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Hearing Diagnostics – Reference Bibliography

Author(s)	Title	Summary	Journal	Year	Vol:Pages
		COCHLEAR HYDROPS			
Don M, Kwong B, Tanaka C	**A Diagnostic Test for Meniere's Disease and Cochlear Hydrops: Impaired High-Pass Noise Masking of ABRs**	Abnormal increase in the volume of endolymph, a fluid of the cochlea defined as Meniere's disease is characterized by symptoms that include episodic vertigo, hearing loss, tinnitus, and fullness or pressure in the ear. These symptoms may not be apparent at the onset or early stages of the syndrome, thus making early and accurate diagnosis a challenge. Since it is now believed that delayed diagnosis reduces the likelihood of successful treatment outcomes, diagnostic tests that differentiate Meniere's disease from other conditions that may present with similar symptoms are needed. To date, existing tests have not demonstrated sufficient control of overlap between Meniere's patients and non-Meniere's patients to be clinically useful. This investigation compares 38 non-Meniere's normal hearing patients with 23 patients exhibiting the symptoms associated with Meniere's disease to determine if changes in the basilar membrane lead to impaired high pass noise masking of the auditory brainstem response to click stimuli. Ipsilateral recordings of the ABR with high pass filtered masking noise filtered at various frequencies were obtained for both groups. The data reveals that, in the Meniere's patients, an undermasked Wave V continues to appear at latencies similar to those obtained in the unmasked condition. In contrast, data from the normal hearing group demonstrates no undermasked Wave V or one that is significantly delayed in latency due to the masking noise. The distribution of differences between groups in these results contains no overlap, providing 100% sensitivity and 100% specificity. The study concludes that this test provides the desired diagnostic test that differentiates Meniere's disease from non-Meniere's and allows tracking of changes that may result from progression of the disease or its treatment.	***Otology and Neurology***	**2005**	**26 (4): 711-22**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
HEARING IN NOISE TEST					
Vermiglio AJ, Soli SD.	**Pure tone thresholds and HINT performance.**	This study examines the relationship between audiometric categories of hearing loss as defined by standard pure tone thresholds and subsequent performance on the Hearing in Noise Test (HINT) to investigate how useful the audiogram may be in predicting speech recognition in noise. Four test sites provided data from 278 subjects whose audiometric data were combined to create pure tone threshold groups that were somewhat symmetrical and homogenous. Bilateral pure tone averages for 500, 1000, and 2000 Hz compared to HINT thresholds in quiet reveal a significant correlation. Increased pure tone averages are accompanied by increased HINT thresholds. Additionally, there are statistically significant correlations between bilateral pure tone averages and the HINT Noise Right and Left Conditions. Conclusions from the study indicate that normal pure tone thresholds are valuable for examining audition in quiet, but are a poor predictor of the ability to hear in the presence of competing noise. This suggests that, despite similar audiometric configurations, patients may require different strategies for fitting hearing aid amplification. HINT results may document the benefit of various hearing aid settings. The study also implies that normal hearing thresholds alone do not predict normal hearing in noise and may that direct measurement of this function may be helpful in assessing Central Auditory Processing Disorders (CAPD) and in employment screening for workers who must hear critical information in noisy environments.	***American Academy of Audiology***	**2005**	**Research Poster: 1-7**
Chan JCY, Vermiglio AJ, Freed DJ, Kessler D, Kruger T, Soli SD	**Assessment of binaural functions in bilateral CI users.**	The emergence of bilateral cochlear implants as an option raises questions regarding the benefit of two cochlear implants (CIs) in contrast to conventional unilateral implantation. Although the restoration of some degree of binaural function represents the hypothetical benefit of two CIs, no clinical test or protocol has been available to assess this. The purpose of this study was to develop and implement a test instrument to evaluate bilateral cochlear implant patients. A computerized device based upon existing HINT (Hearing in Noise Test) and SAINT (Source Azimuth Identification in Noise) tests allows free field or direct input to assess sound localizing abilities. The results of three investigations with acoustic hearing subjects and cochlear implant subjects demonstrate that use of direct coupling provides comparable results to free field testing. Directional hearing as well as sound localization can be easily completed using direct coupling with both groups. Detailed presentation of the data and suggested future modification of the technology are included.	***American Academy of Audiology***	**2005**	**Research Poster**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Vaillancourt, V.	**Adaptation of the HINT (hearing in noise test) for adult Canadian Francophone.**	The HINT provides an efficient and reliable method of assessing speech intelligibility in quiet and in noise by using an adaptive strategy to measure speech reception thresholds for sentences, thus avoiding ceiling and floor effects that plague traditional measures performed at fixed presentation levels A strong need for such a test within the Canadian Francophone population, led us to develop a French version of the HINT. Here we describe the development of this test. The Canadian French version is composed of 240-recorded sentences, equated for intelligibility, and cast into 12 phonemically balanced 20-sentence lists. Average headphone SRTs, measured with 36 adult Canadian Francophone native speakers with normal hearing, were 16.4 dBA in quiet, -3.0 dBA SNR in a 65 dBA noise front condition and -11.4 dBA SNR in a 65 dBA noise side condition. Reliability was established by means of within-subjects standard deviation of repeated SRT measurements over different lists and yielded values of 2.2 and 1.1 dB for the quiet and noise conditions, respectively.	***University of Ottawa, Ottawa, Ontario, Canada, House Ear Institute, Los Angeles, California, U.S.A.***		
AUDITORY STEADY-STATE RESPONSE					
Dimitrijevic, A.	**Auditory steady-state responses and word recognition scores in normal hearing and hearing-impaired adults.**	**Objective:** The number of steady-state responses evoked by the independent amplitude and frequency modulation (IAFM) of tones has been related to the ability to discriminate speech sounds as measured by word recognition scores(WRS). In the present study IAFM stimulus parameters were adjusted to resemble the acoustic properties of everyday speech to see how well responses to these speech-modeled stimuli were related to WRS. **Method:** We separately measured WRS and IAFM responses at a stimulus intensity of 70 dB SPL in three groups of subjects: young normal-hearing, elderly normal-hearing, and elderly hearing-impaired. We used two series of IAFM stimuli, one with modulation frequencies near 40 Hz and the other with modulation frequencies near 80 Hz. The IAFM stimuli, consisting of four carrier frequencies each independently modulated in frequency and amplitude, could evoke up to eight separate responses in one ear. We recorded IAFM responses and WRS measurements in quiet and in the presence of speech-masking noise at 67 dB SPL or 70 dB SPL. We then evaluated the hearing-impaired subjects with and without their hearing aids to see whether an improvement in WRS would be reflected in an increased number of responses tothe IAFM stimulus. **Results:** The correlations between WRS and the number of IAFM responses recognized as significantly different from the background were between0.70 and 0.81 for the 40 Hz stimuli, between 0.73 and 0.82 for the 80 Hz stimuli, and between 0.76 and 0.85 for the combined assessment of 40 and 80 Hz responses. Response amplitudes at 80 Hz were smaller in the hearing-impaired than in the normal-hearing subjects. Response amplitudes for the 40 Hz stimuli varied with the state of arousal and this effect made it impossible to compare amplitudes across the different groups. Hearing aids increased both the WRS and the number of significant IAFM responses at 40 Hz and 80 Hz. Masking decreased the WRS and the number of significant responses. **Conclusion:** IAFM responses are significantly correlated with WRS and may provide an objective tool for examining the brain's ability to process the auditory information needed to perceive speech.	***Ear and Hearing***	**2004**	

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Dimitrijevic, A.	**Estimating the audiogram using multiple auditory steady-state responses.**	Multiple auditory steady-state responses were evoked by eight tonal stimuli (four per ear), with each stimulus simultaneously modulated in both amplitude and frequency. The modulation frequencies varied from 80 to 95 Hz and the carrier frequencies were 500, 1000, 2000, and 4000 Hz. For air conduction, the differences between physiologic thresholds for these mixed-modulation (MM)stimuli and behavioral thresholds for pure tones in 31 adult subjects with a sensorineural hearing impairment and 14 adult subjects with normal hearing were14+/-11, 5+/-9, 5+/-9, and 9+/-10 dB (correlation coefficients .85, .94, .95,and .95) for the 500-, 1000-, 2000-, and 4000-Hz carrier frequencies, respectively. Similar results were obtained in subjects with simulated conductive hearing losses. Responses to stimuli presented through a forehead bone conductor showed physiologic-behavioral threshold differences of 22+/-8,14+/-5, 5+/-8, and 5+/-10 dB for the 500-, 1000-, 2000-, and 4000-Hz carrier frequencies, respectively. These responses were attenuated by white noise presented concurrently through the bone conductor.	***Journal of the American Academy of Audiology***	**2002**	**13**
Dimitrijevic, A.	**Human auditory steady-state responses to tones independently modulated in both frequency and amplitude**	**Objective:** Independent amplitude and frequency modulation (IAFM) of a carrier tone uses two different modulating frequencies, one for amplitude modulation(AM) and one for frequency modulation (FM). This study measured the human steady-state responses to multiple IAFM tones. The first question was whether the IAFM responses could be recorded without attenuation of the AM and FM components. The second question was whether IAFM stimuli would provide a more effective demonstration of responses at intensities near threshold than the responses to AM tones. The third question was whether the responses to multiple IAFM stimuli would relate to the discrimination of words at different intensities. **Method:** Multiple AM, FM, or IAFM stimuli were presented simultaneously. Responses were recorded between the vertex and the neck and analysed in the frequency domain. The first experiment compared IAFM responses with AM and FM responses. The second experiment compared IAFM responses with AM responses between intensities 20 to 50 dB SPL. The third experiment related the IAFM responses to the discrimination of monosyllabic words at intensities between 20 and 70 dB SPL. **Results:** Steady-state responses to the individual component of the IAFM stimuli were clearly recognizable although attenuated a little (14%) from the responses to AM or FM alone. Using IAFM stimuli was not different than simply using AM stimuli when trying to recognize responses at low intensities. The number of responses detected during multiple IAFM stimulation and the amplitudes of these responses correlated significantly with word discrimination. **Conclusion:** IAFM of a carrier using two different modulating frequencies (one for AM and one for FM) elicits separate AM and FM responses that are relatively independent of each other. These separate responses can be used to detect whether a particular carrier has been processed in the cochlea, but they are not as effective as measuring responses to carriers that have been modulated in both amplitude and frequency at the same modulation frequency (mixed modulation). The detectability of eight different responses (four AM and four FM) to an IAFM stimuli relates well to the ability of subjects to discriminate words. IAFM stimuli therefore show promise as an objective test for assessing suprathreshold hearing.	***Ear and Hearing***	**2001**	**22:100-111**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Herdman, A.T.	**Auditory steady-state response thresholds of adults with sensorineural hearing impairments**	This study evaluated the use of multiple auditory steady-state responses (ASSRs) to estimate the degree and configuration of behavioral audiograms of subjects with sensorineural hearing impairments. Place specificity of the multiple-ASSR method was also assessed. Multiple amplitude-modulated (77-105 Hz) tones (500,1000, 2000 and 4000 Hz) were simultaneously presented to one ear. The results showed that, on average, multiple-ASSR thresholds were 14 +/- 13, 8 +/- 9, 10+/- 10 and 3 +/- 10 dB above behavioral thresholds for 500, 1000, 2000 and 4000Hz, respectively. Behavioral and multiple-ASSR thresholds were significantly correlated (r = 0.75-0.89). There were no significant differences between behavioral and multiple-ASSR measures of the audiogram configuration. In subjects with steep-sloping > or = 30 dB/ octave) hearing losses, multiple-ASSR thresholds did not underestimate behavioral thresholds revealing good place specificity. These results indicate that the multiple-ASSR method provides good estimates of the degree and configuration of hearing in individuals with sensorineural hearing impairments.	***International Journal of Audiology***	**2003**	**42(5):237-48**
Herdman, A.T.	**Intracerebral sources of human auditory steady-state responses.**	The objective of this study was to localize the intracerebral generators for auditory steady-state responses. The stimulus was a continuous 1000-Hz tone presented to the right or left ear at 70 dB SPL. The tone was sinusoidally amplitude-modulated to a depth of 100% at 12, 39, or 88 Hz. Responses recorded from 47 electrodes on the head were transformed into the frequency domain. Brain electrical source analysis treated the real and imaginary components of the response in the frequency domain as independent samples. The latency of the source activity was estimated from the phase of the source waveform. The main source model contained a midline brainstem generator with two components (one vertical and lateral) and cortical sources in the left and right supratemporal plane, each containing tangential and radial components. At 88 Hz, the large stactivity occurred in the brainstem and subsequent cortical activity was minor. At 39 Hz, the initial brainstem component remained and significant activity also occurred in the cortical sources, with the tangential activity being larger than the radial. The 12-Hz responses were small, but suggested combined activation of both brainstem and cortical sources. Estimated latencies decreased for all source waveforms as modulation frequency increased and were shorter for the brainstem compared to cortical sources. These results suggest that the whole auditory nervous system is activated by modulated tones, with the cortex being more sensitive to slower modulation frequencies.	***Brain Topography***	**2002**	**15(2):69-86**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Herdman, A.T.	**Thresholds determined using the monotic and dichotic multiple auditory steady-state response technique in normal-hearing subjects.**	Auditory steady-state responses (ASSRs) were elicited by presenting single or multiple, 77-105 Hz amplitude-modulated 0.5, 1, 2, and 4 kHz tones to one or both ears. Objectives of this study were to (i) replicate and extend previous multiple ASSR studies in a quiet double-walled sound booth, and (ii) discover differences (if any) between thresholds assessed in monotic and dichotic conditions, which ranged between 15 and 22dB SPL. The present study's behavioural and ASSR thresholds are 0-10 dB lower (better) than results of previous monotic studies. Further, there are no significant differences in ASSR thresholds between dichotic and monotic stimulus conditions. Therefore, dichotic multiple AM tone stimulation does not produce a change in the ASSR that affects threshold estimation in a clinically significant manner. Thus, at least for detecting normal hearing, the dichotic multiple ASSR technique is a feasible method for estimating hearing thresholds that would substantially reduce recording time compared to conventional single-stimulus techniques.	***Scandinavian Audiology***	**2001**	**30:41–49**
John, M.S.	**Efficient Stimuli for Evoking Auditory Steady-State Responses.**	**Objective:** To compare the magnitudes of the steady-state responses evoked by several types of stimuli, and the times required to recognize these responses as significant. **Method:** In the first two experiments, we examined auditory steady-state responses to pure tones, broadband noise and band-limited noise. The stimuli were amplitude modulated in the 75 to 100 Hz range with sinusoidal or exponential envelopes. A third experiment investigated the effects of exponential envelopes on the responses to broadband noise. The final experiment examined auditory steady-state responses evoked by rapidly presented transient stimuli, such as clicks, brief tones and brief noise-bursts. All stimuli were presented dichotically at intensities 30 to 50 dB above behavioral thresholds. The subjects were adults, who drowsed or slept during the recording sessions. **Results:** The responses to the noise were larger than the responses to the tones. At an intensity of 32 dB nHL, the average amount of time needed to obtain significant responses for the amplitude-modulated noise was 43 sec and the maximum time was 2 minutes. The average time for pure tone stimuli was approximately 2 minutes but 25% of the responses remained undetected after 5 minutes. Combining the responses to all the frequency-specific stimuli showed results similar to using noise stimuli. Using exponential envelopes did not increase response amplitudes for noise stimuli. At 45 dB nHL, the steady-state responses to clicks and other transient stimuli were larger than responses to the broadband noise. The average time to detect steady-state responses to transient stimuli was approximately 20 sec, which was a little faster than for amplitude modulated noise. **Conclusion:** Auditory steady-state potentials evoked by amplitude modulated noise or transient stimuli might be useful in providing rapid and objective tests of hearing during screening procedures. Another approach might be to record responses to multiple frequency-specific stimuli and to evaluate the combined responses for a rapid indication that some hearing is present.	***Ear and Hearing***	**2003**	

Author(s)	Title	Summary	Journal	Year	Vol:Pages
John, M.S.	**Auditory steady-state responses to exponential modulation envelopes.**	**Objective:** This study examined the steady-state responses evoked by tones modulated with exponential envelopes. The hypothesis was that stimuli with envelopes containing more rapid changes would evoke larger responses. **Method:** Multiple auditory steady-state responses were recorded simultaneously to eight tonal stimuli, four in each ear. The carrier frequencies of the stimuli ranged from 500 to 6000 Hz and the modulation rates were between 75 and 95 Hz. The modulation envelopes were based on functions using sin' where N was 1, 2, 3, or4. Setting N to 1 produced the traditional sinusoidal modulation. **Results:** Exponential envelopes with N greater than 1 produced larger steady-state responses than a sinusoidal envelope. For amplitude-modulation (AM), exponential envelopes increased response amplitudes by 21% at 55 dB pSPL, and by 29% at 35dB pSPL. The increases were smaller for carrier frequencies of 1500 to 2000 Hz than for lower and higher carrier frequencies. Latencies calculated from phase data increased significantly with increasing N. This was likely caused by the point of maximal envelope-slope shifting later in time as N increased. For frequency modulation (FM), the steady-state responses did not significantly change with changes in the power of the exponential envelopes. **Conclusion:** When tones are amplitude-modulated with exponential envelopes based on sin(N), the amplitude and latency of the steady-state response increased significantly with increasing N. Using exponential envelopes with N greater than 1 should considerably shorten the time needed for responses to become significant when using steady-state responses in objective audiometry.	***Ear and Hearing***	**2002**	
John, M.S.	**Advantages and caveats of recording steady-state responses to multiple simultaneous stimuli.**	This article considers the efficiency of evoked potential audiometry using steady-state responses evoked by multiple simultaneous stimuli with carrier frequencies at 500, 1000, 2000, and 4000 Hz. The general principles of signal-to-noise enhancement through averaging provide a basis for determining the time required to estimate thresholds. The advantage of the multiple-stimulus technique over a single-stimulus approach is less than the ratio of the number of stimuli presented. When testing two ears simultaneously, the advantage is typically that the multiple-stimulus technique is two to three times faster. One factor that increases the time of the multiple-response recording is the relatively small size of responses at 500 and 4000 Hz. Increasing the intensities of the 500- and 4000-Hz stimuli by 10 or 20 dB can enhance their responses without significantly changing the other responses. Using multiple simultaneous stimuli causes small changes in the responses compared with when the responses are evoked by single stimuli. The clearest of these interactions is the attenuation of the responses to low-frequency stimuli in the presence of higher-frequency stimuli. Although these interactions are interesting physiologically, their small size means that they do not lessen the advantages of the multiple-stimulus approach.	***Journal of the American Academy of Audiology***	**2002**	**13**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
John, M.S.	**Weighted averaging of steady-state responses.**	OBJECTIVE: To compare weighted averaging and artifact-rejection to normal averaging in the detection of steady-state responses. METHODS: Multiple steady-state responses were evoked by auditory stimuli modulated at rates between 78 and 95 Hz. The responses were evaluated after recording periods of 3,6 and 10 min, using 5 averaging protocols: (1) normal averaging; (2)sample-weighted averaging; (3) noise-weighted averaging; (4) amplitude-based artifact-rejection; and (5) percentage-based artifact rejection. The responses were analyzed in the frequency domain and the signal-to-noise ratio was estimated by comparing the signals at the modulation-frequencies to the noise at adjacent frequencies. RESULTS: Weighted averaging gave the best signal-to-noise ratios. Artifact-rejection was better than normal averaging but not as good as weighted averaging. Responses that were not significant with normal averaging became significant with weighted averaging much more frequently than vice versa. False alarm rates did not significantly differ among the protocols. The advantage of weighted averaging was especially evident when stimuli were presented at lower intensities or when smaller amounts (e.g. only 3 or 6 min) of data were evaluated. Weighted averaging was most effective when the background noise levels were variable. Weighted averaging underestimated the amplitude of the responses by about 2%. CONCLUSION: Weighted averaging should be used instead of normal averaging for detecting steady-state responses.	***Clinical Neurophysiology***	**2001**	**112:555-562**
John, M.S.	**MASTER: A Windows program for recording multiple auditory steady-state responses.**	MASTER is a Windows-based data acquisition system designed to assess human hearing by recording auditory steady-state responses. The system simultaneously generates multiple amplitude-modulated and/or frequency-modulated auditory stimuli, acquires electrophysiological responses to these stimuli, displays these responses in the frequency-domain, and determines whether or not the responses are significantly larger than background electroencephalographic activity. The operator can print out the results, store the data on disk for more extensive analysis by other programs, review stored data, and combine results. The system design follows clear principles concerning the generation of acoustic signals, the acquisition of artifact-free data, the analysis of electrophysiological responses in the frequency-domain, and the objective detection of signals in noise. The instrument uses a popular programming language (LabVIEW) and a commercial data acquisition board (AT-MIO-16E-10), both of which are available from National Instruments.	***Computer Methods and Programs in Biomedicine***	**2000**	**61:125-150**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
John, M.S.	**Human auditory steady-state responses to amplitude-modulated tones: phase and latency measurements.**	Human auditory steady-state responses were recorded to four stimuli, with carrier frequencies (f(c)) of 750, 1500, 3000 and 6000 Hz, presented simultaneously at 60 dB SPL. Each carrier frequency was modulated by a specific modulation frequency (f(m)) of 80.6, 85.5, 90.3 or 95.2 Hz. By using four different recording conditions we obtained responses for all permutations of f(m) and f(c). The phase delays (P) of the responses were unwrapped and converted to latency (L) using the equation: L=P/(360xf(m)). The number of cycles of the stimulus that occurred prior to the recorded response was estimated by analyzing the effect of modulation frequency on the responses. These calculations provided latencies of 20.7, 17.7, 16.1 and 16.1 ms for carrier frequencies 750, 1500, 3000 and 6000 Hz. This latency difference of about 4.5 ms between low and high carrier frequencies remained constant over many different manipulations of the stimuli: faster modulation rates (150-190 Hz), binaural rather than monaural presentation, different intensities, stimuli presented alone or in conjunction with other stimuli, and modulation frequencies that were separated by as little as 0.24 Hz. This frequency-related delay is greater than that measured using transient evoked potentials, most likely because of differences in how transient and steady-state responses are generated and how their latencies are determined.	***Hearing Research***	**2000**	**141:57-79**
John, M.S.	**Multiple auditory steady-state responses (MASTER): Stimulus and recording parameters.**	Steady-state responses evoked by simultaneously presented amplitude-modulated tones were measured by examining the spectral components in the recording that corresponded to the different modulation frequencies. When using modulation frequencies between 70 and 110 Hz and an intensity of 60 dB SPL, there were significant interactions between two stimuli when the carrier frequencies were closer than one half of an octave apart, with attenuation of the response to the lower carrier frequency. However, there were no significant decreases in response amplitude with four simultaneous stimuli provided the carrier frequencies differed by one octave or more. Higher intensities (70 dB SPL) resulted in greater interactions between the stimuli than when low intensities (35 dB SPL) were used. Modulation frequencies could be as closely spaced as 1.3 Hz without affecting the responses. Using broad-band noise as a carrier instead of a pure tone resulted in a significantly larger response when the stimuli were presented at the same sound pressure level. At modulation frequencies between 30 and 50 Hz, there were greater interactions between stimuli than at faster modulation frequencies. These results support the following recommendations for using multiple stimuli in evoked potential audiometry: (1) The multiple stimulus technique works well for steady state responses at frequencies between 70 and 110 Hz. (2) Up to four stimuli can be simultaneously presented to an ear without significant loss in amplitude of the response, provided the carrier frequencies are separated by an octave and the intensities are 60 dB SPL or less. (3) Band pass noise might serve as a better carrier signal than pure tones.	***Audiology***	**1998**	**37:59-82**

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Author(s)	Title	Summary	Journal	Year	Vol:Pages
Lins, O.G.	**Frequency-specific audiometry using steady-state responses.**	OBJECTIVE: To evaluate the audiometric usefulness of steady-state responses to multiple simultaneous tones, amplitude-modulated at 75 to 110 Hz. DESIGN: Steady-state responses to multiple tones amplitude-modulated at different rates between 75 and 110 Hz and presented simultaneously were recorded at different intensities in normal adults, well babies, normal adults with simulated hearing loss, and adolescents with known hearing losses. Response thresholds were compared with behavioral thresholds. RESULTS: In normal adults the thresholds for steady-state responses to tones of 0.5, 1, 2, and 4 kHz were 14 +/- 11, 12+/- 11, 11 +/- 8, and 13 +/- 11 dB, respectively, above behavioral thresholds for air-conducted stimuli, and 11 +/- 5, 14 +/- 8, 9 +/- 8, and 10 +/- 10 dB above behavioral thresholds for bone-conducted stimuli. In well babies tested ina quiet environment, the thresholds were 45 +/- 13, 29 +/- 10, 26 +/- 8, and 29+/- 10 dB SPL. In adolescents with known hearing losses, the steady-state responses thresholds predict behavioral thresholds with correlation coefficients(r) of 0.72, 0.70, 0.76, and 0.91 at 0.5, 1, 2, and 4 kHz, respectively. CONCLUSION: Steady-state responses to tone amplitude-modulated at 75 to 110 Hz can be used for frequency-specific objective audiometry. The multiple-stimulus technique allows thresholds to be estimated for eight different stimuli at the same time.	***Ear and Hearing***	**1996**	**17:81-96**
Lins, O.G.	**Auditory steady-state responses to multiple simultaneous stimuli.**	Steady-state responses can follow multiple simultaneous auditory stimuli. If the stimuli are modulated at different rates, responses specific to each stimulus can be assessed by measuring in the frequency domain response the spectral component corresponding to the rate of modulation. When each stimulus has a different carrier frequency or different ear of presentation, the responses when8 stimuli are presented simultaneously are not significantly different than when each stimulus is presented alone. Since significant responses can be recognized down to intensities that average 14 dB above behavioral threshold, this technique may be useful in objective audiometry. It is also possible to record steady-state responses to multiple modulations of the same carrier frequency. In this case, the amplitude of the responses when the stimuli are combined is smaller than when the stimuli are presented alone. The decrease in amplitude depends upon the number of concomitant stimuli and their relative intensities. These effects are probably due to the compressive rectification occurring during cochlear transduction, and the data may be used to model cochlear processing of auditory stimuli.	***Electroencephalography and Clinical Neurophysiology***		**96:420-432**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Lins, O.G.	**Auditory steady-state responses to tones amplitude-modulated at 80-110 Hz.**	Steady-state responses can be recorded from the human scalp in response to tones that are sinusoidally modulated in amplitude at rates between 60 and 120 Hz. For60 dB SPL 1000-Hz tones the maximum baseline-to-peak amplitude of about 0.06microV occurs for modulation rates between 80 and 95 Hz. The phase of the response does not change with modulation depths greater than 25% and the amplitude saturates at modulation depths greater than 50%. The presence or absence of a response can be accurately determined by frequency-domain statistics and the response becomes clearly recognizable at intensities that are16 +/- 8 dB above behavioral thresholds. With increasing intensity the response increases in amplitude at 1.9 nV/dB until an intensity of 70 dB SPL. As the intensity increases above 70 dB SPL the response increases in amplitude more rapidly at 7.8 nV/dB (at 1000 Hz) and contains significant energy at harmonics of the modulation frequency. This second stage of the intensity function is more prominent for stimuli with lower carrier frequencies (500 more than 1000 more than 2000 Hz) and is attenuated by high-pass masking. These steady-state responses should be helpful in evaluating human auditory physiology and in objective audiometry.	***Journal of the Acoustical Society of America***	**1995**	**97:3051-3063**
Picton, T.W.	**Human Auditory Steady-State Responses: Effects of Recording Technique and State of Arousal.**	There is some controversy in the literature about whether auditory steady-state responses (ASSRs) can be reliably recorded in all subjects and whether these responses consistently decrease in amplitude during drowsiness. In 10 subjects, 40-Hz ASSRs became significantly different from background electroencephalogram activity with a probability of $P < 0.01$ and an average time of 22 s (range, 2-92 s), provided that the responses were analyzed with time-domain averaging rather than spectral averaging. In a second experiment with 10 subjects, 40-Hz ASSRs recorded between the vertex and posterior neck consistently decreased in amplitude during drowsiness and sleep. Findings that the ASSR may occasionally increase during drowsiness may be explained by postauricular muscle responses recorded from a mastoid reference. These may occur during drowsiness in association with rolling-eye movements. ASSRs recorded between the vertex and posterior neck are not distorted by these reflexes. These findings combine with previous literature on the effects of general anesthetics on the ASSR to confirm that the ASSR is a valid option for monitoring the hypnotic effects of general anesthetics. IMPLICATIONS: Auditory steady-state responses to stimuli presented at rates near 40 Hz can be used to monitor anesthesia. These responses can be quickly and reliably recorded during both sleep and wakefulness, provided that appropriate averaging techniques are used.	***Anesthesia and Analgesia***	**2003**	

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Picton, T.W.	**Possible roles for the auditory steady-state responses in identification, evaluation and management of hearing loss in infancy.**	Steady-state responses evoked by regularly repeating stimuli are most easily evaluated in the frequency domain, where the spectrum shows peaks at the rate of stimulation and its harmonics. Auditory steady-state responses can be reliably evoked by tones that have been modulated in amplitude and/or frequency at rates between 75 and 110 Hz. These responses show great promise for objective audiometry since they can be readily recorded in infants and are unaffected by sleep. Responses to multiple tones presented simultaneously can be independently assessed if each tone is modulated at a different modulation-frequency. This makes it possible to estimate thresholds at several audiometric frequencies in both ears at the same time. Response to amplitude-modulated wideband noise may be recognized rapidly, and these may prove helpful in screening for newborn hearing loss. Since tones that have been sinusoidally modulated are not significantly distorted by free-field speakers and microphones, they can be used to evaluate the performance of hearing-aids. Responses to amplitude- and frequency-modulation may help determine how well hearing aids improve the discriminability as well as the audibility of sounds.	***Audiology Today***	**2002**	**14**
Picton, T.W.	**Human Auditory Steady-State Responses.**	Steady-state evoked potentials can be recorded from the human scalp in response to auditory stimuli presented at rates between 1 and 200 Hz or by periodic modulations of the amplitude and/or frequency of a continuous tone. Responses can be objectively detected using frequency-based analyses. In waking subjects, the responses are particularly prominent at rates near 40 Hz. Responses evoked by more rapidly presented stimuli are less affected by changes in arousal and can be evoked by multiple simultaneous stimuli without significant loss of amplitude. Response amplitude increases as the depth of modulation or the intensity increases. The phase delay of the response increases as the intensity or the carrier frequency decreases. Auditory steady-state responses are generated throughout the auditory nervous system, with cortical regions contributing more than brainstem generators to responses at lower modulation frequencies. These responses are useful for objectively evaluating auditory thresholds, assessing suprathreshold hearing, and monitoring the state of arousal during anesthesia.	***International Journal of Audiology***	**2003**	**June**
Picton, T.W.	**Multiple auditory steady-state responses.**	Steady-state responses are evoked potentials that maintain a stable frequency content over time. In the frequency domain, responses to rapidly presented stimuli show a spectrum with peaks at the rate of stimulation and its harmonics. Auditory steady-state responses can be reliably evoked by tones that have been amplitude-modulated at rates between 75 and 110 Hz. These responses show great promise for objective audiometry, because they can be readily recorded in infants and are unaffected by sleep. Responses to multiple tones presented simultaneously can be independently assessed if each tone is modulated at a different modulation frequency. This ability makes it possible to estimate thresholds at several audiometric frequencies in both ears at the same time. Because amplitude-modulated tones are not significantly distorted by free-field speakers or microphones, they can also be used to evaluate the performance of hearing aids. Responses to amplitude and frequency modulation may also become helpful in assessing suprathreshold auditory processes, such as those necessary for speech perception.	***Annals of Otology, Rhinology and Laryngology***	**2005**	**111(5):16-21**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Picton, T.W.	**The use of phase in the detection of auditory steady-state responses.**	OBJECTIVE: To investigate how phase measurements might facilitate the detection of auditory steady-state responses. METHODS: Multiple steady-state responses were evoked by auditory stimuli modulated at rates between 78 and 95 Hz and with intensities between 50 and 0 dB SPL. The responses were evaluated in 20 subjects after 1, 2, 4, and 6 min. The responses were analyzed in the frequency domain using 4 different detection protocols: (1) phase-coherence, (2) phase-weighted coherence, (3) F test for hidden periodicity, and (4) phase-weighted t test. The phase-weighted measurements were either based on the mean phase of a group of normal subjects or derived for each subject from the phase of the response at higher intensities. RESULTS: Detection protocols based on both phase and amplitude (F test and phase-weighted t test) were more effective than those based on phase alone (phase coherence and phase-weighted coherence) although the difference was small. Protocols using phase-weighting were more effective than those without phase-weighting. The lowest thresholds for the steady-state responses were obtained using the phase-weighted t test. CONCLUSION: Threshold detection can be improved by weighting the detection protocols toward an expected phase, provided that the expected phase can be reliably predicted.	***Clinical Neurophysiology***	**2001**	**112:1698-1711**
Picton, T.W.	**Potentials evoked by the sinusoidal modulation of the amplitude or frequency of a tone.**	Steady state responses to the sinusoidal modulation of the amplitude or frequency of a tone were recorded from the human scalp. For both amplitude modulation (AM) and frequency modulation (FM), the responses were most consistent at modulation frequencies between 30 and 50 Hz. However, reliable responses could also be recorded at lower frequencies, particularly at 2-5 Hz for AM and at 3-7 Hz for FM. With increasing modulation depth at 40 Hz, both the AM and FM response increased in amplitude, but the AM response tended to saturate at large modulation depths. Neither response showed any significant change in phase with changes in modulation depth. Both responses increased in amplitude and decreased in phase delay with increasing intensity of the carrier tone, the FM response showing some saturation of amplitude at high intensities. Both responses could be recorded at modulation depths close to the subjective threshold for detecting the modulation and at intensities close to the subjective threshold for hearing the stimulus. The responses were variable but did not consistently adapt over periods of 10 min. The 40-Hz AM and FM responses appear to originate in the same generator, this generator being activated by separate auditory systems that detect changes in either amplitude or frequency.	***Journal of the Acoustical Society of America***	**1987**	**82:165-178**

Author(s)	Title	Summary	Journal	Year	Vol:Pages
Purcel, D.W	**Concurrent measurement of distortion product otoacoustic emissions and auditory steady state evoked potentials.**	Distortion product otoacoustic emissions (DPOAEs) and auditory steady state evoked response potentials (ASSRs) can both be evoked by tone pairs with frequencies f(1) and f(2). The DPOAE is maximal at 2f(1)-f(2) and the ASSR is maximal at f(2)-f(1). Since DPOAE magnitude depends on the ratio f(2)/f(1), but ASSR amplitude depends on the beat frequency f(2)-f(1), compromises are necessary when recording both responses concurrently. Tone pairs with f(2) of 900, 1800 and 3600 Hz were presented simultaneously at either 40 or 50 dB sound pressure level (SPL). The f(1) frequency of each pair was approximately 85 or 180 Hz lower than f(2). Phase measurements were used to calculate apparent latencies at 40 dB SPL. For increasing f(2), DPOAE latencies were 14.5, 9.7 and 6.3 ms for 85 Hz beats, and 11.5, 9.0 and 4.3 ms for 180 Hz beats. ASSR latencies were 22.0, 15.7 and 17.8 ms at 85 Hz, and 17.7, 11.3 and 9.6 ms at 180 Hz. From a model of the mechanical transmission in the cochlea, delays between the basilar membrane and the generator of the ASSR were estimated as 15.4, 12.2 and 15.3 ms at 85 Hz and 8.6, 7.6 and 8.0 ms at 180 Hz.	***Hear Res.***	**2003**	**February**
Small, S.	**Multiple Auditory steady-state response thresholds to bone-conduction stimuli in adults with normal hearing.**	Multiple auditory steady-state responses (ASSRs) have been shown to provide reasonably accurate estimations of hearing thresholds for air-conduction stimuli (Dimitrijevic et al., 2002; Herdman and Stapells, 2003; Lins et al., 1996) but few studies have used bone-conduction stimuli. Ideally, techniques that assess hearing thresholds should distinguish between sensorineural, conductive and mixed hearing losses, as is done routinely in behavioural audiometry. Two previous studies have used bone-conduction stimuli to elicit ASSRs (Dimitrijevic et al., 2002; Lins et al., 1996). Both studies reported results that are different for 500 Hz compared to higher carrier frequencies and did not investigate the role of artifact or aliasing in their results (see Small & Stapells, IERASG 2003). These earlier studies also used forehead placement for the bone oscillator. The purpose of this study was to estimate ASSR thresholds to bone-conduction stimuli in adults with normal hearing (N=10) using a B-71 bone oscillator placed on the temporal bone near the mastoid. Stimuli were bone-conduction amplitude-modulated tones (fc: 500-4000 Hz; fm: 77-101 Hz). ASSRs were recorded using the MASTER system (1250-Hz AD rate; 30-250Hz 12 dB/oct EEG filter; 300Hz 115 dB/oct LP anti-aliasing filter). Results: Mean (±1 SD) ASSR thresholds to bone-conduction stimuli were 22±11, 26±13, 18±8 and 18±11 dBHL for 500, 1000, 2000 and 4000 Hz, respectively. Except for 500 Hz, intensity-amplitude functions for the ASSRs to bone-conduction stimuli showed the same slopes as those to air-conduction stimuli (binaural). ASSRs to bone-conducted 500-Hz stimuli show a steeper slope, compared to the air-conduction stimuli and to higher bone-conduction frequencies. Alternating the stimulus polarity had no effect on this steep slope. This steeper slope may reflect a non-auditory contribution to the ASSR, consistent with our results in subjects with severe/profound sensorineural hearing loss (Small & Stapells, IERASG 2003).	***International European Response Audiometry Study Group (IERASG), Spain***	**2003**	