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**Selecting the best tone-pip stimulus-envelope time for estimating an objective middle-latency response threshold for low- and middle-tone sensorineural hearing losses**

**Abstract** The effects of rise-fall and plateau times for the Pa component of the middle-latency response (MLR) were investigated in normally hearing subjects, and an objective MLR threshold was measured in patients with low- and middle-tone hearing losses, using a selected stimulus-envelope time. Our results showed that the stimulus-envelope time (the rise-fall time and plateau time groups) affected the Pa component of the MLR (quality was determined by the $\chi^2$-test and amplitude by the $F$-test). The 4-2-4 tone-pips produced good Pa quality by visual inspection. However, our data revealed no statistically significant Na-Pa amplitude differences between the two subgroups studied when comparing the 2- and 4-ms rise-fall times and the 0- and 2-ms plateau times. In contrast, Na-Pa became significantly smaller from the 4-ms to the 6-ms rise-fall time and from the 2-ms to the 4-ms plateau time (paired $t$-test). This result allowed us to select the 2- or 4-ms rise-fall time and the 0- or 2-ms plateau time without influencing amplitude. Analysis of the stimulus spectral characteristics demonstrated that a rise-fall time of at least 2 ms could prevent spectral splatter and indicated that a stimulus with a 5-ms rise-fall time had a greater frequency-specificity than a stimulus of 2-ms rise-fall time. When considering the synchronous discharge and frequency-specificity of MLR, our findings show that a rise-fall time of four periods with a plateau of two periods is an acceptable compromise for estimating the frequency-specific MLR threshold. The correspondence between MLR and pure-tone audiometric (PTA) thresholds was high, with a correlation coefficient around 0.92-0.96 in these cases with rising low- and middle-tone sensorineural hearing losses. The MLR and PTA thresholds were within 10 dB for all cases. A comparison of the mean difference (MLRt-PTAt) at 0.5, 1 and 2 kHz revealed no significant differences ($F$-test). The MLR threshold in the present study approximated the psychoacoustic threshold in the hearing-impaired subjects, while the MLR using 4-2-4 tone-pips was able to measure objective thresholds across low and middle frequencies. This study has again demonstrated the clinical usefulness of the MLR for estimating low- to middle-frequency auditory thresholds.

**Key words** Stimulus-envelope time · Middle-latency evoked response · Frequency-specific sensorineural hearing losses

**Introduction**

Data on the auditory middle-latency response (MLR) were first published by Geisler et al. [5]. Successful recordings of repeatable and stable MLR from neonates and infants were subsequently reported by McRandle [15] and Mendel et al. [16]. Kavanagh et al. [10] also demonstrated normative values for the MLR by using low-frequency tones in normally hearing adults.

At present the MLR has received little attention in the diagnosis of auditory dysfunction and is not generally used in patients to estimate objective thresholds. This may be due to inability to accurately determine the stimulus-related characteristics of MLR components. This matter is quite complicated and has been discussed previously [1, 2, 6, 12, 14, 17].

As such, the purpose of our study was twofold. First, we investigated the effects of the stimulus rise-fall and plateau times on the characteristics of the MLR waveform. Analyzing the effects of the stimulus-envelope time on the spectrum and characteristics of the MLR waveform, we used a stimulus-envelope time that was considered to be a good compromise between frequency-specificity and a synchronous discharge for measuring the frequency-specific MLR threshold. Secondly, we determined the objective MLR thresholds in low- and middle-tone sensorineural hearing losses using a specific stimulus-envelope time. The purpose of our studies was to define a clinically useful MLR objective threshold in hearing-impaired patients.
Materials and methods

Fourteen normally hearing volunteers were studied initially to determine the effects of rise-fall and plateau times on the characteristics of the MLR waveform. Ages ranged from 20 to 38 years (mean 26 years). All subjects passed a 15-dB HL screening criterion (Interacoustics, AC5). Type A tympanograms were also found in all subjects, and ipsilateral acoustic reflexes were elicited at 95 dB HL at 500 and 1000 Hz (Grason-Stadler GSI 33 Middle-Ear Analyzer).

Following determinations of normative values, pure tone audiometric (PTA) thresholds were measured at low and middle frequencies in 16 patients with sensorineural hearing losses. This group included 10 men and 6 women (average age 42 years, range 30-60 years). MLR thresholds were recorded and analyzed blind to the audiometric evaluations.

Test stimuli were generated by the click-tone module of the NIC SM 100 stimulus controller and were delivered through 300-Ω earphones (Telephonics TDH-39P). In the normally hearing group, the stimulus used was a 0.5-kHz tone-pip at 75 dB HL with different envelope times. In a first group (14 subjects) rise-fall times of 2, 4, 6, or 8 ms were used with a plateau time of 2 ms. In a second group (14 subjects) plateau times were 0, 2, 4, or 6 ms with a rise-fall time of 4 ms. In the hearing-impaired group, the 0.5-, 1-, and 2-kHz tone-pips were presented with the best envelope time selected by comparison of different envelope times affecting the frequency-specificity and characteristics of the MLR components. The tone-pips were presented at a rate of 9.7/s with alternating polarity.

All subjects were placed in a supine position on a comfortable bed in an acoustically shielded room and demonstrated a high degree of muscular relaxation. No pharmacological sedation was employed. Three Ag-AgCl-plated electrodes were filled with electrode gel. The positive electrode was placed on the middle of the forehead below the hairline, the negative electrode on the mastoid ipsilateral to the test ear, and the common electrode was attached to the contralateral mastoid. Inter-electrode impedances were below 5000 Ω. A recording analog Butterworth filter was set to 30 and 500 Hz. Amplification and averaging were done using a Nicolet Pathfinder II.

Since the Pa component of the MLR is the most easily recognizable and stable component in adults, it was used mainly in analyzing effects caused by modification of rise-fall and plateau times on the MLR in the normally hearing subjects. The MLR threshold was then defined as the Pa component in the group with hearing losses.

In the present study, Pa quality was used to identify wave morphology by visual inspection for normally hearing subjects. Using findings by Kodera et al. [11], a broadening of the response waveform was considered to reflect a less synchronized discharge. A sharp, smooth peak in the P6-SN10 response indicated a well-synchronized waveform [4]. Accordingly, Pa was described as having a good morphological quality when it presented with a well-defined sharp and smooth peak and was of low quality when it presented as a broad peak or multiple small peaks.

Pa was analyzed quantitatively as the Na-Pa amplitude in the normally hearing group in this study. All responses were recorded beginning with a stimulus intensity of 85 dB nHL in the hearing-impaired group. Depending on the result, the stimulus level was increased or decreased in steps of 15 or 20 dB nHL. If there was no response, the intensity was increased in 5-dB steps. The threshold level was defined as the lowest intensity level producing a peak Pa that could be visualized in two successively repeated responses.

Results

Normal-hearing controls

Figure 1 shows the the percentage of high-quality Pa responses for the stimulus-envelope times of the two groups at 75 dB nHL when 0.5-kHz tone-pips with different envelope times were presented at 75 dB to the normally hearing subjects. For the 4-2-4 tone-pips a good quality Pa waveform was found in 93% of the subjects, while the 8-2-8 and 4-6-4 envelopes produced a low-quality Pa in 27% and 18% of the subjects, respectively.

To determine whether there were significant differences in the number of good-quality Pa components among the rise-fall times of 2, 4, 6, and 8 ms and the plateau times of 0, 2, 4, and 6 ms, χ² values were calculated. Statistically significant differences were found for Pa quality among different rise-fall times (P<0.01) and among different plateau times (P<0.025).

The means and standard deviations of Na-Pa amplitudes were plotted as a function of rise-fall and plateau times in Fig. 2. Increases in rise-fall and plateau time were associated with smaller peak amplitudes for the Pa component. A significant Na-Pa amplitude change was seen from 4 to 6 ms for the rise-fall time group and from 2 to 4 ms for the plateau time group. Following statistical analysis with the F-test, significantly different mean amplitudes were found among the 2-, 4-, 6-, and 8-ms rise-fall times (P<0.01) and the 0-, 2-, 4-, and 6-ms plateau times (P<0.05). The paired t-test comparison between the two subgroups is shown in Table 1. The statistical data demonstrated little Na-Pa amplitude change when increasing the rise-fall time from 2 to 4 ms or the plateau time from 0 to