

Diagnostic Implications of Stimulus Polarity Effects on the Auditory Brainstem Response

Cynthia G. Fowler*
Christopher D. Bauch†
Wayne O. Olsen‡

Abstract

The purpose of this study was to determine whether clicks presented in rarefaction or condensation modes produce more accurate diagnostic information. Subjects were 20 consecutive patients who were seen at the Mayo Clinic for unilateral acoustic neuromas. The nontumor ear served as a control to minimize intersubject variability in the latencies. A standard audiologic evaluation was followed by an auditory brainstem response (ABR) test for which the stimuli were rarefaction and condensation clicks. Responses were analyzed for the presence of waves I, III, and V; absolute latencies of waves I, III, and V; interpeak intervals I-III, III-V, and I-V; and interaural latency difference for wave V. The results indicated that measures from both polarities were similar in this set of patients and that neither click polarity provided diagnostic advantages over the other. Recommendations are to collect ABRs to both click polarities individually to obtain the full complement of waves on which to base the diagnostic impression.

Key Words: Acoustic neuroma, adults, auditory brainstem response, hearing loss, sensorineural

Abbreviations: ABR = auditory brainstem response; ILD = interaural latency difference; IPI = interpeak interval

Sumario

El propósito de este estudio fue determinar si los clicks presentados en modo de rarefacción o de condensación producen información diagnóstica más exacta. Los sujetos de estudio fueron 20 pacientes consecutivos que se vieron en la Clínica Mayo portadores de neurinomas unilaterales del acústico. El oído sin tumor sirvió como oído control para minimizar la variabilidad intersujeto en las latencias. A la evaluación audiológica convencional le siguió una prueba de respuestas auditivas del tallo cerebral (ABR), para la cuál los estímulos fueron clicks de rarefacción y de condensación. Las respuestas fueron analizadas buscando la presencia de las ondas I, III y V; de la latencia absoluta de las ondas I, III y V; de los intervalos inter-pico I-III, III-V y I-V, y de las diferencias interaurales de latencia de la onda V. Los resultados indicaron que las medidas con ambas polaridades fueron similares en este grupo de pacientes y que ninguna aportó ventajas diagnósticas sobre la otra. La recomendación consiste en coleccionar estudios de ABR con clicks de ambas polaridades, en forma individual, para obtener el complemento de las ondas sobre el cuál basar la impresión diagnóstica.

Palabras Clave: Neurinoma del acústico, adultos, respuesta auditiva del tallo cerebral, hipocusia, sensorineural

Abreviaturas: ABR = respuestas auditivas del tallo cerebral; ILD = diferencia interaural de latencia; IPI = intervalo interpico

Click stimuli are commonly used to elicit the auditory brainstem response (ABR) for the neurodiagnostic assessment of patients suspected of having eighth nerve tumors. Clicks are favored as stimuli because their abrupt onsets elicit good neural synchrony for the production of large amplitudes for the

component waves of the ABR. Clicks can be presented with an onset polarity of rarefaction or condensation, as defined by the initial deflection of the click. The issue of which stimulus polarity provides the more accurate diagnostic information, however, has not been determined.

*Department of Communicative Disorders, University of Wisconsin-Madison, Madison, Wisconsin; †Section of Audiology, Mayo Clinic, Rochester, Minnesota

Reprint requests: Cynthia G. Fowler, Department of Communicative Disorders, 1975 Willow Drive, University of Wisconsin-Madison, Madison, WI 53706

Rarefaction clicks often have been used for routine clinical applications of the ABR because their diagnostic sensitivity is theoretically better than that of condensation clicks (Rosenhamer et al, 1978; Stockard et al, 1978; Chiappa et al, 1979; Kevanishvili and Aphonchenko, 1981; Schwartz and Berry, 1985; Schwartz et al, 1990). The physiologic basis for the use of the rarefaction clicks is that the afferent auditory neurons become activated by the hair cells when the basilar membrane is displaced toward the scala vestibuli (Brugge et al, 1969; Zwislocki, 1975). The rarefaction phase of the click, that is, an outward movement of the tympanic membrane and stapes footplate, theoretically mobilizes the basilar membrane in an upward direction toward the scala vestibuli. The resultant bending of hair cell stereocilia causes the depolarization of the hair cells that leads to neural firing (Peake and Kiang, 1962; Salomon and Elberling, 1971).

The condensation polarity of the click produces effects opposite from those produced by the rarefaction polarity. The condensation click produces an initial inward movement of the tympanic membrane and mobilizes the basilar membrane downward toward the scala tympani, thus hyperpolarizing the hair cells. The result of the condensation click, then, is to delay the neural firings by the time delay between the negative and positive deflections of the click because the neural firings are triggered only on the rarefaction cycle of the signal, at least for signals at high levels (Peake and Kiang, 1962). As compared to condensation clicks, then, rarefaction clicks are expected to produce shorter latencies and greater amplitudes for the ABR. Occasionally in practice, however, condensation stimuli may yield clearer responses than rarefaction stimuli, thus complicating the issue of which stimulus polarity provides the better stimulus to use diagnostically (Terkildsen et al, 1975; Rosenhamer et al, 1978; Maurer et al, 1980; Hughes et al, 1981; Kevanishvili and Aphonchenko, 1981; Borg and Lofqvist, 1982; Ruth et al, 1982).

The differential effects of rarefaction and condensation polarity of clicks are predominantly low-frequency phenomena because the time delay between the negative and positive deflections of the stimuli are greater for lower than for higher frequencies. In people with normal hearing, the ABR is dominated by neurons stimulated by high-frequency components of the click (Don and Eggermont, 1979), which

produce relatively minor latency and amplitude differences with changes in stimulus phase (Fowler, 1992). The responses to rarefaction and condensation stimuli are not substantially different from each other or from the response to clicks in alternating polarity. The major difficulty with the use of alternating clicks, however, occurs with cases with high-frequency hearing losses. Because high-frequency hearing losses effectively lower the dominant frequency for eliciting the ABR, the latencies of responses to the rarefaction and condensation polarities of the stimulus can be substantially different. The result is that the two responses can be smeared, yielding smaller amplitudes and broad or poorly defined peaks from which to determine latency.

Stimulation with both rarefaction and condensation clicks separately has been suggested as a means to obtain more meaningful clinical data (Emerson et al, 1982; Hoult, 1985; Gorga et al, 1991; Fowler, 1992). The differences between the latencies of the ABR waves to condensation and rarefaction clicks reportedly increase as cochlear hearing loss increases (Borg and Lofqvist, 1982; Pijl, 1987). In some cases, the site of the lesion suggested by the ABR is different depending on the polarity of the stimulus that is used (Maurer, 1985), and in other cases, the responses to one stimulus polarity are within normal limits and the responses to the opposite stimulus polarity are beyond normal limits. The appropriate interpretation of these responses may be uncertain because these patterns have been identified in the ABRs of patients with acoustic neuromas and those with multiple sclerosis (Emerson et al, 1982), as well as in patients with cochlear pathology (Maurer, 1985). The issue of selecting an optimal stimulus polarity for neurodiagnostic ABR assessment, therefore, has not been resolved. The norms established for the latencies of the peaks of the ABR are typically determined from the responses of individuals with normal hearing, which yield similar latencies, and thus cannot assist in the resolution of this dilemma.

The purpose of this study was to examine the effect of click polarity on the ABR recordings for nontumor and tumor ears with varying degrees of hearing loss. The effects of click polarity on the ABR were determined for the affected and nonaffected ears of 20 patients with unilateral acoustic neuromas (vestibular schwannomas), thus allowing the use of the nonaffected ear for each person as his/her own control.

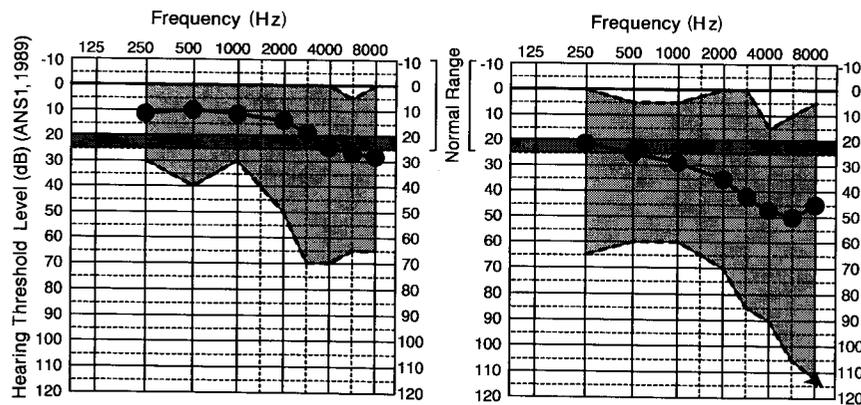


Figure 1 Audiograms, showing mean thresholds and threshold ranges, for the nontumor (*left panel*) and tumor (*right panel*) ears for the group of subjects.

METHOD

Participants in the study were 20 consecutive patients diagnosed as having unilateral eighth nerve tumors (vestibular schwannomas). All participants were evaluated medically by a staff neuro-otologist in the Department of Otorhinolaryngology at the Mayo Clinic, Rochester, Minnesota. Eighth nerve tumors on the poorer ear and absence of a tumor on the better ear were confirmed with magnetic resonance imaging, and the eighth nerve tumor was further verified by surgery in all of the cases. All patients received complete audiologic evaluations (air and bone conduction, speech recognition thresholds, and word recognition), acoustic reflex threshold, reflex decay, and neurodiagnostic ABR evaluations as part of the medical evaluation.

For the ABR recordings, physiologic filters were set to pass activity between 150 and 3000 Hz (3-dB down points) for all recordings. Electrodes were placed at high forehead (Fz), ear canals (TIPtrodes), and nape (C7) for four channel recordings that included Fz to ipsilateral canal, Fz to contralateral ear canal, ipsilateral ear canal to contralateral ear canal, and Fz to noncephalic C7. The ground electrode was located on the forehead. Impedances for the electrodes were at or below 3000 ohms and were equal within 1000 ohms for each pair of electrodes. All recordings were obtained via a Nicolet Spirit signal averaging system.

Click stimuli were nominal 100 μ sec rarefaction and condensation clicks presented at 85 or 90 nHL and a repetition rate of 11.1/sec to each ear via Etymotic ER-3A tube-phones. The polarity of the click was identified by the direction of the first large peak in the temporal waveform; initial negative-going peaks were labeled as rare-

faction and initial positive-going peaks were labeled as condensation. Responses to 2000 sweeps were averaged for each stimulus.

Absolute latencies for waves I, III, and V and the interpeak intervals (IPIs) I-III, III-V, and I-V were determined from the ipsilateral recording of the ABRs from both ears of each patient for both stimulus polarities. In addition, wave V interaural latency differences (ILDs) were determined for each patient for both stimulus polarities. Latencies for the two replications were averaged to form one datum point for each wave. Responses from the other channels were used to confirm the presence and identity of the waves.

RESULTS

The ABR was elicited with rarefaction and condensation clicks in the tumor and nontumor ears of patients with unilateral acoustic neuromas. This protocol allowed a comparison of the effect of the tumor on the latency of the ABR dependent on the polarity of the stimulus while holding intrasubject variability to a minimum. The means (filled circles) and ranges (gray area) of hearing sensitivity for the 20 nontumor (left audiogram) and 20 tumor ears (right audiogram) are shown in Figure 1. In comparison with the nontumor ears, the tumor ears had poorer auditory sensitivity and a greater range of thresholds.

Not all ABR waves were present for all stimulus conditions. Figure 2 presents the number of waves I, III, and V that were present for the rarefaction and condensation clicks for both the nontumor and tumor ears. For the nontumor ears, wave I was absent in only one condition, which was condensation; wave I was always present in the nontumor ears for the rarefaction

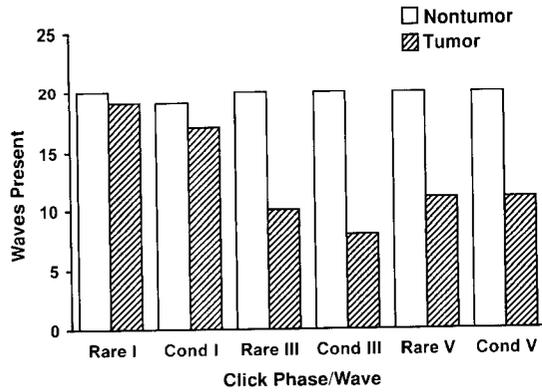


Figure 2 Number of waves I, III, and V present in the nontumor and tumor ears of the patients by wave and stimulus polarity. Rare = rarefaction; Cond = condensation.

clicks. All 20 nontumor ears had waves III and V present for both rarefaction and condensation clicks. Conversely, for the 20 tumor ears, a number of waves were absent. Wave I was absent in 1 ear for rarefaction clicks only and in 3 ears for condensation clicks only, but never for both polarities, for a total of 19 waves I present for rarefaction and 17 for condensation. Wave III was absent in no ears for rarefaction only, 2 ears for condensation only, and 10 ears for both polarities, for a total of 10 waves III present for rarefaction and 8 present for condensation. Wave V was absent in 1 ear for rarefaction only, 1 ear for condensation only, and 8 ears for both polarities, for a total of 11 waves V present for each polarity.

Mean absolute latencies (and standard deviations) for waves I, III, and V for both click polarities and for both ears are shown in Table 1. The individual data points are shown in Figure 3, in which the absolute latencies for waves I, III, and V are depicted with respect to click polarity, with latencies from rarefaction stimuli on the abscissa and latencies from condensation stimuli on the ordinate. Latencies for the nontumor ears are in the left panel and latencies for the tumor ears are in the right panel. The boxed

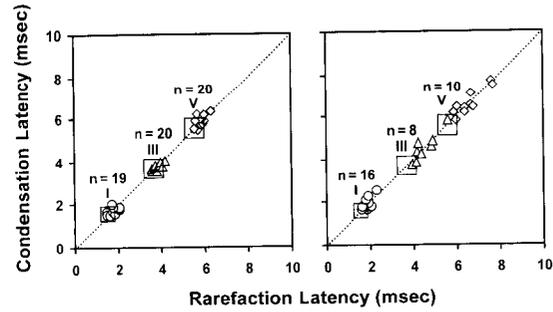


Figure 3 Latencies for waves I, III, and V for the nontumor ears (left panel) and tumor ears (right panel) for the group of subjects. The diagonal line represents latencies that are equal for the two polarities. The boxed area represents the normal range for the latencies. The numbers above the boxed areas are the number of subjects for whom that wave was present for both polarities.

areas indicate the normal absolute latency values established for the equipment and stimulus conditions at the Mayo Clinic (Bauch and Olsen, 1990). The diagonal lines represent equal latencies for rarefaction and condensation stimuli. Data points falling above the diagonal line indicate waves having longer latencies for condensation stimuli; data points below the diagonal line indicate waves having longer latencies for rarefaction stimuli. The values for *n* above the boxed areas are the number of ears that had waves present for both rarefaction and condensation conditions.

As shown in Figure 3, for the ears having waves for both stimulus conditions, no clear trend was observed for the latencies for either stimulus polarity. Although the data for the ears were divided as to whether the latencies were shorter for rarefaction or condensation stimuli, there was a slight predilection for condensation to produce the shorter latencies for all conditions in both ears. For the nontumor ears, shorter latencies for rarefaction stimuli than for condensation stimuli were observed for wave I in 7 of 19 ears (equal latencies for 1 ear), for wave III in 4 of 19 ears (equal for 1 ear), and for wave V

Table 1 Mean Latencies (in msec) with SDs in Parentheses for Waves I, III, and V for the Nontumor and Tumor Ears for Rarefaction (R) and Condensation (C) Clicks

Ear	Wave I		Wave III		Wave V	
	R Clicks	C Clicks	R Clicks	C Clicks	R Clicks	C Clicks
Nontumor	1.75 (0.17)	1.69 (0.14)	3.90 (0.17)	3.80 (0.12)	5.81 (0.21)	5.87 (0.21)
Tumor	1.87 (0.18)	1.85 (0.25)	4.80 (0.80)	4.53 (0.69)	6.72 (0.74)	6.66 (0.65)

Table 2 Correlations (Pearson *r*), with Significance Level in Parentheses, for Waves I, III, and V Elicited with the Rarefaction and Condensation Stimuli

<i>Ear</i>	<i>Wave I</i>	<i>Wave III</i>	<i>Wave V</i>
Nontumor	.424 ($p = .071$)	.718 ($p = .000$)	.593 ($p = .006$)
Tumor	.665 ($p = .005$)	.911 ($p = .002$)	.907 ($p = .000$)

in 7 of 20 ears (equal for 2 ears). For the tumor ears, shorter latencies for rarefaction stimuli were observed for wave I in 8 of 16 ears, for wave III in 3 of 8 ears, and for wave V in 3 of 10 ears. Latencies were not equal for both stimuli in any tumor ears for any waves. The same polarity (either rarefaction or condensation) produced the shorter latencies in both ears for 8 of 16 ears for wave I and 4 of 10 ears for wave V.

The number of waves for which the latencies fell within the normal ranges for each stimulus condition can also be seen in Figure 3. The absolute latencies of waves I, III, and V were normal for nearly all of the nontumor ears, whereas the absolute latencies were clearly abnormal in most cases for the tumor ears, particularly for waves III and V. For the nontumor ears, wave I had prolonged latencies in two cases for rarefaction only and in one case for condensation only. Wave V had abnormal latencies for condensation clicks in only two ears and for both click polarities in one ear. The remaining wave latencies from nontumor ears were normal for both click polarities.

Overall, the tumor ears produced fewer waves than the nontumor ears, but the pattern with respect to stimulus polarity was not substantially different. For wave I, 2 tumor ears had abnormal wave I latencies with condensation clicks only, 1 had abnormal latencies for rarefaction clicks only, and 2 additional ears had abnormal latencies for both rarefaction and condensation clicks. For wave III, 18 ears had abnormal latencies for both click polarities and the other 2 had normal latencies for both click polarities. For wave V, 1 tumor ear had normal laten-

cies for both click polarities, 1 had abnormal latencies only with rarefaction clicks, 1 had abnormal latencies only with condensation clicks, and 7 had abnormal latencies for both click polarities.

Several values for the wave latencies were evaluated with a correlation analysis (SPSS, 2001), with an alpha level reduced to .01 (rather than .05) to account for multiple comparisons. The wave latencies produced by the rarefaction and condensation stimuli were significantly correlated (Pearson r , $p < .01$) for each wave, with the exception of wave I in the nontumor ear (Table 2). In fact, the latencies of the waves for the tumor ears yielded higher correlation values between polarities than the latencies for the waves from the nontumor ears, which may in part reflect the fact that the tumor added similar latency delays to the responses to rarefaction and condensation clicks, which minimized the cochlear contribution to the final latencies. The differences in latencies to the rarefaction and condensation clicks (rarefaction latency minus condensation latency) did not correlate with the high-frequency thresholds (average of 2000, 3000, and 4000 Hz) for any waves in either nontumor or tumor ears. Further, the difference in latencies for waves elicited for the two polarities was not correlated with the threshold slope between 1000 and 4000 Hz or between 2000 and 4000 Hz for either ear.

Mean IPIs (with standard deviations) for I-III, III-V, and I-V are given in Table 3 for nontumor and tumor ears. Individual data for nontumor and tumor ears are depicted for I-III (Fig. 4), III-V (Fig. 5), and I-V IPI (Fig. 6), with

Table 3 Mean Interpeak Intervals (in msec) with SDs in Parentheses for I-III, III-V, and I-V for the Nontumor and Tumor Ears for the Rarefaction (R) and Condensation (C) Clicks

<i>Ear</i>	<i>I-III</i>		<i>III-V</i>		<i>I-V</i>	
	<i>R Clicks</i>	<i>C Clicks</i>	<i>R Clicks</i>	<i>C Clicks</i>	<i>R Clicks</i>	<i>C Clicks</i>
Nontumor	2.15 (0.19)	2.11 (0.13)	1.97 (0.20)	2.11 (0.21)	4.10 (0.20)	4.18 (0.22)
Tumor	2.93 (0.74)	2.96 (0.62)	1.91 (0.15)	1.94 (0.17)	4.84 (0.70)	5.12 (0.64)

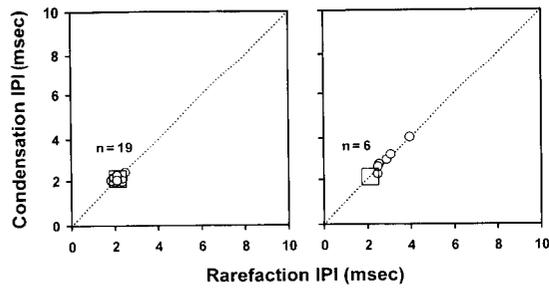


Figure 4 Interpeak intervals (IPI) for I–III by click phase for the nontumor (*left panel*) and tumor (*right panel*) ears with rarefaction on the abscissa and condensation on the ordinate. The diagonal line represents latencies that are equal for the two polarities. The boxed area represents the normal range for the latencies. The *n* is the number of patients having the relevant waves for both stimulus polarities.

rarefaction latencies on the abscissa and condensation latencies on the ordinate. The *n* represents the number of ears for which the value could be measured, and the boxes represent normative values. Again, no clear pattern was observed with respect to stimulus polarity. The distribution of data points above and below the diagonal lines was approximately equal for rarefaction and condensation stimuli, suggesting no substantial difference in the IPIs for the two polarities. For the nontumor ears (left panels), most of the IPIs fell within normal limits. For both I–III and I–V, all 19 nontumor ears had normal values for both stimulus polarities. For III–V, however, the interval was recorded in all 20 patients but was prolonged in 1 ear for rarefaction clicks and in 4 ears for condensation clicks. The ear with the prolongation for rar-

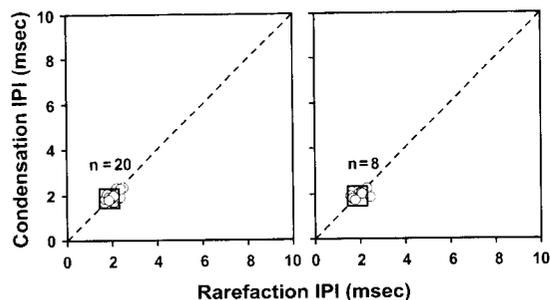


Figure 5 Interpeak intervals (IPI) for III–V by click phase for the nontumor (*left panel*) and tumor (*right panel*) ears with rarefaction on the abscissa and condensation on the ordinate. The diagonal line represents latencies that are equal for the two polarities. The boxed area represents the normal range for the latencies. The *n* is the number of patients having the relevant waves for both stimulus polarities.

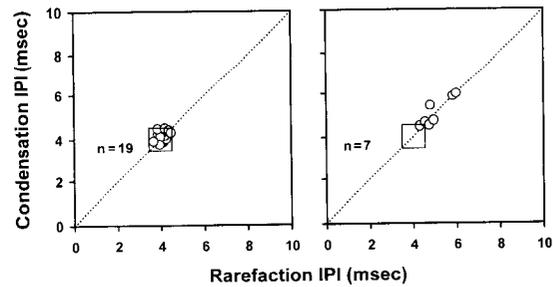


Figure 6 Interpeak intervals (IPI) for I–V by click phase for the nontumor (*left panel*) and tumor (*right panel*) ears with rarefaction on the abscissa and condensation on the ordinate. The diagonal line represents latencies that are equal for the two polarities. The boxed area represents the normal range for the latencies. The *n* is the number of patients having the relevant waves for both stimulus polarities.

efaction also had a prolongation for condensation clicks.

For the tumor ears (right panels of Figs. 4–6), the IPIs for I–III and I–V were generally abnormal regardless of the polarity of the stimuli, whereas the III–V was normal in the 8 cases for whom it could be measured. For the 6 tumor ears with measurable I–III, 5 intervals were abnormal for both stimulus polarities, and 1 was normal I–III for both polarities. For the 7 tumor ears with measurable I–V, 5 intervals were prolonged for both polarities, 1 was normal for both polarities, and 1 was prolonged for condensation clicks but normal for rarefaction clicks.

The last two patients deserve additional comments regarding interpretation of their waveforms. For patient A, who had normal I–V between ears for both polarities, further scrutiny of the other IPIs did not reveal any additional abnormalities. The interaural differences for I–III, III–V, and I–V for both polarities ranged between 0.02 and 0.16 msec for all intervals except the I–III interval for condensation, which was 0.32 msec. The audiometric thresholds for the tumor ear, which show a dip in the mid-frequencies, are shown in Table 4 for patient A. For patient B, whose I–V differed with respect to stimulus polarity, the audiogram was not helpful in explaining the difference. The audiometric thresholds for the tumor ear are given in Table 4 for patient B. The hearing loss is essentially flat and mild to moderate from 1000 to 8000 Hz rather than sharply sloping in the high frequencies as might be expected to produce latency differences between ABR waves evoked by stimuli of different polarities.

Table 4 Auditory Thresholds (in dB HL) for the Tumor Ears of Patient A, Who Had Normal I-V IPIs for Auditory Brainstem Responses Elicited by Both Click Polarities, and for Patient B, Who Had a Normal I-V IPI Elicited by Rarefaction Clicks and Prolonged I-V IPI Elicited by Condensation Clicks

Patient	Frequency							
	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
A	40	40	45	70	65	55	50	30
B	10	5	45	50	40	30	45	45

IPI = interpeak interval.

Wave V ILDs as a function of stimulus polarity are depicted in Figure 7. Only 10 (50%) of the patients yielded measurable waves V in both ears for both polarities to make such judgments. The rectangular areas along the ordinate and the abscissa indicate normal interaural latency differences of 0.40 msec (Bauch and Olsen, 1990). For the 10 tumor patients having measurable ILDs, no clear trend was observed as a function of stimulus polarity, and the correlation between data for the rarefaction and condensation clicks was .9 (Pearson *r*). Six patients had longer ILDs with condensation clicks, but 4 patients had longer ILDs with rarefaction clicks. Six patients demonstrated prolonged ILD results for both rarefaction and condensation clicks, and 2 patients had normal ILDs for both condensation and rarefaction clicks (lower left quadrant). The final 2 patients presented a diagnostic dilemma in which a normal ILD resulted when one stimulus polarity was used, but a prolonged ILD resulted when

the opposite polarity was used. The normal value was obtained with rarefaction clicks for one patient, whereas the normal value was obtained with condensation clicks for the other patient.

Figure 8 presents the audiogram and Figure 9 presents the ABR waveforms from the right (tumor) ear for one of the patients demonstrating differences in waveform morphology and latencies with rarefaction and condensation clicks. The ABR waveforms shown are the ipsilateral and horizontal recordings elicited by the condensation (above) and rarefaction (below) clicks. Stimulation with condensation clicks from this ear yielded only waves III and V for the ipsilateral recordings and only wave III for the horizontal recordings but no wave I in either recording. Stimulation with rarefaction clicks, however, resulted in clear identification of the waves I, III, and V with the ipsilateral and horizontal recordings. Substantial latency differences for waves III and V for the two stimulus polarities were also observed. Whereas all of the absolute latencies from responses to both click polarities were beyond normal limits, the

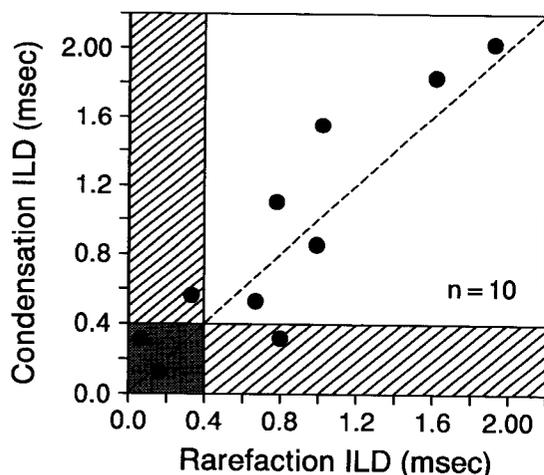


Figure 7 Interaural latency difference (ILD) for the wave V latencies (in msec) from the rarefaction clicks (abscissa) and the condensation clicks (ordinate) for the 10 patients who had wave V for both conditions in both ears. Normative values are shown in the shaded rectangles below 0.4 msec for both axes. The diagonal line represents equal values for rarefaction and condensation ILDs.

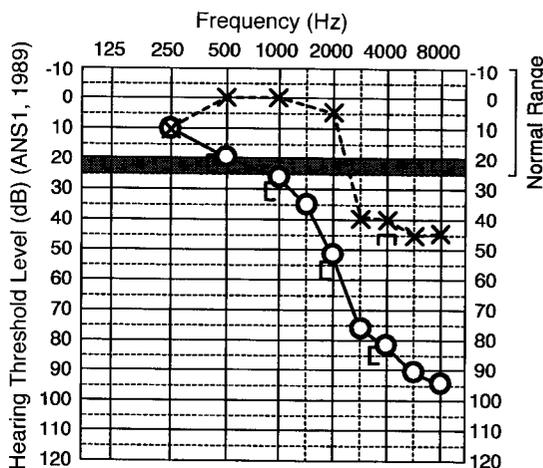


Figure 8 Audiogram from a patient in which the diagnostic interpretation of the auditory brainstem response was different for the rarefaction and condensation click stimuli.

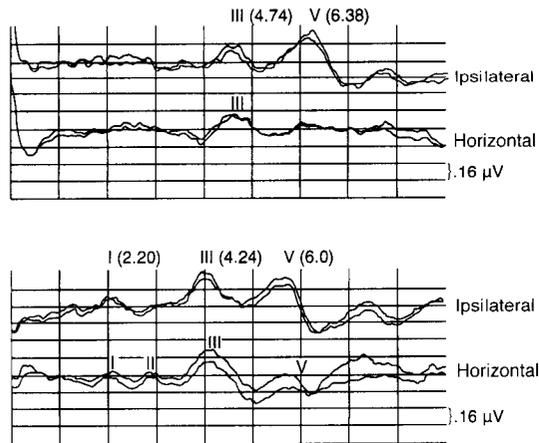


Figure 9 Auditory brainstem response waveforms to condensation clicks (*upper waveforms*) and rarefaction clicks (*lower waveforms*) as recorded from the right (tumor) ear of the patient whose audiogram is shown in Figure 8. For both click polarities, the ipsilateral and horizontal waveforms are shown. For the condensation clicks, waves III and V are shown on the ipsilateral waveform, and only wave III is visible on the horizontal waveform. For the rarefaction clicks, waves I, III, and V are visible on both the ipsilateral and horizontal waveforms.

absolute latencies from rarefaction clicks were considerably shorter than the absolute latencies obtained with condensation clicks. The I–III and I–V intervals, however, were both within normal limits for the rarefaction stimuli and could not be measured for the condensation stimuli. The severe high-frequency hearing loss suggests the possibility of a large cochlear component contributing to the prolonged condensation latencies, but that cannot be proven given the absence of wave I for that condition. Differences in the morphology and latencies from condensation and rarefaction stimuli were not necessarily similar for both ears of a given patient.

With respect to the present data, no consistent pattern emerged with reference to the absolute or relative latencies elicited by either stimulus polarity for any of the measures evaluated. Table 5 presents the summary of the numbers of each wave, IPI, and ILD that were abnormal for both stimulus conditions and the number of instances in which the interpretation was different depending on stimulus polarity. In this summary, the absence of a wave was considered to be an abnormality. The cases demonstrating latencies that differed in interpretation depending on stimulus polarity were typically those near the boundary between normal and abnormal values.

DISCUSSION

Stimulus polarity is a controversial yet critical aspect of neurodiagnostic assessment using the ABR. The literature suggests that rarefaction clicks are usually preferred over condensation clicks for neurodiagnostic evaluation, primarily for theoretical reasons. Variability does exist for wave latency and overall wave morphology for the ABRs elicited by the two click polarities. This variability has been attributed to numerous factors, including hearing sensitivity (Coats and Martin, 1977; Borg and Lofqvist, 1982), middle ear mechanics (Borg and Lofqvist, 1982; Kringlebotn and Gundersen, 1985), inner ear properties (Gerull et al, 1985), frequency content of the click (Coats et al, 1979; Scherg and Speulda, 1982; Salt and Thornton, 1984), the entire acoustic waveform of the clicks (Hughes et al, 1981), transducer “ring” (Arlinger, 1980; Pijl, 1987), response variability (Don et al, 1996), temporal summation of responses from generator sites along the brainstem pathway but initiated in the cochlea (Pratt and Bleich, 1989; Fowler, 1992; Orlando and Folsom, 1995),

Table 5 Number of Abnormal Values for the Latencies of Waves I, III, and V, for the Interwave Intervals I–III and I–V for the Tumor Ears and the Nontumor Ears, and the Interaural Wave V Latency Difference for the 20 Patients

	Tumor Ears						Nontumor Ears			Ears			ILD V
	I	III	V	I–III	III–V	I–V	I	III	V	I–III	III–V	I–V	
Rarefaction	8	18	18	17	10	16	2	1	2	1	0	0	0 17
Condensation	7	18	19	19	13	19	1	0	3	4	0	0	0 17
Difference	6	0	1	2	3	3	3	1	3	3	0	0	0 2

The top two data lines show the number of abnormalities for the rarefaction and condensation clicks and the bottom line shows the number of instances in which the interpretation was different for responses to rarefaction and condensation clicks.

ILD = interaural latency difference.

and various auditory pathologies (Maurer et al, 1980). Together, the large number of possibilities suggests that the phenomenon is not yet completely understood and probably results from more than one factor. Significantly, no study has indicated that the neurons respond differently depending on stimulus polarity once the response is triggered.

In the present sample, there was marked variability for the responses in some ears such that one polarity produced clear waveforms, whereas the opposite polarity produced very poor waveforms, precluding identification of the waves. These differences were also described by Hoult (1985) in a series of patients with varying lesions and by Pijl (1987) with a series of patients with presumably cochlear pathology. This finding is strong support for using stimuli with both polarities recorded separately for neurodiagnostic purposes. The two recordings provide additional data from which to base a diagnostic decision, and, in the event that both stimulus conditions produce poor waveforms, the two can be added together offline to attempt to produce a response with a better signal-to-noise ratio. If the added responses are smeared or double-peaked, then interpretation can still be based on the responses to the individual click polarities. An additional advantage of using both polarities separately is that if the responses elicited by the two polarities are in phase opposition and their addition eliminates the waveforms, a case of auditory neuropathy will not be overlooked (Berlin et al, 1998).

Although high-frequency hearing loss has been suggested as a mechanism for rarefaction-condensation latency differences in the ABR, a review of hearing sensitivity for the patients in the present study revealed that the degree or slope of the audiometric configuration had no consistent influence on the ABR results. This finding is consistent with the results of Pijl (1987), who reported that audiometric configuration in the high frequencies did not predict the amount of latency difference in waves V elicited derived from different click polarities, although the number of cases exhibiting significant latency differences did increase with the degree of hearing loss. Margolis et al (1992) reported that large latency differences could occur for the action potential (wave I) elicited by different click polarities in patients with Meniere's disease without high-frequency hearing loss. In the latter case, the mechanism for the difference in latencies was suggested to be increased endolymphatic pressure in the cochlea.

The group data for absolute latencies and IPIs suggest no clear trend as a function of stimulus polarity for the patients in the present study; rarefaction and condensation clicks produced comparable latency results. These findings are in agreement with previous studies that failed to demonstrate consistent latency differences for waves elicited with the two stimulus polarities (Terkildsen et al, 1975; Maurer et al, 1980; Hughes et al, 1981; Kevanishvili and Aphonchenko, 1981; Borg and Lofqvist, 1982; Ruth et al, 1982). The correlation data for wave V, showing higher correlations between latencies elicited by rarefaction and condensation stimuli for ears with neuromas than for ears without neuromas, suggest that the neural lesion prolongs the latency equally regardless of stimulus polarity and that the lesion effect is stronger than the cochlear effect on the overall latencies of the waves.

There is no theoretical reason for neural responses to differ according to stimulus polarity once the response is initiated. The effects of stimulus polarity at the cochlea are translated into timing differences at the initiation of the neural response. By the time the neural response reaches the generator site for wave V, a number of factors affecting timing may have combined in a complex fashion to produce a latency that does not maintain a simple relation to the polarity of the click. First, frequency-specific latency differences to the two polarities may be initiated in the cochlea. Then, as the signal ascends the brain stem, timing delays from neural synapses and axonal transmission add to the cochlear component of the delay. Given that the individual waves of the ABR are summations of all of the activity from different parts of the cochlea and neural system (Don and Eggermont, 1979), the summation of activity from the rarefaction and condensation clicks may produce different waveform patterns for different individuals. Finally, frequency-specific delays prior to wave I can be added by cochlear pathology depending on the degree and slope of the pure-tone loss (Coats et al, 1979), and neural transmission may be slowed by neural pathology. With all of these factors acting together to produce the final waveform, it is not surprising that one cannot predict the relation between the final wave latencies from the stimulus polarity. Importantly, however, within an individual, the latency of waves elicited by one stimulus polarity accounts for a large part of the latency elicited by the other polarity.

The wave V ILD data illustrate a potentially problematic situation for neurodiagnostic interpretation of the ABR. For the group of 20 patients with unilateral tumors, no clear trends emerged that would favor one stimulus polarity over the other; the results for rarefaction and condensation stimuli were divided in terms of the polarity that produced the shorter latency. Further, the diagnostic interpretation from responses to both polarities was identical, for the most part. For two patients, however, the diagnostic interpretation was questionable because the ILD was normal for one click polarity but abnormal for the opposite click polarity. The ABR of one of these patients would have been labeled abnormal and suggestive of retrocochlear pathology if only the responses from the condensation click had been used, whereas the ABR for the other patient would have been labeled abnormal if only the responses from the rarefaction click were used. Clearly, using one or the other stimulus polarity would not have resulted in more accurate diagnostic information. Data from studies on patients with normal hearing (Stockard et al, 1979) and cochlear pathology (Coats and Martin, 1977; Pijl, 1987) suggest that such disparities occur with sufficient regularity that using the longer latencies would increase the false-positive rates associated with the ABR.

In summary, the clinical neurodiagnostic dilemma involves determining which latencies, from condensation or rarefaction clicks, are the more accurate for interpretation. The use of the longer (poorer) latencies would have resulted in two additional tumor patients being identified correctly. The consistent use of the longer latencies, however, will likely increase the false-positive rate, perhaps to an unacceptable level. A conservative approach would be to accept the normal result when the result differs according to the click polarity. In reality, all measured values are considered before the final interpretation of the ABR is made (Bauch et al, 1996). The present data indicate that both rarefaction and condensation polarities should be used separately to increase the likelihood of eliciting the full complement and clarity of waves, particularly wave I, in the ABR. With the full complement of waves, the clinician can base the interpretation of the ABR on as much information as possible. There does not appear to be a diagnostic advantage in relying on the data from either polarity alone and no advantage to using one stimulus polarity over the other.

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