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# Ipsilateral and contralateral recordings of the 40-Hz auditory steady state response (ASSR): Which one is better?

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**Key-words.** ASSR; modulation frequency; ipsilateral; contralateral; chirps

**Abstract.** *Ipsilateral and contralateral recordings of the 40-Hz auditory steady state response (ASSR): Which one is better? Objective*: Few studies have investigated the auditory steady state response (ASSR) thresholds evoked by ipsilateral and contralateral stimulation. The present study was conducted to compare 40-Hz ASSR thresholds between ipsilateral and contralateral recordings at specific test frequencies.

*Methods*: Twenty young female subjects with normal hearing bilaterally (hearing level ≤20 dB HL across speech frequencies) were included in the study. One-octave-wide narrow band CE-chirp® stimuli centred at 500, 1000, 2000 and 4000 Hz with 40 Hz modulation frequency (MF) were presented ipsilaterally and contralaterally to each subject through insert earphones. The ASSR thresholds were obtained for each recording condition.

*Results*: The mean ASSR thresholds were higher for contralateral recording than for ipsilateral recording at all test frequencies, but analysis using the paired t-test revealed that the differences were not significant at any of the test frequencies ($p>0.05$). Comparing the ASSR thresholds among the test frequencies for the two recording conditions, there were no significant differences as determined using one-way ANOVA ($p>0.05$).

*Conclusion*: The 40-Hz ASSR thresholds can be reliably recorded with ipsilateral and contralateral stimulation. For objective determination of hearing thresholds in young women, either ipsilateral or contralateral ASSR recording is appropriate. Nevertheless, the combination of both recordings might increase the diagnostic value of 40-Hz ASSR in estimating behavioural hearing thresholds.

## Introduction

When testing special populations such as difficult-to-test children, non-organic hearing loss cases and children with auditory neuropathy/dyssynchrony, it is preferable to conduct objective hearing assessments.[1-3] Auditory steady state response (ASSR) testing is a relatively recent method for determining auditory evoked potentials that offers a more convenient way to estimate hearing thresholds. Since the ASSR waveforms are not displayed, the ASSR thresholds are estimated "automatically" by specific response detection algorithms.[4,5] Clinically, this is a clear advantage over conventional auditory evoked potential tests that require subjective interpretation of waveforms.[6]

ASSR is different from other types of electrophysiological tests in that it is typically recorded using pure tones that are modulated in amplitude and/or frequency.[7] More recently, narrow band chirps have been used to record ASSRs.[8] The chirp stimuli are designed to enhance the response amplitude by compensating for the cochlear delay.[9] The generators for ASSR are dependent on its modulation frequency (MF). ASSR is thought to be generated by the auditory brainstem regions when high MF (e.g. 90 Hz) is used.[10] In contrast, when low MF is used (e.g. 40 Hz), the ASSR is generated predominantly by the cortical and subcortical regions and is therefore more sensitive to awareness and sleep state.[11]

Low MF ASSR has been recommended for testing adults as its estimates are closer to behavioural hearing thresholds.[12] Recent data showed that the 40-Hz ASSR amplitudes increase with increasing oestrogen level, particularly during the late follicular phase of the menstrual cycle.[13] Accordingly, this factor should be taken into consideration when

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recording low MF ASSR in female subjects. In fact, it remains unclear which test frequencies are affected (if pure tones are used) as the previous study used only click stimuli to record 40-Hz ASSR.[13] In addition, few studies have investigated the 40-Hz ASSR thresholds evoked by ipsilateral and contralateral stimulation. The present study was performed to compare 40-Hz ASSR thresholds for ipsilateral and contralateral stimulation at specific test frequencies in healthy female subjects.

## Materials and methods

### *Participants*

This comparative study included 20 healthy female subjects (mean age 23.4 ± 2.5 years) with no history of hearing, ear or neurological disorders. All were right-handed and had normal hearing bilaterally as indicated by pure tone audiometry (hearing threshold of 20 dB HL or less at 250, 500, 1000, 2000, 4000 and 8000 Hz). All had normal middle ear function bilaterally as determined by tympanometry and acoustic reflex assessments. Prior to testing, approval was obtained from the Human Ethics Committee of the Universiti Sains Malaysia, and the study was performed in accordance with the 1964 Helsinki declaration and its later amendments. All participants provided informed written consent.

### *ASSR recording*

A two-channel Eclipse system (Interacoustic Corporation, Denmark) was utilized for recording the ASSR. One-octave-wide narrow band CE-chirp® stimuli centred at 500, 1000, 2000 and 4000 Hz (with 100% amplitude modulation and 20% frequency modulation) were presented to the subjects at supra-threshold and threshold levels. All stimuli were modulated around 40 Hz, and the outputs were calibrated in dBnHL. The acquired responses were amplified 100,000 times and filtered between 0.1 and 100 Hz (12dB/octave). For each participant, the non-inverting electrode was placed on the forehead, the inverting one on the mastoids, and the ground electrode on the cheek. To ensure good recording quality, the electrode impedance was maintained below 5 kΩ throughout the recording sessions. For ipsilateral recording, the stimuli were delivered to the right ear, and the ASSRs were analysed in the right channel of the Eclipse system. For contralateral recording, the stimuli were presented to the right ear of the subjects, and the left channel of the device recorded the resultant ASSRs. To shorten the testing time, the stimuli were presented using the multiple auditory steady-state response (MASTER) technique. In this technique, the four test stimuli are presented sequentially to both ears until the required responses are obtained. For an accurate response analysis during testing, each stimulus presented to each ear was assigned a specific MF around 40 Hz. Specifically, for the right ear, the MFs were fixed at 38, 41, 35 and 39 Hz for the 500, 1000, 2000 and 4000 Hz test frequencies, respectively. As for the left ear, the MFs were 43, 45, 42 and 44 Hz for the 500, 1000, 2000 and 4000 Hz test frequencies, respectively. To enhance the response detection rates, the ASSR device used the"full spectrum detection engine" feature in which amplitude, phase and higher harmonics information were analysed.

The ASSR recording was performed according to the directions in the test manual and took place in a sound-proof room at the Audiology Clinic, Universiti Sains Malaysia. After giving the proper instructions to each subject, the stimuli were initially presented at 60 dBnHL through insert earphones. In the Eclipse system, the response is considered present at a particular intensity level if it reaches the 95% confidence level within the default time of 6 minutes. To shorten the testing time, the run was terminated even sooner (i.e. in less than 6 minutes) when the response reached the 95% confidence level. Following a clear response, the intensity level was decreased in 10-dB steps. When the response was unclear at a particular level and did not reach the 50% confidence level within the first 3 minutes, the run was stopped and repeated. If the response was still unclear, the intensity level was increased in 5-dB steps. The testing continued until thresholds were obtained for each recording condition (ipsilateral and contralateral) at all test frequencies. The ASSR threshold was defined as the lowest intensity level that produced a clear response (i.e. reached the 95% confidence level) within the 6-minute default time. To verify response reproducibility, the run was repeated twice at all threshold levels. Since the 40-Hz ASSR is influenced by the subjects' arousal state, all participants were instructed to stay awake during testing.[14] Their arousal state was carefully monitored by the tester throughout the recording sessions. To avoid fatigue and tiredness, participants were given breaks between each run or as requested.

*Data analysis*

Descriptive and inferential statistics were used for the data analyses. Mean, standard deviation (SD) and standard error of the mean (SEM) were computed as applicable. The Kolmogorov-Smirnov test was used to check for data normality. Following this, Levene's test was used to determine whether the data had equal variances. For the main procedure, the paired t-test was used to compare the ASSR thresholds between ipsilateral and contralateral recordings at each test frequency. Then, one-way repeated measures ANOVA was used to compare the ASSR thresholds across the test frequencies for each recording condition. The resultant p values of less than 0.05 were considered statistically significant. All data analyses were carried out using SPSS software version 20 (SPSS Inc., Chicago, IL).

## Results

All data were normally distributed with equal variances ($p>0.05$ for both Kolmogorov-Smirnov and Levene's tests), so parametric statistical analysis was used to analyse the test results. Figure 1 shows the mean and SEM of the ASSR thresholds for each recording condition at different test frequencies. The mean ASSR thresholds for the ipsilateral condition were higher than for the contralateral condition at all test frequencies. The difference in the mean value was the highest at 500 Hz (21.0±7.5 and 18.3±8.3 dBnHL for ipsilateral and contralateral recordings, respectively), and the mean difference was the lowest at 4000 Hz (20.3±6.4 and 19.5±5.6 dBnHL for ipsilateral and contralateral recordings, respectively). To test whether the differences were significant, the values were compared using the paired t-test (Table 1). The ASSR thresholds were not significantly different when the two recording conditions were compared at each test frequency ($p>0.05$).

We also compared the ASSR thresholds among the test frequencies for each recording condition. For the ipsilateral recording condition, the 1000-Hz test frequency produced the lowest mean ASSR threshold (16.0±7.0 dBnHL), and the 500-Hz produced the highest mean (21.0±7.5 dBnHL) (Table 1). For the contralateral recording condition, the lowest mean was noted at 500 Hz (14.8±6.2 dBnHL), and the 4000-Hz test frequency produced the highest mean ASSR threshold (19.5±5.6 dBnHL). As shown in Table 1, one-way repeated measures ANOVA revealed no significant difference among the test frequencies for the ipsilateral condition in terms of the ASSR thresholds ($F_{3,57}=2.62$, $p=0.060$). Similarly, the ASSR thresholds were not statistically different among the test frequencies for the contralateral recording ($F_{3,57}=2.62$, $p=0.059$).

## Discussion

The current study compared the 40-Hz ASSR thresholds for ipsilateral and contralateral recordings at specific test frequencies. Because of a lack of studies, many research questions related to this area of study remain unanswered. Compared to high-MF ASSR, ~40-Hz ASSR is recommended as it shows closer estimates to behavioural hearing thresholds and faster testing time in adults.[12] In the present study, there were no clear differences in the

*Table 1*

Descriptive and inferential statistical analysis of 40-Hz auditory steady state response (ASSR) thresholds for ipsilateral and contralateral recordings at specific test frequencies in 20 female participants

| Test frequency (Hz) | ASSR threshold (mean±SD) (dBnHL) | | p value (paired t-test) |
|---|---|---|---|
| | Ipsilateral | Contralateral | |
| 500 | 21.0±7.5 | 18.3±8.3 | 0.102 |
| 1000 | 16.0±7.0 | 14.8±6.2 | 0.367 |
| 2000 | 20.3±7.0 | 18.5±7.5 | 0.090 |
| 4000 | 20.3±6.4 | 19.5±5.6 | 0.545 |
| p value (ANOVA) | 0.060 | 0.059 | |

*Significant at p<0.05.

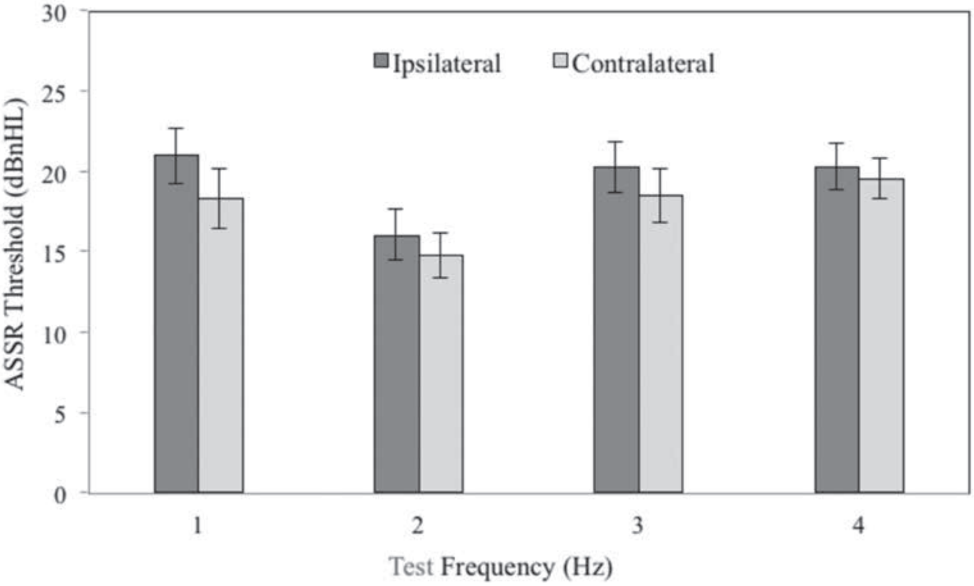


*Figure 1*
Mean and standard error of the mean (SEM) of the 40-Hz auditory steady state response (ASSR) thresholds for ipsilateral and contralateral recordings at specific test frequencies in 20 female participants.

ASSR thresholds between ipsilateral and contralateral stimulations at all test frequencies. This finding is in line with the study outcomes obtained by Kaf and Danesh.[15] In their study, ASSRs were recorded in twenty-five healthy female subjects, and pure tones (100% amplitude modulation) were presented at 65 dB SPL to evoke the ASSRs. The ASSR amplitudes were then compared between ipsilateral and contralateral recordings at carrier frequencies (CFs) of 500, 2000 and 4000 Hz with 39 and 79 Hz MFs. Using 39-Hz MF, even though the mean ipsilateral ASSR amplitudes were higher than the mean contralateral ASSR amplitudes, the inferential statistical analyses revealed that there were no significant differences at any of the tested CFs.[15] It is worth noting that even though the 40-Hz ASSR thresholds for the ipsilateral and contralateral conditions were not statistically different in our study, the mean thresholds for the ipsilateral conditions were consistently higher at all test frequencies (Figure 1). This observation merits further consideration. For example, some differences might be significant if the sample size was larger, but further research is needed to test this possibility.

The current study also found that the mean ASSR thresholds were almost equal across the test frequencies as there were no significant differences for either recording condition. In contrast, in the study by Kaf and Danesh, a 500-Hz CF produced the highest mean ASSR amplitude, followed by 2000- and 4000-Hz CFs.[15] In this regard, if the ASSR thresholds are recorded at these CFs, the lowest ASSR threshold would be expected at a 500-Hz CF, which contradicts the finding of the current study. Nevertheless, supra-threshold ASSR results might not be good indicators of threshold levels. In a study by Vander Werff and Brown, the ASSR thresholds and behavioural thresholds were closely correlated, but the ASSR amplitudes recorded at supra-threshold levels were not good estimators of threshold levels.[16] That is, the highest mean ASSR amplitude may not necessarily produce the lowest ASSR threshold at a particular CF. In fact, as reported by Kaf and Danesh, since the signal-to-noise ratio was not controlled during the measurements, the recorded ASSR amplitudes varied considerably.[15] Therefore, the methodological difference (threshold versus supra-threshold testing) and the response variability are likely the reasons for the discrepancy between the current study and the study by Kaf and Danesh.[15]

The 40-Hz ASSR amplitudes correlate positively with 17β oestradiol (oestrogen) levels during the late follicular phase of the menstrual cycle when the oestrogen level is the highest.[13] Since the present study did not find significant differences, the influence of hormones on the 40-Hz ASSR threshold is unclear. Perhaps hormones play a minor role in modulating ipsilateral and contralateral ASSRs and are not frequency-specific. Nevertheless, the present study did not control for the phases of the menstrual cycle of the female subjects. Further studies are warranted to verify the existing data so that a more concrete conclusion can be drawn.

## Conclusions

The present study found no clear evidence that the 40-Hz ASSR thresholds evoked by contralateral stimulation are better than those obtained with ipsilateral stimulation or vice versa. Moreover, the ASSR thresholds for the test frequencies were not significantly different from each other for the two recording conditions. In this regard, both types of recordings are appropriate for determining ASSR thresholds, at least in healthy subjects. The findings of the present study, however, are only applicable to female subjects. Future studies are warranted to rule out any gender effect on the 40-Hz ASSR thresholds evoked by ipsilateral and contralateral stimulations. Nevertheless, since the 40-Hz ASSR thresholds can be reliably obtained with ipsilateral and contralateral stimulations, the combination of both recordings might offer a better diagnostic value than the conventional one-channel method (i.e. ipsilateral recording) for estimating hearing thresholds.

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