Age Differences in Word and Language Processing
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Do the waves begin to waver? ERP studies of language processing in the elderly*

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Until recently, relatively little research had been done on language processing in the elderly except as an adjunct to the study of aphasia. While language processes have usually been thought to be fairly impervious to aging, it is now clear that some changes do occur. Moreover, many of these changes often seem to be directly linked to changes in the efficacy of other cognitive operations affected by aging, particularly the active suppression of irrelevant information and the management of working memory (WM). One way to study these changes is to record event-related brain potentials (ERPs) from the scalp in response to individual words either in isolation or in sentences. In this chapter, we review what is currently known about the electrophysiology of visual language processing in the elderly, and what ERPs may tell us about age-related changes in the neural substrates of reading.

1. ERP STUDIES OF LANGUAGE PROCESSING IN THE ELDERLY

Much more research has been focused on the development of language abilities from infancy through early adulthood than on changes in language processing over the next forty to fifty years. Notable exceptions are the investigations of individuals with gross disturbances in language caused by certain strokes or dementing illnesses and their age-matched controls. But a variety of subtle changes do occur within the normal aging brain that can have noticeable effects on language processing. In this chapter, we review some of our results from studies of language processing in presumably normal, healthy, elderly individuals employing event-related brain potentials (ERPs). ERPs provide us with a brain imaging technique that is well-suited for mapping processes at the psychological and linguistic level onto the relevant neural physiology. They are especially useful for our purposes because they provide a potentially continuous measure of on-going brain activity which is sensitive to many of the same variables that influence language processing. Further, ERPs give us a useful measure that does not require

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overt behavior, which allows us to study subject groups who are severely affected in their ability to generate motor responses. This feature also allows us to note aging-related differences in central brain processing that might be suggested by, but difficult to pin down from reaction time (RT) data alone, given the well-known increase in the mean and variance of RTs in the elderly! ERPs also allow us to study age-related differences in language processing due to other changes in aspects of cognition such as the flexible deployment of cognitive resources, and the maintenance of items in working memory. These processes can also be studied using RT-based methodologies, but they involve processes that do not always lead to the generation of RTs in natural situations. Before we discuss the ERP evidence, we will address these processes from a psychological and a neurological perspective in turn with the aim of providing a background against which to interpret the ERP data.

1.1. Working Memory

One cognitive process crucial to language processing is working memory, a resource long known to be degraded by aging (see, e.g., Wechsler, 1987, for aging norms). Contemporary views of working memory have emphasized that what had previously been seen as a unitary phenomenon can be analyzed into a system of component subprocesses whose existence has been inferred from the performance of human subjects (e.g., Baddeley, 1986), and verified experimentally in non-human primates (Goldman-Rakic, 1987). Virtually all models of working memory now respect Baddeley's broad distinction between "central" executive and "peripheral," often modality-specific maintenance, processes. Other commonly recognized features of most working memory models include its decay function as well as subprocesses responsible for item-to-item activation and inhibition, and the introduction of items into WM (e.g., Anderson, 1983; Just & Carpenter, 1992).

The efficiency of the working memory system does seem to decline with age (Cohen, 1988) and this decline affects more than just the ability to remember phone numbers. Kemper (1988) in particular has discussed how this decline has an impact on the parsing and production of complex syntactic structures in the elderly, but the specific mechanisms for these age-related changes remain unknown. General slowing of cognitive processes, by virtue of increasing the exposure of memories to potential decay, undoubtedly does contribute to the decline of WM. Recent results, however, also suggest a prominent role for the reduced efficiency of inhibitory processes that serve to "clarify" the contents of working memory via the active removal of irrelevant information (Hasher, Stohzfus, Zacks, & Rypma, 1991). This *inhibitory deficit hypothesis* contrasts with views that attribute age-related changes in working memory capacity (WMC) to a failure in one or several other processes such as the active maintenance of items in WM, the focussing of attention to specific items in WM, or the introduction of new items to WM.

One specific and linguistically relevant prediction that follows from the *inhibitory deficit hypothesis* is that normal elderly individuals would experience difficulties at establishing coreference between a pronoun and the noun phrase it refers to, especially in the presence of multiple possible (even if implausible) candidate noun phrases. This has been observed experimentally (Light & Capps, 1986), and is apparently not due simply to an increase in the

* Note that this is not to suggest that age-related slowing is unimportant, since it is an undeniably critical aspect of the data to be explained (Salthouse, 1985). Instead, we are arguing that ERPs can help clarify the patterns of results seen in RT data in cases where statistical or practical considerations make the latter more difficult to interpret.

absolute amount of information that must be maintained in WM (Zelinski, 1988). These kinds of effects, however, are not unique to the elderly but rather to individuals of any age with reduced WMC. For instance, Gernsbacher and Faust (1991) found that among young adults, less skilled comprehenders were less efficient and slower in their suppression of contextually inappropriate meanings of ambiguous words (once activated) than were more skilled comprehenders.

1.2. Suppression and Long Term Memory

An important corollary of the inhibitory deficit hypothesis of aging in working memory is that a similar inefficiency in inhibitory influences in long term memory (LTM) can account for some of the notable problems the elderly have with retrieving long term memories. Particularly relevant in the language production domain are the *word-finding difficulties* the elderly often experience. At first glance, such difficulties may seem to be a simple failure of item retrieval, but the most exasperating part of such "tip of the tongue" experiences is how much information actually is retrieved, not how little, and how many *incorrect* labels are generated (Brown, 1991). Note that this situation is asymmetric in the sense that normal elderly subjects do not fail to retrieve meaning given a verbal label. This phenomenon might be taken as a particular form of the so-called "fan effect", whereby it becomes more difficult to verify a specific property (here, a name) in a semantic network memory as the number of properties connected with a node increases (see Anderson, 1983; Cohen, 1990). Control over this type of search appears to be related to the ability to inhibit irrelevant (but automatically activated) memory nodes. Thus, according to the *inhibitory deficit hypothesis* the elderly, with deficient inhibitory resources to guide their search through memory, should show increased fan effects, as appears to be the case (Gerard, Zacks, Hasher, & Radvansky, 1991).

A closely related phenomenon that also helps to reveal the nature of such inhibitory factors is *negative priming* which refers to a reliable decrement in performance (speed and/or accuracy) to stimuli that were recently ignored relative to stimuli that are occurring for the first time in that particular experimental situation (e.g., Tipper, 1985). Conditions leading to negative priming are in exact opposition to the usual state of affairs, wherein stimulus analysis is faster and more accurate upon a second presentation (i.e. with repetition) compared to the analysis of new (unrepeated) stimuli. The relevant variable thus seems to be whether the item on its first occurrence is attended or ignored; upon repetition, the former leads to facilitation, the latter to inhibition. Insofar as inhibitory processes are deficient in normal elderly, they should show little or no negative priming in such paradigms, and this also appears to be true in some situations (Tipper, 1991; Hasher et al., 1991).

1.3. Effects on Linguistic Processes

In the preceding paragraphs we have summarized the evidence that some of the more profound effects of aging on psychological and language processes seem to stem from changes in inhibitory processes and their effects on memory. Now we turn briefly to two equally important issues in the psycholinguistic literature, namely lexical access and the processing of syntactic structure. All other things being equal, older individuals appear to have significantly larger vocabularies than younger ones (Botwinick, 1984), but there is little evidence that the receptive comprehension of words in the elderly is compromised by this fact, although the elderly do show some word-finding difficulties as alluded to above. In fact, while older adults are systematically slower at performing tasks involving lexical information (such as lexical decision, word naming, and category membership), a recent analysis by Lima, Hale, and Myerson (1991) suggests that elderly RTs are systematically slower still in task situations relying on *non-lexical* tasks (such as mental rotation, four-choice reaction time, and Sternberg memory scanning). Given the fact that the elderly have larger vocabularies than the young, it would be interesting if lexical processing is relatively spared, although more research on this point is needed. When we move into the realm of syntactic processing, however, the deleterious effects of aging seem relatively greater. Even as the stack-based, strictly serial models of parsing that assumed a critical role of WM have fallen into disfavor in favor of more parallel approaches (e.g. Gibson, 1990; Just & Carpenter, 1992), the vital contribution that working memory capacity makes to syntactic processing has been more frequently acknowledged. This, in turn, explains why the production and processing of syntactic structures making the heaviest demands on WMC might deteriorate with age.

The results of a series of investigations using a variety of techniques have led Kemper and her colleagues to conclude that the elderly (especially those older than 75) are disproportionately impaired in their comprehension, production, imitation of, and memory for certain syntactic constructions (Kemper, 1986a; Kemper, 1986b; Kemper, 1987a; Kemper, 19876; Kemper, Rash, Kynette, & Norman 1990; Kynette & Kemper, 1986). Specifically, these so called "old-old" subjects have trouble with sentences which include embeddings using *that* and *wh-* clauses as sentential subjects, particularly those that produce left-branching structures such as *The reporter who the senator attacked admitted the error;* we will return to these constructions later. By contrast, the processing consequences of sheer length have been found to be less important, although not as negligible as they often seem to be in young subjects. Still, it is important to note that the elderly do not exhibit more difficulties with basic "who did what to whom" questions than the young, unless certain WM-dependent roadblocks are thrown into the path of a syntactic analysis. Richer world knowledge and a larger vocabulary might ameliorate these effects to some extent (as would be suggested by the expert memory literature, e.g. Chase & Simon, 1973), but they cannot eliminate them.

1.4. A Brief Review of ERPs

To a cognitive neuroscientist, knowledge of the relevant cognitive psychology is only a first step in understanding how the language comprehension system really works, and where aging has its most notable effects. For many questions, real insights will come only when the relevant mental processes are reliably associated with specific features of neurophysiological measures. Neurophysiological evidence can not only supply additional constraints to currently popular theories, just as any new data could, but also provide information of a special nature. Specifically, ERPs are a measure of brain activity-the ultimate generator of mentation and cognition that can therefore be discussed in both physiological and psychological terms. Because the ERP is a sign of one level of explanation (neural) and responsive to variables that influence another (behavioral), cataloguing its behavior under controlled conditions will by necessity lead to more explicit psychological theories.

The neurophysiology of cognitive processing in humans can be investigated by the noninvasive recording of event-related brain potential activity from the scalp. ERPs (also known as evoked potentials) are small voltage fluctuations in the electroencephalogram (EEG) that are time-locked to sensory, motor, or cognitive events; ERPs, then, reflect patterned neural activity associated with informational transactions in the brain. While electrical fields measured at the scalp are remote measures of the brain's activity, they constitute one of the few techniques available for recording the dynamic patterns of neuro-electric activity associated with specific cognitive acts and linguistic processes (Callaway et al., 1978; Renault, Kutas, Coles, & Gaillard, 1989; Munte, Heinze, & Mangun, 1993). Used as converging operations with behavioral measures, ERP results can assist in classifying perceptual, cognitive and linguistic processes (reviewed in Naatanen & Michie, 1979; Hillyard & Picton, 1987).

ERPs have several characteristics that make them especially well-suited for addressing issues central to cognition in the elderly. The first is the multidimensional nature of the ERP waveform, which can vary along a number of dimensions; specifically, latency, amplitude, and distribution across the scalp. Thus, in principle, ERPs can reflect not just quantitative fluctuations in some process but the activity of qualitatively different processing events as well. Furthermore, the ERP is both a continuous and a real-time measure that is a record of the brain's processing* over periods that are co-extensive with language- or memory-related operations. They provide not only information about processing before RTs could possibly be measured, but also information about processes that bridge the time between multiple responses when they occur. Importantly, reliable ERP effects can be obtained even in the *absence* of any additional task over and above the natural one of reading or listening, an advantage which becomes even more obvious when working with various patient populations.

Basic research into the brain mechanisms that generate scalp potentials continues to this day, but it is generally agreed that most of the electrical activity observed in faster ERPs (i.e. those lasting less than a second) represents the summation of the excitatory and inhibitory postsynaptic potentials on thousands of large pyramidal neurons aligned perpendicularly to the cortical surface (Nunez, 1981). These groups of neurons can be modelled by an equivalent dipole, whose activity is volume-conducted from its point of origin to recording electrodes on the scalp with no propagation delay, but with substantial smearing of the observed field due to the manner of conduction even in the ideal case ** (Nunez, 1981). It is frequently assumed (and may actually be the case) that an increase in firing rate within a cortical region will be associated with a cortical surface negativity (Speckmann, Caspers, & Elger, 1984), but whether this appears on the scalp as a negative or positive potential depends crucially on the orientation of the equivalent dipole in the activated region of cortex relative to the recording electrode. We raise these issues both because readers might otherwise leap to unwarranted conclusions about the localization of specific generators, and because we sometimes do speculate about localizations, albeit mindful of constraints provided by converging evidence from lesion studies, animal models, or other functional imaging modalities. As detailed below, we do have some *a priori* notions about what structures in the central nervous system are more or less affected by aging, and how these changes affect the cognitive processes described above.

* It is however, important to note that not all brain processes are reflected at the scalp surface. For limits see Allison et al. (1986).

** A point source on cortex abutting the brain case "spreads" to a circular region 2.5 cm in diameter at the scalp, even neglecting the unavoidable conduction of activity through the scalp towards either a current source or sink, depending on which direction current is flowing.

1.5. The Aging Brain and its ERPs

It is well-documented that the relative amounts of white and grey matter change over the course of the lifespan, with adulthood being marked by a slow but steady reduction in grey matter (Henderson, Tomlinson, & Gibson, 1980). Exactly what portion of this shrinkage is due to cell loss (suggested by Henderson et al., 1980) versus the shrinkage of neurons and their dendritic processes is still a subject of debate. However, both processes contribute to this net shrinkage and thus can have potentially serious consequences on the quality of information processing that is possible. A combination of basic neuroscience and better imaging techniques has recently afforded an estimate of changes over the lifespan in neuron counts in specific brain areas from changes in brain volume, which in turn were estimated from MRI scans (Jernigan, Press, & Hesselink, 1990). Averaging over the entire cerebrum, Pfefferbaum et al. (1994) estimated that grey matter volume (and thus cell counts) peaked around age 5, when a grey matter volume of about 130 mL and a white matter volume of only 50 mL rattle around inside an 1175 mL brain case. At age 20, they found that the volume of cerebral grey matter had already decreased by over 15% to ~110 mL, but white matter had increased by 40% to 70 mL. At age 65, grey matter was down another 18% to only about 90 mL, but white matter was unchanged; overall brain volume was maintained by an increase in cerebrospinal fluid.

Jernigan et al. (1991) observed similar effects of aging in a smaller sample of subjects, and also assessed grey matter volume losses for different cortical and subcortical regions. While they found highly reliable losses in almost every sector examined, they noted distinctly greater losses in the caudate nucleus and slightly greater losses in the medial/basal temporal lobes than in other cortical regions. An interesting aspect of these results is that both of these regions have been shown to be crucial for various memory functions, with the medial temporal lobe system involved in explicit memory formation (Zola-Morgan & Squire, 1993), parts of the basal and inferior temporal lobe in visual working memory (Miller & Desimone, 1994), and the caudate apparently critical for implicit motor learning and the organization of motor behavior generally (Graybiel et al., 1994). Both the temporal lobe structures and the caudate are also strongly interconnected with prefrontal areas believed to play a quite prominent role in working memory systems (Goldman-Rakic, 1987). Further, both regions have heavy dopaminergic innervations (reviewed by Berger, 1992), and prefrontal areas at least are known to suffer notable reductions in dopaminergic activity with normal aging (reviewed by Fuster, 1989).

While the functional significance of dopamine in the CNS is still hotly debated, it does appear to be vital to the performance of at least some working memory tasks (Sawaguchi & Goldman-Rakic, 1991), and is hypothesized to play a modulatory role in many areas of primate cortex. Normal aging also is associated with changes in the striatum, (McGeer, McGeer & Suzuki, 1977), and, in particular, reductions in the width of the pars compacta of the substantia nigra, which consists almost solely of dopaminergic neurons; these reductions are significantly correlated with reaction time slowing in a skilled movement task (Pujol et al., 1992). Further, recently it has been noted that the striatum is involved not only with the direct generation of motor behavior, but with other "central" cognitive processes as well (e.g., Eslinger & Grattan, 1993). In summary, aging appears to affect precisely the areas where one would expect damage to be associated with a slowing in motor preparation, declarative memory deficits, and possibly a decrease in working memory capacity.

1.6. Methodological Issues and Recording Parameters

In the data discussed throughout the remainder of this chapter, all subjects were right-handed, neurologically normal, native English monolingual speakers. Young subjects were UCSD students between 18 and 27 years of age who participated either for course credit or $5.00 per hour. Our elderly subjects were generally recruited from continuing education classes or volunteers at the Veterans Administration Hospital and also were paid $5-$7 per hour for their participation. Overall, our elderly subjects had an average education level of about 15 years. Unless otherwise specified, all ERPs were responses to words embedded in normal English sentences between 8 and 18 words in length that were presented to subjects one word at a time in the center of a CRT while their EEG was being recorded. Words were presented for a duration of 200 msec once every 500 or 550 msec. Specific task instructions varied from experiment to experiment, but in all cases comprehending the sentences presented was essential to task performance. Particular electrode montages also varied from study to study, but all included electrodes over lateral sites at standard 10-20 sites (F7, F8, T5, T6, O1, O2), and some non-standard pairs approximately over Broca's area, Wernicke's Area, (and their right hemisphere homologs) and primary auditory cortex (referred to below as Central). All subjects' EEG was amplified using a time constant of about 8 seconds, and digitized on-line with a sampling rate of 250 Hz.; eye movement and blink artifacts were rejected off-line prior to averaging. In the discussion below, the differences we discuss are all statistically reliable at the .05 level, and, unless explicitly noted, the differences in amplitudes or latencies mentioned are based on measures taken from individual subject's average ERPs (see Ridderinkhof & Bashore, this volume, for a discussion of this and other relevant details of ERP methodology). Further details of the general experimental procedure are given in King and Kutas (in press). As suggested in the Introduction, we generally expect ERP effects to match the timecourse of the relevant processing, so where WMC usage is of interest, both short (1 second) and longer (up to 5 second) epochs were prepared from the raw data.

2. SINGLE WORD DATA

2.1. Early Potentials to Words

One of the convenient features of the ERP is that it is possible to examine the integrity, nature, and timecourse of some of the different processes that are critical for successful language comprehension. For instance, although all perceptual processes may not be complete within a hundred milliseconds, there is some relatively early (in both a physiological and psychological sense) selective processing that has an impact on the extent to which items are at the focus of attention. Those items that are at the focus of attention are privileged relative to those that are not, and are therefore processed more efficiently. This facilitated processing, especially for certain sensory and physical features, is indexed by some of the early components of the ERP such as the posterior P1 (peaking around 100 msec) and the posterior N1 (peaking between 170 and 190 msec). The amplitudes of both the P1 and N1 can be changed by a variety of important factors; thus, N1 and P1 amplitudes are larger to items that are presented centrally rather than in the visual periphery, larger to items in the spotlight of attention than to those outside of its purview, and larger to items physically closer to those attended (provided

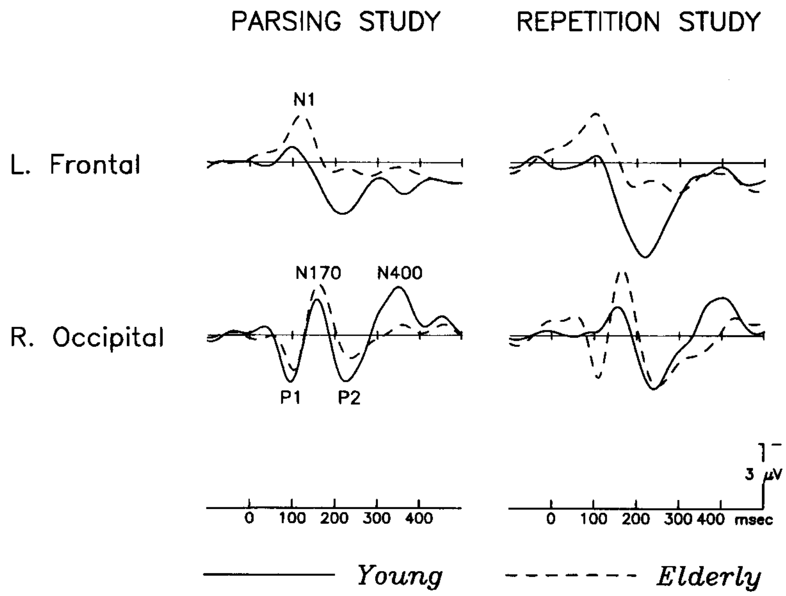

Figure 1. Grand average ERPs from two independent studies at two electrode sites for Young and Elderly subjects. Negative Voltages are plotted up in this and all other figures.

they share attentionally selected features) than to those which are farther away (Mangun, Hillyard & Luck, 1993).

Figure 1 shows ERPs to open class words (e.g. nouns, verbs, adjectives, adverbs) from two of our studies, with the waveforms for young and elderly subjects overlapped to highlight the effects of aging. Over posterior sites, as shown here for the right occipital electrode, young and elderly subjects generate very similar N1 (N170-190) components, suggesting that the early visual and attentional processing, or at least the first 200 msec of such processing, is similar in the two groups. (Note that P1 amplitudes are routinely more variable in our data, so the apparent difference between the young and elderly subjects in the Repetition study is neither a reliable nor necessarily meaningful difference.) As can be seen in Figure 2, these early potentials at the posterior electrode sites distinguish good from poor comprehenders of written text, be they younger or older adults. In both groups the amplitude of the posterior P1-N1-P2 complex is somewhat larger in the poor than good comprehenders, even though the Posterior Temporal N1 of the elderly is drastically reduced in size relative to that of the younger subjects. The posterior P1-N1-P2 complex has been linked to changes in resource allocation (in the form of shifting attention). In general, N1 and sometimes P2 amplitudes are greater for attended stimuli than for unattended stimuli in both the auditory (Hillyard, 1985) and visual (Mangun & Hillyard, 1991) modalities, and the former appears to index the amount of

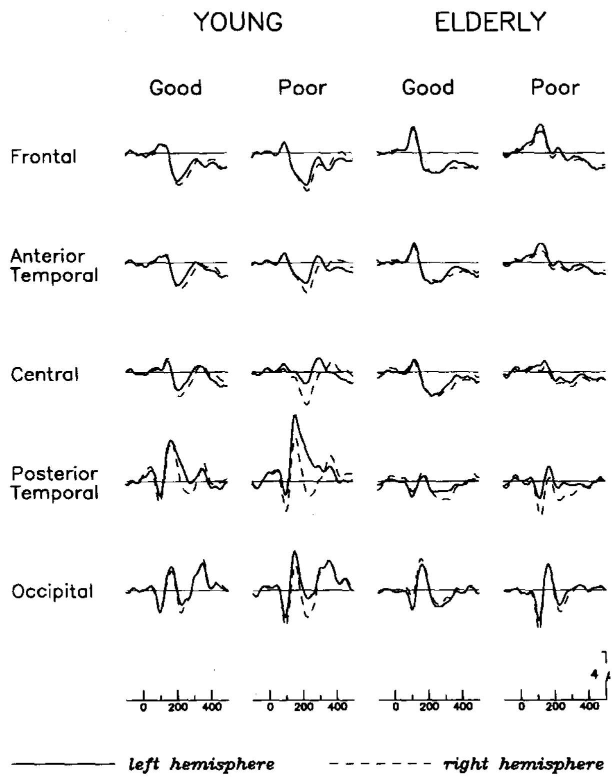

Figure 2. Grand average ERPs to all open class words for Good and Poor comprehenders defined by a median split in both Young (n=24) and Elderly (n=18) subjects, with the left and right hemispheres overlapped.

resources devoted to processing a channel that can be selected on the basis of spatial information. A rationale for such an attentional difference can be found in the now conventional hypothesis that poorer comprehenders may allocate more attentional resources to lower level processes than good comprehenders (Hunt, Lunneborg, & Lewis, 1978; Perfetti & Lesgold, 1977). A somewhat similar Nl-P2 effect has been seen previously in a dual task study carried out by Raney (1993), in which subjects simultaneously read (or re-read) a series of texts while also responding to randomly occurring auditory tones in a secondary task Raney found that the N1-P2 evoked by the tones increased in amplitude when subjects were re-reading a prose passage, consistent with the view that more cognitive resources were available to be devoted to the secondary tone detection task as the processing demands of word recognition decreased.

Contrasting with the equivalent posterior Nls in the young and elderly, are those at the more anterior electrode site, where the elderly subjects show markedly larger Nls than do the young subjects in both studies (see Figure 1). Little is known about the functional significance of the anterior N1 although, like the posterior N1, it is sensitive to manipulations of visuo-spatial selective attention and has been associated with a posterior dipole in various modelling attempts (Hillyard, personal communication).

Following the N1 at fronto-central sites, young subjects display a typical P2 (180-210) component; by contrast, this component is barely evident in the average data from the elderly subjects. In younger adults, the P2 is one of the more robust of the early components of the ERP. Nonetheless, relatively little is known about factors that influence its latency and amplitude. In general, pictures have been shown to yield larger frontal (or vertex) P2s than words, and non-words yield smaller P2s than words (Jeffreys & Tukmachi, 1992). Puce and her colleagues (1994; see also Allison et al., 1994) have suggested that at least one generator of the scalp P2 to faces and words comes from discrete locations on the fusiform gyrus on the bottom of the temporal lobe.* These data were based on investigations of patients with implanted subdural electrode arrays who were being evaluated for surgery to relieve intractable epilepsy.

Anatomically, the fusiform gyrus lies between structures of the medial temporal lobe and other more laterally placed visual association cortices. This region is therefore likely to be within the zone noted by Jernigan and her colleagues as a region of more sharply decreased grey matter volume with aging. However, localizing one of possibly several neural generators to a region whose function is unknown is not particularly revealing about the functional significance of the P2 or the fact it is so drastically reduced in the elderly. One of the few studies addressing cognitive effects on the P2 was performed by Chapman, McCrary, and Chapman (1978; also 1981), who reported that the amplitude of a P2-like component with a peak latency of 250 msec was related to the successful storage of a stimulus into short term memory in a memory probe task. Such a result would be consistent with a hypothesis of reduced efficiency of working memory in the elderly, but further work is needed to determine whether this was a P2 effect or perhaps an early member of the P3 family (Verleger, 1988; Donchin & Coles, 1988). Following the early sensory components (e.g., P1, N1 and P2) are the later, so-called endogenous components of which the N400 is one example. The right occipital site data in Figure 1 clearly show that young and elderly subjects also differ in the prominence of their N400 components; this difference will be discussed in greater detail later in the chapter.

In standard behavioral psycholinguistics, it requires a certain degree of experimental finesse to detect differences between items belonging to distinct lexical classes, although such differences do obviously have some importance in the syntactic processing of sentences. (By lexical classes, we refer to the difference between content words such as nouns, verbs, adjectives and ly-adverbs and function words such as articles, prepositions, pronouns, and conjunctions; the difference between the so-called "Open Class" items and their "Closed Class" cousins.) It is therefore noteworthy that the difference between Open and Closed Class items is quite clear in their ERPs, as can be seen in Figure 3.

At frontal sites, the ERPs to closed class words in both the young and the elderly subjects are characterized by a broad, left-lateralized negativity relative to open class words; this difference begins as early as 100 msec post stimulus-onset and continues throughout the

* On the cortical surface, this potential is a negativity, but the polarity reverses within the brain and would yield a broadly distributed positivity on the scalp.

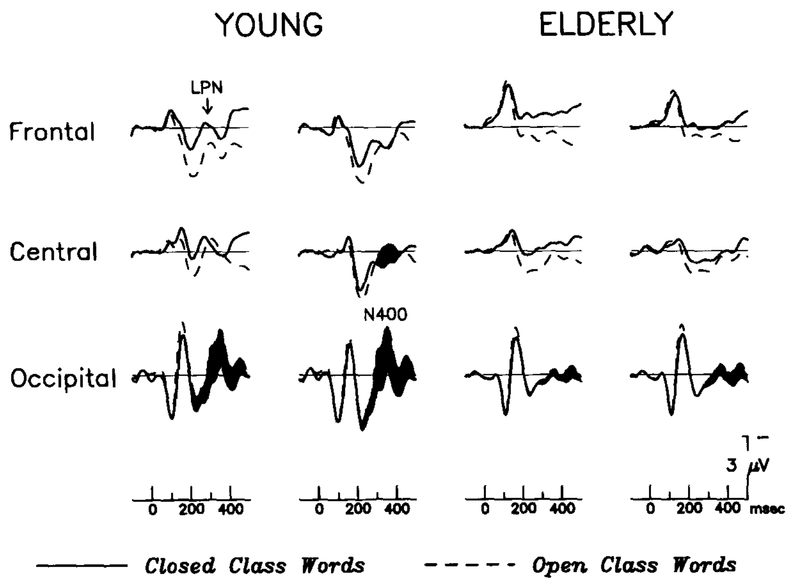

Figure 3. Panel A shows grand average ERPs at 6 electrode sites for Open Class and Closed Class words obtained from Young (n=24) and Elderly (n=18) subjects, with the N400 effect shaded for both groups and the peak of the Lexical Processing Negativity (LPN) indicated for the Young subjects.

epoch. The functional significance of this greater negativity for closed class words is uncertain, although it has been previously noted (e.g. Neville et at, 1992). We have suggested that it might index the expectancy that a content word will occur soon, given that function words in English generally introduce new phrasal units (Kutas & King, in press). If this is the case, then one could expect to see the resolution of this frontal negativity generated by function words as a frontal positivity on the following content words. Figure 3 shows that there is in fact a late, lateralized frontal positivity to open class words whose amplitude is nearly equal to the amplitude of the negativity seen to closed class words. Thus, the pattern we observe in the data is consistent with our expectancy generation and resolution idea, and there appear to be few differences between young and elderly subjects in this pattern.

Whereas the slow potential ERPs from the young and elderly subjects are remarkably similar over frontal sites, the fine structure of the waveform over these sites differs markedly between young and old subjects. The ERPs of the young, but not those of the elderly, exhibit a negative peak at about 280 msec for closed class words and at about 300 msec for open class words. We have found that the peak latency of this negativity, dubbed the Lexical Processing Negativity (LPN) is highly sensitive to the length and frequency of daily usage of the words that elicit them (King & Kutas, submitted). For grand mean data, the proportion of variance in LPN latency explained by length and frequency is 86%, even at the single subject level these two factors explain about 44% of the variance in latencies when we consider the median percentage of variance explained in our set of individual subjects. Neville et al. (1992) suggested this component (referred to as the N280) was reliably evoked only by closed class words and thus indexed the operation of lexical class-specific syntactic processes, but our data suggest this is not the case. First, our data demonstrate that the LPN (aka N280) is not unique to closed class words. Second, it seems rather unlikely that the LPN indexes some obligatory syntactic process since it is virtually absent in elderly subjects, who, nonetheless, comprehended these sentences and appreciated their syntactic structure as well as did younger subjects. Of course, it is possible that the elderly did generate LPNs but with far less synchrony and phase-locking than the younger adults. As an alternative, we have hypothesized that the LPN reflects activity in premotor cortex related to the control of gaze and suppression of voluntary eye movements in our experimental situation (King & Kutas, submitted). In standard ERP experiments, subjects are requested not to move their eyes or blink during the duration of the sentence presentation; honoring this request is quite effortful. Indeed, our elderly subjects are typically less able to abide by these instructions, and may thus be exercising less control over their gaze in the sense that they are less able to inhibit automatic eye movements in this experimental situation. This observation is also consistent with the *inhibitory deficit hypothesis* of aging-related cognitive change.

2.2. N400 and Integration As We "Know" It.

Thus far we have glossed over one of the most obvious differences between the ERPs to content and function words, and between the ERPs to content words in younger and older subjects, namely the large negative wave especially prominent over right posterior scalp. This was done, in part, so that we could consider the earlier and possibly less meaning-driven components of the ERP to words before turning to issues of deeper processing and information integration over the course of the sentence. Both Figures 1 and 3 show that, for young subjects, the ERP to every word in a word-by-word rapid serial visual presentation format is characterized by a negativity, that peaks between 350 and 450 msec (N400), is larger posteriorly than anteriorly, and is slightly larger over right than left hemisphere sites (for a review see Kutas & Van Petten, 1994). Content or open class word ERPs contain larger N400s than do function or closed class word ERPs. In fact, at the beginning of a sentence the most striking difference between the ERPs to content and function words is the presence of a much larger N400 component to the former than to the latter. This relative difference in the N400 amplitude elicited by function and content word ERPs is maintained in the responses to these lexical classes throughout the course of sentences. The relative reduction in the amplitude difference between N400s to content versus function words over the course of a sentence is mostly due to a decrease in the amplitude of N400 to content words; Van Petten and Kutas (1991) showed that this decrease was primarily a consequence of the buildup of semantic (and not syntactic) constraints. The data in Figure 4 show that this reduction in the amplitude of the N400 to content words with increasing context (operationalized in terms of ordinal word position in sentences) is present not only in the young but also in elderly subjects. In fact, the elderly subjects generate large N400s to the first content word in the sentence, but appear to show a faster falloff with accumulating context.

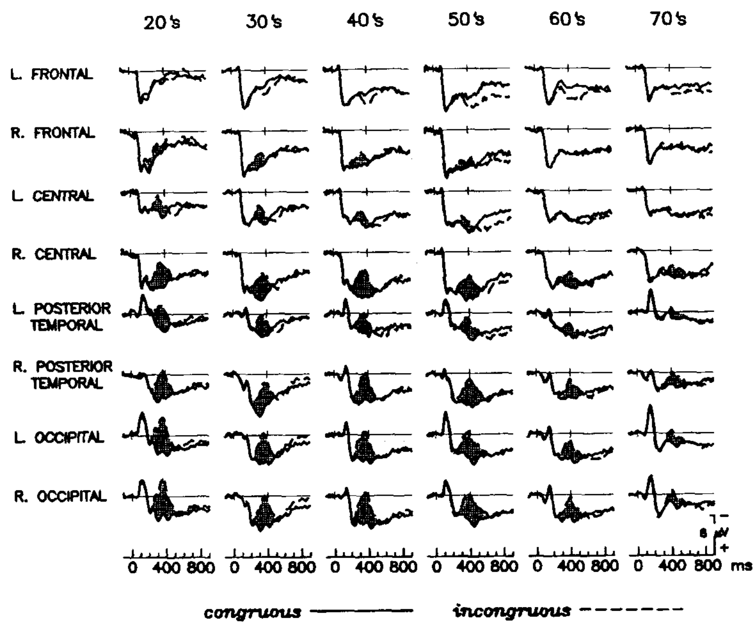

Figure 4. ERPs to visual words presented as congruous or incongruous completions of auditory contexts for groups of subjects (each n=12) varying in age from their 20s to their 70s, with the N400 effect shaded.

These data underscore one important finding since the original reports on the N400, namely that it is not specific to semantic anomalies. The ERPs to all words are characterized by some N400 activity whose amplitude is largely a function of the word's expectancy within its context. In 1984, Kutas and Hillyard demonstrated that the amplitude of the N400 tosentence final words, none of which were anomalous, was inversely correlated with cloze probability (r = -0.80-.90). This correlation has led some to propose that the N400 has nothing to do with semantic compatibility or integration but is merely an index of predictability (subjective conditional probability). However, in the same paper as well as others since (e.g. Kutas, 1993), it was demonstrated that the ERPs to words with identical cloze probabilities can have different amplitude N400s as a function of the semantic relation between the expected word and the eliciting word. Thus, for example, if the sentence frame "The pizza was too hot to-" were completed not by the expected word "eat" but by a word with a subjective conditional probability of zero such as "chew" or "hold", the ERP to both of these would contain a hefty N400; however, the N400 to the word "chew" would be smaller, presumably because of its semantic relation to "eat". A similar effect has been observed for outright semantic incongruities (Kutas, Lindamood & Hillyard, 1984).

Typically, the largest and most robust N400 is elicited by an open class word that is semantically anomalous within its context and unrelated in any way to any word in the sentence or to the expected ending (e.g., Kutas & Hillyard, 1980ab; Kutas & Hillyard, 1982). This finding holds whether the anomalous word occurs at the end or in the middle of a sentence (e.g., Kutas & Hillyard, 1983). In both cases, the semantically anomalous word elicits a significantly larger negativity which diverges from the response to a semantically appropriate word in the same ordinal position (assuming they are matched on length and frequency of usage) at about 200 msec, peaks between 350 and 450 msec, and has, in the average waveform, a duration of 300 to 400 msec; these values refer to the findings in young adults. In older adults, both the onset and the peak latency of the N400 effect during reading are delayed (see below).

In young adults, N400-like responses can be recorded not only to written words but also to semantic violations within spoken sentences (e.g., McCallum et al., 1984) and to visually presented signs in American Sign Language (Kutas, Nevlle, & Holcomb, 1987). There are, however, some differences in the specific characteristics of the visual and the auditory N400s (for comparison see Holcomb & Neville, 1991). Holcomb, Coffey, and Neville (1992) investigated the developmental timecourse of both the auditory and visual N400 to semantic anomalies occurring at the ends of written and spoken sentences. To a large extent, the changes in N400 across the adult lifespan have been limited to written words, although given the current interest in semantic processing in aphasics and other brain-damaged populations, we expect to see more data on N400s elicited by running speech in the near future.

At the moment, there is only one published study that examines aging-related changes in the N400s elicited by semantic incongruities in spoken sentences. Woodward, Ford, and Hammett (1993) found that the N400s to auditory stimuli, like visual N400s, are reduced in amplitude and somewhat delayed in latency relative to that in a sample of young subjects. However, some aspects of their design make it difficult to generalize about the effects of aging from these results; in particular, the sentence materials were repeated across two different conditions, and a one second delay was artificially imposed between the sentence context and the sentence final word.

Harbin, Marsh, & Harvey (1984) were the first to examine the effects of aging on the ERPs in a task (semantic categorization) likely to elicit and modulate the N400. They recorded ERPs from three midline electrodes from both younger (mean age 21 years) and older (mean age 71) subjects as they rendered decisions about the fifth of a series of visually-presented words in an *Identity* and a *Category* condition. In the *Category* condition, the first four words were members of the same semantic category and subjects were asked to indicate whether or not the fifth word was also a member; the fifth word matched the previous four on only 15% of the trials. Both categorization times and the latency of the N400 to mismatches were longer in the older group, although the difference N400 (mismatch minus match ERP) peaked at approximately 540 msec for both groups. The ERPs in the elderly were characterized by smaller N400 effects as well. Gunter, Jackson, & Mulder (1992) compared the ERPs to congruous and incongruous endings of sentences of medium-to-high contextual constraint from a group of young students to those from a group of highly-educated middle-aged academics (mean age 55 years). They used both a fast and a slow rate of sentence presentation, although this factor did not interact with age. Overall, the N400 effect in this middle-aged group was delayed in latency by 120 msec and was somewhat reduced in amplitude.

We have collected N400 data from young and elderly subjects both to sentences presented visually one word at a time and to target words following short phrases. Our results are essentially the same in both cases. We have found that with advancing age N400 latencies are prolonged and amplitudes are reduced. Since the results with short phrases were equivalent, we used those stimuli to investigate men and women from 20 to 80 years old as well as elderly adults suffering from senile dementia of the Alzheimer's type (Kutas, Iragui & Salmon, submitted). Thus, rather than complete sentences, congruent and incongruent words were flashed visually after the context (a short phrase) was spoken aloud by the experimenter. We chose this paradigm with an auditory context and a visual target word specifically because we have found that it is a task that can be performed by patients of various mental capabilities and yields very robust N400s in response to semantically incongruent or unrelated words.

The stimulus set included approximately equal numbers of highly constraining antonym contexts (e.g., "the opposite of black") for which there is only one reasonable outcome (e.g., "white") and moderately constraining category contexts (e.g., "a piece of furniture") for which there are several reasonable alternative members (e.g., "table", "chair", "couch", "cabinet", etc.). These antonymic and categorical relations map loosely onto the distinction that has been made between semantic and associative priming (for review see de Groot, 1990) and more directly onto the distinction between a prediction-based versus an expectancy-based strategy for utilizing contextual information, respectively (e.g., Becker, 1980; 1982).

ERPs were recorded from a total of 72 men and women (between 20 and 80 years old) as they performed this semantic categorization task. Subjects were asked to report the word seen (flash duration was 265 msec) and following the report to indicate whether or not it was appropriate given the prior context. Overall, the waveforms and their modulations with the experimental variables were remarkably similar across the decades. These subjects seemed to process the words in relation to the prior auditory context in a qualitatively similar manner no matter what their ages. The ERPs to all age groups contained larger N400s to words that did not fit with the preceding context than to those that did.

As can be seen in Figure 5, in all age groups, the N400 congruity effect in the opposite condition was larger over the back than the front of the head and larger over the right than the left hemisphere, more so over the front of the head. Thus, over occipital sites, the N400 congruity effect was nearly symmetric whereas over frontal sites it was large over the right hemisphere and essentially absent over the left; for individuals in their 60s and 70s the absence of an N400 congruity effect extended to the left central sites. Over the left frontal sites, incongruity was associated with an enhanced late positivity.

While there did not appear to be any qualitative effects of advancing age on the N400 congruity effect, there were clear quantitative changes. Specifically, the amplitude of the N400 congruity effect was smaller and its onset and peak latencies were later in the older than in the younger adults. Regression analyses revealed that there was a reliable linear decrease in the amplitude (0.05-0.09 uV/year) and a reliable linear increase (1.5-2.1 msec/year, r =.60) in the peak latency of the N400 congruity effect with age.

We found a similar diminution in amplitude and prolongation in latency for the N400 congruity effect in a group of older adults between 63 and 83 years old (relative to college undergraduates) when both the context and the final word were visual (see Figure 6). In that experiment, all the subjects read 120 sentences, presented a word at a time for a duration of 200 msec once every 550 msecs; 2500 msec separated the end of one sentence from the beginning of the next. Half the sentences ended congruously while the remaining half ended with a word that rendered the sentence nonsensical. In this case, the subjects were reading the sentences not only for comprehension but also with the knowledge of an impending cued recall

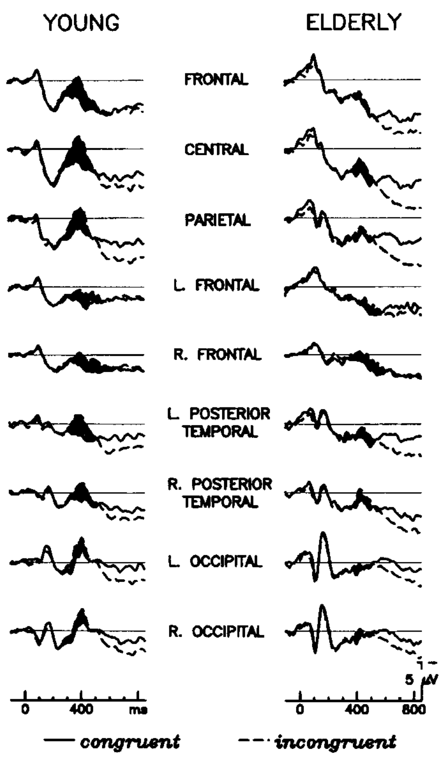

Figure 5. ERPs to congruent and incongruent final words to visually presented sentences for Young (n=18) and Elderly (n=18) subjects with the N400 effect shaded.

experiment, all the subjects read 120 sentences, presented a word at a time for a duration of 200 msec once every 550 msecs; 2500 msec separated the end of one sentence from the beginning of the next. Half the sentences ended congruously while the remaining half ended with a word that rendered the sentence nonsensical. In this case, the subjects were reading the sentences not only for comprehension but also with the knowledge of an impending cued recall test wherein they would be given each sentence context and asked to recall the sentence final word. As with the short phrases, the N400 congruity effect in the elderly was appreciably smaller and later than in the younger subjects. These findings are consistent with less efficient

These age-related changes in the N400 congruity effect are interesting in light of recent reports on the ERP word repetition effect (Hamberger & Friedman, 1992; Rugg et al., 1994; Karayanidis, Andrews, Ward, & McConaghy, 1993). The ERP word repetition effect refers to the greater positivity elicited by items repeated (old) relative to that occurring for the first time in the experiment (new). Typically, it has been argued that the word repetition effect reflects the modulation of multiple ERP components, of which one is the N400. The most consistent finding has been the absence of any statistically significant differences in the size of the ERP word repetition effect between young and elderly subjects. Rugg et al. (1994) did not observe any differences among the subject groups in the onset latency of the word repetition effect either. One methodological difference between these experiments and ours is that we used sentences whereas these other studies used word lists. However, if this is not the explanation, then the dissociation of the effects of aging on the N400 congruity and the N400 word repetition effects must be taken to mean that the two are not the same.

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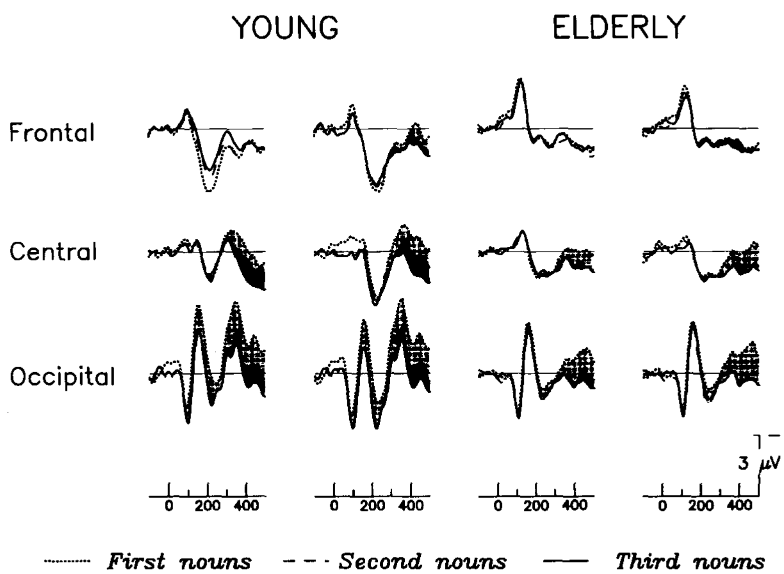

Figure 6. Grand average ERPs at Frontal, Central, and Occipital electrode sites for Young (n=24) and Elderly (n=18) subjects showing the serial position effect on the N400.

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2.3. Sentence-Level Effects

The ERP data we have considered so far have been time-locked to single words. However, many language-related processes must by their nature be active at longer timescales and analyses of their signatures in the brain's response to sentences should be quite revealing. We have begun to examine such data with the goal of understanding the interactions between faster, transient cognitive processes and slower, sustained processes (e.g., Kutas & King, in press). Note that we have already seen the effects of some of these interactions in the ERPs to single words. Earlier, we hypothesized that the sustained frontal negativities characteristic of the latter half of function word ERPs may reflect the fact that such items introduce major syntactic constituents and generate expectations for the following content-related items. Similarly, the contextual and serial position effects on the amplitude of the N400 during reading are clearly dependent on the cumulative action of longer-lasting processes in comprehension.

Changes spanning several words can also be seen in very low frequency ranges of the ERP. Our working hypothesis in this approach is that these slow potential effects reflect ongoing cognitive processes or changes in state caused by their continuing operation (e.g., fatigue). In the literature on very slow brain potentials employing non-linguistic tasks, it has been shown that it is possible to detect systematic fluctuations in the slow potential field on scalp regions that overlie the very neural circuits that are most heavily involved in the processing (Roesler, 1993). In the remainder of this chapter we will discuss slow potentials associated with three subprocesses of reading and describe how they fare during normal aging. Specifically, we will examine slow potential effects that we hypothesize to covary with (1) the continuous encoding of rapidly presented visual information, (2) the construction of higher level representations (discourse) from linguistic input, and (3) the temporary storage of currently unintegrated material within working memory. Based on all that we have argued thus far, we expect that of these three processes, it is the latter (working memory storage) that will show the greatest susceptibility to aging.

The negligible effects of aging on the slow potentials seen at occipital regions (left hemisphere site shown in Figure 7) parallel those we have observed for the early visual EPs to single words (also evident in the middle row, high pass filtered). Both young and elderly subjects show a similar pattern during reading: a slow, negative potential shift away from the resting baseline which appears to level out after approximately the third word in the sentence.

This slow potential shift is relatively independent of the changes in the ERP components that occur from word to word in the sentence, which do vary with word class, serial position and cloze probability, among other factors. Most importantly, for the present purpose, is that this slow potential shift over occipital sites does not seem to be significantly altered by aging. Thus, we seem to find little evidence for aging effects on the continuous encoding of rapidly presented visual stimuli.*

In previous reports of across-sentence ERP data, a consistent but little discussed finding has been a slow, progressive, slightly left-lateralized positive drift at anterior scalp sites (e.g,. Kutas, Van Petten, & Besson, 1988). We have found that the amplitude of this positive shift varies both with the structural complexity of the eliciting sentences and comprehension skill on young adults (Kutas and King, in press). While the largest positive shifts have been seen at electrode sites more anterior than those from which we have recorded in the elderly, our preliminary data indicate that these frontal positivities also are relatively spared by aging. Thus, as shown for the left frontal site in Figure 8a and 8b, while the elderly differ from the young in the morphology of the higher frequency components (especially in their lack of P2 components), they are remarkably similar in their slow componentry. In these data, the slow positive shift represents a steady positive ramp of about 0.3 microvolts per word. As far as comprehension is concerned, performance by young and elderly subjects was virtually identical

* Further tests of this hypothesis are, of course, necessary.

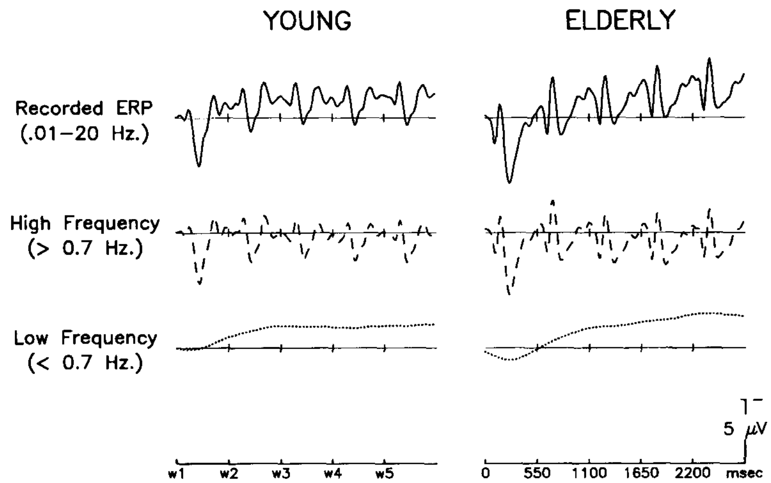


Figure 7. Grand average ERPs spanning the first five words of a sentence at the left occipital electrode site for Young (n=18) and Elderly (n=18) subjects, showing the recorded ERP and its High and Low Frequency components.

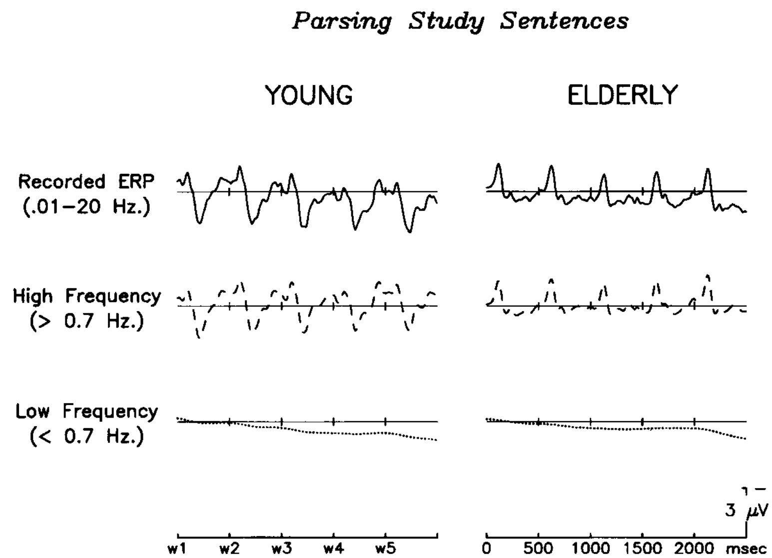
in the Parsing Study. In the Repetition Study, the behavioral measure was tied to explicit memory for sentence final words, and the elderly did perform more poorly on this task, as was expected.

Precisely what cognitive processes are indexed by this positivity is unclear at the moment, although some clues might be taken from its distribution and temporal dynamics. For instance, its distinctly frontal distribution is consistent with processes located in more anterior cortex, (e.g. frontal or anterior temporal regions), which, given the visual stimuli used, would implicate higher level processing more than those indexed by the occipital negativity. Further, the occipital negativity asymptotes relatively early, while this frontal positivity accretes in a manner suggestive of a cumulative rather than transient underlying process.

The reasoning for this argument is as follows. If a given slow potential reflects an increased level of electrical activity in a cortical region whose processing reaches some stable, steady state, then the slow potential should reach some asymptotic voltage.** This case would seem to cover the slow drift over occipital regions quite well if we assume that it represents a change in activity level required by the low level processing of an incoming stream of words. In the second case, if a slow potential reflects increased activity in a cortical region whose

** This is because the capacitance of brain tissue is negligible, so that the instantaneous current flowing from the brain through the scalp is a direct measure of the net current being emitted from the neural generators involved.

Panel **A**:



Panel **B**:

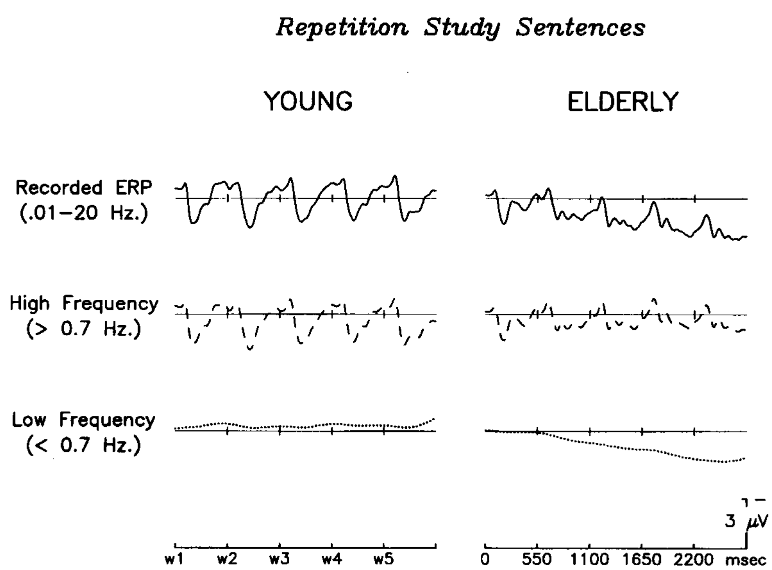


Figure 8. Panel A and Panel B display multi-word ERP data at frontal sites for Young and Elderly subjects, showing the recorded ERP and its High and Low frequency components

processing load increases over time, then the slow potential should track the resource demands of the process, and may not necessarily reach an asymptotic voltage. In a sentence comprehension task, the integration of the linguistic input into a discourse level representation requires continual evaluation and constant linking between the current content and previous knowledge about the topic. This ongoing, accretion of processing might therefore be expected to result in a cumulative effect on slow potentials across the sentence. Conversely, one could argue that, as a sentence progresses, its representation becomes more consolidated and subsequent content becomes more predictable. On this view, the processing load at an integrative level would progressively decrease as more input arrives and it is this that is reflected in the ramp-like slow potentials observed.

Whichever interpretation of the slow frontal positivity is correct, the pattern we observed in the elderly was very similar to that seen in the younger subjects. While this is hardly conclusive proof, it does suggest that integrative processing in structurally simple sentences, as verified by comprehension, is little affected by the aging process. However, we would expect to see a clear effect of aging on integration for sentences whose structure imposes a heavy burden on working memory. This was, in fact, a primary motivation for comparing the performance of young and elderly subjects during the processing of sentences known to tax the limits of working memory and thereby lead to increased comprehension difficulty in all readers, but especially in the elderly.

From the work of Kemper and her colleagues (e.g. Kemper, 1988), we know that older adults change both their use and comprehension of various syntactic structures as they grow older. Further, the structures most likely to cause difficulties in either production or comprehension are precisely those that are generally argued to make the greatest demands on working memory capacity. Investigating these ideas requires sentence types that differ in their WMC demands but are otherwise similar enough to allow comparisons between individual critical words and between the sentences themselves. For these reasons, psycholinguistic investigations have frequently concentrated on two sentence types that contain relative clauses but which differ subtly in their structure:

(1a) The reporter who harshly attacked the senator admitted the error.

(1b) The reporter who the senator harshly attacked admitted the error.

Both sentences (1a) and (1b) contain a relative clause modifying the subject of the sentence, but differ in the role that the main subject noun phrase ("the reporter") plays in the relative clause; in (1a), the main-clause subject is also the subject (and agent) of the verb in the relative clause, while in (1b), it is the object (and patient). Accordingly, sentences like (1a) are known as subject-subject relative (SS) sentences, while those like (1b) are known as subject-object relative (SO) sentences.

As any reader can readily attest to, SO sentences (lb) are generally more difficult to process than SS sentences (1a), although even SS sentences are more difficult than sentences without relative clauses. A long history of linguistic argument starting with work by Chomsky and Miller (1963) suggests that SO sentences tax working memory to a greater extent, and that this load becomes especially acute at and just following the relative clause verb of SO sentences; it is here where, in more modem theories, two separate thematic role assignments

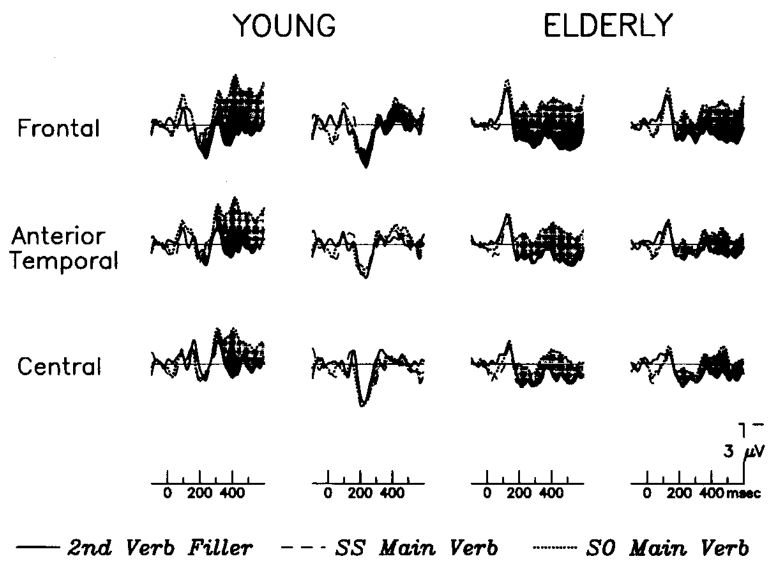


Figure 9. Grand Average ERPs from six anterior electrode sites to SO, SS, and non-relative clause control verbs for Young (n=24) and Elderly (n=18) subjects. The difference between the control verbs and the two relative clause types is shaded dark grey, while the difference between SO and SS verbs is shaded light grey.

must be carried out. That is, it is here that readers encounter the first verb of the sentence and must determine which noun phrase is indeed the subject. Note that, with these materials, neither semantic nor pragmatic information can be used to make this choice. King and Just (1991) verified that the greatest reading time differences are found at this point, and that these differences were larger for readers with relatively small working memory capacities. While some effect of carrying two (rather than one) noun phrases in working memory might be expected before the end of the relative clause, such effects are generally not obtained in reading times (e.g. King & Just, 1991; Ford 1983; Holmes and O'Regan, 1981). Perhaps under these circumstances, RT measures are not sensitive enough to maintaining a load in WM, or, alternatively, are sensitive to a number of different counteracting effects which therefore yields a null effect.

We thus chose to examine the processing of SS and SO sentences in young and elderly subjects by recording ERPs during their extent. In so doing, we uncovered ERP effects that covary with differences in working memory use during parsing, and that also seem to distinguish young readers from elderly readers as well as better comprehenders from poorer comprehenders, presumably in part due to WMC limitations. The sentence location immediately following the end of the relative clause ("admitted" in (1a) and 1b)) where the greatest RT effects between SO and SS sentences are generally found is also a site of large ERP effects (see Figure 9).

In both young and elderly subjects, not only do the ERPs to main clause verbs from the SS and SO sentences differ from each other, but, as expected, both of these differ from comparable verbs in filler sentences that do not contain relative clauses at all. This is consistent with the suggestion that even SS sentences tax WM relative to sentences without relative clauses, albeit in different ways than SO sentences tax WM. In the case of SS sentences, a WM load may arise because of the greater temporal separation between the subject noun phrase and the (main) verb relative to sentences with simpler structures, rather than because of any difficulties in determining which NP is the true subject. For both the young and elderly subjects, the difference between SO and SS verbs is larger over anterior relative to posterior sites and larger at left (than right) hemisphere sites. The difference between SS and filler sentence verbs is also left lateralized in the young subjects, but not in the elderly subjects; older subjects exhibit a more bilateral and distinctly more frontal difference. We still need to see whether this particular aging difference is a replicable finding. This difference notwithstanding, the overall pattern of ERP to the verbs from the various sentence types is quite similar in the young and elderly subjects. In both age groups, a greater load on working memory at the verb seems to be associated with a larger frontal, slightly left-lateralized negativity.

By contrast, much greater age-related differences are revealed by the across-sentence ERP data seen in Figure 10. In the younger subjects, the ERPs to both relative clause sentence types are characterized by a positive frontal drift that is larger for Good compared with Poor comprehenders; likewise, the difference between the two relative clause types is larger for the better comprehenders. This pattern is consistent with the notions that the good comprehenders integrate the content of both sentence types more easily, and that they find the working memory demands made by the two types (relative to their capacity) to be dissimilar. Poor subjects, on the other hand, seem to experience difficulty with SS sentences so that they must stretch their processing capacity even with these "simpler" loads. In brief, at the sentence level, good and poor comprehenders differ in their treatment of SS sentences; their ERPs to SO sentences are roughly similar. Turning to the ERPs of the elderly subjects, we note that the Good comprehenders do exhibit slightly more frontal positivity (i.e. below the baseline) for both sentences types than the Poor comprehenders. However, neither group of elderly subjects shows as much difference between SO and SS sentence types as was present among even the poorer young comprehenders.

Two other features of these data deserve brief mention. First, the ERP data of both the young and elderly subjects show a very clear difference between the SO and SS sentences much earlier in the sentence than is typically observed in RT studies; specifically, this difference occurs at the sentence location where the second noun phrase of the SO sentences must be loaded into working memory. Such memory-loading negativities have been seen in non-linguistic tasks as well (e.g., Ruchkin et al., 1990). Another feature of the data from the elderly is that the end of the SS relative clause is marked by a noticeable negative peak (around 3000 msec or word 7). Closer inspection reveals that there is a similar *relative* negativity for the younger subjects, albeit smaller. We have also observed this clause-ending negativity (CEN), with its fronto-central and left-lateralized distribution in simple declarative sentences (Kutas and King, in press). Thus, the CEN may be an ERP feature of wider interest given the

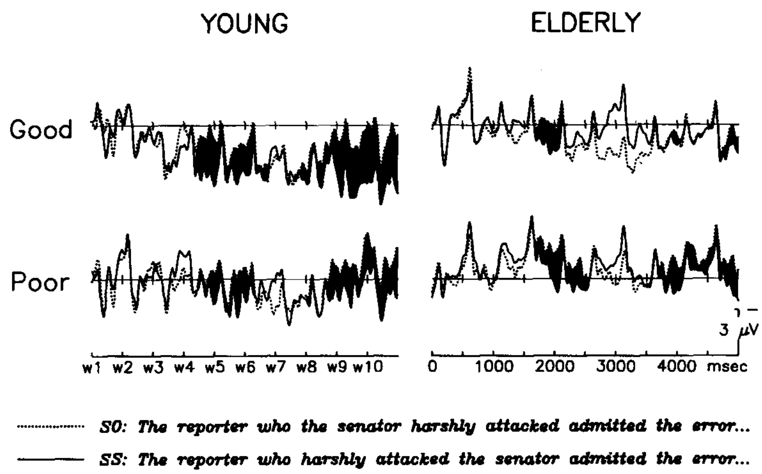


Figure 10. Grand average multi-word ERPs from left frontal sites for Young (n=24) and Elderly (n=18) subjects in response to SO and SS sentences. Good comprehenders in each group (n=12 and n=9 respectively) are shown in the top row and the Poor comprehenders shown in the bottom row. Word labels indicated on the left scale correspond to the onset of words 1 through 10 in the the words in the example sentences given below the waveforms.

known importance that clause endings have both in theoretical models of parsing (e.g., Frazier & Fodor, 1978) and in RT and eye movement data (e.g., Just & Carpenter, 1980). Of greatest relevance here, however, is that these processes, too, are intact in the elderly.

3. CONCLUSIONS

Like too many other topics within the field of cognitive aging research, not enough is known about how language processes change as people age, let alone about the electrophysiology related to these processes. What we do know is restricted to circumscribed situations, and concerns mostly reading rather than listening or language production. Fortunately, we can leverage this relatively scant information with the greater body of information we have about ERPs and language processing in young adults to reach some tentative conclusions and generate testable hypotheses for future research.

From the single word data we report, it appears that the ERPs prominent over the back of the head such as P1 and N1, which presumably reflect primarily early visual processing, are quite similar across the lifespan. Indeed, N1-P2 amplitudes varied with comprehension status in both young and elderly subjects alike. In contrast, both the temporal-parietal N1 and the centro-frontal P2 component were notably (and reproducibly) different in the older subjects, at least under conditions where words were presented at relatively fast rates (i.e. with stimulus onset asynchronies of either 500 or 550 msec in these studies). While neither of these

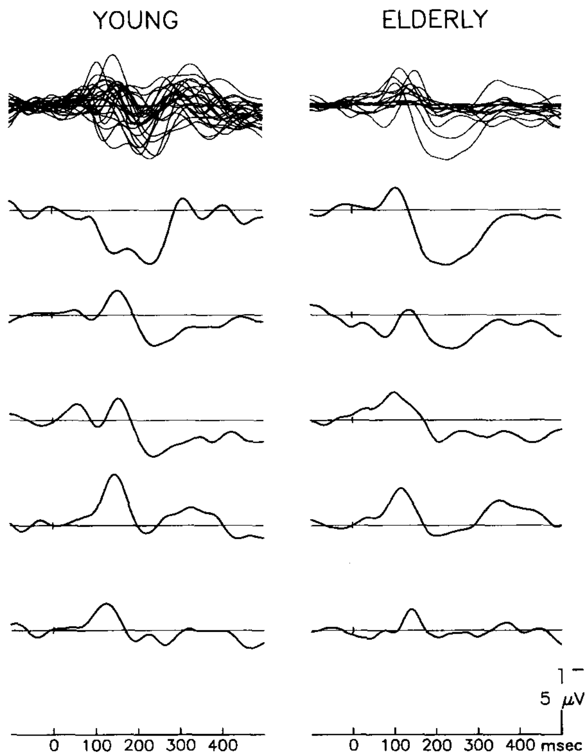


Figure 11. ERPs to all open class words at the left anterior temporal site for Young and Elderly subjects. The top row shows traces for all individual subjects overlapped, while the other rows show traces for approximately matched pairs of Young and Elderly subjects.

components has been studied systematically in language tasks, the localization of an important P2 generator to the basal temporal lobe area suggests that the marked reduction in its size may be related to known reductions in grey matter in that region of the brain. Subcomponents of the P2, likewise, have been implicated in studies of visual working memory, a process also known to be affected adversely by aging. Later components such as the N400 have been better in both young and elderly subjects and show the typical trend of becoming smaller and later with advancing age. These changes in semantic analyses (contextual integration) are clearly quantitative rather than qualitative in nature. The elderly are slower and more variable in their registration of meaning. Exactly what mechanism is at the core of N400 generation remains unclear, although both attentional and inhibitory processes have been suggested. Data from our recordings of longer epochs suggest that much of the normal, sustained processing during reading is essentially unchanged in the elderly, except when their reduced working memory capacity impacts their efficiency at parsing linguistic input and at integrating the results into their ongoing discourse representations.

Our observations on the general consequences of aging on reading notwithstanding, we think it important to emphasize that these effects of aging are neither categorical nor absolute. While we have taken care to exclude subjects whose physical or mental health was in question, what we portray here as the result of "the aging process" is, naturally, the net sum of many influences that differ from individual to individual. As the waveforms in Figure 11 suggest, individual variability is great even at those frontal sites where many aging-related changes are evident on the average; taken one by one, some young and some old subjects look more alike than one would have predicted from examining the averages alone. The grand mean is never the grand meaning.

In the future, we expect to see much more work in the field of geriatric psycholinguistics, not only to understand normal developmental changes in language processing, but also to understand changes caused by diseases such as dementia of the Alzheimer's type, Parkinson's dementia, and strokes that effect both the traditional and nontraditional language areas (Ojemann, 1991). ERP-based research promises to be on the forefront of such research efforts, especially if the ecological validity of ERP paradigms can be increased by technological advances in the presentation of auditory stimuli, and in the use of saccade-related potential research in reading paradigms (e.g. Marton & Szirtes, 1988). The increasing availability of high quality anatomical MRI scans should also be crucial, not only to allow the measurement of age-related changes in the brain (e.g., Jernigan et al., 1991) but also as a way to facilitate the identification of the neural generators of ERPs (e.g., Dale & Sereno, 1993). In the end, however, it will take the efforts of more than just neuroscientists to answer the mysteries of what it means to become older. When that story has been told, we should expect to know more about the brain, but also more about story-telling.

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