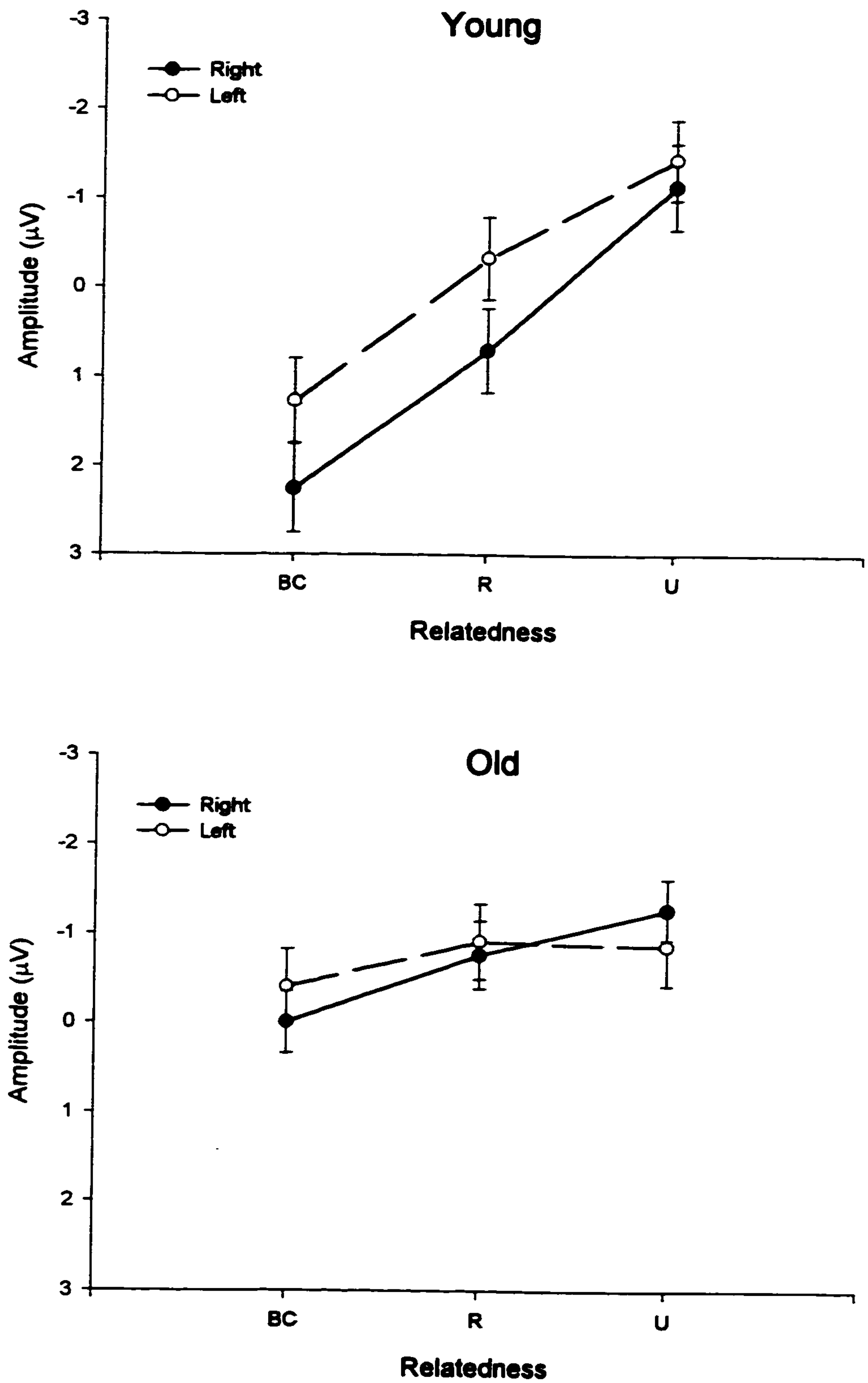

Young
Right
Left
-3
-2
-1
0
1
2
3
Amplitude (μV)
BC
R
U
Relatedness
Old
Right
Left
-3
-2
-1
0
1
2
3
Amplitude (μV)
BC
R
U
Relatedness

Table 2

Mean Amplitude in Microvolts (μV) at the Posterior Right Sites (T4, T6, P4) for Younger and Older Groups by Level of Relatedness for the Sentence Context

	Young		Old	
Relatedness	M	SD	M	SD
BC	3.19	.75	.43	.34
R	1.17	.74	-.48	.53
U	-.29	.73	-1.31	.43

Table 3

Mean Amplitude in Microvolts (µV) at the Posterior Right Sites (T4, T6, P4) for Younger and Older Groups by Level of Relatedness for the Word Context

	Young		Old	
Relatedness	M	SD	M	SD
BC	.58	.61	-.59	.57
R	-.41	.60	-1.31	.55
U	-2.37	.51	-1.52	.58

Overall, the results from these restricted analyses were comparable with those observed for the midline analyses with the following exception: For the young within the word context, N400 amplitude was significantly more negative in the Unrelated condition than in the Related and Best Completion conditions (ps $< .05$); however, the later two conditions did not significantly differ ($p < .05$). This result may be attributable to the lower degree of lateralization of the N400 in the young (Figure 7), suggesting that the N400 amplitude effect was strongest at the midline.

N400 latency

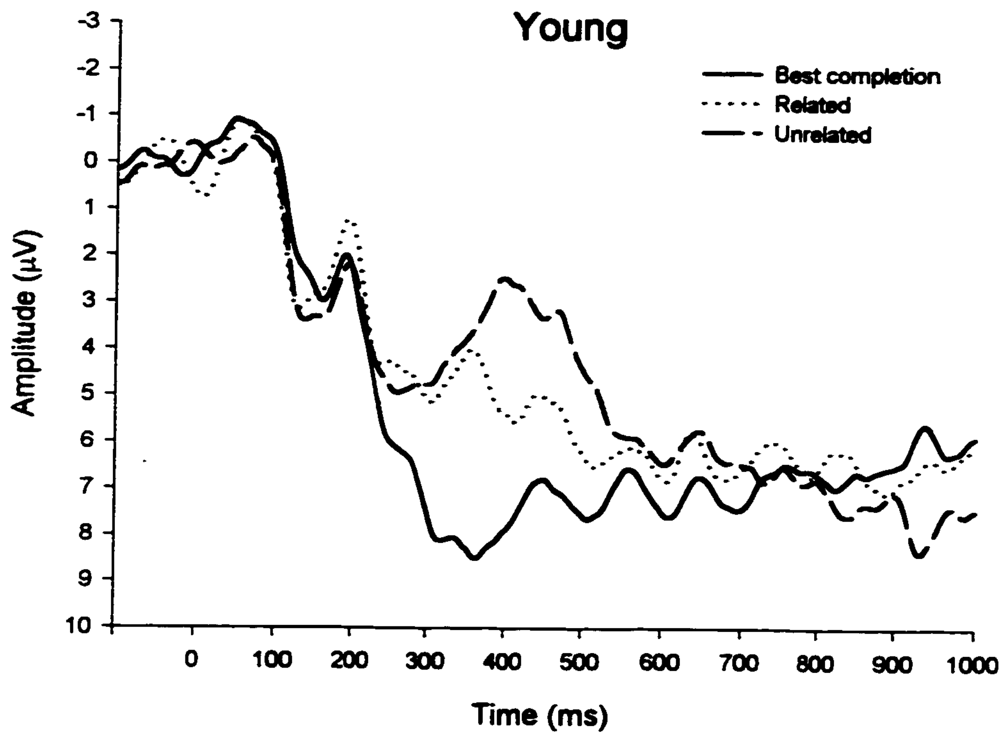
A repeated-measures ANOVA was performed on N400 latency with Age as the between-factor, and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated a significant main effect of Age ($F[1, 38] = 5.61$, $p = .023$). On average, N400 was significantly earlier in young subjects ($M = 408.29$, $SE = 3.11$) than in older subjects ($M = 442.43$, $SE = 3.59$). There were no significant main effects of Relatedness ($F[2, 76] = 0.60$, $p = .551$, $\epsilon = .93$), of Context ($F[1, 38] = .07$, $p = .789$), or of Site ($F[2, 76] = 1.72$, $p = .195$, $\epsilon = .58$). There was, however, a significant interaction of Context X Relatedness ($F[2, 76] = 6.81$, $p = .002$, $\epsilon = .93$) which was clarified in the within context ANOVAs below.

Within Context Analyses

For young subjects within the word context, there was a trend toward a significant main effect of Relatedness ($F[2, 38] = 3.22$, $p = .052$, $\epsilon = .98$). There were no significant main effect of Site ($F[2, 38] = 2.95$, $p = .087$, $\epsilon = .69$), and only a trend toward a significant interaction effect of Relatedness X Site ($F[4, 76] = 2.83$, $p = .070$, $\epsilon = .51$). N400 was significantly earlier in the Best Completion and Related conditions than in the Unrelated condition (ps $< .05$); however, the former two conditions did not differ significantly ($p > .05$).

Figure 8. Grand average waveforms at a P4, a Right Parietal site, for the Sentence condition . Mean amplitude in microvolts (μV) is shown for each Age group as a function of Time in milliseconds (ms) and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated).

Sentence Context



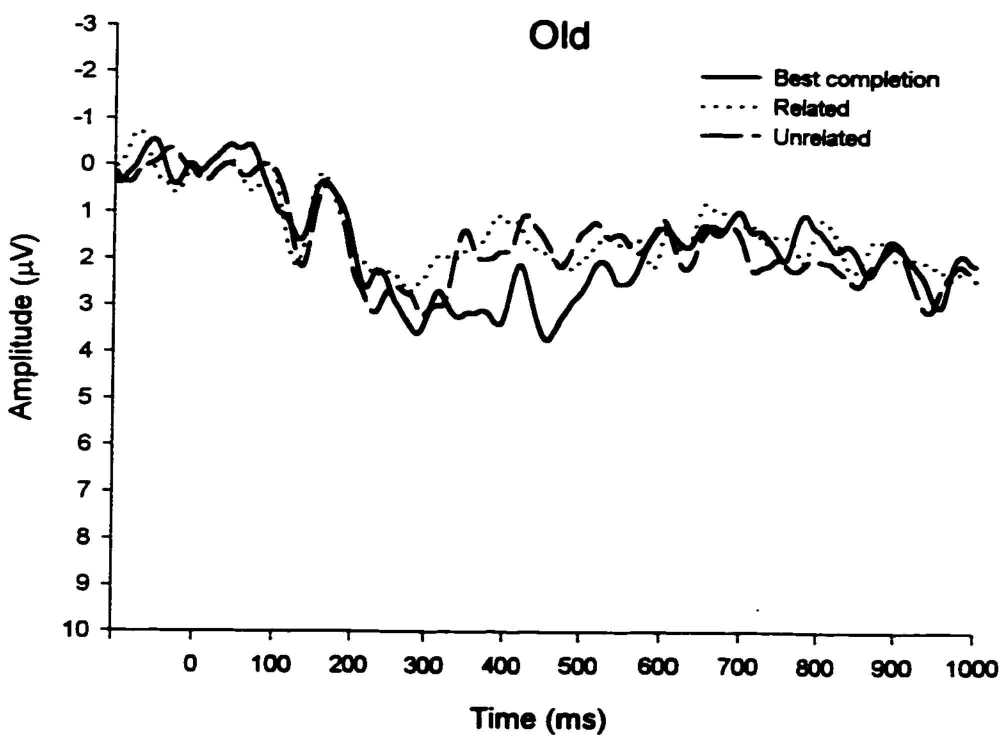


Figure 9. Grand average waveforms at P4, a Posterior Right site, for the Word condition . Mean amplitude in microvolts (μV) is shown for each Age group as a function of Time in milliseconds (ms) and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated).

Word Context

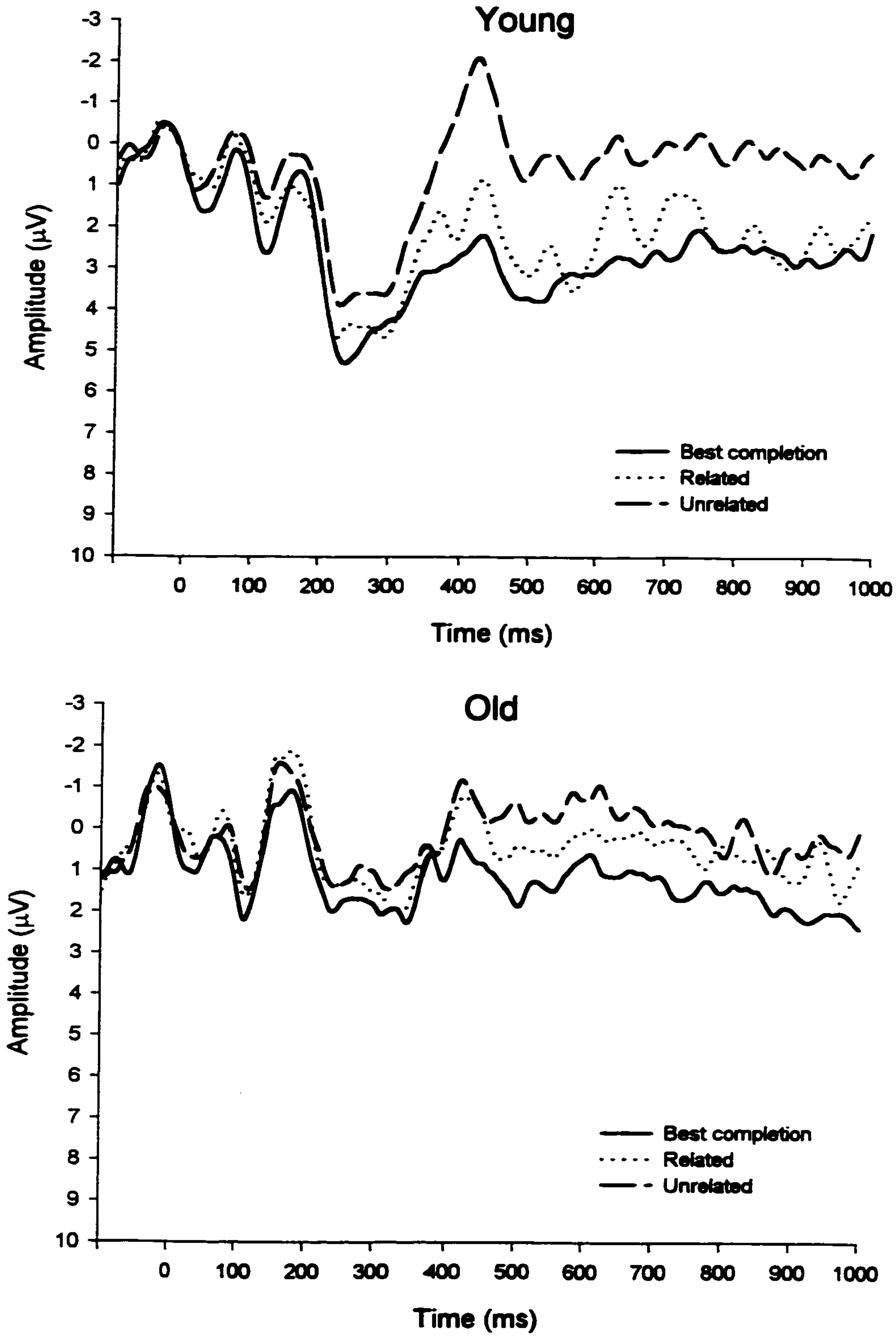
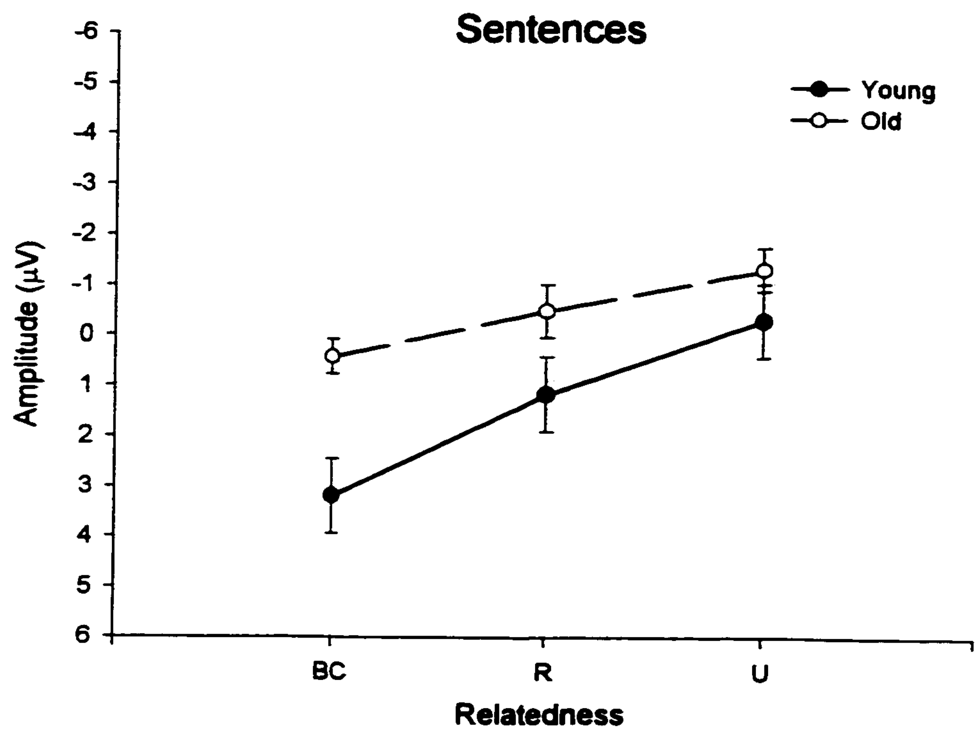
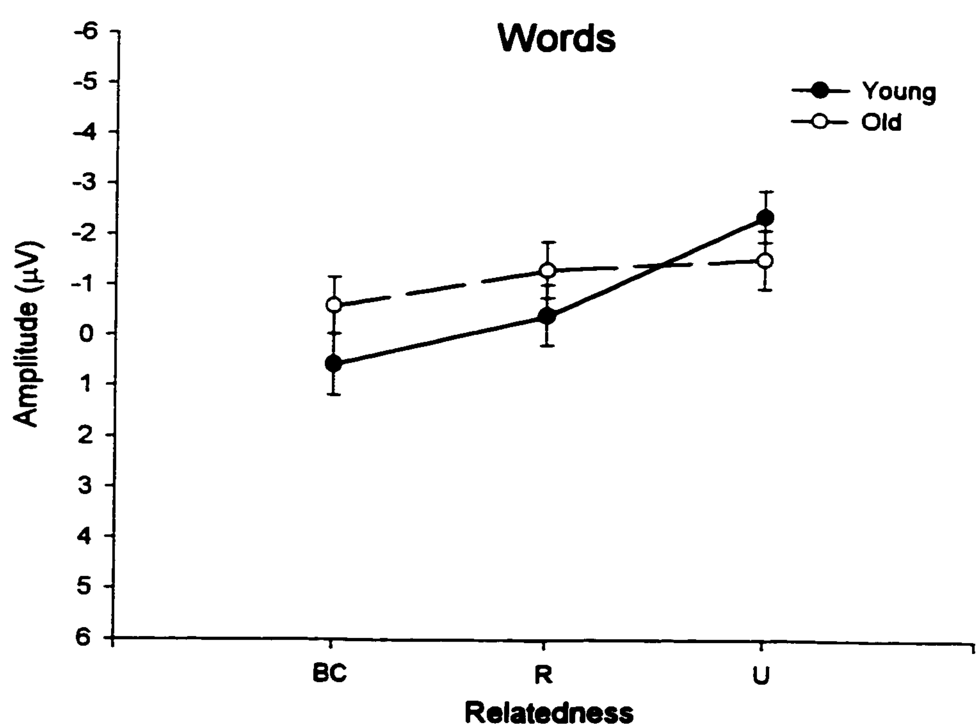


Figure 10. Mean amplitude in microvolts (μV) at the Posterior Right sites (T4, T6, P4) as function of Age group and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated) for each Context (Sentences, Words). Standard errors are shown by vertical bars.


Sentences
Young
Old
Amplitude (μV)
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
BC
R
U
Relatedness


Words
Young
Old
Amplitude (μV)
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
BC
R
U
Relatedness

N400 latency in older subjects within the word context did not differ as a function of Relatedness ($F[2, 38] = .78$, $p = .465$, $\epsilon = 1.00$), nor of Site ($F[2, 38] = .54$, $p = .586$, $\epsilon = .74$), and the two factors did not interact ($F[4, 76] = .26$, $p = .734$, $\epsilon = .42$). For all subjects within the sentence context, there were no significant main or interaction effects of Relatedness and Site (for Relatedness: $F[2, 38] = 1.51$, $p = .234$, $\epsilon = .95$ for the young, and $F[2, 36] = 2.15$, $p = .132$, $\epsilon = .94$ for the old; for Site: $F[2, 38] = .95$, $p = .397$, $\epsilon = .59$ for the young, and $F[2, 36] = .17$, $p = .728$, $\epsilon = .59$ for the old; for Relatedness X Site: $F[4, 76] = 1.20$, $p = .310$, $\epsilon = .45$ for the young, and $F[4, 72] = 1.00$, $p = .395$, $\epsilon = .66$).

Statistical analyses of the LPC and Early sensory components (N1, P2)

Analyses of the N400 have been detailed thoroughly. Results from analyses of the LPC and early sensory components will be described. The analyses were carried out in the same way as for the N400. Results from the overall ANOVA are presented first, followed by within-context analyses.

LPC amplitude

The Late Positive Component (LPC) was scored as the most positive point in the average waveform in the latency range following the N400 to the end of the recording epoch (1000 ms). An overall repeated-measures ANOVA was performed on LPC amplitude with Age as the between factor and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated significant main effects of Age ($F[1, 38] = 4.40$, $p = .04$), Context ($F[1, 38] = 7.01$, $p = .01$), Site ($F[2, 76] = 12.04$, $p < .0001$, $\epsilon = .77$), and a trend toward a significant main effect of Relatedness ($F[2, 76] = 2.83$, $p = .07$, $\epsilon = .99$): However these were modified by the following interaction effects: Age X Site ($F[2, 76] = 8.93$, $p < .0001$, $\epsilon = .77$) and Context X Relatedness X Site ($F[4, 152] = 5.45$, $p < .011$, $\epsilon = .74$).

Within Context Analyses

For young subjects within the sentence context, there were no significant main effects of Relatedness ($F[2, 38] = .98$, $p = .382$, $\epsilon = .93$) or of Site ($F[2, 38] = .30$, $p = .712$, $\epsilon = .86$). There was a significant interaction of Relatedness X Site ($F[4, 76] = 5.16$, $p = .001$, $\epsilon = .58$). LPC amplitude differed significantly at all levels of relatedness (U > R > BC, this time from most positive to most negative since LPC is a positive-going deflection) at Fz only ($ps < .05$). There was no significant effect of relatedness at Cz and Pz ($ps < .05$).

For older subjects within the sentence context, there was a significant main effect of Site ($F[2, 36] = 8.23$, $p = .004$, $\epsilon = .73$), but not of Relatedness ($F[2, 36] = 2.68$, $p = .089$, $\epsilon = .90$). There was a significant interaction effect of Relatedness X Site ($F[4, 72] = 6.50$, $p = .002$, $\epsilon = .64$). Results were comparable to those for the young. LPC amplitude differed significantly at all levels of relatedness (U > R > BC) at Fz only ($ps < .05$). There was no significant effect of relatedness at Cz and Pz ($ps < .05$).

For young subjects within the word context, there was a significant main effect of Relatedness ($F[2, 38] = 20.05$, $p < .0001$, $\epsilon = .78$). LPC amplitude was significantly more positive in the Best Completion and Related conditions than in the Unrelated condition ($ps < .05$); however, the former two conditions did not significantly differ ($p < .05$). No significant main effect of Site ($F[2, 38] = 1.73$, $p = .198$, $\epsilon = .77$) or interaction effect of Relatedness X Site ($F[4, 76] = 2.29$, $p = .092$, $\epsilon = .70$) were found.

For older subjects within the word context, there was a significant main effect of Relatedness ($F[2, 38] = 5.43$, $p = .016$, $\epsilon = .76$). LPC amplitude was significantly more positive in the Best Completion condition than in the Unrelated condition ($p < .05$); however, neither differed from the Related condition ($ps < .05$). In addition, there was a significant main effect of Site ($F[2, 38] = 25.13$, $p < .0001$, $\epsilon = .67$). LPC amplitude differed significantly at all sites ($ps < .05$), with the following gradient of positivity: Fz > Cz > Pz. There was no significant main interaction effect of Relatedness X Site ($F[4, 76] = 1.57$, $p = .218$, $\epsilon = .57$).

LPC latency

An overall repeated-measures ANOVA was performed on LPC latency with Age as the between factor and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated a significant main effect of Relatedness ($F[2, 76] = 9.01$, $p = .0004$, $\epsilon = .99$), which was moderated by a Context X Relatedness X Site interaction ($F[4, 152] = 4.05$, $p = .005$, $\epsilon = .93$). There were no significant main effects of Age ($F[1, 38] = .09$, $p = .762$), Context ($F[1, 38] = .01$, $p = .928$), or Site ($F[2, 76] = .01$, $p = .983$, $\epsilon = .93$).

Within Context Analyses

For young subjects within the sentence context, there was a significant main effect of Relatedness ($F[2, 38] = 9.82$, $p = .001$, $\epsilon = .82$). LPC was significantly earlier in the Unrelated condition than in the Best completion condition ($p < .05$); however, neither differed from the Related condition ($ps < .05$). There was a significant main effect of Site ($F[2, 38] = 5.36$, $p = .016$, $\epsilon = .77$). LPC was significantly earlier at Fz relative to Pz ($p < .05$); however, neither differed from Cz ($ps < .05$). The two factors (Relatedness and Site) did not interact ($F[4, 76] = 2.04$, $p = .110$, $\epsilon = .84$).

For older subjects within the sentence context and for all subjects within the word context, there were no significant main or effect of Relatedness ($F[2, 36] = .32$, $p = .617$, $\epsilon = .59$ for older subjects within the sentence context; $F[2, 38] = 2.12$, $p = .135$, $\epsilon = .98$ for older subjects within the word context; $F[2, 38] = 1.72$, $p = .195$, $\epsilon = .95$ for young subjects within the word context) or Site ($F[2, 36] = 1.47$, $p = .246$, $\epsilon = .84$ for older subjects within the sentence context; $F[2, 38] = .19$, $p = .815$, $\epsilon = .94$ for older subjects within the word context; $F[2, 38] = .89$, $p = ..411$, $\epsilon = .90$), and no significant interaction effect between the two ($F[4, 72] = 2.31$, $p = .083$, $\epsilon = .78$ for older subjects within the sentence context; $F[4, 76] = .75$, $p = .533$, $\epsilon = .79$ for older subjects within the word context; $F[2, 76] = 1.90$, $p = .141$, $\epsilon = .74$).

Early components analyses

The goal of these analyses was to rule out the effect of relatedness on early sensory components. Relatedness was expected to have an effect limited to ERP components indexing semantic processing (N400) and memory (LPC).

N1 amplitude

An overall repeated-measures ANOVA was performed on N1 amplitude with Age as the between factor and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated significant main effects of Context ($F[1, 38] = 4.63$, $p = .04$) and Site ($F[2, 76] = 5.93$, $p = .01$, $\epsilon = .62$). These were moderated by the following interactions: Age X Context X Site ($F[2, 76] = 4.05$, $p = .018$, $\epsilon = .66$) and Age X Relatedness X Site ($F[4, 152] = .26$, $p = .031$, $\epsilon = .66$). There were no significant main effects of Relatedness ($F[1, 76] = .23$, $p = .797$, $\epsilon = .96$) or Age ($F[1, 38] < .01$, $p = .997$).

Within Context Analyses

For young subjects within the sentence context, there was a significant main effect of Site ($F[2, 38] = 4.81$, $p = .031$, $\epsilon = .62$). N1 was significantly more negative at Fz and Cz than at Pz ($ps < .05$); however, the two former sites did not differ ($p > .05$). There was no significant main effect of Relatedness ($F[2, 38] = .40$, $p = .653$, $\epsilon = .91$) or interaction effect of Relatedness and Site ($F[4, 76] = 1.12$, $p = .348$, $\epsilon = .79$).

For older subject within the sentence context, there was also a significant main effect of Site ($F[2, 36] = 5.07$, $p = .026$, $\epsilon = .66$). N1 was significantly more negative at Fz than at Pz ($p < .05$); however, neither differed from Cz ($p > .05$). There was no significant main effect of Relatedness ($F[2, 36] = .48$, $p = .600$, $\epsilon = .88$) or interaction effect of Relatedness and Site ($F[4, 72] = 2.33$, $p = .065$, $\epsilon = .60$).

For young subjects within the word context, there was a significant main effect of Site ($F[2, 38] = 4.81$, $p = .031$, $\epsilon = .62$). N1 was significantly more negative at Cz and Pz than at Fz ($ps < .05$); however, the two former sites did not differ ($p > .05$). There was no significant main effect of Relatedness ($F[2, 38] = 1.30$, $p = .284$, $\epsilon = .96$) or interaction effect of Relatedness and Site ($F[4, 76] = 2.05$, $p = .128$, $\epsilon = .64$).

For the old within the word context, there were no significant main effects of Relatedness ($F[2, 38] = .80$, $p = .452$, $\epsilon = .95$) or Site ($F[2, 38] = 1.14$, $p = .310$, $\epsilon = .61$), and no significant interaction effect of Relatedness X Site ($F[4, 76] = .39$, $p = .761$, $\epsilon = .74$).

N1 latency

An overall repeated-measures ANOVA was performed on N1 latency with Age as the between factor and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated a significant main effect of Context ($F[1, 38] = 21.18$, $p < .0001$) with N1 being significantly earlier in the sentence ($M = 112.18$, $SE = 1.09$) than in the word ($M = 121.85$, $SE = 1.48$) context. There was also a significant main effect of Site ($F[2, 76] = 4.18$, $p = .019$, $\epsilon = .62$). N1 was significantly earlier at Cz than at Pz ($p < .05$); however, neither differed from Fz (ps < .05). There were no significant main effects of Age ($F[1, 38] < .01$, $p = .973$) or of Relatedness ($F[2, 76] = 1.51$, $p = .229$, $\epsilon = .94$). Analyses conducted separately for each age group within each context, yielded no significant main or interaction effects of Relatedness or Site.

P2 amplitude

An overall repeated-measures ANOVA was performed on P2 amplitude with Age as the between factor and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated significant main effects of Age ($F[1, 38] = 6.46$, $p = .015$) and Site ($F[2, 76] = 13.34$, $p = .0001$, $\epsilon = .77$). There were no significant main effects of Relatedness ($F[2, 76] = 1.71$, $p = .187$, $\epsilon = .10$) or Context ($F[1, 38] = .51$, $p = .482$). Age and Site each interacted with Context: Age X Context ($F[1, 38] = 4.05$, $p < .0001$), Context X Site ($F[2, 76] = 2.08$, $p = .015$, $\epsilon = .87$).

Within Context Analyses

For young subjects within the sentence context, there were no significant main effects of Relatedness ($F[2, 38] = .11$, $p = .891$, $\epsilon = .96$) or Site ($F[2, 38] = .10$, $p = .844$, $\epsilon = .73$), and no significant interaction effect between the two ($F[4, 76] = .67$, $p = .552$, $\epsilon = .65$).

For older subjects within the sentence context, there was a significant main effect of Site ($F[2, 38] = 6.74$, $p = .003$, $\epsilon = .99$). P2 was significantly more positive at Fz and Cz than at Pz ($ps < .05$); however, the two former sites did not significantly differ ($p > .05$). There was no significant main ($F[2, 36] = 1.71$, $p = .196$, $\epsilon = .98$) or interaction ($F[4, 72] = .56$, $p = .612$, $\epsilon = .63$) effect of Relatedness.

For young subjects within the word context, there was a significant main effect of Site ($F[2, 38] = 5.21$, $p = .025$, $\epsilon = .63$). P2 was significantly more positive at Cz than at Pz ($ps < .05$); however, the two former sites did not significantly differ from Fz ($p > .05$). There was no significant main ($F[2, 38] = .67$, $p = .513$, $\epsilon = .99$) or interaction ($F[4, 76] = 1.81$, $p = .162$, $\epsilon = .67$) effect of Relatedness.

For older subjects within the word context, there was a significant main effect of Site ($F[2, 38] = 15.58$, $p = .003$, $\epsilon = .62$). P2 was significantly more positive at Fz and Cz than at Pz ($ps < .05$); however, the two former sites did not significantly differ ($p > .05$). There was no significant main ($F[2, 38] = .61$, $p = .546$, $\epsilon = .98$) or interaction ($F[4, 76] = .87$, $p = .430$, $\epsilon = .53$) effect of Relatedness.

P2 latency

An overall repeated-measures ANOVA was performed on P2 latency with Age as the between factor and the following within factors: Context (sentence, word), Relatedness (BC, R, U), and Site (midline). The results indicated significant main effects of Age ($F[1, 38] = 6.47$, $p = .02$), Context ($F[2, 38] = 11.20$, $p = .002$), and Site ($F[2, 76] = 9.92$, $p = .0009$, $\epsilon = .79$). There was no significant main effect of Relatedness $F[2, 76] = .76$, $p = .473$, $\epsilon = .99$). The results indicated significant Age X Context X Site ($F[2, 76] = 3.83$, $p = .047$, $\epsilon = .64$) and Relatedness X Site ($F[4, 152] = 3.49$, $p = .019$, $\epsilon = .74$) interactions.

Within Context Analyses

For young subjects within the sentence context, there was a significant main effect of Site ($F[2, 38] = 12.72$, $p < .0001$, $\epsilon = .74$). P2 was significantly earlier at Pz than at Fz and Cz ($ps < .05$); however, the two latter sites did not significantly differ ($p > .05$). There was no significant main or interaction effect of Relatedness ($F[2, 38] = 1.18$, $p = .315$, $\epsilon = .88$ for the main effect, and $F[4, 78] = 1.32$, $p = .279$, $\epsilon = .61$ for the Relatedness X Site interaction).

For older subjects within the sentence context, there were no significant main effects of Relatedness ($F[2, 36] = .16$, $p = .848$, $\epsilon = .98$) or Site ($F[2, 36] = .38$, $p = .593$, $\epsilon = .63$), and no significant interaction effect between the two ($F[4, 72] = 1.41$, $p = .254$, $\epsilon = .59$).

For young subjects within the word context, there were no significant main effect of Relatedness ($F[2, 38] = .04$, $p = .932$, $\epsilon = .77$) or Site ($F[2, 38] = .55$, $p = .522$, $\epsilon = .69$), or interaction between the two ($F[4, 76] = 2.51$, $p = .073$, $\epsilon = .69$).

For older subjects within the word context, there was a significant main effect of Relatedness ($F[2, 38] = 3.82$, $p < .033$, $\epsilon = .95$). P2 was significantly earlier in the Unrelated condition than in the Best Completion condition ($ps < .05$); however, neither differed from the Related condition ($p > .05$). There were no significant main ($F[2, 38] = 2.12$, $p = .135$, $\epsilon = .98$) or interaction ($F[4, 76] = .45$, $p = .726$, $\epsilon = .79$) effect of Site.

Behavioral data

In addition to ERP data, behavioral data was gathered. After presentation of a block of stimuli, subjects were asked to recall the final word of each sentence or word pair. After recall was tested for a given sentence or word pair, subjects were asked to make a forced choice between two words: one that had completed the sentence or word pair and a foil (a word that had not been presented). The behavioral data of two older subjects was excluded; one because the subject had been the first subject and was tested for memory somewhat differently, and the other due to technical problems during EEG recording.

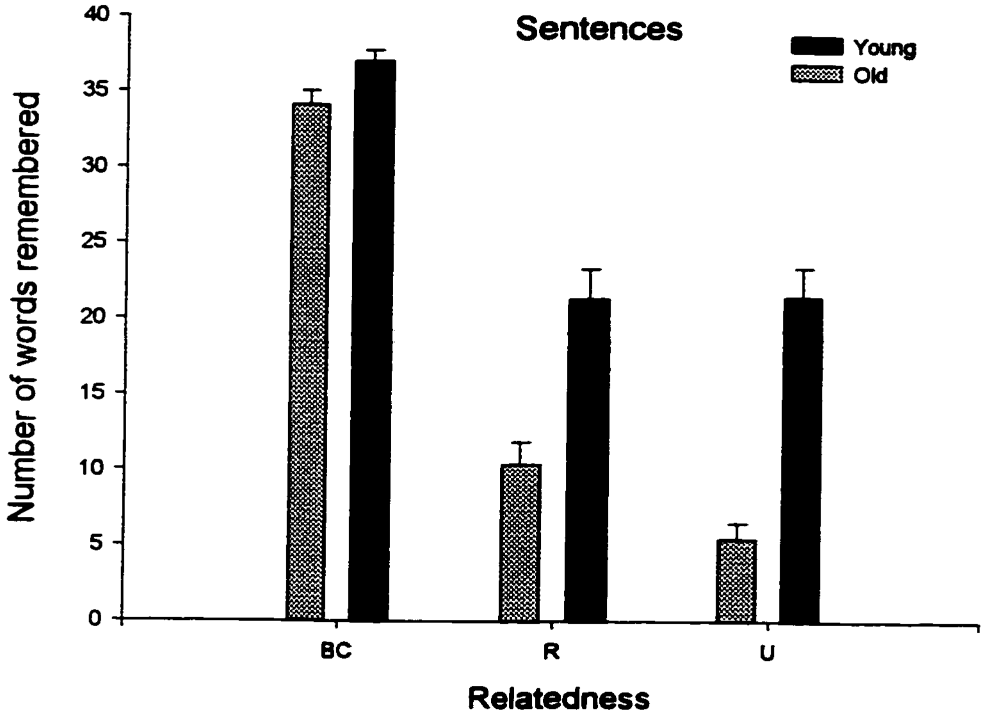
Given that recall and recognition reflect qualitatively different memory processes, separate ANOVAs were conducted for each. Age was the between factor, and Context (sentence, word) and Relatedness (BC, R, U) were the within factors. Mean number of words recalled and recognized (and SEs) for each age group and relatedness condition is illustrated in Figures 11 and 12 respectively.

Recall. The ANOVA on recall data revealed significant main effects of Age ($F[1, 36] = 26.93$, $p < .0001$), Context ($F[1, 36] = 155.35$, $p < .0001$), and of Relatedness ($F[2, 72] = 560.16$, $p < .0001$, $\epsilon = .88$). Their effect was moderated a significant interaction of Age X Context X Relatedness ($F[1, 72] = 17.56$, $p < .0001$, $\epsilon = .83$). Within each context and relatedness condition, young subjects recalled significantly more words than older subjects (ps $< .05$).

From the sentence context, young subjects recalled significantly more terminal words from sentences which ended with the Best Completion than those that ended with Related or Unrelated words (ps $< .05$); however, recall did not differ for the latter two conditions ($p > .05$).

Figure 11. Number of words recalled in each Context as a function of Age group and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated). The maximum possible is 40. Standard errors are shown by vertical bars.

Recall


Sentences
Young
Old
40
35
30
25
20
15
10
5
0
Number of words remembered
BC
R
U
Relatedness

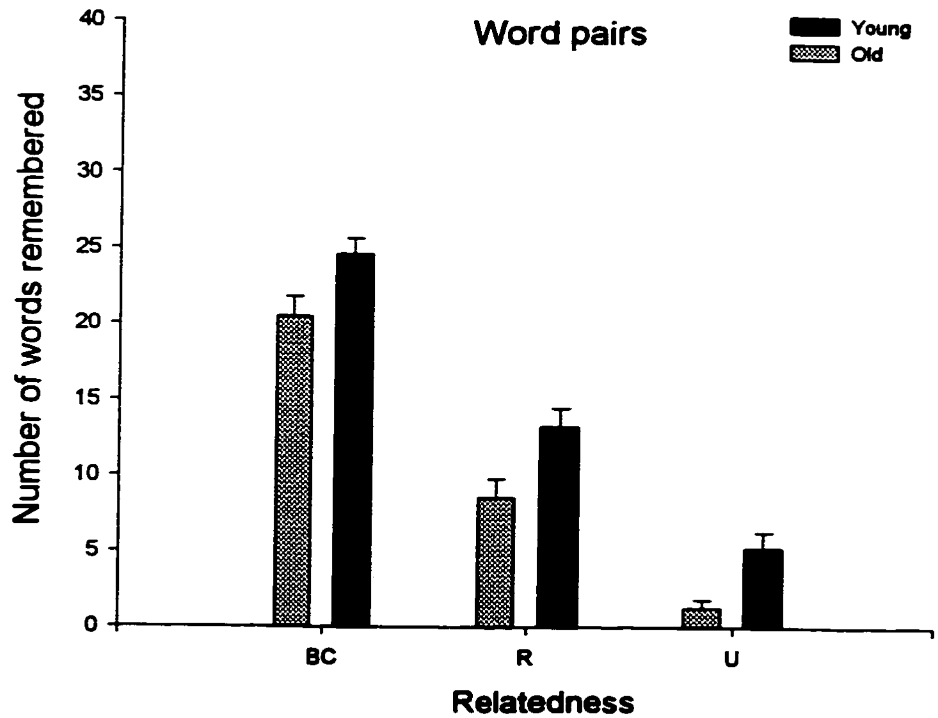
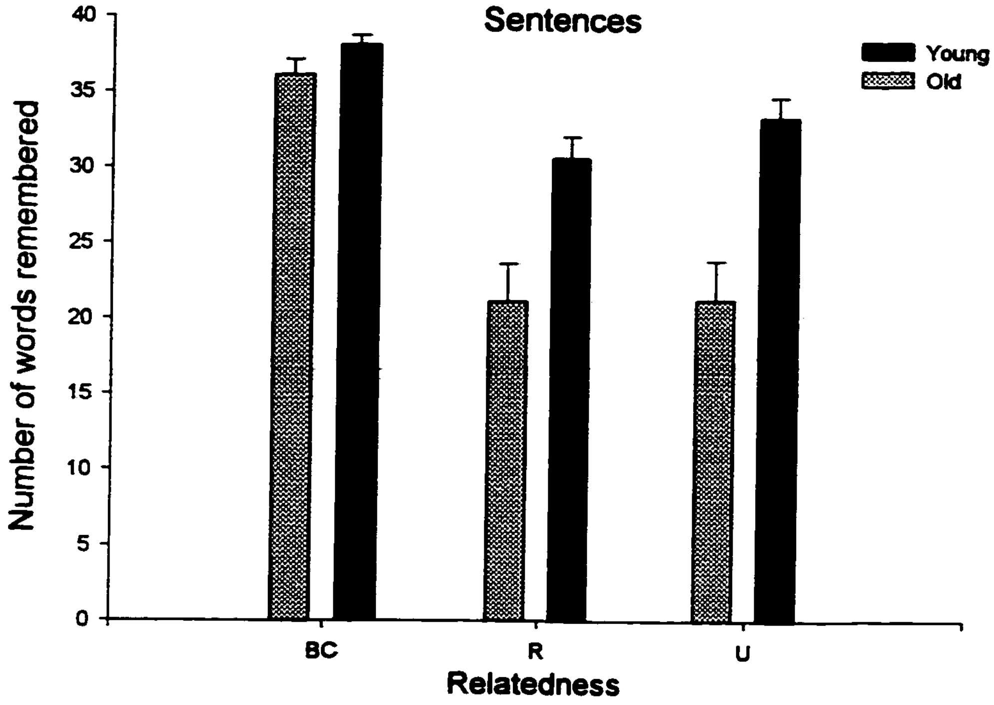
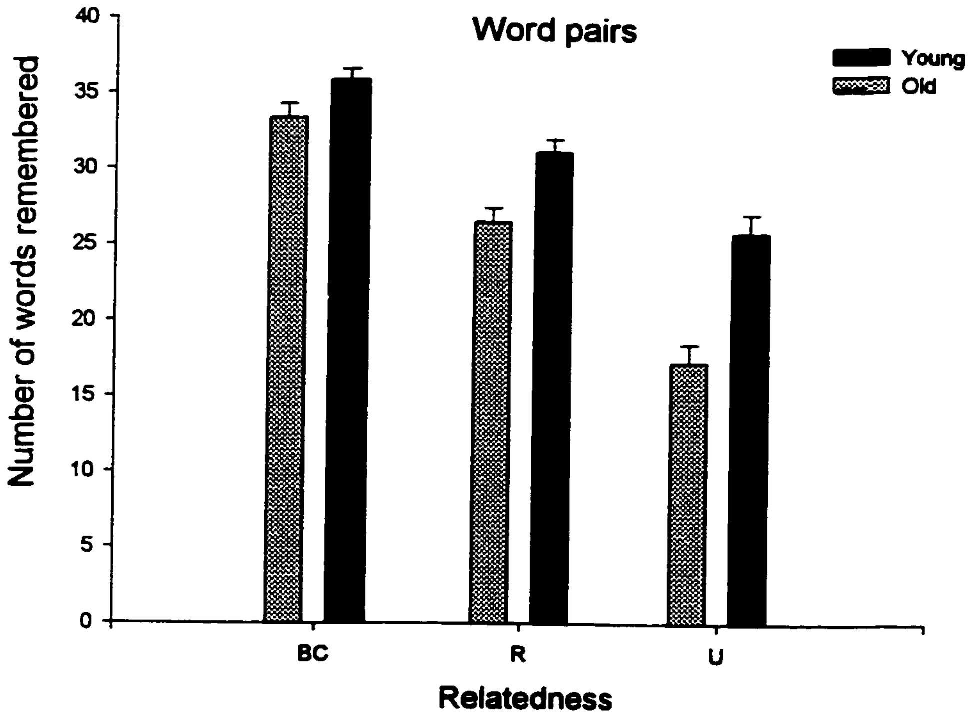

Word pairs
Young
Old
40
35
30
25
20
15
10
5
0
Number of words remembered
BC
R
U
Relatedness

Figure 12. Number of words recognized in each Context as a function of Age group and Level of relatedness (BC = Best completion; R = Related; and U = Unrelated). The maximum possible is 40. Standard errors are shown by vertical bars.

Recognition





Older subjects recalled significantly more terminal words from sentences which ended with the Best Completion than from those terminated by Related words ($p < .05$) and more words from the Related than from the Unrelated condition ($p < .05$).

Within the word context, the pattern of recall was similar for the young and old: both groups recalled significantly more target words from the Best Completion word pairs than from the Related word pairs ($p < .05$) and more words from the Related than from the Unrelated word pairs ($p < .05$).

Recognition. The ANOVA on recognition revealed significant main effects of Age ($F[1, 36] = 33.48$, $p < .0001$) and Relatedness ($F[2, 72] = 91.46$, $p < .0001$, $\epsilon = .70$), and a trend toward a significant main effect of Context ($F[1, 36] = 3.99$, $p = .05$). These effects were moderated by significant Age X Relatedness ($F[2, 72] = 10.61$, $p = .001$, $\epsilon = .70$) and Context X Relatedness ($F[2, 72] = 13.68$, $p < .0001$, $\epsilon = .74$) interactions. Within the sentence context, young subjects recognized significantly more words than older subjects from the Related and Unrelated conditions (ps $< .05$); however, both groups recognized a comparable number of words from the Best Completion condition ($p > .05$). Within the word context, young subjects recognized significantly more words than older subjects from each of the relatedness conditions (ps $< .05$).

Within the sentence context, both groups recognized significantly more words from the Best Completion condition than from the Related and Unrelated conditions (ps $< .05$); however, recognition in the latter two conditions did not differ ($p > .05$). Within the word context, both groups recognized significantly more words from the Best Completion than from the Related condition ($p < .05$) and more words from the Related than from the Unrelated condition ($p < .05$).

Finally, whereas the number of words recognized from the Best Completion condition was comparable across context ($\underline{p}$ < 05), significantly more words were recognized from the Related condition in the word than in the sentence context ($\underline{p}$ < .05) and from the Unrelated condition in the sentence than in the word context ($\underline{p}$ < .05).

Discussion

Results from young subjects will be discussed in the context of the ERP literature. This will set the stage for a meaningful discussion of ERP results from older subjects as they relate to those from young subjects. Interpretations of the age-related differences found in this study will be made within the framework of the IDH, and alternative hypotheses will be examined.

Semantic priming in the young

In the sentence context, young adults demonstrated the typical N400 amplitude gradient (U > R > BC). This indicated that following a sentence prime, the best completion (e.g., "They placed an ad in the daily *paper*.") was significantly more primed than a related ending (e.g., "Dick wrote a chapter in the *novel*." [book]), which in turn was significantly more primed than an unrelated ending (e.g., "Betsy could not read very well without her *dictionary*". [glasses]). This gradient is well documented in the ERP literature (e.g., Kutas et al., 1984; Kutas, 1993). The gradient was significant at the midline and also at right posterior sites. This result is consistent with Kutas & Hillyard (1980, 1984).

In the word pair context, young adults demonstrated a significant N400 gradient at the midline scalp location only. When analyses were restricted to right posterior locations, the gradient only partially reached significance (U > R = BC). This is consistent with Kutas & Hillyard (1989): the authors restricted their analyses to include both midline and right posterior sites and found a marginally significant N400 gradient (U = R > BC). Given that only Kutas (1993) has directly compared N400 responses to word and sentence primes, a discussion of possible differences between sentence and word context effects remain tentative. Nevertheless, these results suggest that although the N400 may be equally prominent at right posterior and midline scalp locations following a sentence context, it may be more prominent at the midline than at right posterior scalp locations following a word context. A difference in the scalp distribution of the N400 for sentence and word contexts would indicate a qualitative difference in the processes assumed to underlie the two context effects, namely top-down (sentence context effects) and bottom-up (word context effects) processes. Finally, in the present study, N400 responses to target words that were unrelated to the prime occurred later than those to target words that were highly or moderately related. Because other N400 studies that have used a single-word priming paradigm have employed a scoring method (interval scoring) that does not allow precise latency measurement, this result cannot be compared to those in the ERP literature. However, it is consistent with results from the behavioral literature indicating inhibition of unrelated targets. In particular, this finding suggests that it is not only the strength of semantic priming of the target that is decreased by an unrelated prime, but also the speed at which activation reaches that target.

Kutas (1993) directly compared sentence and single-word context effects in young subjects. Quantitative differences between the two context effects were reported. The N400 effect was larger and lasted longer for sentences than for word-pairs. Qualitative differences between the two context effects were not found; the N400 had the same scalp distribution in each context, being larger over posterior than anterior scalp locations. Similarly, the onset latency of the N400 did not differ between the two contexts. Kutas (1993) concluded that sentence and single-word context effects differed quantitatively but not qualitatively. Comparable results were found in the present study. As illustrated in Figures 1 and 2, the N400 effect was significantly larger and lasted longer for sentences than for word-pairs, and as illustrated in Figures 4 and 5, the N400 effect in each context was significantly larger over posterior than anterior scalp locations. As in Kutas (1993), onset latency of the N400 did not appear to differ between the two contexts; however, onset was not directly measured. In the present study, the conclusion that sentence and single-word contexts have quantitatively different effects on word processing must be tempered by results for the hemispheric scalp distribution of the N400 in each context. Results indicated that overall N400 amplitude varied as a function of hemisphere in the word context only, being more negative over the left hemisphere. Kutas (1993) found that overall N400 amplitude varied as a function of hemisphere in the sentence context only, being more negative over the right hemisphere. These results suggest that although the two context effects may share a posterior maximum, they may vary in the lateralization of maximal N400 amplitude, which would open the way for the possibility of qualitative differences in the underlying processes. The present study was identical to Kutas (1993), except for the following differences. First, in Kutas (1993), sentences were read for meaning whereas word-pairs were read to identify the letter "p"; in the present study, both sentences and word-pairs were read for meaning. Second, in Kutas (1993), subjects read the sentences first; in the present study, order of presentation of the two block (sentences and word-pairs) was counterbalanced. Third, in Kutas (1993), over a quarter of the sentence primes contained a lexical associate of the sentence final word; for the present study, those were replaced with sentences that did not contain lexical associates. Replication of the results from Kutas (1993) with the above improvements in methodology was important because of the following limitations of her results. In that study, attenuation of the N400 effect in the word context relative to the sentence context, could have been due to shallower processing (letter-search task), fatigue (subjects always read the word pairs last), or the fact that many sentence endings benefitted from sentential and lexical priming from lexical associates.

Despite some methodological differences between Kutas (1993) and the present study, the results were largely comparable. Thus the N400 amplitude gradient (U > R > BC) found in the young, as documented in the literature (e.g., Kutas et al., 1984; Kutas, 1993), is a valid baseline against which to compare the N400 responses of older adults.

Semantic priming in the old

Results indicate a significant age-related decrease in semantic priming. This result is clear whether one looks at the grand average waveforms (Figures 1 and 2) or at the slope of N400 amplitude plotted as a function of degree of relatedness (Figure 3). N400 responses to final words in the unrelated condition can be considered as baseline responses reflecting the processing of a word in the absence of a related priming context. As expected, the two age groups did not differ on this baseline in either context. However, as the context increasingly primed the way for the target in the related and best completion conditions, N400 responses of older subjects did not show a significant reduction in amplitude as observed in the young. In the word context, N400 amplitude in the older adults did not decrease significantly in either of the two conditions that lead to a significant stepwise decrease in N400 amplitude in the young. In the sentence context, attenuation of N400 responses in the old was elicited by best completions, but not by endings related to the best completion (e.g., "Dick wrote a chapter in the *novel.*", instead of "in the *book*").

These results indicate a decrease in the amount of semantic priming of moderately and highly related targets in the old, but it is unclear whether this is due to age-related changes in spreading activation or expectancy. Given the relatively long SOA used in the present study (700 ms), either mechanism could have supported semantic priming. There is, however, three lines of evidence suggesting that expectancy may have been preserved relative to spreading activation in aging in the present study. First, the cost component in semantic priming, assumed to exclusively reflect expectancy-based processes and reflected in the inhibition of unrelated targets, was intact in older subjects, as evidenced by their response to targets in the unrelated condition. Secondly, older adults were able to benefit from priming in the best completion condition in the sentence context, as evidenced by reduced N400 amplitude in this condition relative to the unrelated condition. However, significant priming effects on N400 amplitude were not observed in the older adults in any priming condition in the word context. If highly constraining sentence primes can be assumed to lead to higher levels of expectancy than single word primes, it would follow that age-related constancy in expectancy would result in relatively more priming in the sentence context than in the word context, whereas age-related deficits in expectancy would result in similar priming across context. Thirdly, there were no age-related differences on the cued recall test when subjects had to recall the sentence terminal word when given the sentence fragment in the best completion condition for the sentence context. This was despite age-related deficits on recall in all other conditions (sentences U, R; words U, R, BC). In a significant number of cases, older adults would say, "This sentence should end with ___", which, for best completion sentence fragments yielded accurate performance on the recall test. For the related and unrelated sentence fragments, many older adults made similar comments while noting that these sentences did not end as expected. However, they were unable to recall or recognize what the ending had been. These three points imply that age-related differences in expectancy could not, or at the very least could not entirely, explain the differences between young and older subjects found on semantic priming as measured by the N400. The lack of discrimination in the old between words that were highly related to the previous context and words that were moderately related or unrelated was more apparent when the prime was a single word (leading to the absence of an N400 gradient in the old: U = R = BC) than when it was a sentence (U > BC), consistent with the view that older adults can benefit from the increased contextual support or constraint provided by a sentence.

<u>Comparison with results from the literature on the N400 and aging</u>

First, it should be noted that there are no N400 studies on the effects of aging on word pair priming, and therefore, the comparison to results from the ERP literature is limited to results from the sentence context. At first look, results from the present study appear consistent with those from the literature (Gunter et al., 1992; 1995; Woodward, et al., 1993; Hamberger et al., 1995) in that semantic priming, as measured by the N400 decreases with aging. However, most of the studies cited (Gunter et al., 1992; 1995; Woodward et al., 1993) found significant age-related attenuations in N400 responses to incongruent endings, and no significant age-related differences in response to congruent endings. This is in sharp contrast to results from the present study, in which aging affected N400 responses to related endings and best completions, but did not affect N400 responses to unrelated endings. That is, group differences in N400 amplitude were found in the former two conditions but not the latter. A potential explanation for this difference with previous studies lies in the type of stimuli used. In all N400 studies of semantic priming in aging (Gunter et al., 1992; 1995; Woodward et al., 1993) two levels of relatedness were used: best completions and unrelated nonsense endings. An example of an unrelated sentence, from Woodward et al., (1993) is : "They're out in the garden pulling *voices*." [roots]). In contrast, unrelated endings in the present study were, despite being unlikely, sensible endings (e.g., "Betsy could not read well without her *dictionary*." [glasses]): These endings were simply unrelated *to* the best completion. This difference could explain the first discrepancy between results from the studies mentioned above and those in the present study, namely the finding of an age-related attenuation in N400 response to unrelated endings in those studies, and the lack thereof in the present study. This discrepancy could reflect an age-related decrease in the maximum amplitude of the physiological response underlying the recorded N400. This could lead to a plateau of N400 amplitude response in the old, which may have been reached by unrelated sensible endings (as in the present study), such that the physiological response to unrelated nonsensical endings (as in other studies) would not have increased above that plateau. This would lead to age-related differences in response to unrelated nonsensical endings since the N400 response of younger subjects would increase above that of older subjects but to age-related constancy in N400 response to unrelated sensible endings. There are three lines of evidence to support this suggestion: First, the N400 reflects synchronous firing of populations of neurons (Coles & Rugg, 1995). In normal aging, there is a significant loss of neurons. Scheibel et al., (1975), cited in West (1996) was one of the first investigators to report " a loss of horizontal elements of the dendritic array" with advancing age. Event-related potentials are assumed to reflect post-dendritic potentials, rather than axonal action potentials (Coles & Rugg, 1995), and do require the geometric configuration of neurons to be the same for their activity to be recorded at the scalp (Coles & Rugg, 1995). Given that there are fewer neurons in older adults to produce the N400 through their synchronous firing and orientation, the maximum N400 response may not be expected to be as large as that resulting from the same activity in a young brain. Secondly, and relatedly, there are numerous physiological responses that decrease in strength with aging. Finally, results from Hamberger et al., (1995) indicated that in older adults, N400 amplitude did not differ between sentence endings that were unrelated and sensible and those that were unrelated and nonsense with respect to sentence meaning. In contrast in their study N400 amplitude in the young significantly was significantly larger than response to unrelated-nonsense endings relative to unrelated sensible endings. Overall, these points suggest that in the present study, older adults were able to produce an N400 response to unrelated but sensible endings that was comparable-in strength to that of young adults. However, this may have been as big an N400 response is older-subjects can produce because of a decrease in the size and efficiency on the neuronal substrate of the response.

The second discrepancy between results from other studies (Gunter et al., 1992; 1995; Woodward et al., 1993) and those in the present study is the finding of age-related constancy in N400 responses to endings congruent with a previous ending in those study, and the age-related differences in N400 amplitude in the same condition in the present study. The most likely explanation for this observation is the difference between their studies and the present one in the ratio of related and unrelated targets. In the studies cited above, only two levels of relatedness were used, yielding a 1:1 ratio of best completions to unrelated incongruous targets. In contrast, in the present study, the ratio of best completion targets to targets having no relation or a weak relation to the previous context was 1:2 (i.e., BC versus R and U). It is well known from the literature that semantic priming increases in size as the proportion of highly related prime-target trials increases (De Groot, 1994; Keefe & Neely, 1990). This phenomenon is referred to as the"relatedness proportion effect" (Keefe & Neely, 1990). The fact that sentences in the present study ended with the best completion only one third of the time (instead of half of the time in their studies may have led subjects not to form as strong a prediction of what the ending would be. This may have been the case relatively more so for older than for younger subjects. Older adults have been shown to require more support from the external environment to initiate certain cognitive operations (e.g., those involved in effective encoding, Craik, 1986).

In agreement with findings from the literature (Gunter et al., 1992; 1995; Woodward et al., 1993), results from the present study suggest quantitative differences in semantic priming with aging. Qualitative differences in the cognitive processes underlying the N400, such as the use of a strategy by young or older subjects would have been reflected in differences in the scalp distribution of the N400 between the two groups. Direct evidence of differences in the scalp distribution of the N400 between the two groups was not found. However, indirect evidence (e.g., see Figure 7, and page 63 last paragraph) suggested that the N400 may have been more lateralized in older than in younger subject.

Other ERP components

Early sensory components were also examined in this study to demonstrate that the relatedness manipulation affected cognitive processes (i.e., N400) specifically, and this within each age group and context. This is important in ruling out the possibility that a difference found with N400 amplitude could be due to differences in early stimulus input processes. For instance, if early processes were stronger in response to unrelated sentence endings than in response to best completions, then interpretation of the N400 amplitude difference (U > BC) as an index of the amount of semantic priming would be difficult. This was ruled out in the present study. Consistent with results from other studies (Gunter et al., 1992, Woodward et al., 1993), there were no significant effects of relatedness on N1 amplitude and latency within each age group and context, and no significant effects of relatedness on P2 amplitude within each age group and context. However, for older subjects in the word context P2 was significantly earlier in the unrelated than in the best completion condition. This finding cannot be directly compared to those from the literature since there are no N400 study of single-word priming in the old reported in the literature. Woodward et al. (1993), using auditory sentence primes, observed earlier P2 peaks following incongruent endings, and suggested that this was due to modification of the later portion of the P2 peak by the deflection of the N400 (i.e., the negative-going N400 was attenuating the positive-going P2). Nevertheless, the finding of earlier P2s in the old in the unrelated condition within the word context does not act as a confound. It cannot explain age-related differences in N400 amplitude.

The late positive component (LPC) was also examined because of its link to subsequent memory performance. Various recognition memory paradigms have demonstrated variations in LPC amplitude (e.g., Neville, Kutas, Chesney, & Schmidt, 1986). Typically, LPC is larger to words that are subsequently recognized (e.g., Neville et al., 1986) and recalled (Paller, McCarthy, & Wood, 1988). The LPC has been proposed to index the extent to which a word forms an integrated unit with its context. Words that are better integrated with their context will be better remembered and will yield a stronger LPC response (e.g., Neville et al., 1986). Overall, results from the present study support this account of the LPC. Within the sentence context, a significant gradient of LPC amplitude was obtained for each age group, with LPC being largest for best completions, smallest for unrelated completions, and of intermediate amplitude for related endings. Although not always significant, recall and recognition in the sentence context were always better for the best completion than for the related endings, and were always better for related endings than for unrelated ones (see Figure 11). Within the word context, LPC amplitude was larger for best completions than for unrelated endings for each age group. This is consistent with subsequent memory performance illustrated in Figure 12. To study the LPC, one would ideally re-average the ERP trials into two groups: those in response to words that were subsequently remembered and those in response to words that were not. However, this could not be done for each relatedness condition because of a ceiling effect in memory for the best completions for both age groups and a floor effect for the unrelated condition in many of the older subjects, which would yield too few trials to make reliable ERP averages.

Interpretation of the findings within the framework of the IDH

The IDH posits an age-related decrease in inhibition efficiency. Results from older subjects in the unrelated condition (same N400 amplitude as for the young) do not suggest a gross decrease in inhibition efficiency. However, when within-group differences are considered, all three predictions of the IDH were supported.

The first prediction of the IDH is reduced semantic priming with aging due to inefficient inhibition of unrelated targets. For older subjects in the present study, activation spread almost equally to all targets, related or not (U = R = BC for word pairs and U = R = BC but U > BC for the sentences). This pattern of results is consistent with reduced inhibition efficiency. If there is little inhibition of unrelated targets; then activation will spread equally to unrelated and related targets, such that an equal amount of priming will be observed across relatedness conditions. This result was observed in the word context for the elderly subjects. Alternatively, one could argue that activation "did not spread" to related targets in the word context; the present data cannot resolve this question.

A second prediction of the IDH was that an age-related decrease in semantic priming would be minimized in the sentence context, relative to the word context. According to the IDH, when contextual support is great (e.g., in highly constrained sentences), interference due to inefficient inhibition of not directly relevant information is minimized. Consequently, age-related differences in semantic priming should be less apparent. Consistent with this prediction, older adults significantly activated best completions more strongly than unrelated endings in the sentence context. This is in contrast to the word context, in which no significant relatedness effect was found in the older adults.

Thirdly, the IDH predicted a smaller difference in the semantic priming of related endings and best completions in older subjects relative to young subjects. Related endings are not as relevant as best completions, and according to the IDH, older adults have difficulty inhibiting related but irrelevant information. Consistent with this prediction, N400 amplitude in the young was significantly larger in response to related endings than in response to best completions, whereas N400 amplitude in the older subjects was equivalent in the two conditions. This finding was observed in both contexts.

Results from between-group comparisons were not as informative. The only significant difference in N400 amplitude was in the best-completion condition within the sentence context, indicating significantly more priming of the best completions in the young subjects than in the older subjects. The within-group comparisons were more relevant to the question of whether older adults differentially activate words that are related and unrelated to the context in which they are embedded. Between-group comparisons are not well suited to answer this question. In addition, it is not known whether semantic priming in older adults is on the same scale as that in younger adults. The possibility of a lower ceiling of N400 responses in aging was previously discussed, and a similarly lower ceiling of semantic priming may exist, it is not yet know. To test this question, the relative strength of priming in response to manipulations of relatedness within each age group was analyzed.

Overall, the conclusions that can be drawn from the within-group comparisons are similar to those drawn by Paul (1996) in a study using homographs. Older adults appear able to inhibit clearly irrelevant information (as in the unrelated condition), but may fail to inhibit related but irrelevant information (as in the related condition).

<u>Alternative hypotheses</u>

Alternatively, changes in the structure of the semantic network with aging could account for the three results discussed in the context of the IDH. Having had at least two to three times the number of years of experience with language stimuli as have had younger adults, older adults in the present study may have developed a more elaborate semantic network, with increased interconnections between nodes. This would lead to less semantic priming than for younger subjects overall (U = R = BC) because spreading activation would be more diffuse. It would also lead to priming of irrelevant targets (in the related condition) that is almost as much as that of relevant targets (best completions). Finally, given a highly constraining context (sentence primes), diffusion of the activation due to enhanced interconnections would be reduced and relatively more semantic priming of related targets (BC > U) would occur.

Findings in the present study do not support hypotheses predicting age-related hyperpriming, such as the interactive-compensatory hypothesis. According to the interactive-compensatory hypothesis, older adults would show increased priming of related targets to compensate for an age-related slowing of the perceptual processes involved in word identification. This was clearly not the case in the present study. Older adults did not show priming of related items, as measured by the N400, in the word context. And although they did show priming of best completions in the sentence context, it was significantly less than for younger adults.

Results also do not support the general slowing hypothesis. A main postulate of the general slowing hypothesis is that age-related differences in semantic priming can be accounted for by a single slowing factor. The hypothesis does not specify whether age-related changes are expected in the strength of semantic priming independently of its speed. With RT measures, the general slowing hypothesis predicts hyperpriming in aging, because any factor that slows down word identification will have more of an effect on older adults. Therefore, older adults will show increased inhibition of unrelated targets at least on RT measures. Evidence of delays in the unrelated condition for older adults relative to young adults was not found. In addition, whether or not age-related changes are expected in the strength of semantic priming independently of its speed, the general-slowing hypothesis cannot account for the age-related decrease in the strength of the process of semantic priming found in this study.

Limitations of RT measures that could have lead to the finding of hyperpriming in older subjects were reviewed in the introduction. These included the inability to separate the strength of the process from its timing, and the fact that RT measures reflect an agglomeration of indistinguishable processes (e.g., decision-related processes).

Although ERP measures have the advantage of being on-line and allowing the separation of cognitive processes from their timing, they are not flawless. Subjects in ERP studies of linguistic processes are often asked to refrain from blinking during reading. In the present study, in addition to reading the material for meaning, subjects had to pay attention to their eye movement. Age-related differences in attentional capability, if present, could have somewhat affected the results. However, this additional demand on attention was the same across conditions (BC, R, U) and could not, per se, account for the findings.

Conclusions

Results in young subjects replicated Kutas (1993). In each context, the expected N400 amplitude gradient (U > R > BC) was obtained for young subjects. A larger N400 effect of seemingly longer duration in the sentence context relative to the word context suggested quantitative differences in the mechanisms underlying single-word and sentence context effects. The finding of a similar scalp distribution of the N400 for the two contexts provided evidence against qualitative differences in the underlying mechanisms.

This study provided evidence of an age-related decrease in semantic priming which occurs naturally during reading, and is independent of slowing of perceptual (indexed by the N1 and P2) or cognitive processes (indexed by N400 latency). It was suggested that this decrease in semantic priming resulted from inefficient spreading activation, although age-related changes in expectancy could not be ruled out. The lack of a significant N400 gradient (U > R > BC) in the old in either context, combined with the finding of a significant effect of relatedness (U > BC) in the old limited to the condition providing the most contextual support (the sentence condition) was taken as support for the IDH. Alternatively, the same results could be accounted for by an age-related increase in the elaboration of the semantic network. The results did not support theories that predict hyperpriming in older adults, or cognitive slowing as an explanation for age-related changes in semantic priming. In contrast to the N400 literature on semantic priming in aging, age-related differences in this study were found in the N400 responses to endings congruent with the context in which they are embedded, and not in the N400 responses to endings incongruent with the context in which they are embedded. Possible explanations for this discrepancy, including an age-related decrease in the efficiency of the neural generators of the N400 were discussed.

References

Balota, D.A., & Duchek, J.M. (1988). Age-related differences in lexical access, spreading activation, and simple pronunciation. Psychology and Aging, 3, 84-93.

Balota, D. A., Black, S. R., & Cheney, M. (1992). Automatic and attentional priming in young and older adults: Reevaluation of the two-process model. Human Perception and Performance, 18, 485-502.

Barrett, S. E., & Rugg, M. D. (1991). Event-related potentials and the semantic matching of pictures. Brain and Cognition, 14 (2), 201-212.

Baron, A., & Mattila, W. R. (1989). Response slowing of older adults: Effects of time-limit contingencies on single- and dual-task performances. Psychology and Aging, 4, 66-72.

Bloom, P. A., & Fischler, I. (1980). Completion norms for 329 sentence contexts. Memory and Cognition, 8 (6), 631-642.

Bowles, N. L. (1994). Age and rate of activation in semantic memory. Psychology and Aging, 9, 414-429.

Brandeis, D., & Lehmann, D. (1986). Event-related potentials of the brain and Cognitive Processes: Approaches and applications. Neuropsychologia, 24 (1), 151-168.

Burke, D.M., White, H., & Diaz, D.L. (1987). Semantic priming in young and older adults: Evidence for age constancy in automatic and attentional processes. Journal of Experimental Psychology: Human Perception and Performance, 13, 79-88.

Burke, D.M., MacKay, D.G., Worthley, J.S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults. Journal of Memory and Language, 30, 542-579.

Burke, D. M. (1997). Language, aging and inhibitory deficits: Evaluation of a theory. Journal of Gerontology, 52B (6), 254-264.

Cerella, J., Poon, L.W., & Williams, D.M. (1980). Age and the complexity hypothesis. In L.W. Poon (Ed.), Aging in the 1980's: Psychological issues (pp. 332-340). Washington. DC: American Psychological Association.

Coles, M.G.H., & Rugg, M.D. (1995). Event-related brain potentials: An introduction. In: M.D. Rugg & M.G.H. Coles (Eds.), Electrophysiology of Mind: Event-related brain potentials and cognition. (pp. 1-26), Oxford: Oxford University Press.

Connolly, J. F., & Phillips, N. A. (1994). Event-related potential components reflect phonological and semantic processing of the terminal word of spoken sentences. Journal of Cognitive Neuroscience, 6 (3), 256-266.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds), Human memory and cognitive capabilities, mechanisms, and performance. (pp. 409-422), Elsevier Science Publishers, Amsterdam.

Craik, F. I. M., Anderson, N. D., Kerr, S. A., & Li, K. Z. H. (1995). Memory changes in normal ageing. In A.D. Baddeley, B. A. Wilson & F. N. Watts (Eds.), Handbook of memory disorders. (pp. 211-241). Cambridge: Wiley.

De Groot, A. M. B. (1984). Primed lexical decision: Combined effects of the proportion of related prime-target pairs and the stimulus onset asynchrony of the prime and target. Quarterly Journal of Experimental Psychology, 36 A, 253-280.

Dixon, W. J., Brown, M. B., Engelman, L., Frane, J. W., Hill, M. A., Jennrich, R. I., & Toporek, J. D. (Eds.) (1993). BMDP statistical software. Los Angeles: University of California Press.

Favreau, M., & Segalowitz, N.S. (1983). Automatic and controlled processes in first- and second-language reading of fluent bilinguals. Memory & Cognition, 11, 565-574.

Fozard, J.L. (1990). Vision and hearing in aging. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the psychology of aging (pp. 150-170). San Diego, CA: Academic Press.

Greenhouse, S.W., & Geisser, S. (1959). On methods on the analysis of profile data. Psychometrica, 24, 95-112.

Gunter, T. C., Jackson, J. L., & Mulder, G. (1992). An electrophysiological study of semantic processing in young and middle-aged academics. Psychophysiology, 29, 38-54.

Gunter, T. C., Jackson, J. L., & Mulder, G. (1995). Language, memory and aging: A electrophysiological exploration of the N400 during reading of memory-demanding sentences. Psychophysiology, 32, 215-229.

Hamm, V. P., & Hasher L. (1992). Age and the Availability of Inferences. Psychology and Aging, 7, 56-64.

Hartman, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. Psychology and Aging, 6, 587-594.

Hamberger, M. J., Friedman, D., Ritter, W., & Rosen, J. (1995). Event-related potential and behavioral correlates of semantic processing in Alzheimer's patients and normal controls. Brain and Language, 48, 33-68.

Harbin, T., Marsh, G., & Harvey, M. (1984). Differences in the late components of the event-related potential due to age and to semantic and non-semantic tasks. Electroencephalography and Clinical Neurophysiology, 59, 489-496.

Hartman, M., & Hasher, L. (1991). Aging and supression: Memory for previously relevant information. Psychology and Aging, 6, 587-594.

Hasher, L., & Zacks, R . T. (1988). Working memory, comprehension, and aging: A review and a new view. The Psychology of Learning and Motivation, 22, 193-225.

Holcomb, P. J., & McPherson, W. B. (1994). Event-related potentials reflect semantic priming in an object decision task. Brain and Cognition, 24 (2), 259-276.

Hopkins, K.A., Kellas, G., & Paul, S.T. (1995). Online activation of word meaning during sentence processing by young and older adults. Experimental Aging Research, 21, 123-142.

Jasper, H. (1958). The ten twenty electrode system of the International Federation. Electroencephalography and Clinical Neurophysiology, 10, 371-375.

Kaplan, R. M., & Saccuzzo, D. R. (1993). Psychological testing: Principles, applications and issues. In Pacific Grove, CA: Brooks/Cole Publishing Co.

Kaufman, A. S. (1990). Assessing adolescent and adult intelligence. Needham Heights, MA: In Allyn and Bacon, Inc.

Keefe, D. E., & Neely, J. H. (1990). Semantic priming in the pronounciation task: The role of prospective prime-generated expectancies. Memory and Cognition, 8 (3), 289-298.

Kucera, H., & Francis, W. N. (1967). Computation analysis of present day American English. Providence, RI: Brown University Press.

Kutas, M. (1993). In the company of other words: Electrophysiological evidence for single-word and sentence context effects. Special issue: Event-related brain potentials in the study of language. Language and Cognitive Processes, 8 (4), 533-572.

Kutas, M., & Hillyard, S. (1980a). Event-related brain potentials to semantically inappropriate and surprisingly large words. Biological Psychology, 11, 99-116.

Kutas, M., & Hillyard, S. (1980b). Reading between the lines: Event-related potentials during natural sentence processing. Brain and Language, 11, 354-373.

Kutas, M., & Hillyard, S. (1980c). Reading senseless sentences: Brain potentials reflect semantic incongruity. Science, 207, 203-204.

Kutas, M., & Hillyard, S. (1984). Brain potentials during reading reflect word expectancy and semantic association. Nature, 307, 161-163

Kutas, M., & Hillyard, S. (1989). An electrophysiological probe of incidental semantic association. Journal of Cognitive Neuroscience, 1 (1), 38-49.

Kutas, M., Lindamood, T., & Hillyard, S.A. (1984). In: S. Kornblum & J. Roquin (Eds.), Preparatory states and processes, (pp. 217-238). Erlbaum, Hillsdale, NJ.

Kutas, M., Van Petten, C., & Besson, M. (1988). Event-related potential asymmetries during the reading of sentences. Electroencephalography and Clinical Neurophysiology, 69, 218-233.

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. Psychology of Aging, 8, 34-43.

Lima, S.D., Hale, S., & Myerson, J. (1991). How general is general slowing? Evidence from the lexical domain. Psychology and Aging, 6, 416-425.

Linnville, S. E. (1995). Are there age-related processing differences in semantic priming? Perceptual and Motor Skills, 80, 585-586.

Madden, D.J. (1986). Adult age differences in visual word recognition: Semantic encoding and episodic retention. Experimental Aging Research, 12, 71-78.

Madden, D.J. (1988). Adult age differences in the effects of sentence context and stimulus degradation during visual word recognition. Psychology and Aging, 3, 167-172.

Madden, D. J. (1989). Visual word identification and age-related slowing. Cognitive Development, 4, 1-29.

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G.A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. Psychological Review, 97, 475-487.

Neely, J.H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. Journal of Experimental Psychology: General, 106, 226-254.

Neely, J.H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 264-336). Hillsdale, NJ: Erlbaum.

Neville, H. J., Kutas, M., Chesney, G., & Schmidt, A. L. (1986). Event-related potentials during initial encoding and recognition memory of congruous and incongruous words. Journal of Memory and Language, 25, 75-92.

Ostrosky-Solis, F., Castaneda, M., Perez, M., Castillo, G., & Bobes, M. A. (1998). Cognitive brain activity in Alzheimer's disease: Electrophysiological response during picture semantic categorization. Journal of the International Neuropsychological Society, 4, 415-425.

Paller, K., McCarthy, G., & Wood, C. C. (1988). ERPs predictive of subsequent recall and recognition performance. Biological Psychology, 26, 269-276.

Paul, S. T. (1996). Search for semantic inhibition failure during sentence comprehension by younger and older adults. Psychology and Aging, 11, 10-20.

Pavio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. Journal of Experimental Psychology Monograph Supplement (76), 1, part 2.

Salthouse, T.A. (1985). Speed of behavior and its implications for cognition. In J.E. Birren & K.W. Schaie (Eds), Handbook of the psychology of aging (pp. 400-426). New York: Van Nostrand Reinhold.

Salthouse, T.A. (1988). Initiating the formalization of theories of cognitive aging. Psychology and Aging, 3, 3-16.

Semlitsch, H. V., Peter, A., Schuster, P., Presslich, O. (1988). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. Psychophysiology, 23 (6), 695-703.

Silverstein, A. B. (1982). Two- and four-subtest short forms of the Wechsler Adult Intelligence Scale-Revised. Journal of Consulting and Clinical Psychology, 50 (3), 415-418.

Spencer, W. D., & Raz, N. (1996). Differential effects of aging on memory for content and context: A meta-analysis. Psychology and Aging, 10, 527-539.

Stanovich, K.E., Nathan, R. G., West, R.F., & Vala-Rossi, M. (1985). Children's word recognition in context: Spreading activation, expectancy, and modularity. Child Development, 56, 1418-1428.

Van-Petten, C. (1993). A comparison of lexical and sentence-level context effects in event-related potentials. Special issue: Event-related brain potentials in the study of language. Language and Cognitive Processes, 8 (4), 485-531.

Vasey, M. W., & Thayer, J. F. (1987). The continuing problem of false positives in repeated measures ANOVA in psychophysiology: A multivariate solution. Psychophysiology, 24 (4), 479-475.

West, R.F., & Stanovich, K.E. (1978). Automatic contextual facilitation in readers of three ages. Child Development, 49, 717-727.

West, R. (1996). An application of prefrontal cortex function theory to cognitive aging. Psychological Bulletin, 120 (2), 272-292.

Woodward, S. H., Ford, J. M., & Hammett, S.C. (1993). N4 to spoken senten]ces in young and older adults. Electroencepahlography and Clinical Neurophysiology, 87, 306-320.

Appendix A

Health Screening Questionnaire

Health Questionnaire

In this research, we need to know whether there are any factors, in addition to the ones we are studying, that may be affecting the results. Your answers to a few short questions will aid us in this effort. All answers will be kept strictly confidential. Thank you for your help.

Demographics

Number: Referral Source:

Name: Date:

Place of Birth:

First language:

When did you learn English?

Address:

Phone Number:

Age: D.o.B.:

Gender:
Handedness:

Education: How many years (not including kindergarten)?

Have you ever skipped or failed a grade? Why?

Occupation (past or present)?

Medical History

What is your general state of health?

Excellent Very good Good Fair Poor

How would you describe your level of physical fitness, endurance?

Excellent Very good Good Fair Poor

How satisfied are you with your health and physical condition?

Very satisfied Moderately satisfied Moderately dissatisfied Very dissatisfied

Have you been seriously ill or hospitalized in the past 6 months? How many days?

Visual problems?
Color blind?
Trouble hearing?
Trouble walking?

Have you ever been unconscious, had a head injury or had blackouts?

Do you have now, or have you had in the past (yes/no)

Frequent headaches
Serious illness (liver disease, etc.)
Epilepsy
Seizures
Diabetes
Exposure to toxic chemicals
Thyroid disease
Surgery
High blood pressure
Stroke

Heart disease
Psychiatric problems, like depression

Have you ever consumed the following?

	Amount	How long
Alcohol		
Tobacco		
Medications		

Present problems (if yes, how much does it bother you? Quite a lot, a little)

Aches/pain
Colds/flu
Fatigue
Concentration
Attention
Nervousness
Memory
Finding words
Weakness
Personality changes

Appendix B
Demographic and WAIS-R Data for Each Subject

	Age (Years)	Gender (Male/Female)	Education (Years)	Vocabulary	Block Design	IQ
Subject 1	66	f	11	12	9	105
Subject 2	79	f	11	10	12	98
Subject 3	72	f	11	11	9	101
Subject 4	75	f	15	13	9	108
Subject 5	75	f	14	14	11	114
Subject 6	65	f	13	11	12	108
Subject 7	75	f	12	13	10	108
Subject 8	77	f	11	8	9	88
Subject 9	80	f	15	12	8	101
Subject 10	63	f	12	10	12	103
Subject 11	81	f	11	8	10	92
Subject 12	82	f	11	12	13	114
Subject 13	67	m	11	12	11	108
Subject 14	66	m	14	10	11	102
Subject 15	88	m	9	11	10	101
Subject 16	67	m	15	12	10	102
Subject 17	70	m	12	11	11	104
Subject 18	70	m	13	12	11	108
Subject 19	62	m	13	11	7	93
Subject 20	66	m	13	10	11	99

Subject 21	21	f	15	13	15	120
Subject 22	24	f	17	10	13	110
Subject 23	24	f	14	10	9	94
Subject 24	23	f	17	11	8	94
Subject 25	24	f	17	10	11	107
Subject 26	25	f	18	11	15	116
Subject 27	22	f	16	11	12	107
Subject 28	20	f	14	12	12	110
Subject 29	23	f	17	17	13	130
Subject 30	22	f	16	10	8	88
Subject 31	21	f	15	10	15	114
Subject 32	19	f	14	12	6	92
Subject 33	23	m	17	10	13	107
Subject 34	29	m	17	13	11	111
Subject 35	26	m	11	7	8	83
Subject 36	23	m	17	10	16	120
Subject 37	20	m	14	11	15	114
Subject 38	25	m	18	13	13	113
Subject 39	24	m	17	7	10	88
Subject 40	22	m	15	14	18	133

Note. Scores on the Vocabulary and Block Design subtests are age-corrected. IQ scores were obtained by adding the scaled Vocabulary and Block Design scores for each subject and looking up the corresponding estimated IQ in Table 1 of Silverstein (1982).

Appendix C

Consent Form

Jewish General Hospital
Department of Clinical Neurosciences
Electrophysiological Study of Age-Related Changes in Semantic Priming and Language Processing

Consent Form for the Jewish General Hospital
Electrophysiological Study of Age-Related Changes in Semantic Memory

Purpose of the Study:

The purpose is to compare the performance of older adults to that of younger adults on linguistic tests in order to better understand age-related changes in language processing and the brain processes associated with those changes.

Details of the Study:

The study will take place in the EEG laboratory of the Department of Neurology, Jewish General hospital. To record the electroencephalogram (EEG), which is a measure of electrical activity at the scalp, a nylon cap containing small sensors (electrodes) will be placed on my head. In order to prepare the skin to obtain proper readings, the scalp area underneath each sensor will be lightly rubbed with electrolytic gel. The gel resembles a facial scrub and is used to clean the skin surface of any oil or dirt which would affect the quality of the recordings. While the recordings are being made, I will be watching a computer screen on which there will be some words or sentences presented one word at a time. For maximum comfort, I will determine the amount of time in between words. I will be asked to pay attention to the information in order to be able to answer questions about it later. I understand that while I may not be able to answer every question perfectly, the most important thing will be that I will try to do my best.

This study will require one (1) visit to the EEG laboratory, which should last approximately 2 to 3 hours. Transportation can be arranged for me or I will be reimbursed for my travel. This test is for research purposes only. It is not diagnostic, meaning that it will not yield any results about myself as an individual. Therefore, I understand that the study results will not be made available to me. However, any potentially significant abnormality in my EEG will be communicated to my physician with my permission.

Disadvantages and Risks of Participating in the Study:

EEG testing is a non-invasive (no foreign substance like medication, tubes or needles are used) and painless procedure. Nevertheless, while the scalp is being prepared for recording, some people may experience a mild and temporary discomfort where the skin is being rubbed. It is also possible that I will find it boring or frustrating to look at the information on the computer screen. However, I will be given frequent breaks whenever required in order to avoid this. If any abnormality in my EEG is found and communicated to my physician with my permission, this may lead to additional testing which would not have taken place had I not participated in this study.

Jewish General Hospital
Department of Clinical Neurosciences
Electrophysiological Study of Age-Related
Changes in Semantic Priming and Language
Processing

Consent Form for the Jewish General Hospital
Electrophysiological Study of Age-Related Changes in Semantic Memory

Advantages to Participating in the Study:

The researchers hope to learn more about what brain processes are involved when one sees a meaningful word, and how these processes change with normal aging. Although this will not benefit me directly, this research could add to our scientific understanding of how everyday knowledge is represented in the brain, and of how these representations change with normal aging and with age-related diseases.

Confidentiality:

All information about my case is confidential and I will not be identified in any published report.

Withdrawal from the Study:

My participation in this study is voluntary and, if I agree to participate, I may withdraw my consent and discontinue participation at any time without affecting my medical care.

Patient Rights:

I have fully discussed and understood the purpose and procedure of this study and have had the opportunity to ask any questions.

The following is the name, address, and telephone number of the Hospital's Patient representative, who is not associated with this study and to whom I may address my concerns about my rights as a participant in this study:
Mrs. Lianne Brown, 3755 Côte Ste. Catherine Road, Montreal, Quebec, H3T 1E2; tel: 340-8222 ext. 5833.

The following is the name, address, and telephone number of the researcher whom I may contact for answers to questions about the research or any injuries or adverse reactions which might occur:
Dr. Natalie Phillips, Dept. of Psychology, Concordia University, 7141 Sherbrooke Street West, Montreal, Quebec, H4B 1R6; tel: 848-2218.

Jewish General Hospital
Department of Clinical Neurosciences
Electrophysiological Study of Age-Related Changes in Semantic Priming and Language Processing

Consent Form for the Jewish General Hospital
Electrophysiological Study of Age-Related Changes in Semantic Memory

Signature:

I have understood the contents of this consent form, have had the opportunity to ask questions, and agree to participate in this study.

All participants will receive a copy of this consent form.

____
Date

____________________	____________________
Signature of Subject	Print Name
____________________	____________________
Signature of Investigator	Print Name
____________________	____________________
Signature of person explaining informed consent	Print Name

Appendix D
List of Stimuli

List of Stimuli Grouped by Degree of Relatedness: Best Completion, Related and Unrelated

For the Best Completions, the word most highly related to the Best Completion is presented as the first word in brackets. For the Related and Unrelated completions, the word that would normally have been the Best Completion in the sentence is presented as the first word in brackets. The resulting word-pair in the bracket is then used as a stimuli for the word context in the alternate list of stimuli.

Best Completions

1. Joe stood up and the canoe tipped over. [under-over]

2. The waitress rang the bill on the cash register. [sign-up-register]

3. The racing cars received the checking flag. [flagpole-flag]

4. Father carved the turkey with an electric knife. [fork-knife]

5. Jean hurriedly shoved her way through the crowd. [mob-crowd]

6. The basketball players were all over six feet tall. [short-tall]

7. Even for an amateur he was pretty good. [bad-good]

8. The teacher wrote the problem on the board. [chalk-board]

9. Lois is taller than most girls of her age. [mature-age]

10. The dough was put in the hot oven. [bake-oven]

11. He couldn't see without his glasses. [eye-glasses]

12. The summer was so hot they decided to install an outdoor pool. [sauna-pool]

13. The surprise party made him feel very happy. [sad-happy]

14. Cathy is liked by all her friends. [buddies-friends]

15. Abby brushes her teeth after every meal. [food-meal]

16. He lay down and went to sleep. [slumber-sleep]

17. The piano was out of tune. [melody-tune]

18. Jane's new outfit made her the center of attention. [concentration-attention]

19. Bill jumped in the lake and made a big splash. [lake-splash]

20. The grocer checked his stock before going out. [going-out]

21. Jan tried to squeeze in but there was no room. [squeeze-room]

22. He crept into the room without a sound. [crept-sound]

23. He sanded the wood until it was smooth. [sanded-smooth]

24. They raised pigs on their farm. [farm-barn]

25. In the morning Jim woke up and jumped out of his bed. [woke-bed]

26. The child learned to count to ten. [count-ten]

27. The train is never on time. [train-time]

28. To keep the dogs out of the yard he put up a fence. [yard-fence]

29. In the morning he forgot to take his vitamin pill. [vitamin-pill]

30. I like hot fudge with ice cream. [ice-cream]

31. When the power went out the house became dark. [power-dark]

32. The towels were hung on the line to dry. [wet-dry]

33. Instead of wine, the children drank grape juice. [orange-juice]

34. The lecture should last about one hour. [lecture-hour]

35. To pay for the car Al simply wrote a cheque. [pay-cheque]

36. Water and sunshine help plants to grow. [plants-grow]

37. He was so frightened he was as white as a ghost. [goul-ghost]

38. It's unlucky to walk under a ladder. [under-ladder]

39. My car needs a new coat of paint. [brush-paint]

40. The fertilizer enriched the soil. [potting-soil]

41. The defendant pleaded not guilty be reason of insanity. [craziness-insanity]

42. He loosened the tie around his neck. [tie-neck]

43. The butler hung their coats in the closet. [clothes-closet]

44. For graduation Lucy received a pen and pencil set. [pair-set]

45. Children learn to read and write in the first grade. [learn-grade]

46. My cat is covered with white fur. [mink-fur]

47. The winter was very harsh this year. [month-year]

48. They drank champagne to celebrate their tenth wedding anniversary. [commemoration-anniversary]

49. I want mustard, ketchup and relish on my hot dog. [hot-dog]

50. Ray fell down and skinned his knees. [elbows-knees]

51. Jay was so drunk that he passed out. [in-out]

52. The winning candidate was preparing his acceptance speech [lecture-speech].

53. The maid loaded the laundry into the washing machine. [washing-machine]

54. The hungry bear dipped his paw into the sweet honey. [bee-honey].

The Canadian flag is red and white. [black-white]

56. The old house will be thorned down. [thorned-down]

57. The organist accompanied the church choir. [church-choir]

58. It's easy to get lost without a map. [atlas-map]

59. Jack decided to wear a three piece suit. [tuxedo-suit]

60. Most people see the chimpanzees at the zoo. [animals-zoo]

61. The young boy punted the football. [quarterback-football]

62. She seasoned the steak with black pepper. [salt-pepper]

63. Sally fell in the water and was dripping wet. [dry-wet]

64. The rainstorm was followed by a beautiful rainbow. [multicolored-rainbow]

65. Jason called directory assistance for the number. [numeral-number]

66. George put the record on the record player. [teammate-player]

67. The ambulance rushed him to the hospital. [doctor-hospital]

68. The construction worker wore a hard hat. [cap-hat]

69. The lost dog was returned to his owner. [landlord-owner]

70. A bicycle has two wheels. [tires-wheels]

71. The company president decided to cancel the board meeting. [board-meeting]

72. The exit was marked by a large sign. [exit-sign]

73. He hung the picture on the living room wall. [poster-wall]

74. The bathroom faucet sprung a leak. [faucet-leak]

75. There are twenty-six letters in the alphabet. [letters-alphabet]

76. He put the ring on her finger. [hand-finger]

77. All the planets circle around the sun. [moon-sun]

78. The TV was so loud that he couldn't hear himself think. [ponder-think]

79. Phil put some drops in his eyes. [retina-eyes]

80. The mouse ate the cheese. [cheddar-cheese]

<u>Related-completions</u>

1. The pizza was too hot to chew (eat). [eat-chew]
2. The wild birds at the zoo are kept in captivity (cages). [cages-captivity]
3. The ship disappeared into the thick mist (fog). [mist-fog]
4. Nothing can beat a bowl of hot broth (soup). [soup-broth]
5. The dirty clothes were piled up in the laundry hamper (basket). [basket-hamper]
6. The mail should get there very shortly (soon). [soon-shortly]
7. They heated the pool with solar power (energy). [energy-power]
8. The game was called when it started to lightning (rain). [rain-lightning]
9. The office held a new year's eve bash (party). [party-bash]
10. He wondered if the storm had done much harm (damage). [damage-harm]
11. Next year my little son will be going to college (school). [school-college]
12. Larry made a full pot of tea (coffee). [coffee-tea]
13. Al wrote her a love note (letter). [letter-not]
14. They sat together without speaking a single syllable (word). [word-syllable]
15. He went to the factory where the toys were designed (made). [made-designed]
16. They raised pigs on their ranch (farm). [farm-ranch]
17. In the first space enter your last address (name). [name-address]
18. The better students thought the test was too simple (easy). [easy-simple]
19. The sink was clogged so they called a handyman (plumber). [plumber-handyman]
20. His wealthy parents enrolled him in a private academy (school). [school-academy]

21. The movers put the sofa on the bear ground (floor). [floor-ground]

22. The theater ushers walked up and down the rows (aisle). [aisle-rows]

23. He had to wake up early to get there on schedule (time). [time-schedule]

24. They ate ice cream and cake at his birthday celebration (party). [party-celebration]

25. Each night the campers built a huge blaze (fire). [fire-blaze]

26. Tim put his feet up on his father's oak chair (desk). [desk-chair]

27. Jean was glad the affair was finished (over). [over-finished]

28. The wet towels were hung on the line to air (dry). [dry-air]

29. The soldier complained that his portion was too little (small). [small-little]

30. The movie was so crowded they could not find a single chair (seat). [seat-chair]

31. Fred realized the old house was up for auction (sale). [sale-auction]

32. Cathy was glad that Friday was payday because she was poor (broke). [broke-poor]

33. The important papers were locked in a vault (safe). [safe-vault]

34. The business man took the receipts and cheques to the teller (bank). [bank-teller]

35. While skiing Randy broke his arm (leg). [leg-arm]

36. As soon as they got in they turned off the porch lamp (lights). [lights-lamp]

37. Through the rain it was hard to read the signals (signs). [signs-signals]

38. The girl knew most of the words for her spelling quiz (test). [test-quiz]

39. They're out in the garden pulling roots (weeds). [weeds-roots]

40. They went to pick up their parents at the railway depot (station). [station-depot]

41. She sewed the button on with needle and black string (thread). [thread-string]

42. We stopped at the water fountain to get a sip (drink). [drink-sip]

43. He heard a knock at the front entrance (door). [door-entrance]

44. The driver of the speeding car was given a citation (ticket). [ticket-citation]

45. Three people were killed in a major highway crash (accident). [accident-crash]

46. Tim threw a rock and broke the glass (window). [window-glass]

47. the doctor set the man's broken leg in a splint (cast). [cast-splint]

48. New York is a very busy town (city). [city-town]

49. The gas station is about two kilometers down the path (road). [road-path]

50. The children held hands and formed a ring (circle). [circle-ring]

51. The fire engine raced down the main street (road). [road-street]

52. The picnic was ruined by the downpour of showers (rain). [rain-showers]

53. She tied up her hair in a yellow bow (ribbon). [ribbon-bow]

54. Sharon dried the dishes with a kitchen rag (towel). [towel-rag]

55. He bought the chocolates at the candy shop (store). [store-shop]

56. After the accident they went for aid (help). [help-aid]

57. Jill decided to put vanilla icing on the chocolate cookie (cake). [cake-cookie]

58. The store detective accused him of theft (shoplifting). [shoplifting-theft]

59. After being robbed the victim called the cops (police). [police-cops]

60. He likes lemon and sugar in his coffee (tea). [tea-coffee]

61. She made a salami sandwich on wheat rolls (bread). [bread-rolls]

62. the kids fed the ducks some stale crumbs (bread). [bread-crumbs]

63. Yesterday they canoed down the rapids (river). [river-rapids]

64. Burt used a match to light the dying flame (fire). [fire-flame]

65. The society's annual dues were fifty bucks (dollars). [dollars-bucks]

66. We had bacon and eggs for dinner (breakfast). [breakfast-dinner]

67. She liked to eat buttered popcorn at the play (movie). [movie-play]

68. The boy put an apple on the teacher's table (desk). [desk-table]

69. She looked at herself in the glass (mirror). [mirror-glass]

70. My family moved from the country to the town (city). [city-town]

71. He liked the scent of her new fragrance (perfume). [perfume-fragrance]

72. He fried an egg and two strips of pork (bacon). [bacon-pork]

73. The athlete won a gold prize (medal). [medal-prize]

74. I like hot fudge with ice milk (cream). [cream-milk]

75. The children watched the cars go down the path (road). [road-path]

76. The story had a happy beginning (ending). [ending-beginning]

77. The unhappy marriage ended in a separation (divorce). [divorce-separation]

78. Let me take your hat and jacket (coat). [coat-jacket]

79. The academic year began in the spring (fall). [fall-spring]

80. The magician pulled the rabbit out of the cap (hat). [hat-cap]

<u>Unrelated-completions</u>

1. During the volley someone stepped on Joe's watch (foot). [foot-watch]

2. The paint turned out to be the wrong consistency (color). [color-consistency]

3. All guests had a very good excuse (time). [time-excuse]

4. It's hard to admit when one is asleep (wrong). [wrong-asleep]

5. She's afraid of deep water because she can't see (swim). [swim-see]

6. One of the scouts did not know the way and got hurt (lost). [lost-hurt]

7. At first the woman refused but she changed her clothes (mind). [mind-clothes]

8. She was docked one hour's pay for coming to work drunk (late). [late-drunk]

9. The baby weighted six pounds at noon (birth). [birth-noon]

10. I added my name to the top of the wall (list). [list-wall]

11. Our guests should be arriving hungry (soon). [soon-hungry]

12. The children went outside to shower (play). [play-shower]

13. The prisoners were planning their picnic (escape). [escape-picnic]

14. They went as far as they dared (could). [could-dare]

15. Mary looked at her watch to check the band (time). [time-band]

16. George had been fired but he could not tell his staff (wife). [wife-staff]

17. The mole lived in a hole in the pipe (ground). [ground-pipe]

18. The bad boy was sent to his counselor (room). [room-counselor]

19. When the shooting started they ran for help (cover). [cover-help]

20. The barbells the man lifted were very rusty (heavy). [heavy-rusty]

21. The boss refused to give him a car (raise). [raise-car]

22. The doctor told him he had high blood sugar (pressure). [pressure-sugar]

23. Dillinger once robbed that train (bank). [bank-train]

24. He looked up the misspelled word in the index (dictionary). [dictionary-index]

25. She called her husband at his convenience (office). [office-convenience]

26. On hot days many people sun themselves on the roof (beach). [beach-roof]

27. John was so exhausted he took a vacation to get some help (rest). [rest-help]

28. He made a holster for his father (gun). [gun-father]

29. The milk was left out of the refrigerator and turned yellow (bad). [bad-yellow]

30. Fred put the worm on the table (hook). [hook-table]

31. It's raining and I forgot my coat, hat and keys (umbrella). [umbrella-keys]

32. The whole town came to see the mayor resign (speak). [speak-resign]

33. They left the dirty dishes in the bedroom (sink). [sink-bedroom]

34. Shuffle the cards before you leave (deal). [deal-leave]

35. He took the money from his leather vest (wallet). [wallet-vest]

36. The tickets for the opening concert were sold privately (out). [out-privately]

37. Betsy could never tell a soul (lie). [lie-soul]

38. The addict was caught pushing illegal movies (drugs). [drugs-movies]

39. George kept his pet on a diet (leash). [leash-diet]

40. They asked Dave to play tennis but he was too good (tired). [tired-good]

41. Jeff felt sorry but it was not his turn (fault). [fault-turn]

42. Karen awoke after a bad hangover (dream). [dream-hangover]

43. He shouted at the top of his stairs (lungs). [lungs-stairs]

44. The tenants decided to take their landlord to lunch (court). [court-lunch]

45. Joan boiled the eggs in minutes (water). [water-minutes]

46. A dog has a good sense of loyalty (smell). [smell-loyalty]

47. She went to the salon to color her toes (hair). [hair-toes]

48. We sprayed the yard to keep away the skunks (bugs). [bugs-skunks]

49. He hung her coat in the back (closet). [closet-back]

50. The lawyer feared that his client would be found crazy (guilty). [guilty-crazy]

51. Be careful because the top of the stove is very cluttered (hot). [hot-cluttered]

52. John filled the pen with care (ink). [ink-care]

53. Don't believe everything you suspect (hear). [hear-suspect]

54. He put a clean sheet on the clipboard (bed). [bed-clipboard]

55. The parents pleaded with their daughter to come quietly (home). [home-quietly]

56. When the two met one of them held out his ID (hand). [hand-ID]

57. The boat passed easily under the falls (bridge). [bridge-falls]

58. Most cats can see very well at distances (night). [night-distances]

59. The janitor washed the dirty ashtrays (floors). [floors-ashtrays]

60. Alice could not read very well without her dictionary (glasses). [glasses-dictionary]

61. The gambler had a streak of bad temper (luck). [luck-temper]

62. Pam did not have any clothes to wash (wear). [wear-wash]

63. The child was born with a rare gift (disease). [disease-gift]

64. Bill played his stereo much too often (loudly). [loudly-often]

65. After dinner they washed the clothes (dishes). [dishes-clothes]

66. The squirrel stored some nuts in the hole (tree). [tree-hole]

67. Don't touch the wet dog (paint). [paint-dog]

68. Motorcycles can create a lot of problems (noise). [noise-problems]

69. A future energy source is the coal (sun). [sun-coal]

70. Jason called directory assistance for the telephone repairman (number). [number-repairman]

71. She was named after her conversion (mother). [mother-conversion]

72. He bought a wall to wall bed (carpet). [carpet-bed]

73. None of his books made much sense (money). [money-sense]

74. He was knocked off his surfboard by the first bully (wave). [wave-bully]

75. Her new shoes were the wrong color (size). [size-color]

76. When the national anthem plays everyone is expected to behave (stand). [stand-behave]

77. The prisoner was sent back to his duties (cell). [cell-duties]

78. It was important to be on top (time). [time-top]

79. Because he had a toothache he called his boss (dentist). [dentist-boss]

80. They drove to a private airport to catch the thieves (plane). [plane-thieves]

<u>Stimuli as Presented to subjects: Lists One and Two</u>

<u>List One</u>

1. The clerk put the groceries in the shopping carts. (R)

2. Joe stood up and the canoe tipped over. (B)

3. The pizza was too hot to chew. (R)

4. They drove to a private airport to catch the thieves. (U)

5. During the game someone stepped on Joe's watch. (U)

6. The waitress rang the bill on the cash register. (B)

7. The children held hands and formed a ring. (R)

8. The racing cars received the checkered flag. (B)

9. The paint turned out to be the wrong consistency. (U)

10. The wild birds at the zoo are kept in captivity. (R)

11. She went to the salon to color her elbows. (U)

12. Father carved the turkey with an electric knife. (B)

13. The ship disappeared into the thick mist. (R)

14. Jean hurriedly shoved her way through the crowd. (B)

15. Nothing can beat a bowl of hot broth. (R)

16. The basketball players were all over six feet tall. (B)

17. The dirty clothes were piled up in the laundry box. (R)

18. It is hard to admit when one is asleep. (U)

19. She's afraid of deep water because she can't hear. (U).

20. Even for an amateur he was pretty good. (B)

21. The mail should get there very shortly. (R)

22. One of the scouts did not know the way and got hurt. (U)

23. The teacher wrote the problem on the board. (B)

24. They heated the pool with solar power. (R)

25. The school year began in the spring. (R)

26. At first the woman refused but she changed her clothes. (U)

27. Lois is taller than most girls of her age. (B)

28. She was docked one hour's pay for coming to work drunk. (U)

29. The dough was put in the hot oven. (B)

30. The game was called off when it started to lightning. (R)

31. The baby weighed six pounds at noon. (U)

32. I added my name to the top of the wall. (U)

33. He couldn't see without his glasses. (B)

34. The office held a New Year's Eve bash. (R)

35. Our guests should be arriving hungry. (U)

36. The children went outside to shower. (U)

37. The summer was so hot they decided to install an outdoor pool. (B)

38. The surprise party made him feel very happy. (B)

39. The prisoners were planning their picnic. (U)

40. He had to fill the car's radiator with powder. (U)

41. He wondered if the storm had done much harm. (R)

42. Cathy is liked by all her friends. (B)

43. They went as far as they dared. (U)

44. Next year my little son will be going to college. (R)

45. Abby brushes her teeth after every meal. (B)

46. George was fired but he could not tell his staff. (U)

47. The mole lived in a hole in the pipe. (U)

48. He lay down and went to sleep. (B)

49. Larry made a full pot of tea. (R)

50. Al wrote Cathy a love note. (R)

51. The bad boy was sent to his counselor. (U)

52. He went to the factory where the toys were designed. (R)

53. When the shooting started they ran for help. (U)

54. The piano was out of tune. (B)

55. They sat together without speaking a single syllable. (R)

56. The barbells he lifted were very rusty. (U)

57. In the Old West stagecoaches were pulled by oxen. (R)

58. The boss refused to give him a car. (U)

59. Jane's new outfit made her the center of attention. (B)

60. The doctor told him he had high blood sugar. (U)

61. Let me take your hat and sweater. (R)

62. Bill jumped in the lake and made a big splash. (B)

63. Bonnie and Clyde once robbed that train. (U)

64. In the first space enter your last address. (R)

65. Smoking may be hazardous to your neighbors. (U)

66. The grocer checked his stock before going out. (B)

67. Jan tried to squeeze in but there was no room. (B)

68. The better students thought the test was too simple. (R)

69. The sink was clogged so they called a handyman. (R)

70. He crept into the room without a sound. (B)

71. The kids fed the ducks some stale crumbs. (R)

72. He sanded the wood until it was smooth. (B)

73. They raised pigs on their farm. (B)

74. She called her husband at his convenience. (U)

75. In the morning Jim woke up and jumped out of bed. (B)

76. On hot days many people sun themselves on the roof. (U)

77. The movers put the sofa on the bare ground. (R)

78. The theater ushers walked up and down the rows. (R)

79. The child learned to count to ten. (B)

80. John was so exhausted he took a vacation to get some help. (U)

81. The train is never on time. (B)

82. After dinner they washed the clothes. (U)

83. He was stung by a wasp. (R)

84. The squirrel stored some nuts in the shed. (U)

85. They ate ice cream and cake at his birthday celebration. (R)

86. Each night the campers built a huge blaze. (R)

87. To keep the dogs out of the yard he put up a fence. (B)

88. The gas station is about two miles down the path. (R)

89. He mailed the letter without a thought. (U)

90. William went to the bank to borrow some pens. (U)

91. Jean was glad the affair was finished. (R)

92. In the morning he forgot to take his vitamin pill. (B)

93. I like hot fudge with ice cream. (B)

94. The whole town came to see the mayor resign. (U)

95. When the power went out the house became dark. (B)

96. They left the dirty dishes in the bedroom. (U)

97. The towels were hung on the line to dry. (B)

98. The soldier complained that his portion was too little. (R)

99. He scraped the cold food from the dinner platter. (R)

100. Shuffle the cards before you leave. (U)

101. Instead of wine the children drank grape juice. (B)

102. The lecture should last about one hour. (B)

103. He took the money from his leather vest. (U)

104. He hung her coat in the back. (U)

105. Fred realized the house was up for auction. (R)

106. To pay for the car Al simply wrote a cheque. (B)

107. Cathy was glad that Friday was payday because she was poor. (R)

108. Betsy could never tell a soul. (U)

109. Water and sunshine help plants to grow. (B)

110. The addict was caught pushing illegal movies. (U)

111. The important papers were locked in a vault. (R)

112. He was so frightened he was as white as a ghost. (B)

113. It is unlucky to walk under a ladder. (B)

114. The business man took the receipts and cheques to the teller. (R)

115. While skiing Randy broke his arm. (R)

116. My car needs a new coat of paint. (B)

117. When they got in they turned off the porch lamp. (R)

118. George kept his pet on a diet. (U)

119. The girl knew most of her words for the spelling quiz. (R)

120. The fertilizer enriched the earth. (R)

1. tired-good (U)

2. craziness-insanity (H)

3. weeds-roots (M)

4. fault-turn (U)

5. strangle-neck (H)

6. station-depot (M)

7. thread-string (M)

8. clothes-closet (H)

9. drink-sip (M)

10. door-entrance (M)

11. dream-hangover (U)

12. mark-grade (H)

13. ticket-citation (M)

14. signs-signals (M)

15. lungs-stairs (U)

16. window-glass (M)

17. court-lunch (U)

18. cast-splint (M)

19. mink-fur (H)

20. library-bag (U)

21. month-year (M)

22. smell-loyalty (U)

23. shoes-boots (M)

24. city-town (M)

25. mother-chair (U)

26. bugs-skunks (U)

27. commemoration-anniversary (H)

28. cat-dog (H)

29. out-privately (U)

30. elbows-knees (H)

31. guilty-crazy (U)

32. hour-minute (H)

33. hot-cluttered (U)

34. gas-fuel (M)

35. dentist-boss (U)

36. lecture-speech (H)

37. cars-autos (M)

38. ribbon-bow (M)

39. ink-care (U)

40. sewing-machine (H)

41. towel-rag (M)

42. bee-honey (H)

43. black-white (H)

44. store-counter (M)

45. up-down (H)

46. help-aid (M)

47. hear-suspect (U)

48. chorus-choir (H)

49. bed-clipboard (U)

50. cake-cookie (M)

51. atlas-map (H)

52. home-quietly (U)

53. tuxedo-suit (H)

54. hand-ID (U)

55. animals - zoo (H)

56. divorce-separation (M)

57. quarterback-football (H)

58. bridge-falls (U)

59. shoplifting-theft (M)

60. salt-pepper (H)

61. dry-wet (H)

62. night-distances (U)

63. police-cops (M)

64. gathering-meeting (H)

65. rent-bill (M)

66. omen-sign (H)

67. floors-ashtrays (U)

68. poster-wall (H)

69. steak-meat (M)

70. bread-rolls (M)

71. luck-temper (U)

72. school-academy (M)

73. drip-leak (H)

74. wear-donate (U)

75. disease-gift (U)

76. spelling-dictionary (H)

77. river-rapids (M)

78. fire-flame (M)

79. multicolored-rainbow (H)

80. loudly-often (U)

81. door-paper (U)

82. numerals-number (B)

83. bad-yellow (U)

84. teammate-player (H)

85. tree-cabinet (U)

86. doctor-hospital (H)

87. dollars-bucks (M)

88. noise-problems (U)

89. breakfast-dinner (M)

90. hug-cup (U)

91. cap-hat (H)

92. umbrella-keys (U)

93. mother-conversion (U)

94. landlord-owner (H)

95. ending-beginning (M)

96. money-sense (U)

97. baby-infant (M)

98. tires-wheels (H)

99. wave-bully (U)

100. city-town (R)

101. perfume-briefcase (U)

102. hand-finger (H)

103. size-color (U)

104. bacon-pork (M)

105. moon-sun (H)

106. medal-prize (M)

107. ponder-think (H)

108. tip-card (U)

109. desk-chair (M)

110. hook-table (U)

111. retina-eyes (H)

112. race-contest (M)

113. bill-fee (M)

114. cheddar-cheese (H)

115. stand-behave (U)

116. pair-set (H)

117. cry-sob (M)

118. church-congregation (M)

119. cell-duties (U)

120. broom-mop (U)

<u>List Two</u>

1. They asked Dave to play tennis but he was too good. (U)

2. The defendant pleaded not guilty by reason of insanity. (B)

3. They are out in the garden pulling roots. (R)

4. Jeff felt sorry but it was not his turn. (U)

5. He loosened the tie around his neck. (B)

6. They went to pick up their parents at the railway depot. (R)

7. She sewed the button on with needle and string. (R)

8. The butler hung their coats in the closet. (B)

9. We stopped at the water fountain to get a sip. (R)

10. He heard a knock at the front entrance. (R)

11. Karen awoke after a bad hangover. (U)

12. Children learn to read and write in the first grade. (B)

13. The driver of the speeding car was given a citation. (R)

14. Through the rain it was hard to read the signals. (R)

15. He shouted at the top of his stairs. (U)

16. Tim threw a rock and broke the glass. (R)

17. The tenants decided to take their landlord to lunch. (U)

18. The doctor set the man's broken leg in a splint. (R)

20. My cat is covered with white fur. (B)

20. I returned the overdue books to the bag. (U)

21. The winter was very harsh this year. (B)

22. A dog has a good sense of loyalty. (U)

23. She put on her high heeled boots. (R)

24. New York is a very busy town. (R)

25. The cub scouts needed a new den chair. (U)

26. We sprayed the yard to keep away the skunks. (U)

27. They drank champagne to celebrate their tenth wedding anniversary. (B)

28. I want ketchup, mustard, and relish on my hot dog. (B)

29. The tickets for the opening concert were sold privately. (U)

30. Ray fell down and skinned his knees. (B)

31. The lawyer feared that his client would be found crazy. (U)

32. He ran the mile in under four minutes. (B)

33. Be careful because the top of the stove is very cluttered. (U)

34. The attendant filled the car with fuel. (R)

35. Because he had a toothache he called his boss. (U)

36. The winning candidate was preparing his acceptance speech. (B)

37. The parking lot was full of expensive foreign autos. (R)

38. She tied up her hair in a yellow bow. (R)

39. John filled the pen with care. (U)

40. The maid loaded the laundry into the washing machine. (B)

41. Sharon dried the dishes with a kitchen rag. (R)

42. The hungry bear dipped his paw in the sweet honey. (B)

43. The Canadian flag is red and white. (B)

44. He bought the chocolates at the candy counter. (R)

45. The old house will be torn down. (B)

46. After the accident they went for aid. (R)

47. Don't believe everything you suspect. (U)

48. The organist accompanied the church choir. (B)

49. She put a clean sheet on the clipboard. (U)

50. Jill decided to put vanilla icing on the chocolate cookie. (R)

51. It is easy to get lost without a map. (B)

52. The parents pleaded with their daughter to come quietly. (U)

53. Jack decided to wear a three piece suit. (B)

54. When the two men met, one of them held out his ID. (U)

55. Most people see the chimpanzees at the zoo. (B)

56. The unhappy marriage ended in a separation. (R)

57. The young boy punted the football. (B)

58. The boat passed easily under the falls. (U)

59. The store detective accused him of theft. (R)

60. She seasoned the steak with black pepper. (B)

61. Sally fell in the water and was dripping wet. (B)

62. Most cats see very well at distances. (U)

63. After being robbed the victim called the cops. (R)

64. The company president decided to cancel the board meeting. (B)

65. The tenants were evicted when they did not pay the last month's bill. (R)

66. The exit was marked by a large sign. (B)

67. The janitor washed the dirty ashtrays. (U)

68. He hung the picture on the living room wall. (B)

69. Brian poured some sauce on his rare meat. (R)

70. She made him a salami sandwich on wheat rolls. (R)

71. The gambler had a streak of bad temper. (U)

72. His wealthy parents enrolled him in a private academy. (R)

73. The bathroom faucet sprung a leak. (B)

74. Pam did not have any clothes to donate. (U)

75. The child was born with a rare gift. (U)

76. He looked up the misspelled word in the dictionary. (B)

77. Yesterday they canoed down the rapids. (R)

78. Burt used a match to light the dying flame. (R)

79. The rainstorm was followed by a beautiful rainbow. (B)

80. Bill played his stereo much too often. (U)

81. When you leave, please close the paper. (U)

82. Jason called directory assistance for the number. (B)

83. The milk was left out of the refrigerator and turned yellow. (U)

84. George put the record on the record player. (B)

85. His kite got tangled in the oak cabinet. (U)

86. The ambulance rushed him to the hospital. (B)

87. The society's annual dues were fifty bucks. (R)

88. Motorcycles can create a lot of problems. (U)

89. We had bacon and eggs for dinner. (R)

90. My uncle kissed my mother and gave her a big cup. (U)

91. The construction worker wore a hard hat. (B)

92. It is raining and I forgot my coat, hat, and keys. (U)

93. She was named after her conversion. (U)

94. The lost dog was returned to his owner. (B)

95. The story had a happy beginning. (R)

96. None of his books made much sense. (U)

97. The mother fed the newborn infant. (R)

98. A bicycle has two wheels. (B)

99. He was knocked off his surfboard by the first bully. (U)

100. My family moved from the country to the town. (R)

101. He liked the scent of her new briefcase. (U)

102. He put the ring on her finger. (B)

103. Her new shoes were the wrong color. (U)

104. He fried an egg and two strips of pork. (R)

105. All the planets circle around the sun. (B)

106. The athlete won a gold prize. (R)

107. The TV was so loud that he couldn't hear himself think. (B)

108. The rude waiter was not left a big card. (U)

109. Tim put his feet up on his father's oak chair. (R)

110. Fred put the worm on the table. (U)

111. Phil put some drops in his eyes. (B)

112. The horse collapsed right after the contest. (R)

113. George made out a cheque to pay for the monthly telephone fee. (R)

114. The mouse ate the cheese. (B)

115. When the national anthem plays everyone is expected to behave. (U)

116. For graduation Lucy received a pen and pencil set. (B)

117. The movie ended so sadly that Julie started to sob. (R)

118. Every Sunday morning people pray in their local congregation. (R)

119. The prisoner was sent back to his duties. (U)

120. John swept the floor with a mop. (R)

1. bags-carts (M)
2. under-over (H)
3. eat-chew (M)
4. plane-thieves (U)
5. foot-watch (U)
6. sign-up -register (H)
7. circle-ring (M)
8. flagpole-flag (H)
9. color-consistency (U)
10. cages-captivity (R)
11. hair-elbows (U)
12. fork-knife (H)
13. fog-mist (M)
14. mob-crowd (H)
15. soup-broth (M)
16. short-tall (H)
17. basket-box (M)
18. wrong-asleep (U)
19. swim-hear (U)
20. bad-good (H)
21. soon-shortly (R)
22. lost-hurt (U)

23. chalk-board (H)
24. energy-power (R)
25. fall-spring (M)
26. mind-clothes (U)
27. mature-age (H)
28. late-drunk (U)
29. bake-oven (H)
30. rain-lightning (M)
31. birth-noon (U)
32. list-wall (U)
33. eye-glasses (H)
34. party-bash (M)
35. soon-hungry (U)
36. play-shower (U)
37. sauna-pool (H)
38. sad-happy (H)
39. escape-picnic (U)
40. water-powder (U)
41. damage-harm (M)
42. buddies-friends (H)
43. could-dared (U)
44. school-college (M)

45. food-meal (H)

46. wife-staff (U)

47. ground-pipe (M)

48. slumber-sleep (H)

49. coffee-tea (M)

50. letter-note (M)

51. room-counselor (U)

52. made-designed (M)

53. cover-help (U)

54. melody-tune (H)

55. word-syllable (M)

56. heavy-rusty (U)

57. horses-oxen (M)

58. raise-car (U)

59. concentration-attention (H)

60. pressure-sugar (U)

61. coat-sweater (M)

62. splatter-splash (H)

63. bank-train (U)

64. name-address (M)

65. health-neighbors (U)

66. in-out (H)

67. chamber-room (H)

68. easy-simple (M)

69. plumber-handyman (M)

70. sight-sound (H)

71. bread-crumbs (M)

72. rough-smooth (H)

73. barn-farm (H)

74. office-convenience (U)

75. bunk-bed (H)

76. beach-roof (U)

77. floor-ground (M)

78. aisles-rows (M)

79. nine-ten (H)

80. rest-help (U)

81. clock-time (H)

82. dishes-clothes (U)

83. bee-wasp (M)

84. tree-shed (U)

85. party-celebration (M)

86. fire-blaze (M)

87. picket-fence (H)

88. road-path (M)

89. stamp-thought (U)

90. money-pens (U)

91. over-finished (M)

92. tablet-pill (H)

93. milk-cream (H)

94. speak-resign (U)

95. light-dark (H)

96. sink-bedroom (U)

97. wet-dry (H)

98. small-little (M)

99. plate-platter (M)

100. deal-leave (U)

101. orange-juice (H)

102. minute-hour (H)

103. wallet-vest (U)

104. closet-back (U)

105. sale-auction (M)

106. bankbook-cheque (H)

107. broke-poor (M)

108. lie-soul (U)

109. enlarge-grow (B)

110. drugs-movies (U)

111. safe-vault (M)

112. goul-ghost (H)

113. footstool-ladder (B)

114. bank-teller (M)

115. leg-arm (M)

116. brush-paint (B)

117. light-lamp (M)

118. leash-diet (U)

119. test-quiz (M)

120. soil-earth (M)

Appendix E

Means of the Stimuli on a Variety of Linguistic Variables for Each List

Appendix E

Table E1

Means and Standard Deviations of the Stimuli in List One on Important Linguistic Variables For Each Relatedness Condition

	Best Completion		Related		Unrelated	
Linguistic Variables	M	SD	M	SD	M	SD
Words/sentences	8.35	1.76	8.50	1.41	8.30	1.68
Letters: Word 1	5.69	2.33	4.90	1.33	4.81	1.15
Letters: Word 2	4.94	1.63	5.55	1.98	5.60	1.88
Frequency: Word 1	81.57	95.17	136.57	191.85	117.57	118.85
Frequency: Word 2	195.49	414.95	76.59	131.67	129.58	215.61
Concreteness: Word 1	658.26	761.01	542.34	89.19	504.11	94.27
Concreteness: Word 2	520.42	101.37	514.59	106.25	521.65	96.92
Imagery: Word 1	536.20	107.43	549.67	96.65	527.62	83.73
Imagery: Word 2	547.37	96.71	524.09	97.29	530.75	105.83

Table E2

Means and Standard Deviations of the Stimuli in List Two on Important Linguistic Variables For Each Relatedness Condition

	Best Completion		Related		Unrelated	
Linguistic Variables	M	SD	M	SD	M	SD
Words/sentences	7.80	1.34	8.45	1.63	8.15	1.64
Letters: Word	6.03	2.54	5.15	1.55	4.88	1.30
Letters: Word 2	5.15	1.86	5.48	2.05	5.70	1.88
Frequency: Word 1	97.75	109.40	114.56	143.41	124.89	142.74
Frequency: Word 2	146.75	405.48	47.46	50.78	124.38	197.94
Concreteness: Word 1	544.44	75.20	570.91	51.57	509.54	90.14
Concreteness: Word 2	533.36	94.31	515.50	120.28	506.54	101.76
Imagery: Word 1	570.31	62.84	574.09	53.20	536.07	77.31
Imagery: Word 2	546.89	73.79	514.85	112.56	532.29	86.68