J Am Acad Audiol 13: 383–391 (2002)

Electrophysiologic Correlates of Attention versus Distraction in Young and Elderly Listeners

Albert R. De Chicchis*
Michael Carpenter†
Jerry L. Cranford†
Murvin R. Hymel†

Abstract

This study examined the effects of selective attention versus stimulus competition on the late auditory evoked potential (LAEP) in 20 young and 20 elderly listeners. In a series of test runs, different oddball tonal sequences were presented to one or both ears, and listeners were instructed to attend to tones at a specific target ear. Peak amplitudes were recorded for the N1, P2, and the early and late N2 components of the LAEP. Significant attention effects were found for all four components. N1 amplitudes increased significantly when participants attended to the target stimuli, whereas the amplitudes of P2, N2e, and N2l decreased. For all LAEP components except N2l, the attention effect did not differ between young and elderly listeners. Significant competition effects also were found for all four components. Amplitudes were significantly larger in monaural than binaural conditions for all components except N2l. The magnitude of this competition effect also was significantly larger for the young listeners than the elderly for all components except N1. These results suggest that the ability to attend selectively to sounds may be more resistant to normal aging than are effects related to stimulus competition.

Key Words: Attention, auditory event-related potential, competition, N1, P2, N2e, N2l, processing negativity

Abbreviations: ERP = event-related potential; LAEP = late auditory evoked potential; PN = processing negativity

Sumario

Este estudio examinó los efectos de la atención selectiva y de la competencia del estímulo en los potenciales evocados auditivos tardíos (LAEP) en 20 sujetos jóvenes y 20 viejos. En una serie de pruebas, diferentes extrañas secuencias tonales fueron presentadas a uno o a los dos oídos, y los sujetos fueron instruidos para responder a los tonos en un oído blanco específico. Las amplitudes pico fueron registradas para N1, P2 y para los componentes tempranos y tardíos de N2 en los LAEP. Se encontraron efectos significativos de atención para los cuatro componentes. Las amplitudes N1 se incrementaron significativamente cuando los participantes pusieron atención a los estímulos blanco, mientras que las amplitudes de P2, N2e y N2l disminuyeron. Para todos los componentes de los LAEP excepto N2l, el efecto de atención no fue diferente entre los sujetos jóvenes y viejos. Efectos de competencia significativos fueron encontrados también para los cuatro componentes. Las amplitudes fueron significativamente mayores en condiciones monoaurales que binaurales para los cuatro componentes excepto en N2l. La magnitud de este efecto de competencia fue significativamente mayor para sujetos jóvenes que para los viejos en los cuatro componentes excepto N1. Estos resultados sugieren que la habilidad para escuchar selectivamente a sonidos puede ser más resistente al envejecimiento normal que los efectos relacionados con la competencia del estímulo.

Palabras Clave: Atención, potenciales auditivos relacionados con el evento, N1, P2, N2e, N2l, negatividad de procesamiento

Abreviaturas: ERP = potencial relacionado con el evento; LAEP = potencial evocado auditivo tardío; PN = negatividad de procesamiento

*Department of Communication Sciences and Disorders, The University of Georgia, Athens, Georgia; †Department of Communication Sciences and Disorders, East Carolina University, Greenville, North Carolina

Reprint requests: Albert R. De Chicchis, Department of Communication Sciences and Disorders, The University of Georgia, 564 Aderhold Hall, Athens, GA 30602

The ability to selectively attend to auditory and visual stimulation in the presence of competition has been shown to decline in the elderly population (Plude et al, 1994). This decline has been reported with both behavioral and electrophysiologic measures (Cranford and Martin, 1991; Martin and Cranford, 1991; Jerger et al, 1995). For example, in a study comparing the ability of young and elderly listeners to repeat digits presented dichotically, Martin and Cranford (1991) found that performance was significantly poorer in older listeners beginning at approximately 50 years of age. Similar age-related declines in test performance have been reported with other behavioral test paradigms (e.g., Jerger and Jordan, 1992; Jerger et al, 1994). It has been suggested that these decreases in performance are attributable to an age-related decline in selective attention (Martin and Cranford, 1991; Jerger et al, 1995; Sommers, 1997). It is believed that, in later years of life, a decline occurs in the ability to selectively attend to a signal in one ear while simultaneously ignoring signals presented to the opposite ear.

The ear's ability to attend selectively to particular auditory signals while ignoring other different sounds has been investigated using electrophysiologic methods. It has been reported (e.g., Hillyard et al, 1973; Hymel et al, 2000; Carpenter et al, 2001) that the amplitude of the N1 component of the late auditory evoked potential (LAEP) is increased when sound stimuli are attended to, in contrast to when sound stimuli are ignored. Hillyard and colleagues (1973) were the first investigators to provide controlled evidence of an enhanced N1 in a selective attention task. Subsequent studies indicated that the N1 effect found in the selective attention paradigm was, in part, attributable to the activation of an endogenous neural process called the "processing negativity (PN)" (Näätänen et al, 1978; Parasuraman, 1978; Hanson and Hillyard, 1980; Alho et al, 1987; Alho, 1992; Woods, 1995). The PN involves a negative voltage shift of ongoing brain activity. When it occurs, this attention response can add to or subtract from the normally occurring components of the LAEP. If this attention response occurs early, it can add to the already negative N1 response and make it larger. If it occurs later, it can subtract from the positive voltage P2 response and make it smaller. The latency at which the PN occurs appears to be dependent on different stimulus or task variables (Woods, 1990).

More recently, the effects of stimulus competition on different components of the LAEP have been investigated (Cranford and Martin, 1991; Hymel et al, 1998; Fisher et al, 2000). In these studies, rather than examining amplitude differences between attend and ignore conditions, comparisons were made between evoked potentials recorded to signals at one ear in the presence or absence of multitalker speech babble presented to the opposite ear. These studies investigated whether elderly listeners had more difficulty attending to signals presented to one ear when potentially "distracting" sounds were present at the opposite ear. Although Hymel and colleagues (1998) reported reduced amplitudes for both N1 and P2 in the presence of competition, it was only the N1 component that exhibited an age-related effect in which elderly listeners exhibited significantly larger amplitude reductions than young participants. In contrast, Fisher and colleagues (2000) found that although N1 showed no competition-related amplitude changes, the P2 component was reduced in amplitude, with elderly listeners exhibiting significantly larger changes. Although both studies employed multitalker speech babble as the competing stimulus, Hymel and colleagues used pure tones as the target stimuli, whereas Fisher and associates used nonsense syllables as target stimuli.

In contrast to Cranford and Martin's (1991) earlier use of speech babble competition, the present study used a special oddball stimulus paradigm recently developed in our laboratory (Hymel et al, 2000), which allows a direct comparison of "selective attention" versus "stimulus competition" effects in groups of young and elderly listeners. A modified version of the Hillyard et al (1973) test was used that involved, on different test runs, presenting discriminably different oddball tonal sequences to one or both ears and having listeners selectively listen to target stimuli at one ear. To examine attention effects, evoked potentials recorded to target stimuli that the listeners attended were compared to stimuli that they ignored. Stimulus competition effects involved comparing waveforms to target stimuli recorded in the presence or absence of tonal stimuli at the contralateral ear. The direct comparison of attention versus distraction effects in the same experiment is important because both problems are common symptoms that underlie a multitude of brain pathologies ranging from dementia in aging to attention-deficit disorders in children.

METHOD

Participants

Twenty young and 20 elderly volunteers participated in this investigation. The young listeners ranged in age from 18 to 25 years (mean = 22 years), whereas the older listeners ranged from 65 to 82 years (mean = 72 years). Each group contained equal numbers of males and females. All of the young volunteers had hearing within normal limits (< 20 dB HL) for the frequencies 250 to 8000 Hz. The older participants had normal thresholds from 250 to 1000 Hz, with thresholds no poorer than 40 dB HL at 2000 Hz. All listeners demonstrated normal acoustic immittance at both ears (ASHA, 1990).

Electrophysiologic Testing

Neuroelectric activity was recorded from 21 scalp locations (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2, M1, and M2) placed in accordance with the International 10-20 electrode system nomenclature (Jasper, 1958) and referenced to the tip of the nose. Ocular movements were monitored by electrodes placed above and below the left eye. Participants were instructed to maintain visual fixation on a target placed at eye level in front of them and to blink normally to minimize contamination by ocular movement. Electrode impedances were maintained below 3000 ohms. Electroencephalographic (EEG) activity was amplified 1000 times, analog filtered (1 to 70 Hz, 24 dB/octave slope), and digitized at an analog-to-digital rate of 500/sec with a PC-based NeuroScan system and SynAmps 16-bit amplifiers. All evoked potentials were recorded in an electrically shielded sound-treated room, with the participant seated in a reclining chair.

The EEG was stored to compact disc for offline processing. Ocular artifacts were digitally removed from the EEG (Semlitsch et al, 1986). The EEG was divided into epochs that extended from –100 to +600 msec relative to the onset of each stimulus presentation. The epochs recorded from similar stimulus test conditions (i.e., right monaural, left monaural, right binaural, left binaural) were added together. A 100-msec prestimulus recording served as a baseline reference to correct for the direct current (DC) level of background EEG activity. The

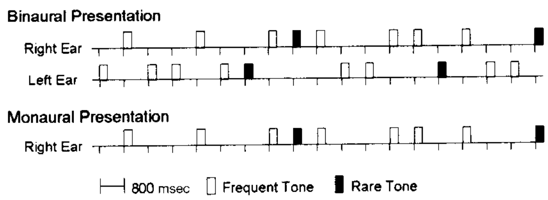

Figure 1 Representative segments of stimulus test runs taken from the binaural and monaural oddball tonal sequences.

epochs were sorted by type and averaged into frequent and rare stimulus waveforms. Epochs containing artifacts exceeding ±50 μV were rejected from averaging. Grand-averaged waveforms were constructed for analysis.

Recording Conditions

LAEPs were recorded while participants listened to different sets of oddball stimuli presented, on different test runs, to one or both ears. During binaural test runs, volunteers received sequences of 1000-/1100-Hz tone bursts in one ear and sequences of 2000-/2200-Hz tone bursts in the opposite ear. Tonal stimuli were 50 msec in duration (10-msec rise–fall, 30-msec plateau) and were presented at 85 dB peak SPL, with a stimulus onset asynchrony, in the binaural presentation mode, of 800 msec. Figure 1 illustrates samples of tonal sequences taken from the binaural and monaural test runs. The probability of occurrence was 84 percent and 16 percent for the frequent and rare tones, respectively. Half of the participants received the lower-frequency tones in the left ear and the higher-frequency tones in the right ear. The remaining half had the frequency order reversed. A PC-based computer package (NeuroScan STIM) was used to generate and randomize the tone-burst stimuli employed during this study. Four randomized recording conditions (two monaural and two binaural) were obtained per participant. The order of presentation of the four stimulus conditions was counterbalanced using a digram-balanced Latin square design (Wagenaar, 1969). For each monaural condition, the participant listened for the higher pitch tone (rare event) presented either to the left ear (left monaural) or right ear (right monaural) and responded by pressing a button. On monaural runs, half of the participants had the left ear as the designated target ear; the right ear served as the target ear for the other half. For each binaural condition, the participant was asked to attend to a particular ear and respond to the rare tonal events, while ignoring stimuli in the opposite ear. Stimuli were presented in four blocks of 200 (100 stimuli to each ear) for each of the four recording conditions. Thus, a total of 16 evoked potential recordings were obtained for each participant. To keep the interstimulus interval, the number of stimulus presentations to the attending ear, and the test time for each recording condition constant for both monaural and binaural test conditions, the insert earphone was left in the nonattending ear but was disconnected from the transducer during monaural stimulus presentations. Participants were allowed to practice listening to the experimental stimuli prior to data collection to make sure that they understood the task instructions and that the task could be performed satisfactorily. On all monaural and binaural test runs, listeners in both groups exhibited performance levels of 90 percent or better.

To investigate attention effects, evoked potential waveforms recorded to frequent tones at the ear the listener had been instructed to ignore were subtracted from the response to the frequent tones at the ear the participant was instructed to attend. Competition effects were measured by subtracting the responses to attended frequent tones recorded in the binaural test conditions from responses to attended frequent tones recorded during monaural test runs.

Group-averaged LAEP peak amplitudes recorded to the frequent tones were measured for N1, P2, and the early and late components of N2 (N2e and N2l). N1 was defined as the lowest absolute negative voltage (from baseline) that occurred between 75- and 150-msec poststimulus onset (Alexander et al, 1996). P2 was defined as the highest positive voltage peak following N1 that occurred between 150 and 250 msec, whereas N2e and N2l were defined as the lowest absolute negative peaks in the epochs 250 to 350 msec and 350 to 500 msec, respectively. On those occasions where wave bifurcation occurred or multiple peaks were present in the wave component of interest, amplitude was measured for the largest individual peak. The mean amplitudes of each of these four LAEP components (N1, P2, N2e, and N2l) were determined for each of the three listening conditions: attend-binaural, ignore-binaural, and attend-monaural. Data were examined for possible effects related to (1) test condition (i.e., attend versus ignore or monaural versus binaural) and (2) age (i.e., young versus elderly).

RESULTS

Examination of topographic maps (not shown) indicated that, for both participant groups, maximum amplitude of the neuroelectric activity was centered in the region of Cz. Grand-averaged LAEP waveforms recorded at Cz for both the attention effect and the competition effect are illustrated in Figure 2. A series of mixed three-factor repeated-measures analyses of variance were performed on the amplitude data obtained at Cz to examine the effects of condition, age, and ear on N1, P2, N2e, and N2l. No significant main effects for ear were found, nor were there any interactions involving ear. All analyses were performed using a statistics computer software package (SPSS for Windows, Releases 6.14 and 9.0.0). Relative treatment magnitude sizes (i.e., the proportion of variation "explained" by the independent variable) are indexed by omega-squared values (Keren and Lewis, 1979; Keppel, 1991). Omega-squared values of .01, .06, and .15 are considered to represent small, medium, and large effect sizes, respectively (Cohen, 1977).

Attention Paradigm

When attending to a particular stimulus in one ear and ignoring stimuli at the opposite ear, N1 amplitudes were significantly larger at the attended ear than the nonattended ear for both young and elderly listeners ($F = 8.65$, $df = 1, 36$, $p = .006$, $\omega^2 = .161$). This attention effect is shown in Figure 3A. The magnitude of this attention effect did not differ between the young and elderly participant groups ($F = .102$, $df = 1, 36$, $p = .751$, $\omega^2 = .003$).

As shown in Figure 3B, both groups showed a statistically significant decrease in the amplitude of P2 ($F = 7.04$, $df = 1, 36$, $p = .012$, $\omega^2 = .125$) when participants attended to the test stimulus. Thus, in the present study, the PN (i.e., the negative polarity shift in baseline activity associated with selective attention) overlapped the latency window of both N1 and P2 components of the LAEP. A main effect for age also was found for this wave component ($F = 7.81$, $df = 1, 36$, $p = .008$, $\omega^2 = .028$). As noted in Figure 3B, the amplitude of P2 was significantly larger for the younger listeners as compared with the elderly listeners. As with N1, the attention effect for P2 (i.e., the magnitude of the amplitude change between the attend and the ignore condition) did not differ between the two age groups ($F = 1.59$, $df = 1, 36$, $p = .215$, $\omega^2 = .012$).

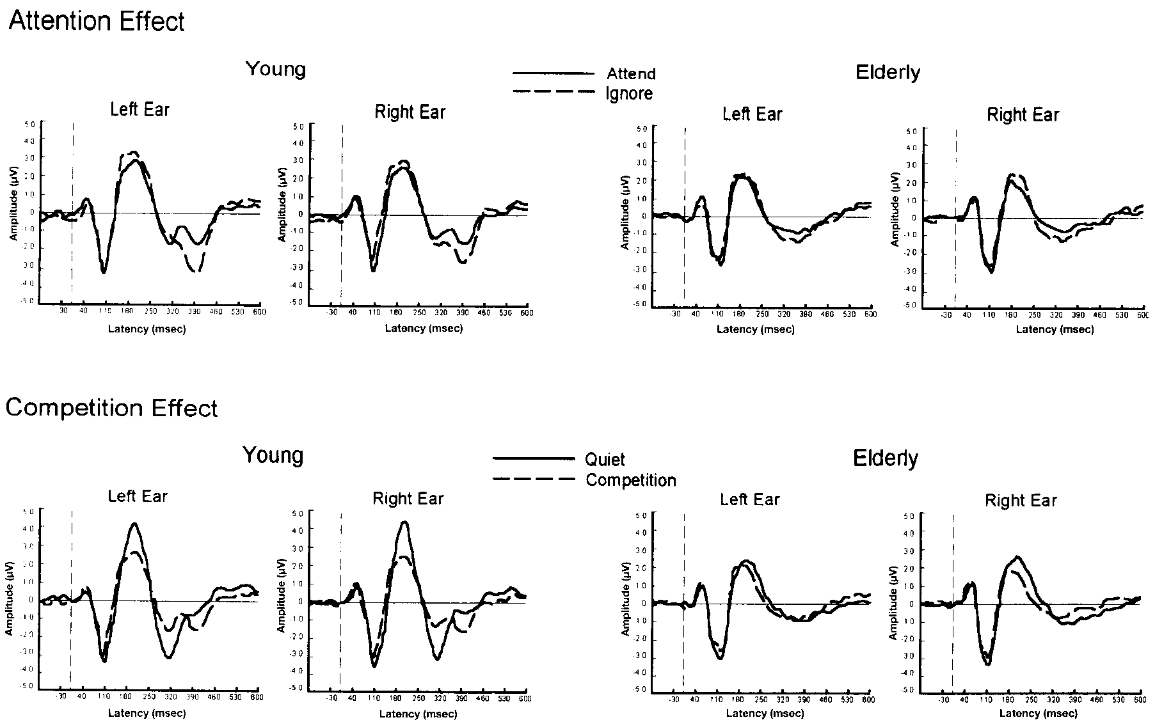

Figure 2 Grand-averaged event-related potential waveforms recorded from the vertex (Cz) in the attention and competition test paradigms.

In the latency window of N2e, when participants attended to the tones, a positive rather than a negative baseline shift occurred, as evidenced by the finding of a statistically significant reduction in the amplitude of this component ($F = 5.85$, $df = 1, 36$, $p = .021$, $\omega^2 = .112$). No significant age effect (i.e., no difference in amplitudes between young and elderly listeners) was found for this component, nor was any age by condition interaction found ($F = .797$, $df = 1, 36$, $p = .067$, $\omega^2 = .022$). These findings are illustrated in Figure 3C. Thus, the degree of attention-related change in N1, P2, and N2e amplitudes was all found to be relatively resistant to age.

Somewhat different findings were found for N2l. For the young listeners, the amplitude of this component was reduced significantly in the attend condition ($F = 7.09$, $df = 1, 36$, $p = .011$, $\omega^2 = .110$). A significant effect of age also was found, in which young listeners demonstrated significantly larger N2l amplitudes than did the elderly ($F = 15.6$, $df = 1, 36$, $p < .001$, $\omega^2 = .096$). Finally, for this component, an age by condition interaction was found ($F = 9.6$, $df = 1, 36$, $p = .004$, $\omega^2 = .155$). These results are illustrated in Figure 3D. For the young listeners, the response amplitude of N2l decreased dramatically during the attend condition, whereas a slight increase in amplitude was found when elderly listeners attended to the tones. This apparent age-related effect may have resulted from a ceiling effect as elderly participants exhibited very low-amplitude N2l components.

Competition Paradigm

The effects of competition on the N1 response are shown in Figure 4A. The amplitude of N1 for both young and elderly listeners was significantly larger in the monaural condition than in the binaural condition ($F = 17.629$, $df = 1, 36$, $p < .001$, $\omega^2 = .287$). The magnitude of this competition effect did not differ between the young and elderly groups ($F = .036$, $df = 1, 36$, $p = .85$, $\omega^2 = .004$).

In addition to P2 being significantly larger ($F = 7.02$, $df = 1, 36$, $p = .012$, $\omega^2 = .032$) in young listeners than in the elderly (on both monaural and binaural test runs), the amplitude of the P2 component also was found to be significantly larger in the monaural condition than in the binaural condition ($F = 29.557$, $df = 1, 36$, $p < .001$, $\omega^2 = .385$). These findings are reflected in Figure 4B. A significant age by condition interaction also was found ($F = 6.98$, $df = 1, 36$, $p = .012$, $\omega^2 = .081$). The magnitude of the amplitude increase in the monaural test condition was

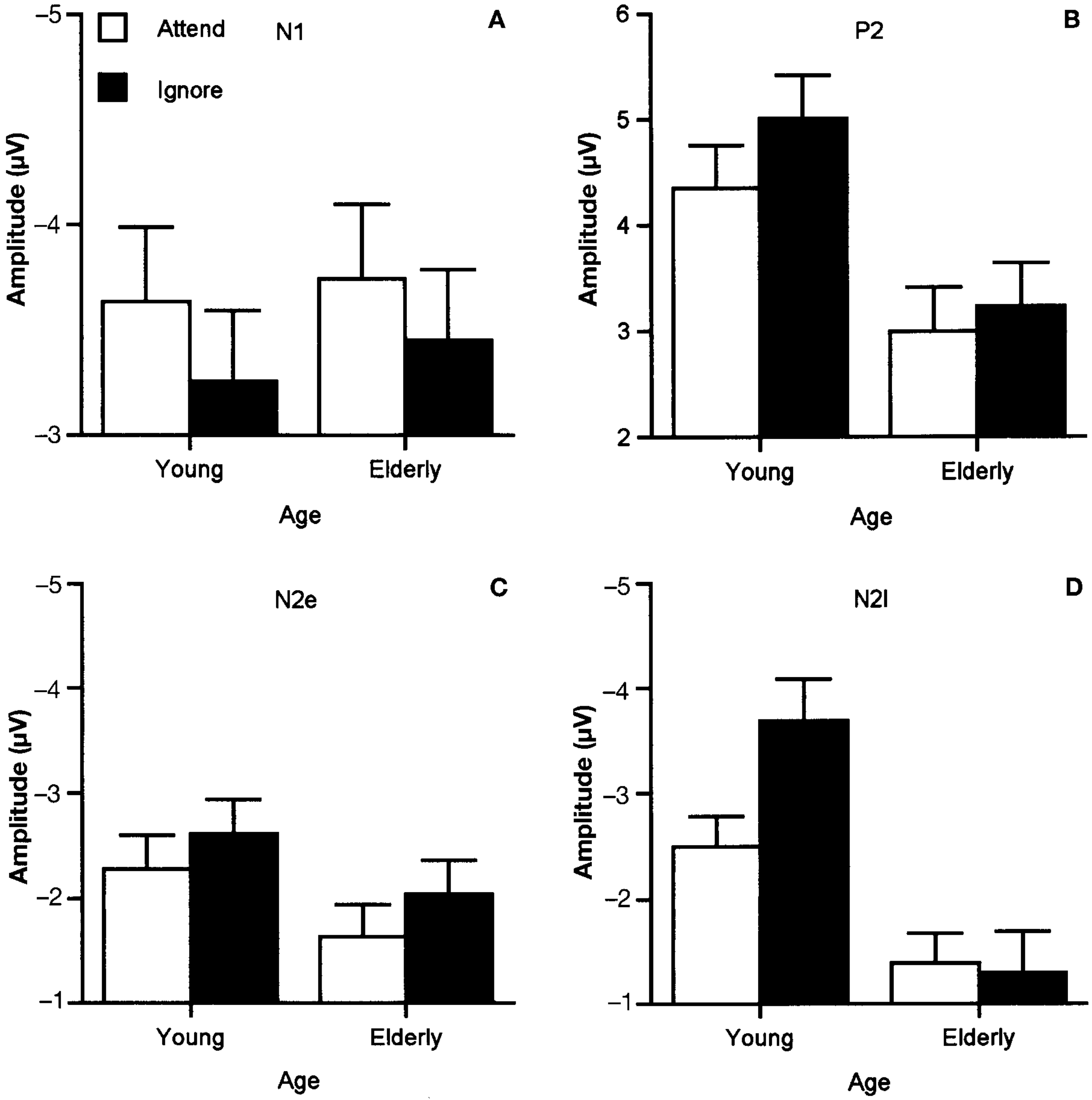

Figure 3 The effect of attention as a function of listening condition and age. Shown are the mean amplitudes for N1 (*A*), P2 (*B*), N2e (*C*), and N2l (*D*).

found to be significantly larger for the young participants than the elderly.

Figure 4C shows findings for N2e. Similar to N1 and P2, the amplitude of N2e was found to be significantly larger in the monaural condition ($F = 20.649$, $df = 1, 36$, $p < .001$, $\omega^2 = .217$) and significantly larger for the young listeners as compared with the elderly ($F = 10.51$, $df = 1, 36$, $p = .003$, $\omega^2 = .064$). In contrast to N1 and P2, the N2e component increased in amplitude in the monaural condition only for the young group of listeners, which resulted in a significant condition by age interaction ($F = 26.73$, $df = 1, 36$, $p < .001$, $\omega^2 = .285$). In comparison with the monaural condition, the amplitude of N2e decreased significantly in young listeners when tones were presented binaurally, whereas elderly listeners showed a slight increase in this component when tones were presented binaurally.

The apparent age-related changes involving significant decreases in the amplitudes of N1, P2, and N2e in the binaural conditions were in contrast to those found with N2l. The results with N2l are depicted in Figure 4D. Although a significant main effect for condition was found for this component ($F = 4.98$, $df = 1, 36$, $p = .032$, $\omega^2 = .076$), it was only the young participants who exhibited larger amplitudes in the binaural listening task. A significant condition by age interaction also was found ($F = 7.49$, $df = 1, 36$,

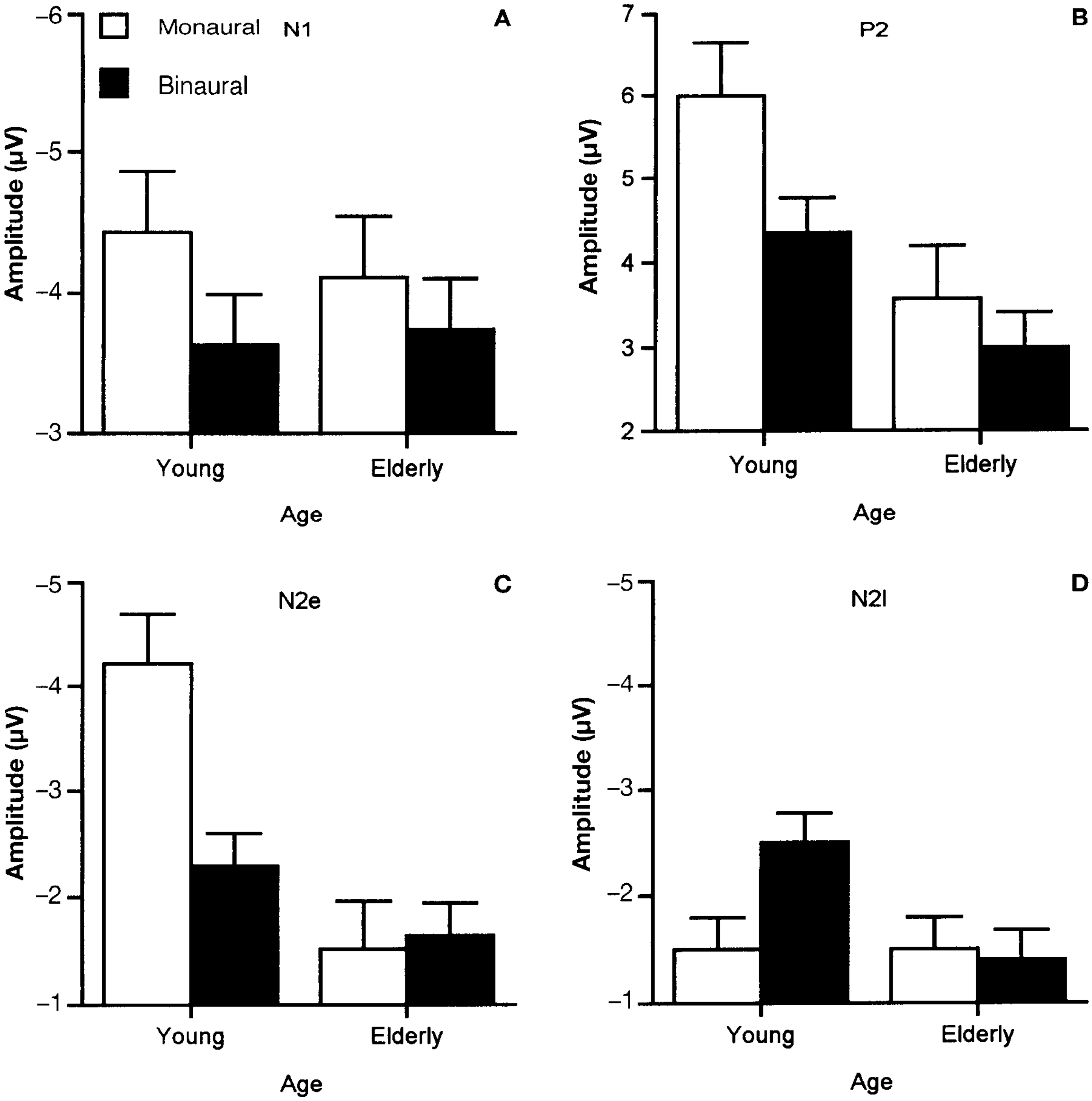

Figure 4 The effects of competition as a function of age. Shown are the mean amplitudes for N1 (*A*), P2 (*B*), N2e (*C*), and N2l (*D*).

$p = .01$, $\omega^2 = .124$). In the binaural task, the young participants showed an increase in the amplitude of N2l, whereas, for the elderly participants, the amplitude of this component decreased slightly. Similar to the findings with the attention paradigm, this finding may have resulted from a ceiling effect as the amplitude of the N2l component was very small for the elderly group.

DISCUSSION

The purpose of the present experiment was to compare possible electrophysiologic correlates of selective attention versus stimulus competition in young and elderly listeners. Selective attention effects were measured by having a listener attend to tones delivered to one ear while ignoring different tones delivered to the opposite ear. Evoked responses obtained to stimuli in the attending ear were then subtracted from similar responses obtained in the ear ignoring the other stimuli (attend minus ignore). Competition effects were measured by subtracting ERP responses to tones obtained in a binaural condition from ERP responses obtained in a monaural condition.

The present finding of significant increases in N1 peak amplitudes when young and elderly listeners attended to tonal stimuli in one ear and ignored different stimuli at the opposite ear is consistent with previous reports in the literature (Hillyard et al, 1973; Woldorff and Hillyard, 1991). In contrast to this earlier LAEP component, P2 was found to be significantly smaller in amplitude in the attend condition in contrast to the ignore condition. This most likely was owing to the fact that the PN (i.e., the negative voltage shift of EEG baseline activity that has been reported to be associated with selective attention; e.g., Näätänen et al, 1978) overlapped the time window of both the N1 and P2 components of the exogenous LAEP response. The PN, which begins around 150 msec and lasts for several hundred milliseconds, has been reported to be a slow negative component generated by an endogenous neural process in the brain that is independent of the cerebral mechanism responsible for generating the different components of the LAEP (Näätänen et al, 1978; Woods, 1990, 1995). The occurrence of this endogenous brain process can add to or subtract from the normally occurring components of the LAEP. However, the magnitude of these attention-related changes with both N1 and P2 was not found to differ between the young and elderly listening groups.

The present stimulus competition test paradigm, in contrast, yielded different and somewhat surprising findings. Although the observed changes in N1 and P2 amplitudes were in the expected direction (i.e., smaller in binaural as compared with monaural test conditions), for all of the components except N1, these amplitude differences between the monaural and binaural listening conditions were significantly greater for the young group as compared with the elderly. This is in marked contrast to previous investigations (e.g., Cranford and Martin, 1991; Hymel et al, 1998; Fisher et al, 2000) in which, in the presence of contralateral multitalker speech babble, elderly listeners exhibited significantly larger reductions in the earlier N1 and/or P2 components of the LAEP.

There were, however, several procedural differences between the present investigation and our earlier competition paradigm, some or all of which may account for these discrepant research findings. In all three earlier investigations, the target and competing stimuli temporally overlapped since the competing speech babble was presented continually throughout the test run. The earlier studies also used either tonal (Hymel et al, 1998) or nonsense syllables (Fisher et al, 2000) as the target stimuli, whereas the current project employed discriminably different oddball tonal sequences as the target and competing stimuli. Also, in the present study, the target and competing tonal signals were presented in a temporally nonoverlapping fashion with the signals at the two ears separated by a constant 800-msec temporal gap (see Fig. 1).

Because the earlier research paradigm (e.g., Cranford and Martin, 1991) involved temporally overlapping target and competing stimuli, we cannot rule out the occurrence of some form of central "masking" (albeit suprathreshold in nature) and/or central interference effect that possibly differed between the young and elderly listeners. In the present investigation, however, the fact that the effective interstimulus intervals on monaural runs was twice that of binaural runs (i.e., 800 versus 1600 msec) also suggests that some binaural form of neural refractory or recovery effect may have occurred. In terms of monaural refractoriness, it has been shown that the later potentials (e.g., N1 and P2) have recovery periods that may exceed 1 sec in length (Nelson and Lassman, 1973; Picton et al, 1977). However, whereas monaural refractoriness is known to affect both N1 and P2, the present effect appeared to be limited to P2. This suggests that if the present finding is attributable to a binaural refractory event, then neural mechanisms different from those responsible for monaural refractoriness may be involved.

In a recent study, Carpenter and colleagues (2002) attempted to further differentiate monaural from binaural neural refractory or recovery effects by adding special monaural test runs to the present experimental paradigm to control for differences in interstimulus intervals between monaural and binaural test conditions. Unfortunately, this study did not satisfactorily rule out the possibility that some kind of passive or active endogenous attention effect, rather than neuronal refractoriness, was the basis for the observed binaural competition effect. What is needed to resolve this issue is a "sleep" study, which would test for the presence of possible binaural forms of neuronal refractory or recovery phenomenon in volunteers who are documented (by EEG analysis) to be in stage II or deeper levels of sleep. This procedure should eliminate any known overt or covert attention response to the target stimuli. The identification of binaural neural refractoriness in the human brain would be a very important finding since it could substantially alter our theoretical interpretations of the results of a myriad of earlier published binaural listening studies.

Finally, the significant effects found for late components of N2 are less clear. Although the change in the amplitude of the response for both attention and competition tends to follow, in general, that observed for P2, the response amplitudes for the elderly listeners were often very small, and it is thought that these findings may reflect ceiling effects. The authors are unaware of any other studies examining the effects of attention or competition on these later ERP components, and replication of these findings is essential before any significance can be attributed to them.

REFERENCES

Alexander JE, Bauer LO, Kuperman S, et al. (1996). Hemispheric differences for P300 amplitude from an auditory oddball task. *Int J Psychophysiol* 21:189–196.

Alho K. (1992). Selective attention in auditory processing as reflected by event-related brain potentials. *Psychophysiology* 29:247–263.

Alho K, Töttölä K, Reinikainen K, et al. (1987). Brain mechanism of selected listening reflected by event-related potentials. *Electorencephalogr Clin Neurophysiol* 68:458–470.

American Speech-Language-Hearing Association. (1990). Guidelines for screening for hearing impairments and middle ear disorders. *ASHA* 32(Suppl 2):17–24.

Carpenter M, De Chicchis AR, Cranford JL. (2001). Electrophysiologic correlates of attention versus stimulus competition in young male and female listeners. *J Am Acad Audiol* 12:142–149.

Carpenter M, Cranford JL, Hymel MR, et al. (in press). Electrophysiologic signs of attention versus distraction in a binaural listening task. *Journal Clin Neurophysiol* 19:55–60.

Cohen J. (1977). *Statistical Power Analysis for the Behavioral Sciences*. Rev. Ed. New York: Academic Press.

Cranford JL, Martin DR. (1991). Age-related changes in binaural processing: I. Evoked potential findings. *Am J Otol* 12:357–364.

Fisher AL, Hymel MR, Cranford JL, De Chicchis AR. (2000). Electrophysiologic signs of auditory distraction in elderly listeners. *J Am Acad Audiol* 11:36–45.

Hanson J, Hillyard S. (1980). Endogenous brain potentials associated with selective auditory attention. *Electroencephalogr Clin Neurophysiol* 49:277–290.

Hillyard S, Hink R, Schwent V, Picton T. (1973). Electric signs of attention in the human brain. *Science* 182:177–180.

Hymel MR, Cranford JL, Stuart A. (1998). Effects of contralateral speech competition on auditory event-related potentials recorded from elderly listeners: brain map study. *J Am Acad Audiol* 9:1–13.

Hymel MR, Cranford JL, Stuart A. (2000). Electrophysiologic signs of auditory competition in the human brain. *Neurosci Lett* 283:105–108.

Jasper HH. (1958). The ten twenty electrode system of the international federation. *Electroencephalogr Clin Neurophysiol* 10:371–375.

Jerger J, Jordan C. (1992). Age-related asymmetry on a cued-listening task. *Ear Hear* 13:272–277.

Jerger J, Alford B, Lew H, et al. (1995). Dichotic listening, event-related potentials and interhemispheric transfer in the elderly. *Ear Hear* 16:482–489.

Jerger J, Chmiel R, Allen J, Wilson A. (1994). Effects of age and gender on dichotic sentence identification. *Ear Hear* 15:274–286.

Keppel G. (1991). *Design and Analysis: A Researcher's Handbook*. 3rd Ed. Upper Saddle River, NJ: Prentice Hall.

Keren G. Lewis C. (1979). Partial omega squared for ANOVA designs. *Educ Psychol Meas* 39:119–128.

Martin DR, Cranford JL. (1991). Age-related finding in binaural processing: II. Behavioral findings. *Am J Otol* 12:365–369.

Naatanen R, Gaillard A, Mantysalo S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta Psychol* 42:313–329.

Nelson DA, Lassman FM. (1973). Combined effects of recovery period and aperiodic stimulation on the auditory-evoked vertex response. *Audiology* 16:409–418.

Parasuraman R. (1978). Auditory evoked potentials and divided attention. *Psychophysiology* 15:460–465.

Picton TW, Woods DL, Baribeau-Braun J, Healey TMG. (1977). Evoked potential audiometry. *J Otolaryngol* 6:90–119.

Plude DJ, Enns JT, Brodeur D. (1994). The development of selective attention: a life-span overview. *Acta Psychol* 86:227–272.

Semlitsch HV, Anderer R, Schuster P, Presslich O. (1986). A solution for reliable and valid reduction of ocular artifacts applied to the P300 ERP. *Psychophysiology* 23:695–703.

Sommers MS. (1997). Stimulus variability and spoken word recognition II. The effects of age and hearing impairment. *J Acoust Soc Am* 101:2278–88

Wagenaar WA. (1969). Note on the construction of digram-balanced Latin squares. *Psychol Bull* 72:384–386.

Woldorff MG, Hillyard S. (1991). Modulation of early auditory processing during selective listening to rapidly presented tones. *Electroencephalogr Clin Neurophysiol* 79:170–191.

Woods DL. (1990). The physiological basis of selective attention: implications of event-related potential studies. In: Rohrbaugh JW, Parasuraman R, Johnson R Jr, eds. *Event-Related Potentials*. New York: Oxford University Press, 178–209.

Woods DL. (1995). The component structure of the N1 wave of the human auditory evoked potential. *Electroencephalogr Clin Neurophysiol* (Suppl):102–109.

Woods DL, Clayworth CC. (1985). Age-related changes in human middle latency auditory evoked potentials. *Electroencephalogr Clin Neurophysiol* 65:297–303.