RUNNING HEAD: Assessing Noise-Induced Changes

Assessing Noise-Induced Changes in Forward Masking of the ABR Wave I Latency

Honors Research Thesis

Presented in partial fulfillment of the requirements for graduation *with honors research distinction* in Speech and Hearing Science in the undergraduate colleges of The Ohio State University

By

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The Ohio State University

May 2012

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CERTIFICATION FOR GRADUATION ***WITH RESEARCH DISTINCTION***

TO: Arts and Sciences

DATE OF EXAMINATION: May 17, 2012

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THESIS TITLE: Assessing Noise-Induced Changes in Forward Masking of the ABR Wave I Latency

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Abstract

Exposure to loud noise causes trauma to the outer hair cells (OHC), which improve hearing sensitivity and frequency discrimination. The damage done can be permanent causing a significant hearing loss. Detecting noise-induced hearing loss (NIHL) early is crucial for hearing conservation programs. The current study was undertaken as part of a larger study that looks at forward masking (FWM) of the rat auditory brainstem response (ABR). FWM causes a change in ABR response by delivering a masker sound earlier in time than the probe signal. Death of OHC creates marked changes in FWM patterns. The current study assessed FWM of the latency of wave I of an ABR wave and how it changes with NIHL due to damage to the OHC. Nine Sprague-Dawley rats were tested before and after extreme noise exposure. Probe signals at 7 kHz were used to elicit the ABR. A FWM tone was played for 40 ms followed by silence for 5 ms then a 1 ms tone burst. The Sprague-Dawley rats were then exposed to a noise band ranging from 5-10 kHz at a level of 115 dB for 90 minutes. A 21 day rest period followed to ensure permanent hearing loss. The resulting ABR waves were analyzed to calculate wave I latencies. The results demonstrated that the FWM induced a prolongation of latency in an intensity-dependent fashion. An on-frequency FWM induced linear prolongation of latency, while the off-frequency FWM required much higher levels to induce prolonged latencies. Noise exposure rendered the off-frequency masking much more linear, and similar to the on-frequency masking effects. The work suggests that latency of the ABR wave I is affected by FWM, and behaves in a manner similar to ABR amplitudes for both on- and off-frequency maskers, and before and after noise exposure.

Assessing Noise-Induced Changes in Forward Masking of the ABR Wave I Latency

Introduction

Many people are exposed to high levels of recreational or occupational noise every day. When an individual exposes his or her ears to loud music, or a sudden loud noise like a gun firing, damage is done to the ears. After noise exposure people experience a threshold shift, meaning they cannot hear as well as they could before the noise exposure. This is often just a temporary sensation called temporary threshold shift. However, established research in the field has shown that continued exposure to loud noise can cause a permanent threshold shift (Howgate & Plack, 2011).

When a person is exposed to high-intensity noise, it causes trauma to their outer hair cells (OHC). OHC act as an amplifier for sound coming into the ear, aiding the basilar membrane of the cochlea in frequency precision and improving hearing sensitivity (Brownell et al., 1985). Neural synchrony occurs, in normal hearing ears, when the OHC amplify the sound signal. Neural synchrony is a coordinated firing of neurons in the auditory nerve that allows for precise preservation of the acoustic properties of complex auditory signals. If damage is done to the OHC at a certain frequency then a tone at that frequency will have to be presented at a greater intensity level in order for the tone to be heard. In an extreme case the OHC can die resulting in a moderate-to-severe hearing loss at that frequency (Henderson et al., 2006).

Being able detect noise induced hearing loss (NIHL) as early as possible is important for hearing conservation. The current project is part of a larger study that aims to find ways to detect NIHL before it becomes clinically significant.

Oxenham and Plack (1997) studied the basilar membrane of normal and cochlear impaired hearing listeners. In their study, forward masking (FWM) was used. Forward masking, much like its name suggests, is when a masker sound is presented before a signal sound is presented. FWM occurs when a sound is presented before a signal probe that effectively alters the listener's sensitivity to the sound. Figure 1 shows and example stimulus for a FWM paradigm. The masker is 5 kHz at 70 dB SPL and is 40 ms in duration. The probe is 10 kHz at 70 dB SPL and is 1 ms in duration. The silent gap between the masker and probe is 5 ms. When a masker is played for a normal hearing listener at the characteristic frequency (CF), or the same frequency as the signal tone to follow (called on-frequency FWM), then a linear growth-of-masking function was found. A linear growth-of-masking function means that, as the probe signal intensity increases, the masker level required to mask that probe signal must increase by an equivalent amount. For example, if a 60 dB SPL 4,000 Hz masker will effectively mask a 50 dB SPL 4,000 Hz signal tone, then a 70 dB SPL 4,000 Hz masker will be required to mask a 60 dB SPL 4,000 Hz signal tone, etc.

If the masker is presented at an octave lower than the CF (called off-frequency FWM) the result will be a non-linear growth-of-masking function. For example, for off-frequency masking it would require a 90 dB SPL 2,000 Hz masker to mask a 50 dB SPL 4,000 Hz signal tone. It also requires a 90 dB SPL 2,000 Hz masker to mask a 60 dB SPL 4,000 Hz signal tone. However, for a listener with a cochlear hearing impairment that affects the OHC, the off-frequency masking pattern will become more linear and look more like the on-frequency masking pattern (Oxenham & Plack, 1997). The non-linear growth function in off-frequency masking is the result of the contributions of the OHC to cochlear processing of sound. Therefore, it is expected that off-frequency FWM would change with NIHL that causes death/damage to the OHC.

The goal of this study was to see if FWM reflects sensitivity changes in the latency of Wave I in the auditory brainstem response (ABR), an electrophysiological response from the cochlea. Latency in Wave I indicates the synchrony with which the cochlea is communicating with the auditory nerve in response to a signal. Neural synchrony is crucial for effective processing of complex auditory signals, including speech. The amplitude of the waves reflects the number of neurons that respond to the auditory stimulus. As the intensity of the stimulus increases, the latency of the ABR waveform decreases and the amplitude increases.

It is known that on-frequency and off-frequency FWM is affected by noise, which results in a more linear growth-of-masking function for off-frequency conditions. However, little is known about how ABR latency changes with on- and off-frequency FWM as well as how the on- and off-frequency FWM-latency relationship changes with the NIHL. This study will further understanding of the differences in the FWM results of an ABR test in normal ears and ears with NIHL. The goal of this and other FWM ABR studies is to try and find a way to detect NIHL early in hopes of being able to prevent it from happening.

Methods and Materials

This project assessed FWM of the ABR, which is a physiologic test that measures electrical activity of the auditory nerve and brainstem in response to sound. The Sprague-Dawley rat's ABR is characterized by three waves with predictable latencies (Fig. 2), which is the time after the stimulus is presented when the response occurs. Latency in the ABR reflects the synchrony with which the cochlea and the number of afferent auditory nerve fibers that are firing.

In order to assess hearing thresholds and the forward masking compression functions, the rats were tested using free-field ABR. Free-field ABR utilizes a speaker placed at a location near the animal's head, and contrasts with pressure-field, which utilizes an earphone placed in the animal's ear canal. For all ABR test procedures, the animals were anesthetized with inhalant isoflurane (4% for induction, 1.5% for maintenance, 1 L/min O_2 flow rate). Needle recording electrodes were placed at the vertex (non-inverting), below the left pinna (inverting) and behind the shoulder blade (ground). During ABR recording, the rats were placed on a homeothermic blanket to maintain body temperature. All stimuli were generated using Tucker Davis Technologies (TDT, Gainesville, FL) SigGen software. Each tone burst was 1 ms in duration, and had a 0.5 ms rise/fall time with no plateau. Stimuli were presented at a rate of 19 Hz. Signals were routed to a speaker (TDT Model MF1) positioned at zero degrees azimuth, 10 cm from the vertex of each rat's head. Acoustic stimuli were calibrated prior to each testing session, by recording the output of the speaker with a microphone placed at the animals' head level. The rats' evoked responses were amplified with a gain of 50,000, using a TDT RA4LI headstage connected to an RA4PA pre-amplifier, and bandpass filtered from 100-3000 Hz. The duration of each testing session was approximately 90 minutes. Following the session, the animals were monitored for 10 minutes until completely recovering from the anesthetic. No negative consequences to the animals' health were noted to result from the anesthetized testing procedure.

The data used in the current were from an ongoing study of FWM of the ABR in rats. A probe tone burst signal at 7 kHz was used to elicit the ABR. A FWM tone, either on-frequency (at the same frequency as the probe tone burst, 7 kHz) or off-frequency (one octave below the probe tone burst, 3.5 kHz) was played for 40 ms followed by 5 ms of silence then the 1 ms tone burst signal (see Figure 1 for an example of the stimulus). Each masker was presented at: 0, 20, 30, 40, 50, 60, 70, 80, and 90 dB for each probe level. Each probe tone burst signal was presented at 90, 80, 70, 60, 50, 40, and 30 dB. Both on- and off-frequency conditions were tested, created a matrix of 112 combinations tested before and after the noise exposure.

For behavioral masking, the masked threshold is the level of the masker at which the subject indicates that they can no longer hear the signal tone. For the ABR waves, the amplitudes and latencies change with the onset of masking. The current study assessed the effects of FWM on latency and amplitude of the Wave I of the rats' ABR (see Figure 2 for an example of the ABR waveform with Wave I denoted). Wave I of the ABR reflects the activity of the cochlea. Wave I was analyzed by placing cursors over the important positive and negative peaks in the waveform using BiosigRZ analysis software (see Figure 3 for a representative series of cursored waveform). The data were then exported from BioSigRZ to a spreadsheet and analyzed to determine whether the FWM effects on latency of the ABR are influenced by noise exposure.

To assess noise-induced changes in the FWM patterns of the ABR, the rats were exposed to a continuous band of noise ranging from 5-10 kHz at a level of 115 dB SPL for a duration of 90 minutes. They were then given a rest period of 21 days to ensure that the threshold shift measured was permanent rather than temporary. After the recovery period, the rats were re-tested for threshold shift and the FWM growth function (Bielefeld, Hoglund, & Feth, 2012).

Results

Pre-noise exposure forward masking latency input-output functions

Figure 4 shows the off-frequency FWM latency input-output functions for the 7 kHz probe signal prior to noise exposure. Figure 5 is showing the on-frequency FWM latency input-output functions for the 7 kHz probe signal prior to noise exposure. The data in both figures are plotted as the masker level, in dB SPL, along the X axis and Wave I latency, in ms, along the Y axis. Each curve in these two figures represents a different probe level. Multiple regression analyses confirmed that the slopes of the off-frequency curves were shallower than the on-frequency curves after onset of masking, and that the onset of latency changes occurred with higher masker levels in the off-frequency condition than in the on-frequency condition. The results indicate a compressive non-linear relationship in the off-frequency condition. Missing data points on the figures indicate no discernible Wave I, and therefore, no measurable latency. This is most notable for the 40 and 50 dB SPL probes in the on-frequency condition.

Post-noise exposure forward masking latency input-output functions

Figure 6 displays the permanent threshold shift induced by the noise exposure, based on the test on Day 21 post noise. The noise induced roughly 25-40 dB of permanent threshold shift in the frequency range of 5-15 kHz, with specifically a mean shift of 27 dB at the probe frequency of 7 kHz. Figure 7 shows the off-frequency FWM latency input-output functions for the 7 kHz probe signal 21 days after noise exposure. The data are plotted as the masker level, in dB SPL, along the X axis and Wave I latency, in ms, along the Y axis. The data in both figures are plotted as the masker level, in dB SPL, along the X axis and Wave I latency, in ms, along the Y axis. Multiple regression analyses confirmed that the slope of the off-frequency curves and the on-frequency curves were not significantly different from one another after the noise exposure. The permanent threshold shifts induced by the noise exposure averaged between 30 and 40 dB in the 3-20 kHz frequency range, encompassing all of the probe and masker frequencies in the experiment.

Forward masking amplitude input-output functions

Figure 8 shows the FWM amplitude input-output functions for the 7 kHz probe for off frequency FWM conditions (A) and on-frequency FWM conditions (B) prior to noise exposure.

Figure 8 shows the FWM amplitude input-output functions for the 7 kHz probe for off-frequency FWM conditions (A) and on-frequency FWM conditions (B) post noise exposure. Each curve represents data from different probe levels at which each masker level along the X axis and amplitude along the Y axis. Generally, the trend of larger amplitudes for higher probe intensity levels occurred consistently. Regression analyses detected no consistent relationship between the on-frequency and off-frequency FWM conditions before and after noise exposure.

Discussion

The current study used ABR FWM growth functions to test Wave I latency pre- and post-noise exposure. The goal was to see if FWM was a good indicator of sensitivity changes in the latency of ABR Wave I. The findings showed that Wave I latency was a stable and consistent dependent variable in the FWM conditions prior to noise exposure. Latency input-output functions for the on-frequency FWM conditions pre-noise exposure showed a potentially linear growth-of-masking function; while off-frequency FWM conditions showed more shallow curves indicating a compressive non-linear relationship. The on-frequency conditions effectively masked allowing for less neural synchrony. Less neural synchrony renders longer latency of Wave I. Off-frequency masking conditions did not affect neural synchrony as heavily as the on-frequency conditions did. The data showed that Wave I latency was a stable and consistent dependent variable in the FWM conditions prior to noise exposure.

NIHL rendered the off-frequency latency input-output function more linear and consistent with the on-frequency condition. A more linear graph occurred as a result of less neural synchrony. The OHC had effectively been damaged resulting in less amplification and therefore longer latencies as the masking increased in intensity. Wave I latency changes with FWM conditions may be a sensitive indicator of NIHL.

While the amplitude of Wave I did change, amplitude was not as stable or consistent measure as latency. The lack of consistent patterns in amplitude may have been due to the measurement and analysis techniques employed. As can be seen in Figures 8 and 9, the absolute amplitudes in μV were extremely low for 40-50 dB SPL probes in the pre-noise tests, and then the 60-70 dB SPL probes post-noise. Therefore, the curves are largely intersecting one another, and there is also a floor effect. The amplitudes are so low in the unmasked condition, that there is no room for them to decrease greatly when masking is added. A better measure would be to set the unmasked condition as the baseline, and measure the masked amplitudes as a percentage of the unmasked amplitude. These measures are currently ongoing.

The current study confirms that NIHL leads to changes in the off-frequency masking patterns of the ABR as indexed by changes in latency. Future studies could gradually expose Sprague-Dawley rats to noise while testing for FWM off-frequency latency changes to the ABR to determine if there is a point where clinicians could decide if NIHL is starting to occur. If early noise damage to the OHC leads to small but consistent changes in off-frequency latency patterns, the test could become an effective clinical tool for early detection of NIHL.

References

Bielefeld, E. C., Hoglund E. M., & Feth L. L. Noise-induced changes in cochlear compression in the rat as indexed by forward masking of the auditory brainstem response (ABR). Manuscript in preparation.

Brownell, W. E., Bader, C. R., Bertrand, D., & de Ribaupierre, Y. (1985). Evoked mechanical response of isolated outer hair cells. Science, 227, 194-196.

Henderson, D., Bielefeld, E.C., Harris, K.C., & Hu, B.H. (2006). The role of oxidative stress in noise-induced hearing loss. Ear Hear, 27, 1-19

Howgate, S., & Plack, C.J. (2011). A behavioral measure of the cochlear changes underlying temporary threshold shifts. Hear Res, 277(1-2), 78-87.

Oxenham, A.J., & Plack, C.J. (1997). A behavioral measure of basilar-membrane nonlinearity in listeners with normal and impaired hearing. JASA, 101(6), 3666-3675.

Figure Legends

Figure 1: Example stimulus for the off-frequency masking paradigm. The masker is 5 kHz at 70 dB SPL and the probe is 10 kHz at 70 dB SPL. The masker is 40 ms in duration. The probe is 1 ms in duration, and is presented at the 45 ms point on the figure. The silent gap between masker and probe is 5 ms and appears at 40-45 ms on the figure.

Figure 2: Cursors were put on the first three waves of each ABR waveform. This is an example of an ABR wave where the masker is 30 dB SPL with a probe signal of 90 dB SPL at 7 kHz. Cursors I, III, and V are placed at the positive peaks of the first three component waves of the ABR response in order to measure wave I latencies. Cursors II, IV, and VI are placed at the corresponding negative peaks in order to allow peak-to-peak amplitude calculations.

Figure 3: Representative ABR waveforms where FWM levels were played at 0, 20, 30, 40, 50, 60, 70, 80 , and 90, dB (from top to bottom)

A) Probe level at 90 dB at 7 kHz off-frequency pre noise exposure

B) Probe level at 90 dB at 7 kHz off-frequency post noise exposure

C) Probe level at 90 dB at 7 kHz on-frequency pre noise exposure

D) Probe level at 90 dB at 7 kHz on-frequency post noise exposure

Figure 4: FWM latency input-output functions for the 7 kHz probe prior to noise exposure in the off-frequency FWM condition. Each curve represents data from different probe levels with each masker level along the x-axis. Multiple regression analyses confirmed that the slopes of the off-

frequency curves were more shallow than the on-frequency (Figure 5) curves, indicating a compressive non-linear relationship in the off-frequency condition.

Figure 5: FWM latency input-output functions for the 7 kHz probe prior to noise exposure for the On-frequency FWM condition. Each curve represents data from different probe levels with each masker level along the X axis. Multiple regression analyses confirmed that the slopes of the on-frequency curves were steeper from the point of onset of masking than the off-frequency curves.

Figure 6: Permanent threshold shift of the ABR induced by exposing the Sprague-Dawley rats to a continuous band of noise ranging from 5-10 kHz at a level of 115 dB for 90 minutes.

Figure 7: FWM latency input-output functions for the 7 kHz probe 21 days after noise exposure for the off-frequency FWM condition. Each curve represents data from different probe levels with each masker level along the X axis. Multiple regression analyses confirmed that the slope of the off-frequency curves and the on-frequency (Figure 8) curves were not significantly different from one another after the noise exposure.

Figure 8: FWM latency input-output functions for the 7 kHz probe 21 days after noise exposure for the on-frequency FWM condition. Each curve represents data from different probe levels with each masker level along the X axis. Multiple regression analyses confirmed that the slope of

the off-frequency (Figure 7) curves and the on-frequency curves were not significantly different from one another after the noise exposure.

Figure 9: FWM amplitude input-output functions for the 7 kHz probe prior to noise exposure.

A) The off-frequency FWM condition.

B) The on-frequency FWM condition.

Each curve represents data from different probe levels at with each masker level along the X axis. Regression analyses detected no consistent relationship between the on- and off-frequency FWM conditions pre and post noise (Figure 10).

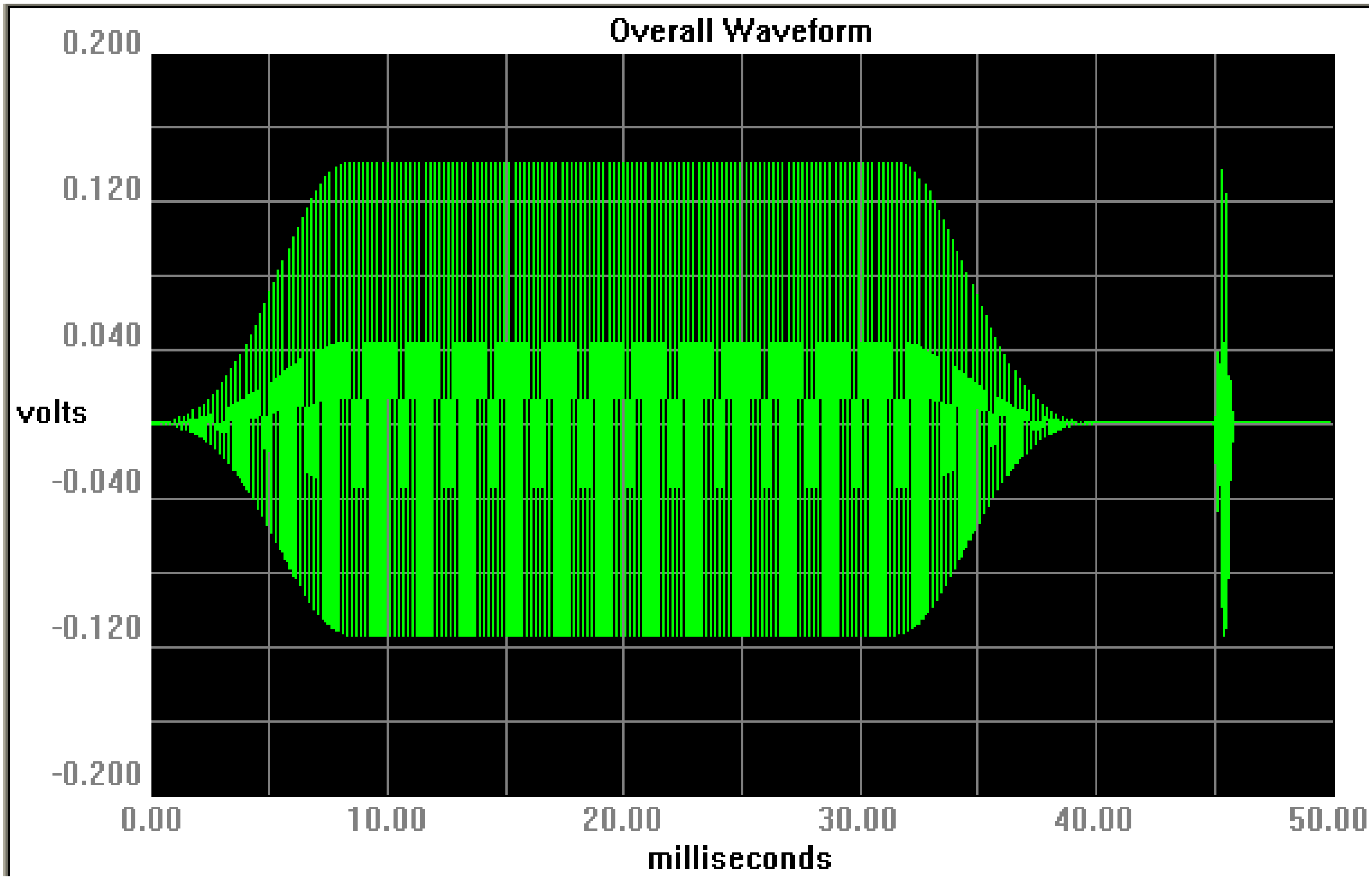
Figure 10: FWM amplitude input-output functions for the 7 kHz probe after noise exposure.

A) The off-frequency FWM condition.

B) The on-frequency FWM condition.

Each curve represents data from different probe levels at with each masker level along the X axis. Regression analyses detected no consistent relationship between the on- and off-frequency FWM conditions pre (Figure 9) and post noise.

Figures



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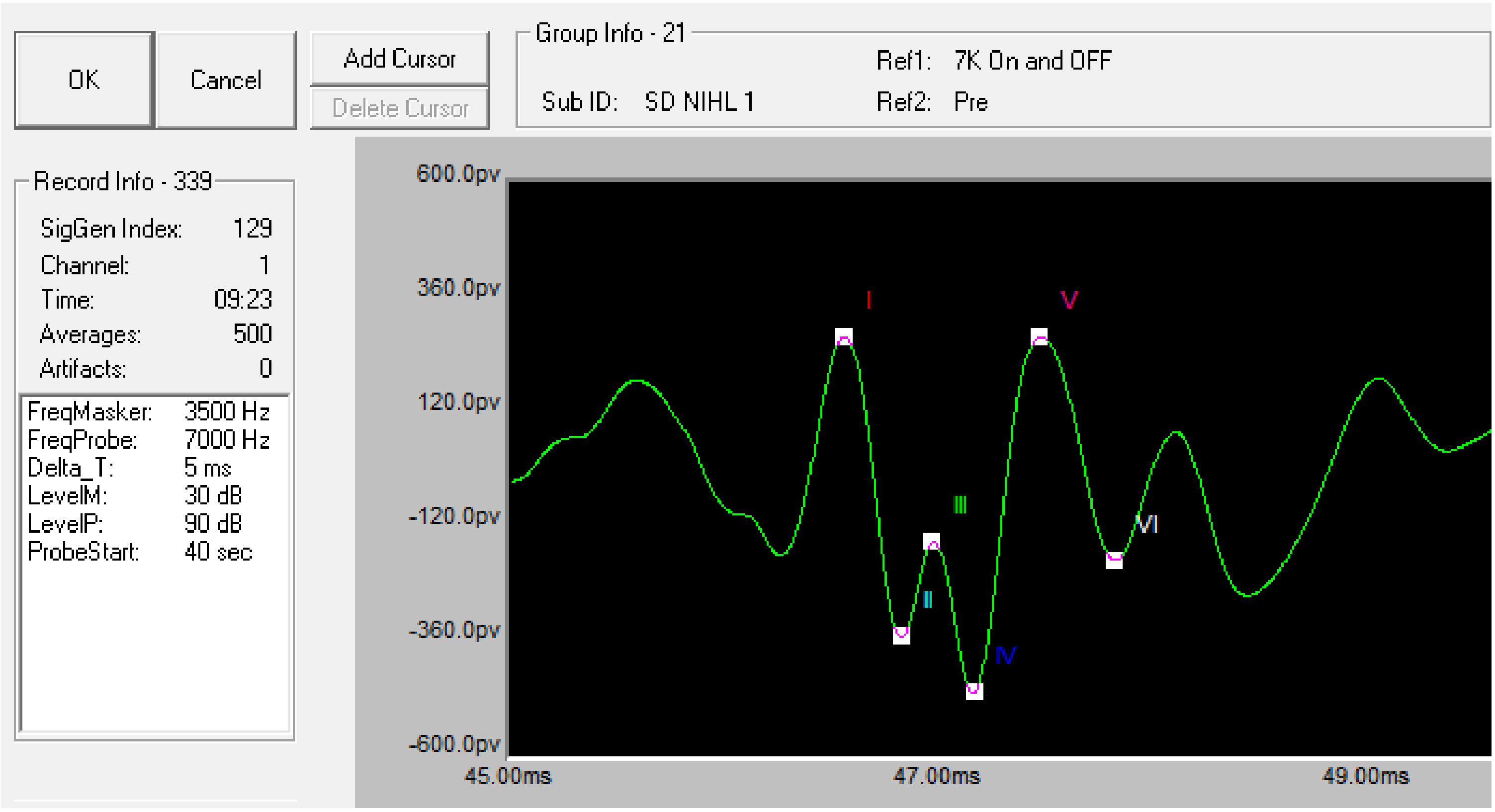

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V
VI

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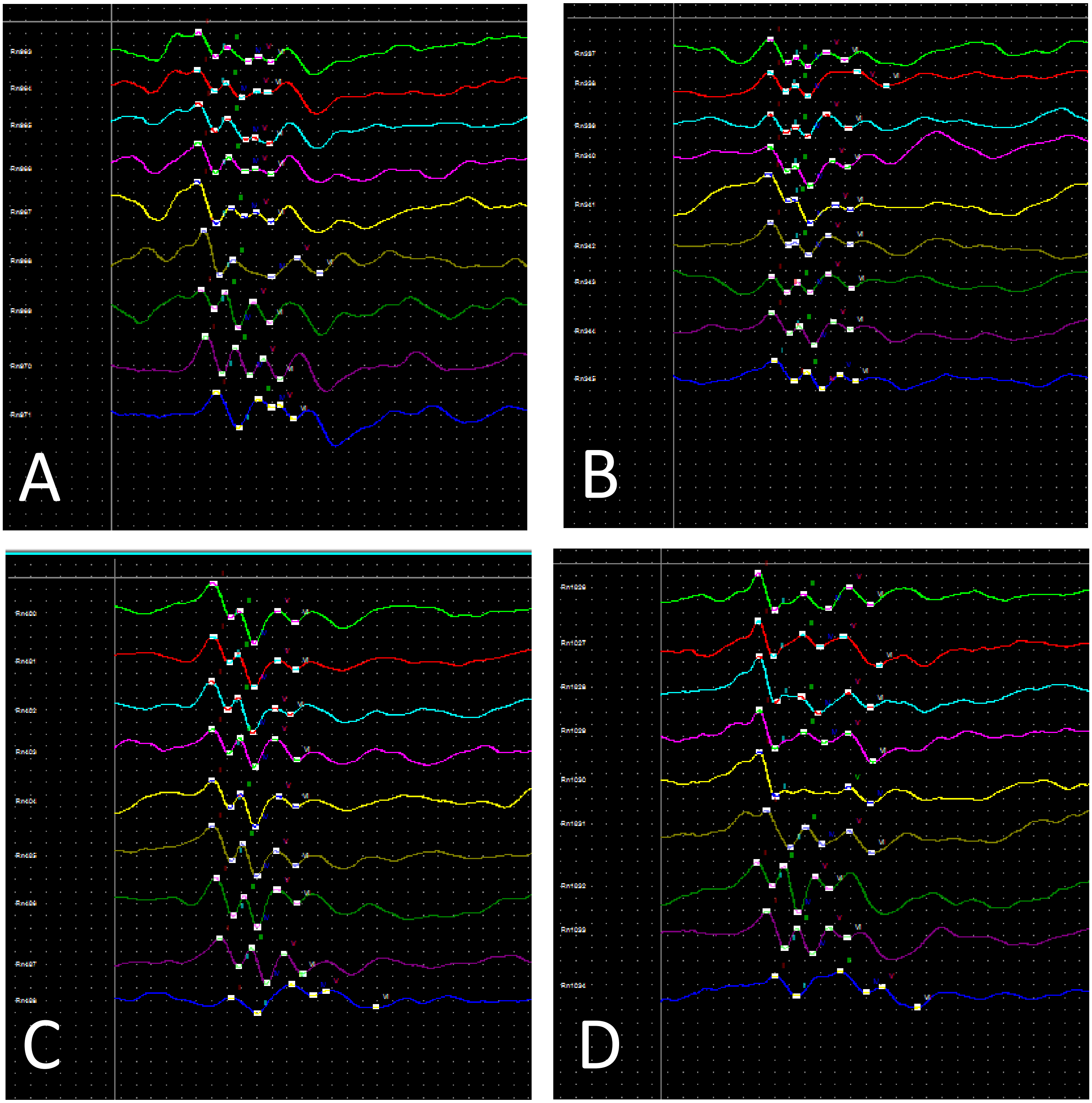

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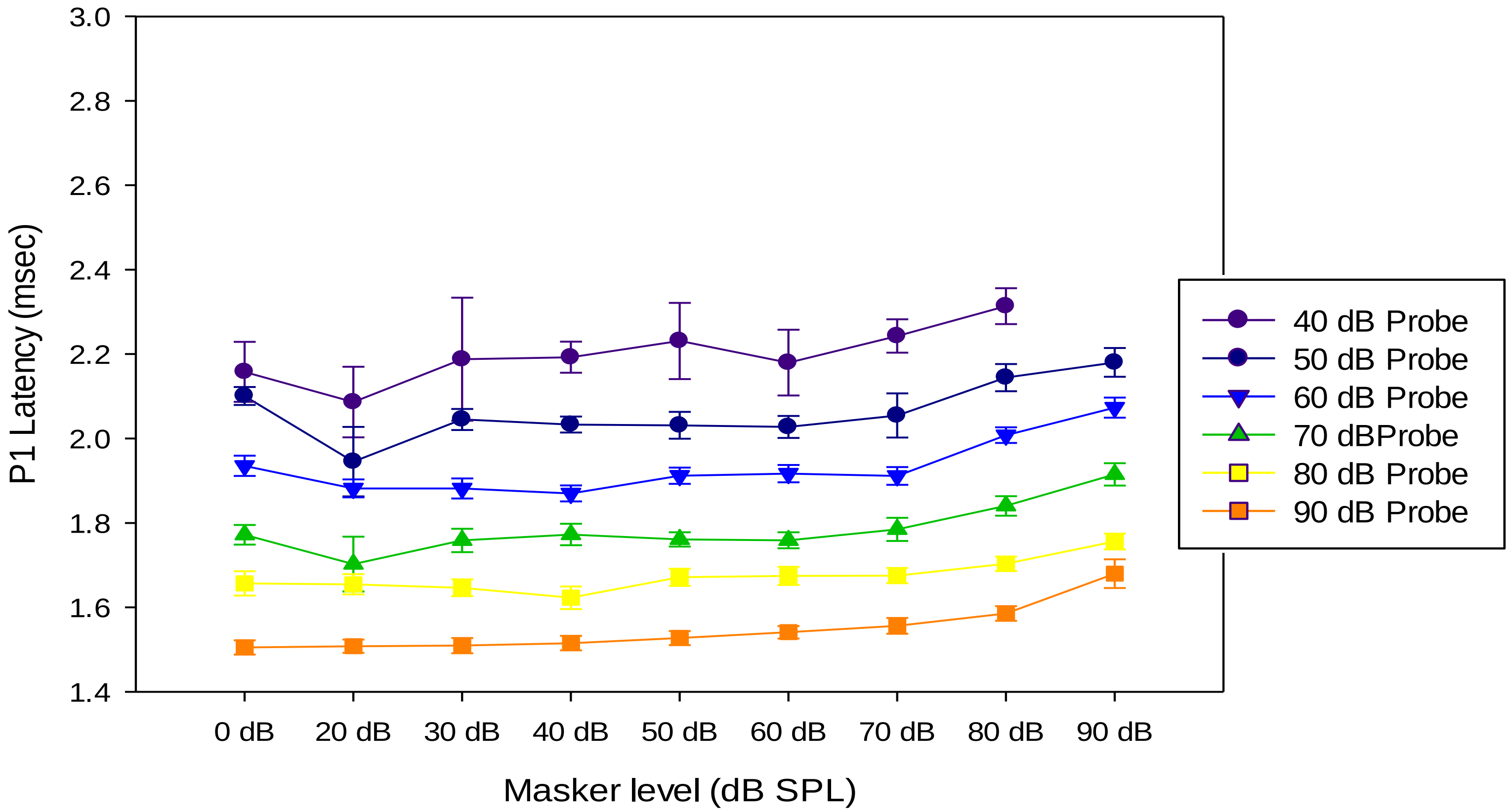
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P1 Latency (msec)
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Masker level (dB SPL)
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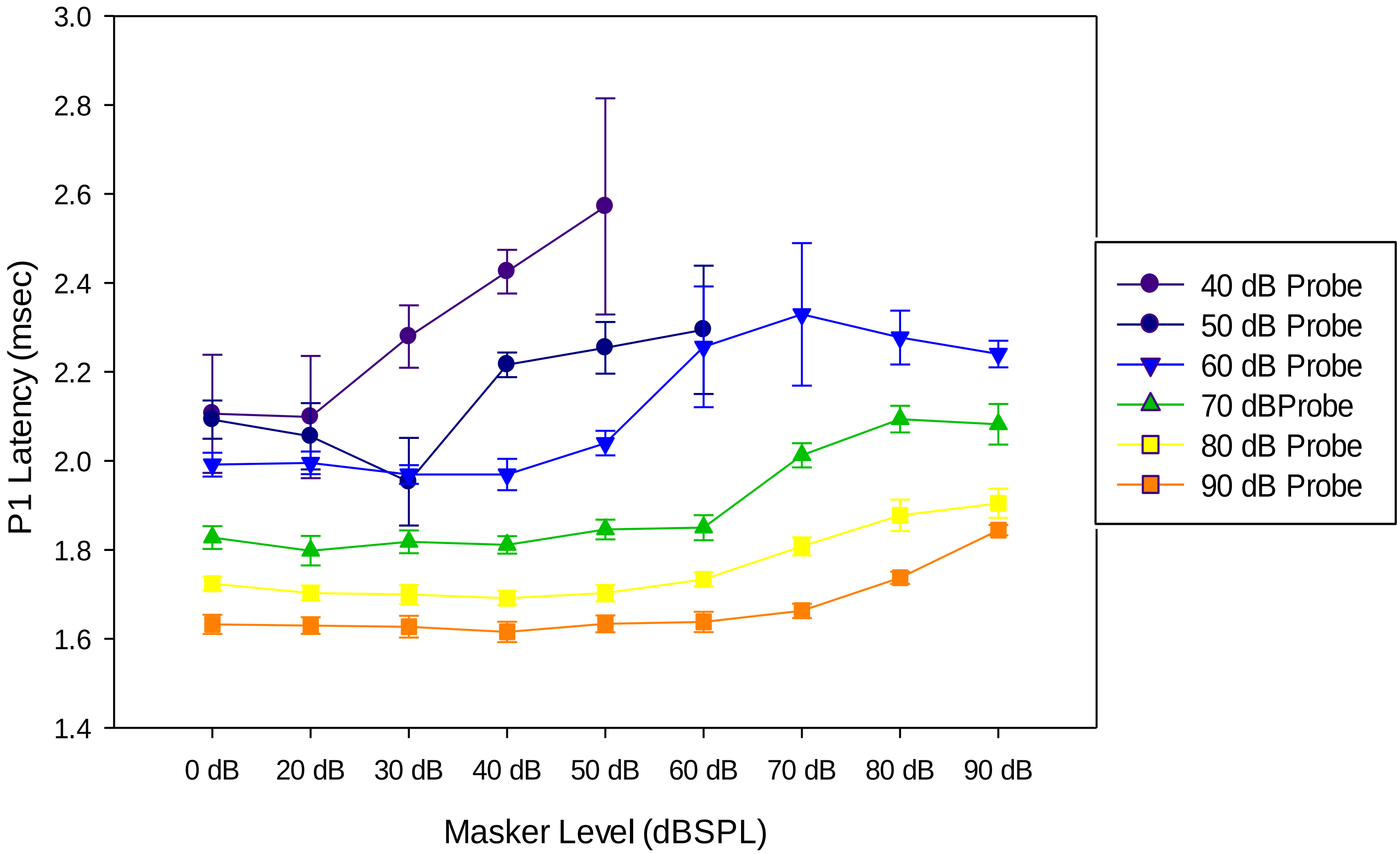
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Masker Level (dBSPL)
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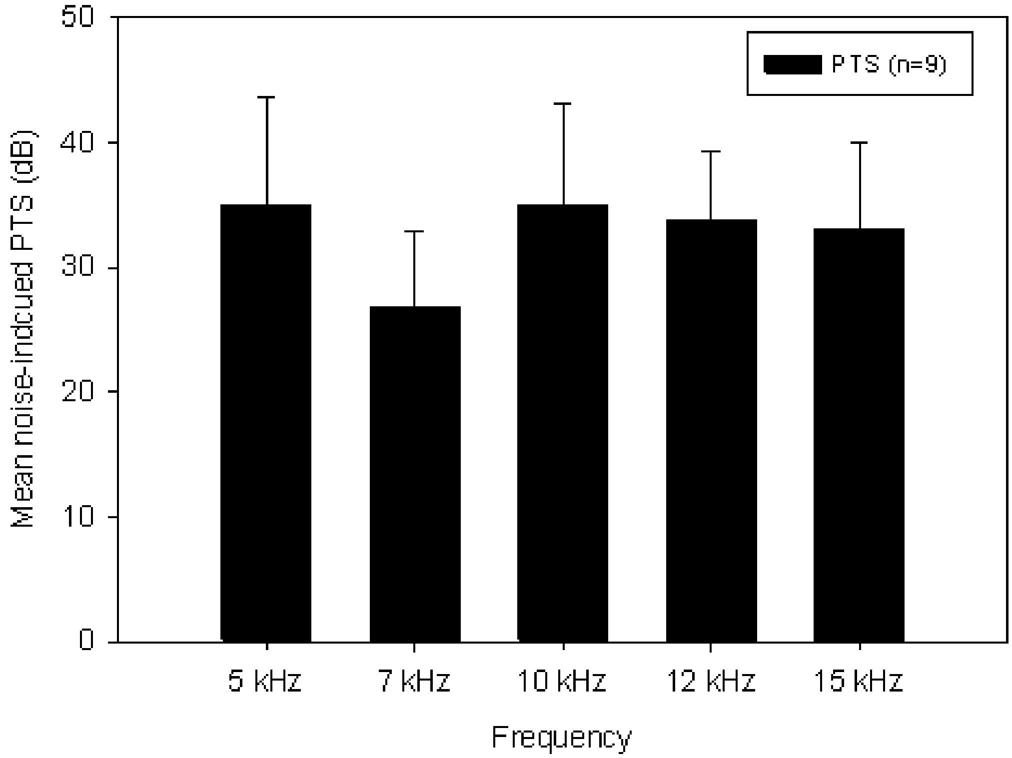
90 dB Probe

Figure 5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15 kHz
Frequency

Figure 6

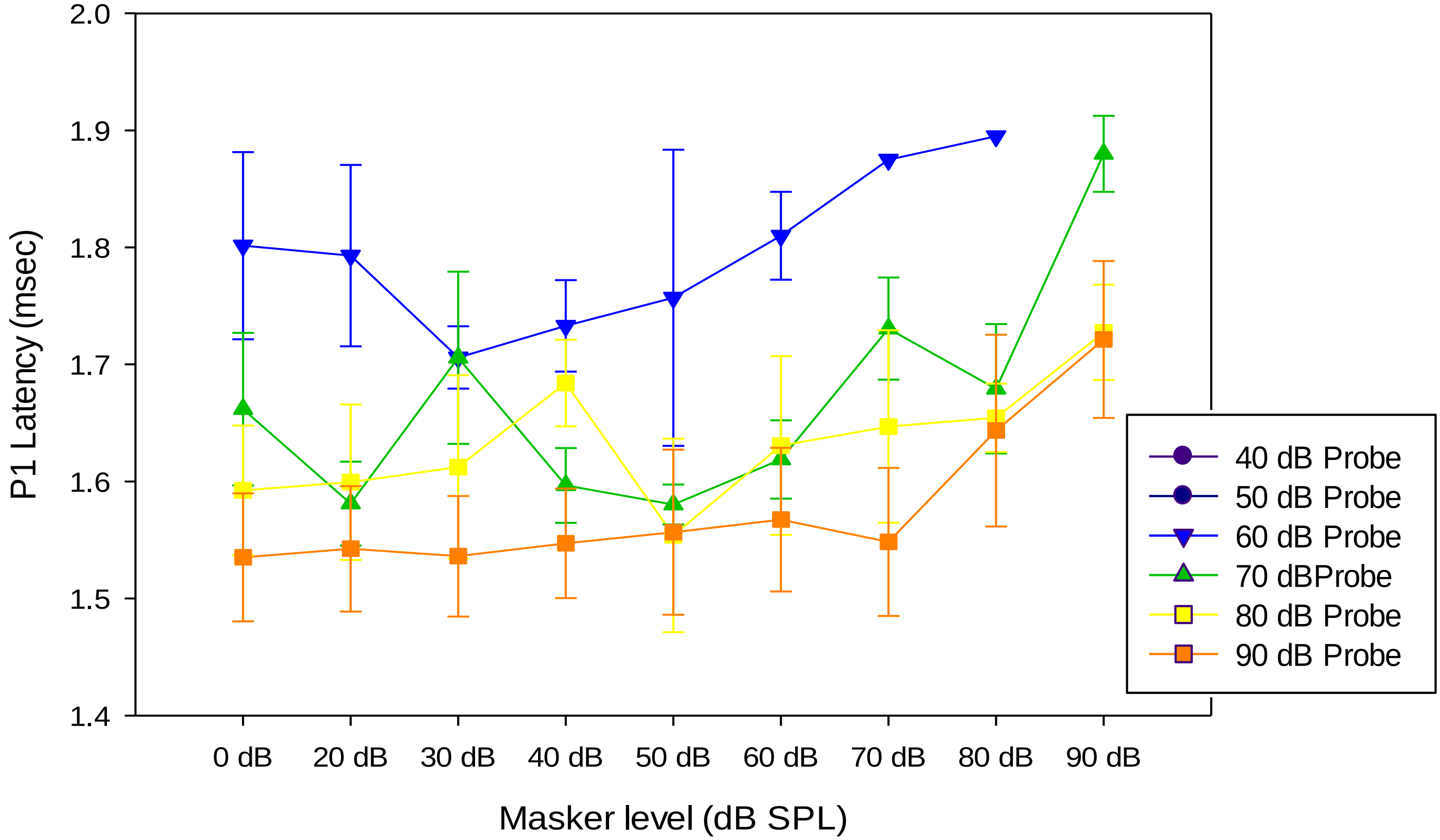
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Figure 7

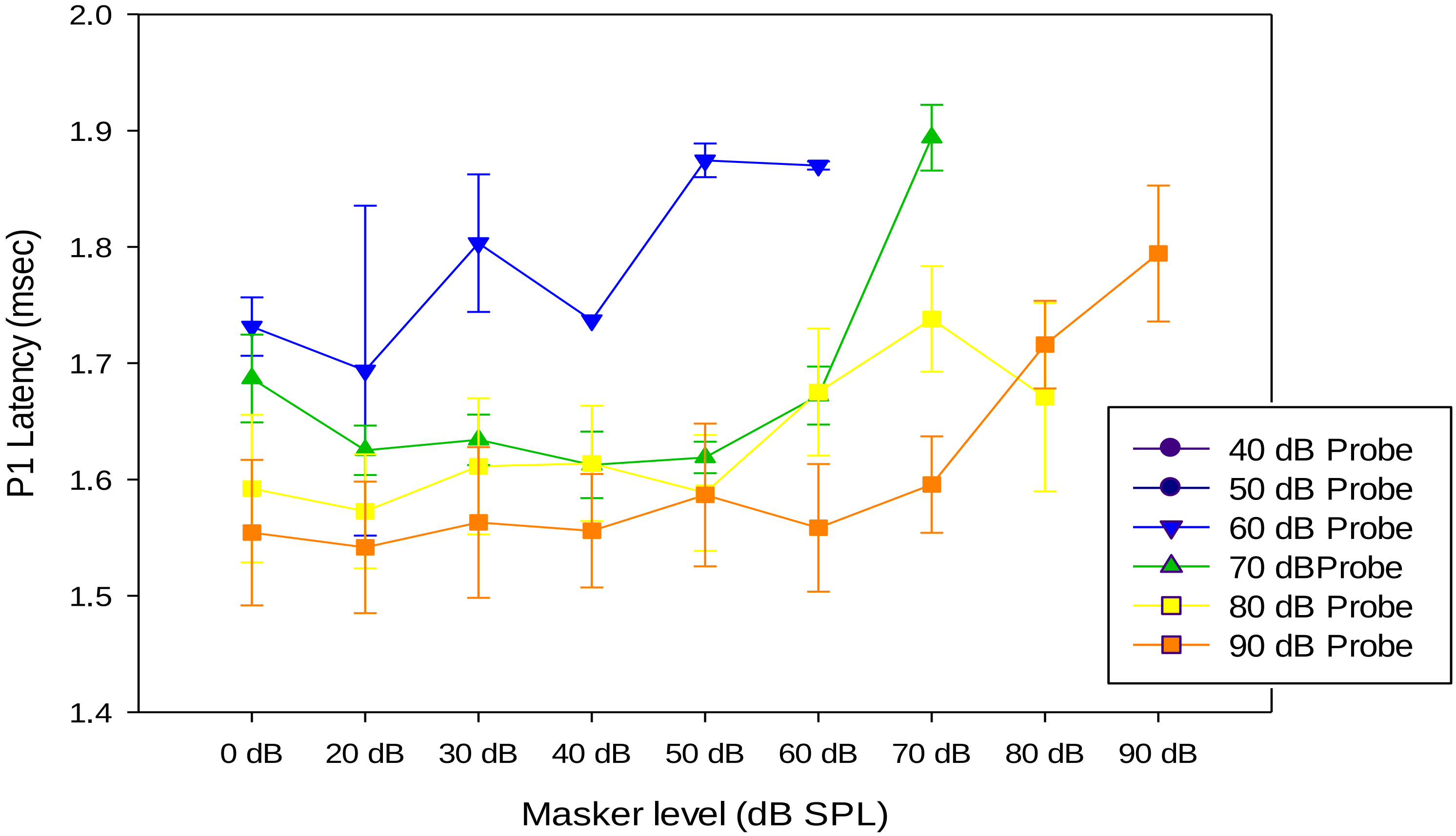
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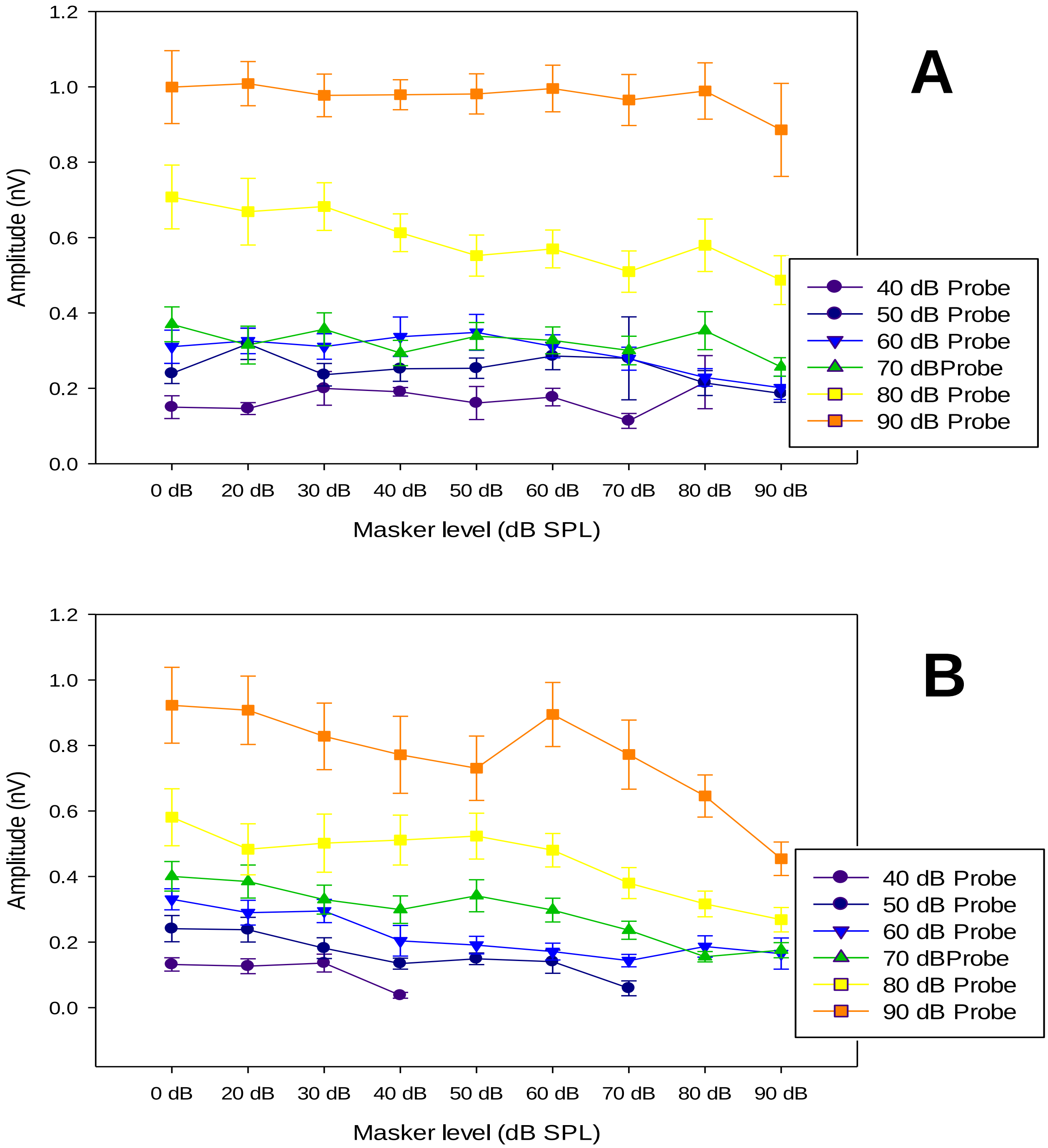
Figure 8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Masker level (dB SPL)
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0.6
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Amplitude (nV)
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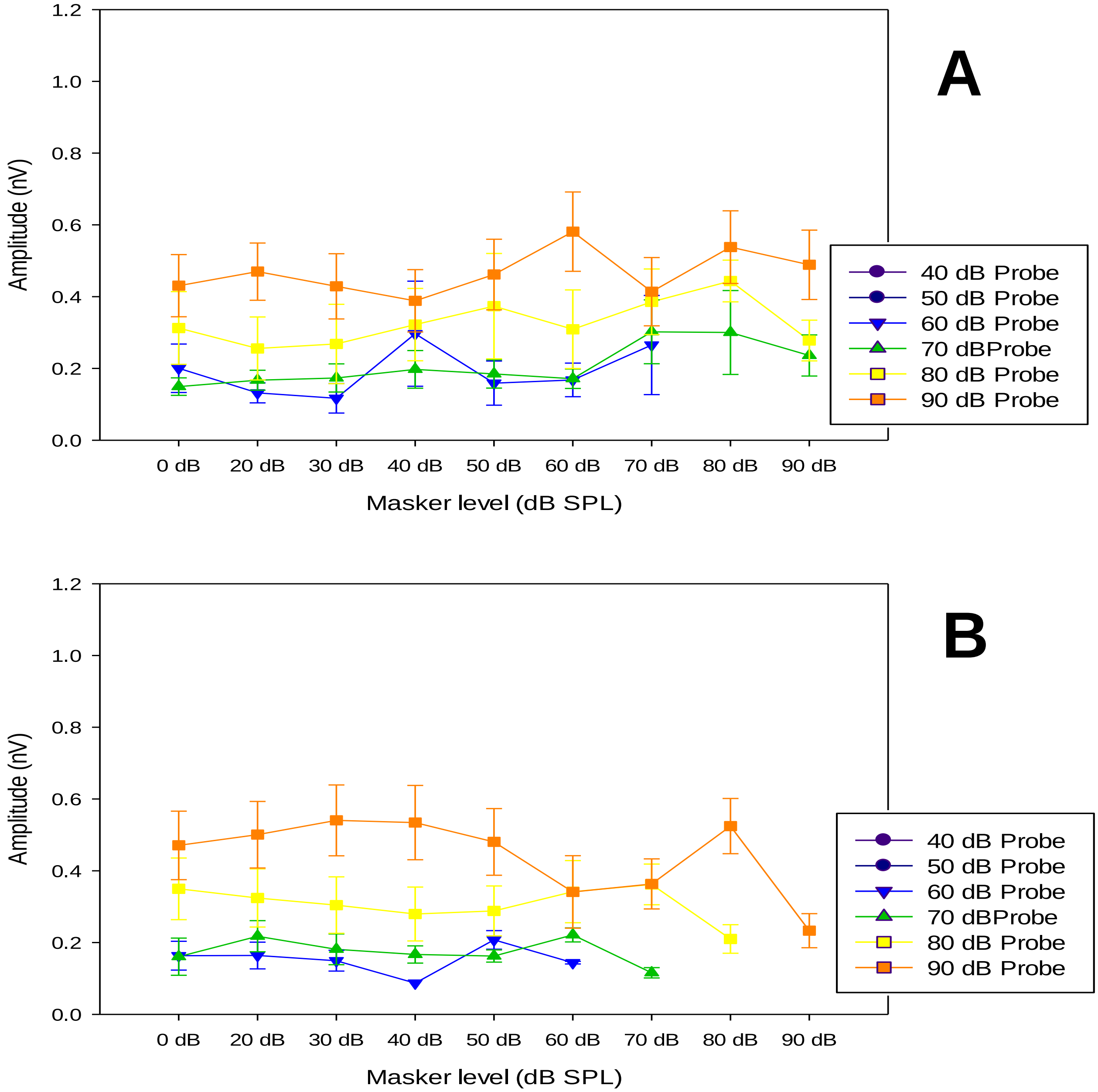
90 dB
Masker level (dB SPL)

Figure 9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Masker level (dB SPL)
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50 dB Probe
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Figure 10