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Effect of Age on Interaural Asymmetry of Event-Related Potentials in a Dichotic Listening Task

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Abstract

Three groups of subjects, children, young adults, and elderly persons with presbyacusis, were tested in a directed attention, quasidichotic paradigm in which continuous speech was monitored for syntactically and/or semantically anomalous words. The task evoked an event-related potential (ERP) characterized by a positive peak in the latency region of 600 to 1000 msec. ERPs were separately averaged for target-word-right and target-word-left conditions. Amplitude and latency measures at the peak of the global field power waveform were calculated. Amplitude was significantly larger in children than in either adult group. In children and young adults, both amplitude and latency measures were equivalent for target-right and target-left conditions, but in elderly persons, latency was significantly greater in the target-left than in the target-right condition. Topographic maps of amplitude at the peak of the ERP waveform showed maximal positivity symmetrically distributed around the midline centroparietal area in both right-attended and left-attended conditions. In elderly persons, however, maximal positivity in the left-attended condition was significantly delayed relative to maximal positivity in the right-attended condition. Results are consistent with previous findings of interaural asymmetry in a dichotic listening task in elderly persons.

Key Words: Aging, dichotic, event-related potential, interaural asymmetry

Abbreviations: ERP = event-related potential, GFP = global field power, VEOG = vertical electro-ocular activity

Previous research has suggested that aging may alter auditory evoked potentials, especially event-related potentials (ERPs), in two ways. First, there is evidence that amplitude declines and latency increases with age (for a comprehensive review, see Hall, 1992). Second, there is evidence that, in dichotic listening tasks, interaural asymmetry increases with age (Jerger, 1997). The bulk of this research has been carried out using, as stimuli, either pure tones, nonsense syllables, or single-syllable words. In the present study, however, we have sought to extend the investigation to a task more representative of the problems encountered in real-life listening to ongoing speech.

To this end, we have devised a procedure patterned loosely after a vigilance task. The speech material is a recording of two classic children's fairy tales, "Cinderella" and "Snow White." The recording is presented via loudspeakers situated directly to the right and directly to the left of the subject's head. The presentation is quasidichotic. The subject hears one part of the fairy tale from one loudspeaker but a different part of the same fairy tale from the other loudspeaker. Throughout the story, some words have been replaced by inappropriate or anomalous words—for example, "Thank you kind fairy godmother, said Cinderella jump sincerely."

The subject's task is to make an appropriate response whenever an anomalous word is heard. The subject is told to respond only to what is heard from one side and to disregard what is

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heard from the other side. On one half of the trials, attention is directed to the right side, on the other half to the left side. In effect, the subject must attend to what is heard from one direction while simultaneously suppressing what is heard from the other direction and, upon command, to reverse the side to be attended and the side to be suppressed. We have sought, in this paradigm, to create a laboratory version of the situation that elderly persons frequently encounter in real life, the problem of attending to real speech from one direction in the presence of competing real speech from a different direction.

In a prior publication (Jerger et al, 2000), we studied this paradigm in 20 young adults with normal hearing. The anomalous words evoked an ERP showing robust positivity in the midline centroparietal region at a latency of about 900 msec. We related this response to the classic positive ERP in the 600- to 1000-msec latency region, sometimes called the late positive component (Gunter et al, 1997), associated with the processing of syntactic and other grammatical anomalies (Herning et al, 1987; Osterhout, 1992; Friederici et al, 1993; Osterhout and Holcomb, 1993; Coulson et al, 1998). In our study of young adults (Jerger et al, 2000), there was no significant difference between "attend-to-target-right" and "attend-to target-left" conditions.

The purpose of the present investigation was to study how age affects the ERP evoked by anomalous words in this quasidichotic paradigm.

METHOD

Subjects

We tested a total of 30 subjects in three age groups: (1) children, (2) young adults, and (3) elderly persons (seniors). One group consisted of 10 children. All were 11 years old. There were 7 boys and 3 girls. Each had been tested as part of a separate study of dichotic listening in developmentally dyslexic children (Moncrieff, 1999). They had served as the control group for that study. All had passed a hearing screen at 15 dB HL over the frequency range from 500 to 4000 Hz.

A second group consisted of 10 young adults ranging in age from 18 to 33 years. All had passed a hearing screen at 20 dB HL over the frequency range from 500 to 4000 Hz. There were 4 men and 6 women.

The third group consisted of 10 seniors with mild or moderate presbyacusic hearing sensitivity loss. There were 6 men and 4 women. Average audiograms for right and left ears were similar and showed a gradually poorer theshold level with increasing frequency. The average threshold level at 1000 Hz was 26.0 dB HL for the right ear and 25.5 dB HL for the left ear. In the high-frequency region, sensitivity was slightly better in the left ear. Mean thresholds were similar at 4000 Hz, 52.0 dB HL in the right ear and 51.5 dB HL in the left ear, but at 6000 Hz mean thresholds for right and left ears were 66.5 and 55.5 dB HL, respectively. Similarly, at 8000 Hz, thresholds were 79.0 dB HL in the right ear and 73.5 dB HL in the left ear. It should be noted, therefore, that, in this group, any evidence of poorer performance for left-sided targets cannot be attributed to greater high-frequency sensitivity loss on the left ear. All elderly subjects passed the Mini-Mental Status Examination (Folstein et al, 1975).

Four of the 10 elderly subjects were hearing aid users. One wore a monaural aid, the remaining three were binaural users. All 10 subjects were tested without their aids.

All 30 subjects were right handed by questionnaire (Annett, 1970), had learned English as their first language, and had no history of neurologic or other serious disease.

Test Stimuli

For a complete description of the present test paradigm, see Jerger et al (2000). Briefly, the subject heard the story of "Cinderella" and a portion of the story of "Snow White," recorded by a male voice and divided into 200 segments at natural pause breaks. Segments were approximately equivalent in length. One hundred of the segments contained target word anomalies. The 100 remaining segments contained no anomalies. The segments to be altered were chosen at random. The test stimuli were stored in digital form and delivered to the subject via digital-to-analog conversion.

Target words were drawn from a pool of single-syllable words derived primarily from the phonemically balanced (PB) word lists of Egan (1948). Target words were intentionally selected without regard for (1) the particular semantic and/or morphosyntactic anomaly created or (2) its position in the phrase or sentence. Our goal was not to study a particular form of linguistic anomaly but simply to randomly interrupt the semantic and/or grammatical integrity of the story. However, anomalous nouns in the final position of the sentence or phrase predominated. Of the total pool of target words, 66 were nouns, 15 were verbs, 12 were adjectives, 5 were adverbs, and 1 was a pronoun. Fifty-seven target words occurred as the final word in the sentence or phrase, 42 within the sentence or phrase. Thirty-three target words produced purely semantic anomalies (e.g., "she had to sweep the sky"). The remaining 66 target words produced both semantic and grammatical anomalies (e.g., "and you shall deep to the ball").

The same recording was presented from both loudspeakers but was delayed by 20 segments on one side relative to the other side. For example, if the segment "Once upon a time" was presented from the right side, the segment "be allowed to go to the ball" was presented simultaneously from the left side. The entire sequence of 200 segments was divided into 8 blocks of 25 segments each. Within each block, there were 12 to 14 target stimuli and 11 to 13 nontarget stimuli. Prior to each block of 25 stimuli, the subject was instructed, via computer monitor screen, to either listen for target words on the right side and ignore the left side or listen for target words on the left side and ignore words on the right side. The sequence of the 8 blocks was quasi-randomly chosen with the constraint that there must be exactly 4 right-attend and 4 left-attend conditions. The subject's task was to maintain a silent count of the number of anomalous words heard during the block, to call out that number at the end of the block, and then to start a new count in the next block.

Testing Apparatus

The subject was seated comfortably in a dental examining chair. Target stimuli were delivered from two loudspeakers at ear height and 1 meter to the left and right of the subject's ears. A 38-cm computer screen, placed at eye level 1.7 meters in front of the subject, presented directions pertaining to the procedure. The arrangement of the apparatus is illustrated in Figure 1. In this example, the phrase "once upon a time" is presented from the left side while the phrase "be allowed to go to the ball" is presented simultaneously from the right side.

Recording Apparatus

Brain electrical activity was recorded from 30 silver-silver chloride electrodes mounted in an elastic cap (Neurosoft) and affixed to the scalp according to a modification of the International 10-20 system. Vertical electro-ocular activity (VEOG) was monitored by electrodes mounted above and below the left eye. Electrical activity was referred to linked mastoid electrodes with F_{PZ} as ground.

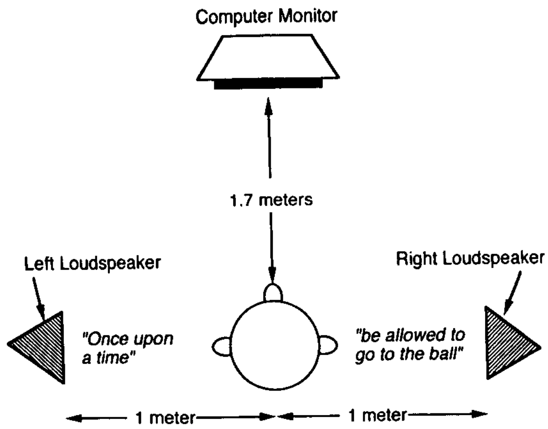

Figure 1 Arrangement of testing apparatus.

Individual sweeps of electroencephalic (EEG) activity, time-locked to the onsets of the target words, were stored for offline analysis. Ongoing EEG activity was amplified and bandpass, analog filtered from 0.15 to 125 Hz. Analog filter skirts were sloped at –12 dB per octave. The amplified and filtered EEG activity was then digitized through an acquisition interface system (Neuroscan) and, finally, routed to a computer for individual sweep storage, display, averaging, and final digital filtering (SCAN 4.0 software). Signal averaging was carried out after offline artifact rejection and baseline correction. Individual epochs were examined and rejected whenever electrical activity in the eye channel (VEOG) exceeded ± 50 μvolts. If more than 30 epochs of the 50 epochs of a given target condition were rejected for any reason, then the entire data set for that subject was rejected. Thus, each averaged ERP was based on a minimum of 20 epochs. Successfully averaged evoked potential waveforms were then linearly detrended, digitally low-pass filtered at 20 Hz, and baseline corrected. Digital filter slope was –48 dB per octave.

Topographic maps of the digitally filtered auditory ERPs were constructed by interpolation of voltages between adjacent electrodes, using a 4-point linear interpolation algorithm. Colors representing the range of observed voltages were then assigned to the resulting voltage matrix.

Procedure

Prior to the actual testing of each subject, the speech levels from the two loudspeakers were adjusted to achieve median plane localization for that subject. The phrase "once upon a time" was presented diotically (identical stimulus to both loudspeakers) and repeated three times, at each of 11 interaural intensity ratios. In the two youngest groups, children and young adults, where hearing sensitivity was within normal limits in both ears, the speech level was initially set to 40 dB HL from both loudspeakers. Then the intensity level from the left loudspeaker was varied over a range from +14 to −14 dB in 2-dB steps. After each presentation, the subject judged the apparent position of the sound image on an 11-point scale ranging from 5 on the extreme right, through 0 at the midline, to 5 on the extreme left. The interaural intensity ratio corresponding to perception in the median plane was defined as the midpoint of the range of "0" judgments between consistently right-sided and consistently left-sided responses. This interaural intensity ratio was then used as the presentation level from the two loudspeakers for presentation of the fairy tales. In the elderly group, where varying degrees of presbyacusic hearing sensitivity loss were present, the speech presentation level was raised, if necessary, to the level that the subject judged comfortable for sustained listening. This level varied, in individual subjects, from 40 to 55 dB HL. Interaural differences in pure-tone average (average of the hearing threshold levels at 500, 1000, and 2000 Hz) in the elderly group varied from 0 to 10 dB and averaged 2.6 dB.

After the electrode cap had been affixed, the subject was familiarized with the task. Subjects were instructed to count, silently, the number of anomalous words in a given block and report that number at the end of the block. Two practice blocks (25 segments per block) of the fairy tales were played, and the subject was instructed to note and count the anomalous words. During actual testing, subjects began the silent count anew at the start of each new block. Actual testing began in the "listen-right" condition in half of the subjects and in the "listen-left" condition in the other half. The test phase lasted approximately 25 minutes with a rest period of about 1 minute halfway through the 8 blocks.

Data Analysis

Epochs were separately averaged for (1) target words from the right side and (2) target words from the left side. In order to derive, from the array of waveforms at the various electrode sites, single measures of peak latency and amplitude for each subject, individual global field power (GFP) waveforms (Skrandies, 1989, 1990) were computed. The GFP waveform is defined by calculating, at each time sample of the epoch, the square root of the mean of the squared deviations of each voltage from the common average reference voltage. When this value is plotted as a function of time across the epoch, the result is the GFP waveform. Such a waveform is typically similar in morphology to the waveforms at the individual electrodes but has the advantage that, by taking into account activity at all electrodes, it resolves the dilemma over determining the appropriate electrode at which to measure latency and amplitude in individual subjects.

The mean amplitudes and latencies measured at the peak positivity of the individual GFP waveforms in the target-right and target-left conditions were compared as a function of group (children vs young adults vs elderly persons) and target side attended (right or left) by means of conventional, mixed-design, analysis of variance (ANOVA). There was one between-subjects factor, group, and one within-subjects factor, target side attended. Post hoc comparisons were carried out by Student's t tests. Statistical significance was evaluated at an alpha level of 0.05.

RESULTS

Figure 2 shows grand-averaged GFP waveforms for target-right and target-left conditions in the three groups. In the children's group, waveforms are similar for the two target conditions. Both show a positive peak in the 600- to 800-msec latency region. Amplitude is slightly greater in the target-left condition, but the difference is small. In the young adult group, both target-right and target-left conditions show similar peak amplitudes, although the rise to peak is slightly delayed in the target-left relative to the target-right condition. But peak latencies and amplitudes are similar for the two conditions. In the senior group, however, there is a clear difference between target-right and target-left waveforms. In the target-right condition, the peak latency is earlier and the peak amplitude is greater than in the target-left condition.

Table 1 summarizes peak amplitudes, peak latencies, and their standard errors, averaged across the individual GFP waveforms in the three groups. Figures 3 and 4 show the same

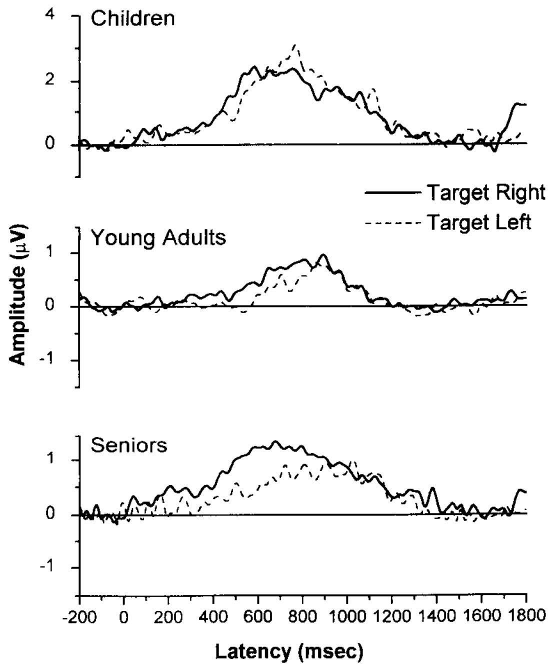

Figure 2 Global field power (GFP) event-related potential (ERP) waveforms for target-right and target-left conditions in three groups of subjects: children, young adults, and seniors.

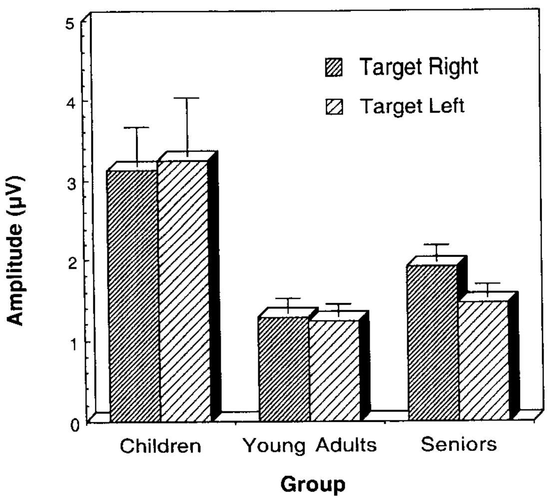

Figure 3 Means and standard errors of amplitudes of individual GFP-ERP waveforms for target-right and target-left conditions in the three subject groups.

data in graphic form for amplitude and latency, respectively. Surprisingly, average amplitudes (see Fig. 3) were larger in the children's group than in either the young adult or senior groups. Note also that average amplitudes in the elderly group were comparable to analogous amplitudes in the young adult group.

Relative to individual peak amplitudes, a mixed-design ANOVA with one within-subjects factor (target condition) and one between-subjects factor (group) showed a significant main effect for group ($p = .0002$) but no significance for the main effect of target condition ($p = .627$) and no significant interaction between group and target condition ($p = .658$).

Relative to individual peak latencies, a similar mixed-design ANOVA showed no significant main effect for either group ($p = .577$) or target condition ($p = .062$) but a significant interaction between the two main effects ($p = .047$). Post hoc paired t test, carried out on each group separately, showed no significant effect of target condition in either the children's group ($p = .581$) or the young adult group ($p = .241$) but a significant difference between target-right and target-left conditions ($p = .011$) in the senior group.

Figure 5 shows topographic maps of evoked brain activity at the peak latencies of the grand-averaged GFP waveforms for target-right and target-left conditions in the children's group. Figures 6 and 7 show analogous maps for the young adult and senior groups, respectively. In the children's group, there is little difference between target-right and target-left conditions. Positivity is maximal in the centroparietal region and is reasonably symmetrically distributed around the mid sagittal plane. Peak latency is slightly longer (39 msec) in the target-right condition. Topographic maps are similar in the young adult group. Amplitude is attenuated relative to the children's group, but, again, positivity

Table 1 Means and (Standard Errors) of Amplitudes and Latencies at the Peak of the GFP Waveforms for Three Age Groups and Two Target Conditions

Group	*Target Right*		*Target Left*	
	Amplitude	*Latency*	*Amplitude*	*Latency*
Children	3.14 (0.46)	804.1 (63.1)	3.26 (0.71)	764.9 (16.6)
Young adults	1.28 (0.18)	783.3 (31.0)	1.23 (0.15)	843.2 (35.1)
Seniors	1.91 (0.22)	674.2 (41.7)	1.46 (0.17)	849.5 (62.8)

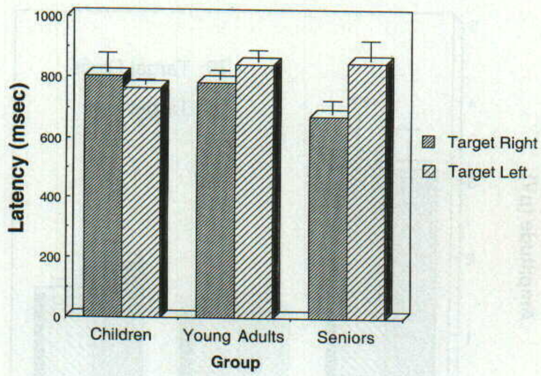

Figure 4 Means and standard errors of latencies of individual GFP-ERP waveforms for target-right and target-left conditions in the three subject groups.

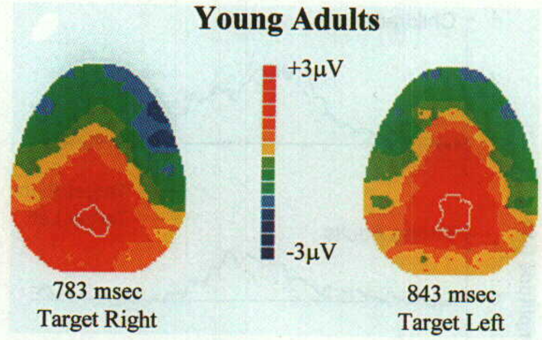

Figure 6 Topographic maps of amplitude at the peak positivity of the grand-averaged GFP-ERP waveform for target-right and target-left conditions in the young adult group. Area outlined in white is area of maximal positivity.

is maximal in the centroparietal region and is reasonably symmetrically distributed over the midline. Peak latency, however, is slightly longer (60 msec) in the target-left condition. In the senior group, however, amplitude at peak positivity is attenuated and latency is substantially greater (356 msec) in the target-left than in the target-right condition. Examination of the topographic maps of individual members of the senior group revealed that the asymmetric pattern characterizing the grand-averaged maps of Figure 7 (reduced amplitude and extended latency in the target-left condition) was present in 8 of the 10 members of the senior group. In one of the remaining two senior subjects, there was little difference between target-right and target-left maps. In the remaining subject, the response amplitude was minimal in both target conditions and the latency was substantially delayed.

DISCUSSION

Our purpose in this investigation was to assess the effect of age on the ERPs evoked by anomalous words in a quasidichotic listening task. Four findings were noteworthy:

1. The amplitude of this ERP was significantly larger in children than in either young adults or elderly persons. This finding appears to be in sharp contrast to previous studies of developmental changes of P_{300} amplitude in childhood. Hall (1992) summarizes the results of a number of studies covering the range from school age to late adolescence. The general finding was that P_{300} amplitude increased over this age range. But in the present results, we observe a substantial decrease in amplitude between 11 year olds and young adults in their 20s.

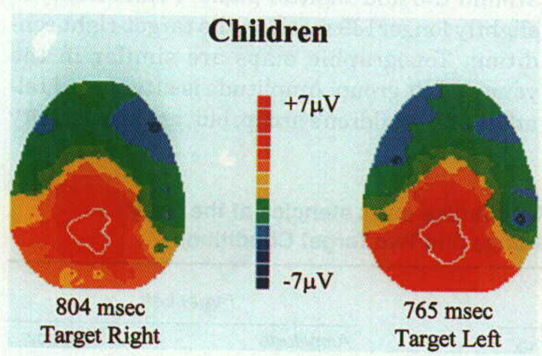

Figure 5 Topographic maps of amplitude at the peak positivity of the grand-averaged GFP-ERP waveform for target-right and target-left conditions in the children's group. Area outlined in white is area of maximal positivity.

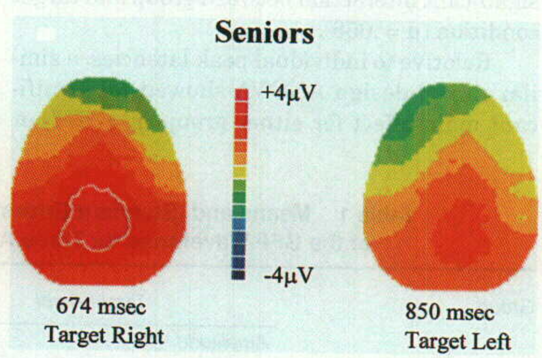

Figure 7 Topographic maps of amplitude at the peak positivity of the grand-averaged GFP-ERP waveform for target-right and target-left conditions in the senior group. Area outlined in white is area of maximal positivity.

2. In contrast to previous studies of age-related changes in ERP latency, the latency of this ERP did not increase with age. If the present GFP results are collapsed across target-right and target-left conditions, the average latency for children is 784.5 msec, for young adults 813.2 msec, and for seniors 761.8 msec. These results suggest no real change in latency on this task from childhood to advanced age. Yet Goodin et al (1978), studying the P_{300} response to a change in the frequency of a tone burst, observed a linear increase in P_{300} latency from 300 msec to 400 msec over the age range from 12 to 80 years. A possible explanation for both this and the amplitude discrepancy noted above may lie in the differing nature of the tasks employed (i.e., listening for a tone burst of different pitch versus listening for an anomalous word in a familiar fairy tale).
3. There was no significant difference between attend-right and attend-left conditions for either children or young adults. This result is consistent with expectation in consideration of the minimal right-sided advantage for linguistic tasks observed in young persons and the present small sample size.
4. Elderly persons with symmetric presbyacusic hearing sensitivity loss showed substantial asymmetry on this task. The latency of the ERP in the attend-left condition was significantly longer than the latency of the ERP in the attend-right condition. This result is consistent with previous demonstrations of an age-related decline in left-ear performance on dichotic listening tasks (Jerger et al, 1990, 1994, 1995; Jerger and Jordan, 1992; Jerger, 1997; Jerger and Chmiel, 1997; Strouse and Wilson, 1999). The present results are consistent with the hypothesis that there may be age-related decline in the interhemispheric transfer of auditory information (Jerger et al, 1995).

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