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Effect of Hearing Impairment on Event-Related Potentials for Tone and Speech Distinctions[1]

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Introduction

The major thrust of research with the late event-related potentials (ERPs) has been in the fields of psychology and neurology, where results obtained from both normal and cognitively disabled populations have been studied. The late components, which occur between 50 and 300 ms after stimulus onset, include two negative peaks – N_1 and N_2 – and three positive peaks – P_1, P_2 and P_3. The P_3, occurring between 250 and 300 ms after stimulus onset, is considered to be an 'endogenous' potential, i.e., a potential unaffected by the parameters of the stimulus [1]. However, Roth et al. [2–4] have challenged the endogeny of the P_3 component with respect to stimulus intensity. Roth et al. [2] reported that P_3 amplitude showed a marked intensity effect. In this investigation, the P_3 behaved like an exogenous component in that stimulus intensity was the most powerful variable in determining its amplitude. In 1982, Roth et al. [3] again reported that P_3 amplitude varied as a function of stimulus intensity. In a subsequent study, Roth et al. [4] also reported that P_3 amplitude is strongly controlled by stimulus intensity. Roth et al. [2] suggested that the criteria proposed by Donchin et al. [1] for distinguishing exogenous from endogenous components define a continuum. At one end of the continuum lie brainstem potentials, which are closely dependent on the physical properties of the stimulus, whereas at the other end, slow waves are primarily dependent on the subject's task. Components such as the P_3 lie between these two ends in both latency and endogenous properties.

Backs [5] also reported that P_3 amplitude differed significantly among three stimulus intensity levels; however, amplitude did not vary with intensity in a linear manner. In contrast, Papanicolaou et al. [6] found that P_3 amplitude remained invariant over six intensity levels; however, significant intensity effects were observed for the latency of

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the P_3 peak. The latency of P3 appeared to be linearly related to stimulus intensity, i.e., latency decreased systematically as stimulus intensity increased. The investigators noted that the lack of intensity effects on P_3 amplitude in their study did not nullify the findings reported by Roth et al. [2–4], since those results were obtained in the context of a very different paradigm involving high-intensity stimuli and drastically different task demands. In agreement with the findings of Papanicolaou et al. [6], Polich [7] determined that variations in stimulus intensity produced minimal effects on P_3 amplitude; however, increases in stimulus intensity did result in significant decreases in P_3 latency. Squires et al. [8] reported on results recorded from 3 subjects while stimulus intensity was varied. Stimulus intensity had no effect on the latency of the P_3 component until it was decreased to within 15 dB of threshold, at which point the P_3 latency increased by an average of only 15 ms.

Thus, it appears that variations in auditory stimulus parameters may affect P_3 amplitude and latency. Because the amplitude and latency properties of the P_3 component comprise the primary bases for comparison when studying normal, aging and pathological populations, auditory stimulus parameters are important considerations. Further, these considerations raise the possibility that peripheral hearing impairment, which imposes an intensity reduction across at least a portion of the frequency spectrum, may alter the auditory stimulus in a manner that is similar to reducing the intensity of the physical stimulus. Therefore, P_3 latency could be delayed and/or P_3 amplitude decreased in the presence of peripheral hearing impairment.

Polen [9] reasoned that the late components of the auditory ERP might be altered in the presence of a sensorineural hearing impairment because (1) loss of high-frequency information, common to sensorineural hearing impairment, can cause detriment to the individual's ability to discriminate phonemes; (2) loss of frequency-resolving power, also common to sensorineural hearing loss, may compound this problem, and (3) increased difficulty in discrimination for any task is known to increase the latency of the P_3. Following this line of reasoning, he evaluated normally hearing and sensorineurally impaired subjects with phonemic stimuli and found a trend toward reduced amplitude for all late components in the hearing-impaired group; but N_1 and P_3 were not significantly reduced in amplitude. Of all the components investigated in Polen's [9] study, P_2 was most drastically reduced in amplitude due to sensorineural impairment. Therefore, Polen suggested that diminishment of P_2 would seem to implicate this component as the chief indicator of the reduction in sensitivity and the inferred loss of input to the primary receiving area. Polen concluded that P_3 amplitude does not appear to be directly affected by stimulus parameters so long as the change in stimulus can be detected. Rather, P_3 amplitude appears to be affected by task demand and the nature or significance of the stimuli. Further, the fact that P_3 amplitude was virtually unchanged for the hearing-impaired group would appear to imply that this group attached as much significance to the target phoneme as normally hearing people do. That is, hearing-impaired individuals use whatever cues are available to them in order to attach significance to a phoneme, in a manner similar to the way in which normally hearing persons attach significance to phonemes. According to Polen [9], this indicates that the process

Table 1. Test ear thresholds of hearing-impaired subjects

Subject	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz	8,000 Hz
VW	10	10	0	10	70	75
KW	10	30	30	35	30	50
NG	55	45	25	25	40	90
VK	40	35	35	50	60	65
SS	40	35	50	60	55	60

Tabled values are reported in dB HL.

remains the same even though the input is different. Finally, Polen reported that, for all components, peak latencies were prolonged for the sensorineural group. The latency increase, moreover, seemed to be more than a simple intensity effect, as the presentation level was well above the individual's pure-tone threshold.

Polen made no attempt to match subjects on degree of hearing impairment; therefore, uncontrolled frequency/intensity factors caused by the hearing impairment may have confounded the results. Thus, this study was designed to (1) determine whether the amplitude and latency of the pure-tone ERPs are altered in subjects with similar peripheral sensorineural hearing loss, and (2) determine whether the latency and amplitude of the phonemic ERPs are altered in subjects with similar peripheral sensorineural hearing loss.

Method

Subjects

Ten subjects participated in the investigation, 5 subjects with normal hearing sensitivity and 5 subjects with essentially symmetric, moderate, sensorineural hearing impairments. The pure tone thresholds for the hearing-impaired subjects are given in table 1. The hearing-impaired subjects ranged from 19 to 56 years of age, with a mean age of 32 years. Each normally hearing subject was age-matched to a hearing-impaired subject. The normally hearing subjects exhibited pure tone thresholds of less than 15 dB HL at all octave frequencies between 250 and 8,000 Hz and had normal middle ear function as defined by normal tympanograms and acoustic reflex thresholds. Both normally hearing and hearing-impaired subjects were screened for central auditory function using a comparison of performance-intensity functions generated with words (CID W-22) and sentences (Synthetic Sentence Identification with ipsilateral competing message) presented at 40 dB HL, 60 dB HL and 80 dB HL [10]. A 20% discrepancy between the functions excluded a subject from further participation in the study. In conjunction with the performance-intensity functions, the Staggered Spondaic Word Test [SSW;11] and the Pitch Pattern Sequence Test [12] were performed.

Procedure

All behavioral testing was completed using an audiometer (Grason-Stadler 16) and headset (TDH-50 earphones with MS-41/AR cushions). Routine speech testing and all behavioral tests of central auditory function were tape recorded and input to the audiometer from a cassette recorder (Nakamichi CR-2). All event-related potential responses were collected using the Bio-logic Navigator Auditory Evoked Potential System which was interactive with two voice-activated switches (Gerbrand, G1341T) and coupled to the cassette recorder for speech token presentation.

P_3 waveforms were evoked using three pairs of stimuli presented in an oddball paradigm (80% frequent and 20% infrequent). One pair of stimuli consisted of 1,000- and 2,000-Hz pure tones. The second pair of stimuli were speech tokens which consisted of two different stop consonant+vowel (CV) monosyllables differing only in place of articulation [bɛ]/[dɛ]. A third pair of speech tokens consisted of stop consonant+vowel (CV) monosyllables differing only in voice onset time (VOT; [bɛ]/[pɛ]. All speech tokens were created using the Klatt cascade/parallel software synthesizer [13] implemented on a Hewlett-Packard microcomputer. A complete description of the speech tokens can be found elsewhere [14].

The pure tones, (1,000 and 2,000 Hz) and speech tokens [bɛ]/[dɛ] and [bɛ]/[pɛ] were presented monaurally to the test ear of each subject through an earphone (TDH-50) at a rate of 1.1 stimuli per second, at a level of 85 dB nHL, and filtered between 1 and 100 Hz. Fifty infrequent targets were presented for each tone trial (2,000 Hz) and each speech trail ([dɛ] for targets differing in place of articulation and [pɛ] for targets differing in VOT). Event-related potentials were obtained with the noninverting electrode at the vertex (Cz), the inverting electrode on the right mastoid and the common electrode on the forehead (Fpz) in accordance with the International 10–20 system [15]. The fifty infrequent responses were averaged and displayed over an 800 ms time window. Eye movement artifacts were reduced by having the subjects fixate on a visual target located on a computer screen placed in front of them. Artifacts exceeding 45 μV were automatically rejected. In order to monitor vigilance, subjects were asked to count infrequent stimuli. A typical waveform from one of the normally hearing subjects is shown in figure 1. These waveforms were generated using speech tokens.

Data Analysis. P_3 latency and amplitude were defined according to the procedure used in our lab [16]. Briefly, if a single peak was present after 250 ms and in the anticipated target window, the latency of the P_3 was defined as the time (in ms) from stimulus onset to that single peak. If multiple peaks were evident, the latency of the component was defined as the time (in ms) from stimulus onset to the midpoint of the P_3 waveform deflection above baseline. The amplitude of the P_3 component was defined as the distance (in μV) from the highest point of the P_3 waveform to the following most negative excursion (or the P_3 trough) as suggested by Goodin et al. [17] with modifications [16].

Results

P_3 Latency and Amplitude

Table 2 displays the means and standard deviations for the P_3 latencies for the normal and hearing-impaired groups across all three stimulus conditions. Table 3 shows the means and standard deviations for P_3 amplitudes for the same groups and stimulus conditions. As is evident, very little difference is seen between the groups for any of the stimulus conditions. In order to examine the data more completely, a multivariate repeated measures ANOVA was performed which indicated there were no significant differences between the normal and hearing-impaired groups for P_3 latency [$F(1, 8) = 0.47$, $p < 0.513$] or amplitude [$F(1, 8) = 0.07$, $p < 0.793$] for any stimulus condition. Consequently, group data were combined for further examination of the effects of stimulus conditions.

A trend is evident in the P_3 latency across stimulus conditions; the shortest latency values occurred for the tones and the longest latencies occurred for the speech distinctions. A multivariate analysis of variance indicated that significantly [$F(2, 16) = 10.88$, $p < 0.001$] longer latencies occurred for the speech stimuli (both VOT and place of articulation distinctions) as compared to the tone stimuli. Graphic representation of the data (fig. 2) indicated a systematic increase in latency across stimulus conditions.

Amplitude values for a within subjects analysis of variance were not significant [$F(2, 16) = 0.86$, $p < 0.443$], nor were there any interaction effects for group × stimulus conditions [$F(2, 16) = 1.11$, $p < 0.353$]. P_3 amplitude values across stimulus conditions are shown in figure 3. As can be seen, amplitude decreases from the tone condition to the place-of-articulation discrimination, with the VOT discrimination amplitude values falling between those for the other two stimulus conditions.

P_2 Latency and Amplitude

Means and standard deviations for the P_2 latency are shown in table 4. While no systematic trend is evident for either group across stimulus conditions, it should be noted that for two stimulus conditions (tone and VOT) the hearing-impaired individuals performed as well or better than the normally hearing listeners. The place-of-articulation distinctions were the exception. For this stimulus condition, the hearing impaired listeners did not perform as well. This finding is not surprising given that place of articulation distinctions are particularly difficult for listeners with high-frequency hear-

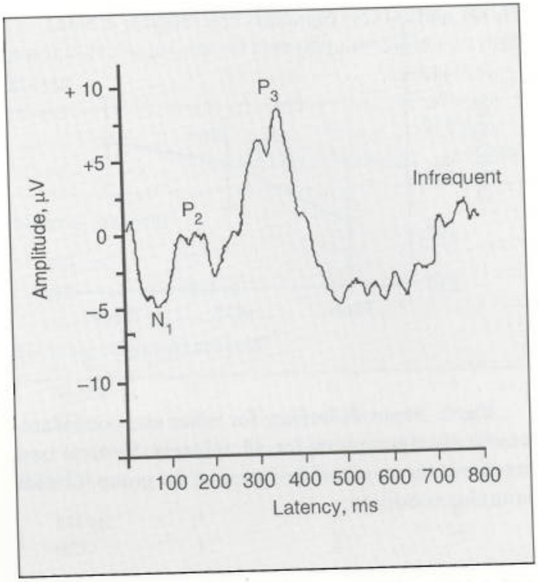

Fig. 1. Representative waveform response elicited with a speech token from one of the normally hearing subjects.

Table 2. Means and standard deviations for P_3 latencies (in ms) for all stimulus conditions in both groups

	Tones 1 kHz/2 kHz	VOT [bɛ]/[pɛ]	Place [bɛ]/[dɛ]
Normal subjects			
Mean	308	371	358
SD	37	71	36
Hearing-impaired subjects			
Mean	290	319	370
SD	41	52	61
Total			
Mean	299	346	364
SD	38	65	48

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

Table 3. Means and standard deviation of P3 amplitude (in µv) for all stimulus conditions in both groups

	Tones 1 kHz/2 kHz	VOT [bɛ]/[pɛ]	Place [bɛ]/[dɛ]
Normal hearing			
Mean	11	10	11
SD	5	7	4
Hearing-impaired			
Mean	12	11	7
SD	6	4	2
Total			
Mean	12	10	9
SD	5	6	4

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

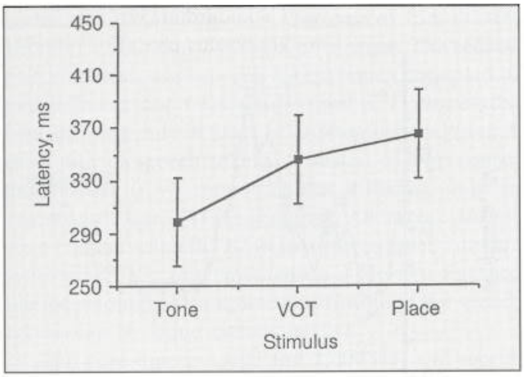

Fig. 2. Mean P_3 latency for tones and consonant-vowel discriminations for all subjects. Vertical bars represent the standard deviation of the group for each stimulus condition.

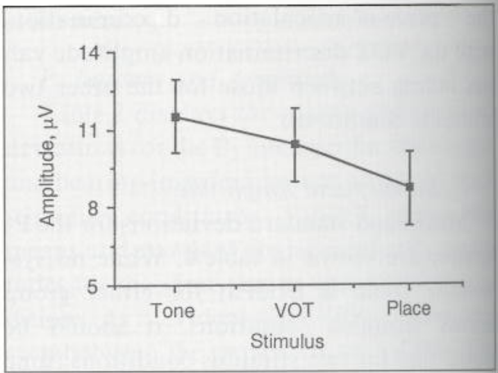

Fig. 3. Mean P_3 amplitude for tones and consonant-vowel discriminations for all subjects. Vertical bars represent the standard deviation of the group for each stimulus condition.

ing loss. Large standard deviations for both groups are apparent for all stimulus conditions. An analysis of variance for between-subjects effects for P_2 latency indicated no significant differences [$F(1, 8) = 1.87$, $p < 0.209$] between the normally hearing and hearing-impaired listeners nor was there a significant difference [$F(2, 16) = 0.42$, $p < 0.663$] within subjects or across stimulus conditions. A group × stimulus interaction, however, was significant [$F(2, 16) = 4.10$, $p < 0.037$], indicating that the groups performed differently across stimulus conditions.

Means and standard deviations for P_2 amplitude for both groups (table 5) did not indicate a trend across-stimulus conditions. Analysis of variance indicated that P_2 amplitude was not significantly different [$F(1, 8) = 0.03$, $p < 0.856$] between the two listener groups. However, amplitude values within a subject group across stimulus conditions were significantly different [$F(2, 16) = 4.55$, $p < 0.027$]. Amplitude values for the tones were consistently smaller than the amplitude values for the speech distinctions for both groups.

N_1 Latency and Amplitude

Means and standard deviations for N_1 latency for both groups and all stimulus conditions are shown in table 6. No significant differences were found between groups [$F(1, 8) = 0.76$, $p < 0.410$] or across stimulus conditions for either group [$F(2, 16) = 3.10$, $p < 0.073$].

Table 7 shows the means and standard deviations for N_1 amplitude values for both listener groups and all stimulus conditions. Analysis of variance indicates a significant difference [$F(1, 8) = 5.94$, $p < 0.041$] between groups but no significant difference [$F(2, 16) = 0.55$, $p < 0.590$] within subject groups across the three stimulus conditions.

Discussion

N_1, P_2, P_3 Latency

In contrast to the delayed P_3 latency found with the hearing-impaired listeners in Polen's [9] study, the hearing-impaired listeners in this study performed as well as the

Table 4. Means and standard deviations for P_2 latency (in ms) for all stimulus conditions in both groups

	Tone 1 kHz/2 kHz	VOT [bɛ]/[pɛ]	Place [bɛ]/[dɛ]
Normal hearing			
Mean	193	203	164
SD	32	71	15
Hearing-impaired			
Mean	149	128	204
SD	8	27	84
Total			
Mean	171	166	184
SD	32	64	60

The stimulus pairs listed in the column headings represent the nontarget and targe stimuli, respectively.

Table 5. Means and standard deviations for P_2 amplitude (in μv) for all stimulus conditions in both groups

	Tone 1 kHz/2 kHz	VOT [bɛ]/[pɛ]	Place [bɛ]/[dɛ]
Normal hearing			
Mean	3	5	7
SD	0.9	2	3
Hearing-impaired			
Mean	4	6	5
SD	3	0.8	3
Total			
Mean	3	5	6
SD	3	2	3

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

Table 6. Means and standard deviations for N_1 latencies (in ms) for all stimulus conditions and both groups

	Tone 1 kHz/2 kHz	VOT [bɛ]/[pɛ]	Place [bɛ]/[dɛ]
Normal hearing			
Mean	93	104	79
SD	6	45	12
Hearing-impaired			
Mean	91	73	86
SD	9	21	10
Total			
Mean	92	88	83
SD	7	37	11

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

Table 7. Means and standard deviations for N_1 amplitude (in μV) for all stimulus conditions in both groups

	Tone 1 kHz/2 kHz	VOT [bɛ]/[pɛ]	Place [bɛ]/[dɛ]
Normal hearing			
Mean	8	9	9
SD	5	3	4
Hearing-impaired			
Mean	7	4	9
SD	4	1	2
Total			
Mean	8	6	7
SD	4	3	4

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

normally hearing subjects. There were no increases in P_3 peak latencies for the hearing-impaired subjects. The fact that the presentation level was 40 dB SL (i.e., at a level at which the hearing-impaired listeners could easily perceive the stimulus) may have masked group differences. Perhaps a presentation level that was closer to the behavioral threshold values would have made the group differences more apparent. These data are, however, in agreement with other studies [18, 19] which indicate that as task complexity increases, the latency of the P_3 increases. In this study, P_3 peak latencies for both the normal and hearing-impaired listeners were delayed as the stimulus changed in complexity from tones to speech. However, no significant differences were noted in P_3 latency between the two speech stimuli (VOT and Place). Differences had been expected for the hearing-impaired subjects since VOT should be an easier discrimination for them than place of articulation. This expected difference may have occurred had the stimuli been presented at lower sensation levels than used in the present investigation.

The P_2 component, according to Polen [9], should be the component that is most sensitive to alterations in stimulus parameters and to sensorineural hearing loss. In contrast, the results from this study did not indicate any significant latency differences between the normal and hearing-impaired group or across any of the stimulus conditions. Again, the fact that the presentation level was 40 dB SL may have masked group differences. Further research would be needed with larger subject populations in order to determine whether stimulus parameter changes are reflected in P_2 latency effects.

N_1 latency was similar for both groups, again in contrast to increased latency values reported by Polen [9] for his hearing-impaired listeners. However, the N_1 and P_2 findings from this study support the concept that N_1 and P_2 are stimulus-related potentials; that is, they are primarily related to the physical parameters of the stimulus [17]. latency increased for both groups of listeners as the physical parameters changed; however, latency for the hearing-impaired group was not different from that of the normal group.

N_1, P_2, P_3 Amplitude

It has been suggested [20] that N_1 amplitude would be reduced in cases of reduced hearing sensitivity. In other words, if there is a loss of sensitivity, some frequency information entering the system would be lost and this loss of 'information load' would be reflected in N_1 amplitude. Data from this study are in agreement with this concept and in disagreement with Polen's [9] results which indicated no group differences for N_1 amplitude.

Polen also found that P_2 amplitude was reduced within the hearing impaired group. Whereas P_2 amplitude was affected in this study, the amplitude effect was not observed between the normal and hearing-impaired groups; rather the effect was present across speech distinction conditions. This would suggest that a change from a pure tone to a complex signal would account for the reduced amplitude, rather than the loss of hearing sensitivity. However, since there were considerable differences between the speech stimuli used in this study and Polen's study, no specific statements can be made.

No group differences were apparent for P_3 amplitude; however, a trend toward decreasing amplitude with increasing stimulus complexity was seen with the amplitude values for this component. According to Fitzgerald and Picton [21], a decrease in P_3 amplitude would be expected as task complexity increased. The lack of significant differences between the normal and hearing-impaired groups for P_3 latency and amplitude may be attributed to the high presentation level (85 dB nHL) for all of the stimuli used in this study. Additionally, since the hearing-impaired listeners exhibited excellent speech discrimination according to standard word tests, it is not surprising that they experienced no discrimination difficulty when the P_3 stimuli were presented at suprahreshold levels. In other words, the task demands were relatively simple because of the presentation level.

The discrepancies found between this study and that of Polen cannot be clarified at this time because of major differences in subject populations and stimulus presentation levels. Polen did not have similar hearing impairments among his subjects and presentation levels were considerably lower and closer to behavioral thresholds. Further research is needed to determine whether hearing impairment does in fact produce measurable effects on the stimulus-related or event-related potentials.

Einfluss einer Hörstörung auf ereignisbezogene Potentiale für Ton- und Sprachmerkmale

In der Forschung im Zusammenhang mit dem P_{300}-Potential (P_3) wurde gewöhnlich der Zustand des peripheren auditorischen Systems ignoriert. Sensorische Einflüsse auf die späten «endogenen Potentiale», wie P_3, wurden gewöhnlich als unbedeutend angesehen, aber neuere Befunde legen nahe, dass die Intensität des Stimulus das P_3-Potential beeinflusst. Ausgehend von der Annahme, dass zwischen Intensitätseffekten und Gehörschaden Zusammenhänge bestehen, wurden P_3-Potentiale von 10 Versuchspersonen aufgenommen: 5 Normalhörende und 5 Personen mit kochleären Gehörschäden. Als Stimuli wurden Sinustöne und Konsonant-Vokal-Einsilber verwendet, welche entweder in ihrer Artikulationsstelle oder hinsichtlich ihrer Stimmeinsatzzeitpunkte variierten. Die P_3-Latenz stieg an und die Amplituden de P_3 sanken bei den Sprachstimuli; Gruppenunterschiede wurden jedoch nicht beobachtet.

Influence des troubles de l'audition sur la distinction des potentiels pour les sons et le langage

La recherche du potentiel P_{300} (P_3) ignore en général l'état du système auditif périphérique. On estimait habituellement que les influences sensorielles sur les «potentiels endogènes» tels que P_3 étaient insignifiants, mais des travaux récents suggèrent que l'intensité du stimulus agit sur le P_3. Partant de l'idée qu'il existe des corrélations entre les effets de l'intensité et les atteintes auditives, on détermina les potentiels P_3 de 10 personnes: 5 ayant une audition normale et 5 présentant une surdité neurosensorielle. Les stimuli étaient des sons purs et des consonnes et voyelles monosyllabiques variant quant au point d'articulation ou quant au début du temps d'émission (VOT). Lors des stimuli vocaux les latences des P_3 augmentaient, alors que les amplitudes des P_3 diminuaient mais on ne constata pas de différence entre les deux groupes.

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