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Effect of Speech Distinctions and Age Differences on Auditory Event-Related Potentials

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Abstract

P3 event-related potentials were recorded from 37 subjects in two age groups (19–25 and 61–75 years) listening to tones, stop+vowel (CV) monosyllables, and isolated vowels. P3 latencies were found to be significantly longer for older subjects in all stimulus conditions. CV latencies were also significantly longer than simple tone latencies with the increase being approximately 1.30 msec/year. Latencies to the vowel stimuli were somewhat more variable but also tended to be greater than the tone latencies. P3 amplitudes were greater for the tone stimuli than for the speech stimuli, but no significant age effects were found.

Key Words: Auditory event-related potentials, P3 latency, P3 and aging effects, consonant-vowel distinctions and P3

Event-related potentials represent electrical fields in the brain time-locked to patterns of neural activity associated with perceptual (or cognitive) processing (Donchin, 1979; Meador et al, 1987). The fact that the event-related potentials can be seen as a measure of the level of information processing complexity in speech-related tasks (Donchin, 1979; Kutas et al, 1977; Ritter et al, 1983; Novick et al, 1985; Meador et al, 1987) has stimulated interest in the neurophysiologic basis of cognition and age-related changes in cognitive processing. One component studied extensively with age-related changes, the P3 or P300, is a late positive event-related potential occurring between 250–600 msec in response to an infrequently occurring stimulus.

Age-related changes elicited in response to rarely occurring auditory stimuli were first reported by Goodin et al (1978). These researchers indicated that the latency for the P3 in older subjects was consistently longer than the latency for the younger subjects. In particular, the P3 latency was found to increase with age systematically at the rate of 1.6 msec/year with a standard deviation of 27 msec for subjects between the ages of 17–76 years. This work has been replicated by others (Ford et al, 1979; Squires et al, 1979; Michalewski et al, 1982; Syndulko et al, 1982; Brown et al, 1983; Papanicolaou et al, 1984; Pfefferbaum et al, 1984; Picton et al, 1984; Polich et al, 1985; Gordon et al, 1986; Kraiuhin et al, 1986; Romani et al, 1986; Knight, 1987; Patterson et al, 1988; Fein and Turetsky, 1989; Pollock and Schneider, 1989) with the general agreement that the P3 increases in latency at the rate of 1–2 msec per year with age. However, some of these studies suggested the P3 latency did not change significantly until age 45 (Brown et al, 1983) and then increased dramatically (3.14 msec/yr), while others using visual stimuli (Beck et al, 1980) suggested the latency changed only minimally until age 63 years. Similarly conflicting results have been reported for P3 amplitude. Goodin et al (1978) and Brown et al (1983) reported decreasing P3 amplitude with age, while Beck et al (1980) and Pfefferbaum et al (1984) reported

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that P3 amplitude remained stable with increasing age.

Picton et al (1984), however, confirmed the work of Goodin et al (1978) and found a systematic linear increase in the latency of the P3 component with increasing age. The rate of latency increase found by Picton et al was 1.36 msec per year with a decrease in amplitude occurring at a rate of 0.18 mV per year. Fein and Turetsky (1989) suggested that the discrepancies between studies disappeared when similar test paradigms and measurement techniques were used. Fein and Turetsky (1989) found that a two-tone oddball paradigm and a peakpicking analysis procedure yielded results similar to those of Goodin et al (1978). Thus there is basically general agreement within these studies concerning the increased latency and decreased amplitude in the P3 associated with aging. However, all of these studies used only simple pure-tone stimuli to evaluate P3 changes in the aging subjects. Age-related studies that involve more complex stimuli such as place-of-articulation distinctions, voice onset time (VOT) distinctions, and consonant perception in different vowel environments with an *elderly* population are limited.

Two recent studies examining P3 latencies and amplitudes with more complex speech stimuli are relevant to our interests. First, Meador et al (1987) evaluated P3 latency in subjects aged 19 to 48 using phoneme targets (requiring subjects to listen for word rhymes) and semantic targets (requiring subjects to listen for words in specific semantic categories) in an oddball paradigm. They found the latencies for P3 were significantly increased for the semantic task (592 msec) relative to the phonemic task (503 msec). These results are consistent with the claim that P3 latencies (and possibly amplitudes) may vary with the complexity of the monitoring task. That is, if semantic-level processing is more complex than phonemic-level processing then P3 latencies should be longer when subjects are making semantic decisions rather than phonemic decisions. However, Meador et al (1987) did not specifically examine possible age-related differences in the P3 measure obtained.

A second study by Chmiel and Jerger (1990, a summary of an oral presentation) examined an older group of subjects ranging in age from 50 to 85 years using the same type of oddball paradigm. The auditory stimulus used included pure tones (1000 and 500 Hz) and monosyllabic words. Subjects were required to count the rare stimulus events that occurred 20 percent of the time—the 500 Hz tone or words with "specific phonemic or semantic characteristics" (Chmiel and Jerger, 1990, p. 52). Longer P3 latencies were obtained in both the phonemic (640 msec) and semantic (660 msec) conditions than in the pure-tone condition (350 msec), consistent with Meador et al (1987). However, although an increase in pure-tone latency was associated with an increase in age (their report did not indicate whether or not this increase was statistically significant), they found no increase in phonemic or semantic latencies with increasing age.

Since little information is available concerning the use of phonemic tokens with older individuals, and since there is a suggestion that a systematic increase in latency does not occur with phonemic stimuli as it does with pure-tone stimuli, this study was designed to evaluate possible age-related effects on the P3 in the discrimination of pure tones and consonant-vowel contrasts (including a place-of-articulation distinction and a voice onset time distinction), and vowel quality contrasts.

METHOD

Subjects

Thirty-seven normally hearing subjects participated in the study. Seventeen subjects were between the ages of 19–25 years and 20 subjects were between the ages of 61–75 years. Normal hearing was defined as pure-tone thresholds of 25 dB HL or better at frequencies 500, 1000, 2000, and 3000 Hz. Central auditory function was screened using the Staggered Spondaic Word (SSW) test, performance-intensity functions for monosyllabic words (CID W-22), and Synthetic Sentences with an ipsilateral competing message (SSI-ICM) and the Pitch Pattern Sequence Test. Early and middle latency responses were screened to assess neural integrity. Cognitive function was screened (28 correct out of 30 was passing) using the Mini Mental State test developed by Folstein et al (1975). Medical history, as reported by the subjects, indicated all subjects were right-handed and had no history of head injury or neurologic disorder.

Procedure

Records of electrophysiologic activity from listeners were obtained while the listener was seated in a sound-treated booth (IAC 403) facing a monitor with a stable visual target. Listeners were asked to fixate on the visual target to minimize eye-movement artifacts (artifacts above 45 μV were automatically rejected), while silently counting the infrequent auditory targets. Subjects reported the number of infrequent stimuli heard to provide an estimate of task vigilance. All listeners identified 92–100 percent of the target tokens correctly.

The event-related responses were generated with either pure tones or speech stimuli presented in an oddball paradigm in which one stimulus is presented 80 percent of the time and the other stimulus is presented 20 percent of the time. The order of stimulus presentation was pseudorandomized across each separate stimulus tape with the constraint that two infrequent target tokens were never presented in sequence. The time-locked electrophysiologic responses to 50 infrequent and 250 frequent stimuli were averaged separately.

Responses were obtained with gold-surface cup electrodes on the subject's scalp with the noninverting electrode at Cz and Fz, the inverting electrode on the right earlobe, the common electrode on the forehead (Fpz) according to the 10–20 electrode system (Jasper, 1958). All electrode impedances were below 3000 ohms and interelectrode impedance did not exceed 1000 ohms. All data were collected using the Biologic Navigator Evoked Potential System, which was interactive with two voice-activated switches (Gerbrand, G1341T) and a cassette tape recorder (Nakamichi, CR-2).

Stimuli

Stimuli for the test sessions included pure tones and speech tokens in the seven stimulus conditions outlined in Table 1. The pure-tone stimuli consisted of a 1000-Hz tone as the frequently occurring nontarget and a 2000-Hz tone as the infrequently occurring target. The tone bursts were 20 msec in duration with a rise/fall of 9.9 msec and were presented monaurally to the right ear (TDH-50 earphone) at a rate of 1.1 per second. Stimuli were presented at an intensity of 85 dB nHL and were filtered between 1 Hz and 100 Hz. Masking was presented to the contralateral ear.

The speech tokens consisted of three different stop consonant+vowel (CV) monosyllables ([bɛ], [dɛ] and [pɛ]) and three isolated vowel tokens ([i], [ɩ] and [ɛ]). All speech tokens were created using the Klatt cascade/parallel software synthesizer (Klatt, 1980).

The CV tokens were 240 msec in total duration and were created using the parameter values suggested in Klatt (1979). Each CV began with a 10-msec stop release burst synthesized by shunting aperiodic fricative noise through the parallel circuit with the frequencies of the first three formants (F1, F2, and F3) set to the values noted in Table 2. Following this release burst, the formant transitions of the first three formants went from the onset values listed in Table 2 to the corresponding steady-state values (appropriate to the vowel [ɛ]). The duration of these formant transitions was 40 msec. In the two tokens with voiced stops ([bɛ] and [dɛ]), voicing began 5 msec after the stop release burst. In the voiceless stop [pɛ], voicing did not begin until 65 msec after the release burst, and aperiodic energy ("hiss") was shunted through the cascade circuit during the voiceless period to synthesize aspiration. In each CV token the fundamental frequency (F0) began at 117 Hz and dropped linearly to 111 Hz by the end of the token. The falling F0 produced a more natural sounding speech token.

Two test tapes were created using these three tokens. The first tape consisted of [bɛ] as the frequently occurring nontarget token and [dɛ] as the infrequent target. The second tape consisted of [bɛ] as the frequent nontarget and [pɛ] as the infrequent target. Using these two tapes the P3 latencies and amplitudes obtained with either a place of articulation distinction (bilabial versus alveolar) or a voice onset time

Table 1 Summary of the Tone and Six Tapes Constructed for Use with the Oddball Paradigm*

	Frequent Nontarget	*Infrequent Target*
Tone Stimuli	1000 Hz tone	2000 Hz tone
Consonant + Vowel Stimuli		
Tape 1	[bɛ]	[dɛ]
Tape 2	[bɛ]	[pɛ]
Isolated Vowel Stimuli		
Tape 3	Step 3 [i]	Step 11 [ɛ]
Tape 4	Step 8 [ɩ]	Step 11 [ɛ]
Tape 5	Step 11 [ɛ]	Step 3 [i]
Tape 6	Step 11 [ɛ]	Step 8 [ɩ]

*On each tape one stimulus (the "frequent nontarget" stimulus) occurred 80% of the time. A second stimulus (the "infrequent target" stimulus) occurred 20% of the time.

Table 2 Selected Synthesizer Parameter Values Used in the Construction of the Speech Tokens Using the Klatt Software Synthesizer*

Speech Token	Release Burst F1	Release Burst F2	Release Burst F3†	Transition Onset F1	Transition Onset F2	Transition Onset F3†	Steady-State Vowel F1	Steady-State Vowel F2	Steady-State Vowel F3†
CV Tokens									
[bɛ]	303	1339	2208	406	1579	2367	472	1920	2539
[dɛ]	231	1658	2595	326	1835	2367	472	1920	2539
[pɛ]	303	1339	2208	406	1579	2367	472	1920	2539
Vowel Tokens									
Step 3 [i]							297	2230	2912
Step 8 [ι]							397	2030	2632
Step 11 [ɛ]							472	1930	2539

* The formant frequency values for transition offset for the CV tokens are the same as those for the steady-state vowel.
† Values are in Hertz

(VOT) distinction (voiced versus voiceless) could be examined.

The three isolated vowel tokens represented three different steps of the 13-step [i]-[ι]-[ɛ] vowel continuum developed by Pisoni (1971; see also Repp et al, 1979). One vowel represented step 3 of the continuum, which is identified primarily as [i]. A second vowel, representing step 8 of this continuum, is predominantly identified as [ι], while the third vowel, representing step 11 of the continuum, is usually identified as [ɛ]. The frequency values of the first three formants used in the synthesis of these three vowel stimuli are shown in Table 2. All vowels were steady-state (i.e., no change in formant frequency over time) and the F0 for each vowel token began at 125 Hz and dropped linearly to 105 Hz at the end of the token.

Four test tapes were constructed using these three vowel tokens. One tape consisted of [ɛ] as the frequent nontarget and [i] as the infrequent target. A second tape consisted of [ɛ] as the frequent nontarget and [ι] as the infrequent target. In both tapes the two vowels used represented distinct phonemic categories; however, one pair of vowels ([ɛ]/[i]) incorporates greater acoustic/phonetic differences than the other vowel pair ([ɛ]/[ι]). One might expect that the acoustically more distinct vowel pair might be easier for subjects to differentiate, which could have a significant effect on the associated P3 latencies and/or amplitudes.

Two additional vowel tapes were constructed that utilized the same vowel pairs but switched the tokens used as the frequent nontargets and the infrequent targets. This was done because some anchoring studies (e.g., Cowan and Morse, 1986) have shown that the identification of less frequently presented vowels can be affected (a contrast effect) by the presence of a frequently occurring anchor. However, there is evidence that this contrast effect is asymmetrical (Cowan and Morse, 1986). In particular, when the vowel [ι] was used as an anchor it produced more contrast than when the vowel [ɛ] was used as an anchor. If this phenomena occurs in the oddball paradigm, then the choice of which vowel token is used as the frequent nontarget token may produce a significant difference in P3 latencies and/or amplitudes.

Determination of P3 Latency

The general location of the P3 component associated with the perception of the infrequent target stimulus was initially determined by comparing the waveform of the frequent target with that of the infrequent target. If a single peak was present after 250 msec and in the anticipated target window, it was identified as the P3. If broad or multiple peaks were evident, then P3 latency was defined as the midpoint between two cursors placed at baseline on either side of the waveform (Wall et al, 1991).

Determination of P3 Amplitude

The amplitude of the P3 component was defined as the distance (in µV) from the highest point of the P3 waveform to the following most negative excursion of the following N3 trough (Wall et al, 1991).

RESULTS

The obtained P3 latency and amplitude data were subjected to a number of different statistical analyses designed to investigate the results from different perspectives. Given the number of statistical tests to be completed on the same set of data, Bonferroni t-tests were

Table 3 Means and Standard Deviations for P3 Latencies (in msec) for Both Age Groups in All Stimulus Conditions

	Tones	*VOT*	*Place*	*Vowel Quality Differences*			
	1 kHz/2 kHz*	[bɛ]/[pɛ]*	[bɛ]/[dɛ]*	[ɛ]/[i]*	[i]/[ɛ]*	[ɛ]/[ɩ]*	[ɩ]/[ɛ]*
Younger Subjects							
Mean	289	305	352	314	326	351	356
SD	28	53	32	29	47	36	37
Older Subjects							
Mean	359	374	416	376	363	384	385
SD	43	58	46	52	41	47	37
Total							
Mean	326	342	388	349	346	368	372
SD	51	65	52	53	47	52	37

*The stimulus pairs listed in the column headings represent the nontarget and the target respectively.

used to evaluate differences between individual stimulus conditions. Analyses of variance were used to determine the significance of experimental factors (such as age and stimulus type and their interaction); regression analyses were used to evaluate (and predict) the change in P3 latency and amplitude as a function of age.

Analysis of P3 Latencies

Table 3 shows mean P3 latencies and standard deviations obtained with the tone and speech stimuli for both age groups. Two general patterns are in evidence. First, P3 latencies obtained using the tones are less than those obtained using the speech stimuli, although these differences are not as great as the tonal versus phonemic differences obtained by Meador et al (1987). Results from Bonferroni t-tests indicated that the mean latencies obtained from each of the six speech tapes were significantly longer (at a level of $p < 0.03$ or better) than the mean latency obtained using the tone stimuli. Representative waveforms for two subjects for all three test stimuli conditions are shown in Figures 1 and 2. The increase in P3 latency for each of the two speech conditions as compared to the tone condition is evident for both the young and old subject. The place of articulation condition yielded the longest latency for both subjects, and the tone condition yielded the shortest latency.

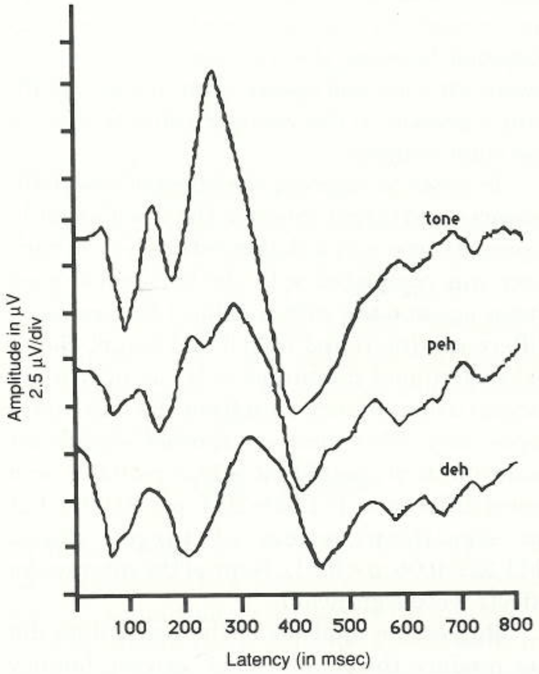

Figure 1 P3 waveforms for tone, place of articulation, and voice onset time conditions for a representative young subject.

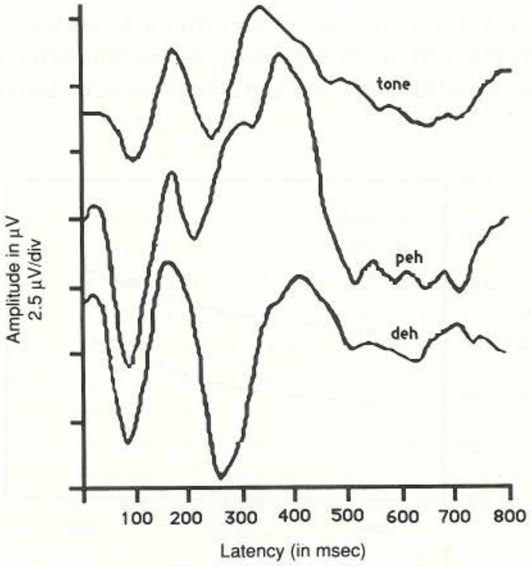

Figure 2 P3 waveforms for tone, place of articulation, and voice onset time conditions for a representative older subject.

Second, it is clear that older subjects show longer latencies than younger subjects across all stimulus conditions. One-way analyses of variance using an unbalanced design with the between-subject factor age were completed on the P3 latencies obtained with each of the seven stimulus tapes. Results showed a significant age difference for all seven stimulus conditions at the 0.03 level or better.

To examine the patterns evident in the latency data in more detail, multivariate analyses of the CV and vowel data were done separately. Since these analyses involve within-subject factors (i.e., represent multiple measurements obtained from each individual subject), all the data from a given subject may be eliminated from a given statistical analysis if one of the subject's data points is missing (e.g., if an accurate latency or amplitude measurement could not be made). The degrees of freedom for individual statistical tests may thus not sum to 37.

Graphically shown in Figure 3 are the latency data obtained with the tone, place, and VOT stimuli. A two-way unbalanced analysis of variance with the between-subject factor age (younger and older) and the within-subject factor stimulus type showed significant main effects of age ($F[1,32]=32.5$, $p < 0.001$) and stimulus type ($F[2,64]=21.6$, $p < 0.001$) but no significant age x stimulus type interaction. Post hoc analysis showed that the tone latencies were significantly shorter than both the place latencies ($t[35])=2.21$, $p < 0.034$) and VOT latencies ($t[35]=6.56$, $p < 0.001$) and that the place and VOT latencies were significantly different ($t[35]=4.32$, $p < 0.001$). Both groups thus demonstrated the same pattern of increased P3 latencies to speech distinctions as opposed to tonal (nonspeech) distinctions, although the place distinctions produced significantly longer latencies.

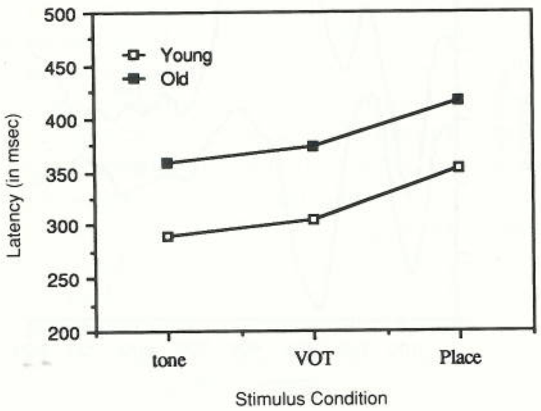

Figure 3 Mean P3 latencies for tone, place of articulation, and voice onset time conditions.

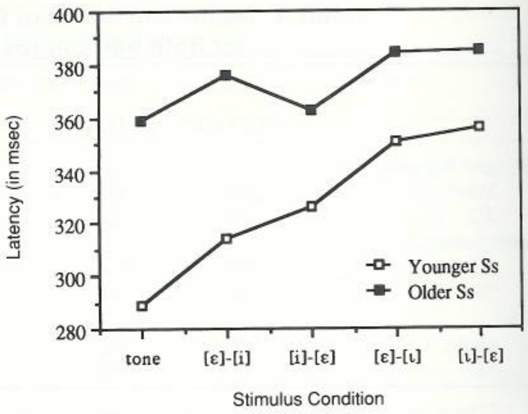

Figure 4 Mean P3 latencies for tone and vowel conditions.

Graphically shown in Figure 4 are the P3 latencies obtained using the vowel stimuli (along with tone data for comparison). First a two-way unbalanced analysis of variance with the factors age and stimulus type (tone and [ɛ]/[i], [i]/[ɛ], [ɛ]/[ι], [ι]/[ɛ] vowel sets) showed a significant main effect of age ($F[1,31] = 18.62$, $p < 0.001$) and stimulus type ($F[4,124]=15.2$, $p < 0.001$). There was also a significant age x stimulus type interaction ($F[4,124]=2.60$, $p < 0.039$). Post hoc analysis revealed that the significant interaction was obtained because the increase in latency between the tone and speech stimuli was significantly greater in the younger subjects than in the older subjects.

In order to examine the effect of vowel differences and target choice in the vowel stimuli, a second three-way unbalanced analysis of variance was completed with the between-subject factor age and the within-subject factors vowel difference ([ɛ]-[i] and [ɛ]-[ι]) and target choice ([ɛ] as frequent nontarget or [ɛ] as infrequent target) using latency data from the four-vowel tapes only. This analysis showed significant main effects of age ($F[1,32] = 13.2$, $p < 0.001$) and vowel difference ($F[1,32]=20.1$, $p < 0.001$), but no significant effect of target choice ($F[1,32]=0.06$, $p < 0.81$). None of the interaction effects were significant.

Regression analysis of the vowel data did not produce the clear trends between latency and age found for the tone and CV data. The increase in latency was less than 1 msec per year for two of the test conditions ([i]/[ɛ]: 0.73

Table 4 Means and Standard Deviations for P3 Amplitudes (in μV) for All Subjects in All Stimulus Conditions

	Tones	*VOT*	*Place*	*Vowel Quality Differences*			
	1 kHz/2 kHz*	[bɛ]/[pɛ]*	[bɛ]/[dɛ]*	[ɛ]/[i]*	[i]/[ɛ]*	[ɛ]/[ι]*	[ι]/[ɛ]*
Younger Subjects							
Mean	13.2	9.4	7.8	10.3	9.3	9.4	6.9
SD	7.0	3.8	3.7	4.0	4.6	3.6	3.4
Older Subjects							
Mean	9.2	7.6	7.0	8.3	9.3	6.3	7.6
SD	5.8	5.1	3.8	3.7	4.9	2.7	6.1
Total							
Mean	11.1	8.5	7.3	9.2	9.3	7.8	7.3
SD	6.6	4.6	3.7	3.9	4.7	3.5	5.0

*The stimulus pairs listed in the column headings represent the nontarget and target stimuli respectively.

msec/yr, $r=0.36$, $p < 0.03$; [ι]/ɛ]: 0.56 msec/yr, $r=0.33$, $p < 0.05$) and not significant for a third condition ([ɛ]/[ι]). Only the [ɛ]/[i] condition produced an association between age and latencies similar to that of the tone and CV conditions (1.30 msec/yr, $r=0.58$, $p < 0.001$).

Analysis of P3 Amplitudes

Table 4 shows mean P3 amplitudes and standard deviations obtained with the tone and speech stimuli for each age group. Two tendencies in the data emerge, although the patterns are not as clear as the patterns seen in the latency data. First, amplitudes obtained in the speech conditions were generally smaller than the tone amplitudes. Bonferroni t-tests showed that the amplitudes from all but one set of speech stimuli (the [i]-[ɛ] vowel tape) were significantly smaller than the tone amplitudes at the 0.03 level or better. Second, there was a slight tendency (although nonsignificant) for the amplitudes from the older subjects to be smaller than those from the younger subjects, but there were several exceptions. However, recent results obtained related to the duration of the interstimulus interval (ISI). Increasing the ISI may have the effect of making the amplitude measures more stable and establish a significant age difference.

DISCUSSION

These results confirm the findings of an increase in the P3 latency and a decrease in the P3 amplitude with age with pure-tone stimuli. Results also indicate a consistent increase in latency with age for the consonant-vowel discriminations, which varied in either VOT or Place. The obtained increase in CV latencies with age is somewhat different than the results reported by Chmiel and Jerger (1990). Whereas Chmiel and Jerger (1990) reported a systematic increase in P3 latency for pure-tone stimuli, they did not find an increase with age for the phonemic and semantic distinctions. It is, however, difficult to make direct comparisons between the two studies. Listeners in the Chmiel and Jerger study responded to words that changed in either phonemic or semantic character. Both tasks (including the phonemic task) almost certainly required lexical processing of the stimuli (including access to or retrieval from lexical memory) and thus may involve relatively high levels of psycholinguistic processing. In the present study the stimuli were not real English words, and the decisions listeners were making could thus be considered purely phonetic and/or auditory in nature. Whether or not this distinction might have produced the latency differences observed must be examined in future studies.

The latencies obtained with the vowel stimuli demonstrate that P3 latencies are sensitive to varying degrees of vowel quality distinctions. These latencies thus do not reflect simply a category distinction made by listeners between two phonemically distinct vowels, but seem to represent acoustic distinctions as well. These data may thus reflect the operation of two different levels of perceptual processing (acoustic and phonetic) that have long been hypothesized in the literature (e.g., Fujisaki and Kawashima, 1969).

While the results of this study clearly indicated increased P3 latency for tones, vowels, and CV stimuli with increasing age, the implications surrounding the increased latency are unclear. Certainly the possibility exists that the increased P3 latency exhibited by the older adult is associated with a decreased auditory processing ability as opposed to a decreased linguistic ability. However, the increase in latency associated with the linguistic stimuli compared with the tones would suggest that an effect related to higher levels of cognitive processing may be present. Older subjects may have more difficulty with processing the changing formant transitions in the CV tokens than do the younger listeners. To address this general issue, further research is needed to separate effects related to a general decrease in auditory ability in the older population from a specific linguistic decrement in, perhaps, phonetic processing abilities. This should be done by carefully controlling the nature of the stimuli used. For example, one might compare the P3 latencies in the identification of stop+vowel tokens (CVs) with a set of complex tone glides whose sinusoidal components are matched to the CV formant frequencies (i.e., sinewave analogs to the speech tokens). This would allow collection of P3 data using the same basic acoustic stimuli while varying the nature of the identification test itself. Although increases in P3 latency may allow insight into changes in perceptual processes associated with age (and perhaps, changes related to communicative disorders), we must first be able to model the source of these changes.

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