Objective Binaural Loudness Balancing Based on 40-Hz Auditory Steady-State Responses. Part I: Normal Hearing

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Abstract

Psychophysical procedures are used to balance loudness across the ears. However, they can be difficult and require active cooperation. We investigated whether 40-Hz auditory steady-state response (ASSR) amplitudes can be used to objectively estimate the balanced loudness across the ears for a group of young, normal-hearing participants. The 40-Hz ASSRs were recorded using monaural stimuli with carrier frequencies of 500, 1000, or 2000 Hz over a range of levels between 40 and 80 dB SPL. Behavioral loudness balancing was performed for at least one reference level of the left ear. ASSR amplitude growth functions were listener dependent, but median across-ear ratios in ASSR amplitudes were close to 1. The differences between the ASSR-predicted balanced levels and the behaviorally found balanced levels were smaller than 5 dB in 59% of cases and smaller than 10 dB in 85% of cases. The differences between the ASSR-predicted balanced levels and the reference levels were smaller than 5 dB in 54% of cases and smaller than 10 dB in 87% of cases. No clear hemispheric lateralization was found for 40-Hz ASSRs, with the exception of responses evoked by stimulus levels of 40 to 60 dB SPL at 2000 Hz.

Introduction

Psychophysical procedures for finding binaural loudness balance are used in binaural research and have recently received increased attention due to an increase in patients with bimodal hearing, who likely have a mismatch in loudness between the ears (e.g., Francart, Brokx, & Wouters, 2009; Reiss, Ito, Eggleston, & Wozny, 2014). The current procedures can be judged as difficult, require active cooperation which is not possible for, for example, patients with intellectual disabilities, and take a lot of testing time. Therefore, this study aims to explore the feasibility of finding an objective and more automatic measure for binaural loudness balancing.

In the field of auditory evoked potentials, mainly the electrically evoked compound action potential and the auditory brainstem response have been of interest in previous studies for predicting balanced loudness across the ears (Gordon, Abbasalipour, & Papsin, 2016; Kirby, Brown, Abbas, Etler, & O'Brien, 2012; Salloum

et al., 2010). However, the responses could not reliably predict balanced loudness in a significant proportion of the participants (e.g., 31% in Gordon et al., 2016). Furthermore, these responses still require the interpretation of a skilled clinician and are therefore not fully objective.

In this study, we investigated whether the 40-Hz auditory steady-state response (ASSR) amplitudes can be used to objectively estimate the loudness balance point across the two ears. ASSRs are stable auditory brain potentials, reflecting synchronized neural activity to long-duration repetitive stimuli. Various modulation frequencies have been used to evoke ASSRs, and the largest signal-to-noise ratios in adult awake participants are

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found with a modulation frequency near 40 Hz (Picton, 2011). Since ASSRs can be detected fully automatically using a statistical test, they have gained interest over the years for more automatic or objective hearing assessments and hearing aid fitting.

In a previous study, we demonstrated that the amplitude of the 40-Hz ASSR increases with increasing level (dB SPL) and is related to loudness growth (Van Eeckhoutte, Wouters, & Francart, 2016). The stimuli used to evoke the ASSR amplitude growth functions were always presented monaurally and for most of the participants (26/30) to the left ear. Even though there is large variability in 40-Hz ASSR amplitudes across participants, we hypothesize that ASSR amplitudes at balanced loudness would be the same across the ears within each participant, as Gransier, Wieringen, and Wouters (2017) reported no significant differences between left and right ear stimulation for 40-Hz ASSR amplitudes, for both the left hemisphere (LH) and right hemisphere (RH).

It has been shown that the LH and RH have their own functional specializations and this is also true for the processing of auditory stimuli (e.g., Zatorre & Belin, 2001; Zatorre, Belin, & Penhune, 2002), with a LH specialization for rapid temporal processing and a RH specialization for spectral processing. For example, stimuli with amplitude modulation at low rates (e.g., 4 Hz) are more dominantly processed by the RH (Abrams, Nicol, Zecker, & Kraus, 2008; Boemio, Fromm, Braun, & Poeppel, 2005; Hämäläinen, Rupp, Soltész, Szücs, & Goswami, 2012; Millman, Prendergast, Kitterick, Woods, & Green, 2010), while stimuli with modulation at high rates (e.g., 40 Hz) are thought to be more dominantly processed by the LH (Jamison, Watkins, Bishop, & Matthews, 2006; Poeppel, Idsardi, & van Wassenhove, 2008; Schonwiesner, Rübsamen, & Von Cramon, 2005; Zaehle, Wüstenberg, Meyer, & Jäncke, 2004). For 40-Hz ASSRs specifically, potential ear or hemispheric lateralization effects can vary with level or carrier frequency, and this needs further investigation. Some studies have suggested a right hemispheric dominance for 40-Hz ASSR amplitudes (Goossens, Vercammen, Wouters, & van Wieringen, 2016; Ross, Herdman, & Pantev, 2005; Yamasaki et al., 2005), but these studies have always focused on one stimulation level and carrier frequency.

The aim of this study was to investigate whether (a) there are any effects of ear, carrier frequency, hemisphere, and level when measuring ASSR growth functions for each ear monaurally and (b) whether ASSR amplitudes are the same at balanced loudness levels across the ears for young, normal-hearing (NH) participants.

In an accompanying paper (Van Eeckhoutte, Spirrov, Wouters, & Francart, 2018), we present the results for a group of participants with asymmetric hearing loss and a group of participants with bimodal hearing, who have a cochlear implant in one ear and a hearing aid in the nonimplanted ear.

Material and Methods

Participants

In total, 38 NH, native Dutch (Flemish) speakers (28 women and 10 men) participated. All participants were young adults, with an average age of 22 ± 2 (*SD*) years. Scores on the Edinburgh Handedness Inventory (Oldfield, 1971) indicated that 29 participants were right handed, 4 were ambidextrous, and 5 were left handed. Participants answered Questions 13 to 16 of the questionnaire of Coren (1993), and the responses were used to determine ear preference.[1] All participants who were left handed had a left-ear preference. Participants who were right handed had a right-ear preference in 25 cases, no ear preference in 3 cases, and a left-ear preference in 1 case (NH14). The participants who were ambidextrous had no-ear preference in three cases and a right-ear preference in one case. All participants had unobstructed ear canals, as revealed by otoscopic examination. Most participants reported that they did not have tinnitus, but three reported a very soft tinnitus. All participants had normal thresholds (25 dB HL or better) for all octave frequencies between 0.125 and 8 kHz, as assessed by a Madsen Electronics Orbiter 922 audiometer and TDH-39 headset, with the exception of one ambidextrous participant who had a threshold of 35 dB HL at 500 Hz in both ears. The average difference across ears was -0.5 ± 7.4 dB (*SD*), -2.6 ± 4.2 dB, and -0.3 ± 6.8 dB for the carrier frequencies of 500, 1000, and 2000 Hz, and the differences were not significantly different from zero ($p > .05$). The Medical Ethical Committee of the University Hospital of Leuven (UZ Leuven) approved the project and all participants gave their written informed consent prior to testing.

Stimuli and Apparatus

All tests took place in soundproof booths, one of which was electromagnetically shielded for the electroencephalographic (EEG) measurements.

The stimuli were 100% sinusoidally amplitude-modulated sinusoids with a modulation frequency of 40 Hz and a carrier frequency of 500, 1000, or 2000 Hz. The participants were split into two groups. The first group of 19 (16 right handed) was tested using the 500- and 2000-Hz carrier frequencies, and the second group of 19 (13 right handed) was tested using the 1000-Hz carrier frequency.

The stimuli were created in MATLAB R2013a (The MathWorks, Inc., Natick, MA) and were presented through Etymotic Research ER-3 A insert ear phones,

connected to an RME Hammerfall DSP Multiface II sound card. Each insert phone was calibrated using a 2CC Brüel & Kjær coupler, type 4152. Stimulus levels are described later.

For the behavioral tasks, the stimulus duration was 1 s, since temporal loudness integration is certainly complete after 1 s (Marks & Florentine, 2011). For the EEG recordings, the stimulus duration was 307.2 s, which was necessary to reduce the EEG recording noise, as the noise is random and can be averaged out, while the response remains stable. Since low stimulus levels that could lead to behavioral loudness adaptation (Van Eeckhoutte, Wouters, & Francart, 2015) were not used, and we did not expect adaptation of the 40-Hz ASSR amplitudes (Van Eeckhoutte, Luke, Wouters, & Francart, 2018), the stimulus duration probably did not affect the results.

The behavioral tasks were conducted using the software platform APEX3 (Francart, van Wieringen, & Wouters, 2008). For the EEG recordings, the stimuli were presented using the software platform for the recording and analysis of brain responses to auditory stimulation (Hofmann & Wouters, 2012), with a signal sampling rate of 96 kHz. The EEG was recorded using the ActiveTwo System Software (Biosemi) with a recording sampling rate of 8192 Hz and a head cap of $64 + 2$ Ag/AgCl active scalp electrodes that followed the standard 10 to 20 electrode position system (see Figure 1).

Procedures and Data Analysis

Behavioral loudness balancing. Binaural loudness balancing was performed using an adjustment procedure, with simultaneous stimulation of the left and the right ear, as described in Van Eeckhoutte, Spirrov, and Francart (2018). The level at the reference, left, ear was fixed and the level at the right ear was varied. This simultaneous presentation usually resulted in a fused, auditory image that was lateralized toward one side of the head if the stimuli were not balanced in loudness. If the stimuli were balanced in loudness, the participants perceived the auditory image in the center of the head. It was clearly mentioned to the participants that their task was to find equal loudness at the two ears, which could be judged as occurring when the auditory image was centered in the head. A schematic circle of the head with a vertical line in the center was used to illustrate this. Simultaneous presentation of the stimuli in contrast to sequential presentation was chosen because it resembles a natural listening situation.

For the participants who were tested using the 1000-Hz carrier frequency, a reference level of 60 dB SPL was used. For the participants who were tested using the 500 - and 2000-Hz carrier frequencies, reference levels of 50 and 70 dB were used. The order of testing the

different reference levels and carrier frequencies (i.e., conditions) was randomized across participants.

During the adjustment procedure, the participants had to adjust the level at the right ear such that the loudness was balanced across the two ears. The participants could increase or decrease the level of the variable ear. Participants were asked to find the balanced loudness across the two ears at least twice, once using a start level 10 dB below the reference level (i.e., the "Up track") and once using a start level 10 dB above the reference level (i.e., the "Down track"). The experimenter controlled the buttons and encouraged the participants to find the balanced loudness by asking the experimenter to press on the right or left button (">" or " < "). Each button press resulted in an increase or decrease in level of 1 dB in the right ear. The experimenter made sure that the participants found at least two reversals for each balanced loudness judgment to avoid bias. The average of the balanced levels of the "Up track" and the "Down track" was used as the final loudness balance estimate.

EEG measurements. Subsequently, the EEG was recorded while the participant sat in a comfortable chair and watched a silent but subtitled movie of their own choice. The movie was used to prevent the participant from falling asleep and to keep the attentional state constant across participants and measurement conditions. At least one break was given halfway through testing, and more breaks were given when desired. The left and the right ears were stimulated in alternation, for each condition. The interstimulus interval was at least 10 s.

Monaural stimuli with levels of 40, 50, 60, 70, and 80 dB SPL were used. In addition, for the participants who were tested for the 1000-Hz carrier frequency, stimulus levels of 45, 55, 65, and 75 dB SPL were used.

A second-order butterworth high-pass filter with a cutoff frequency of 2 Hz was applied to the recordings using MATLAB R2013a (The MathWorks, Inc., Natick, MA). Then, the recordings were divided into epochs of 1.024 s (300 epochs) and the epochs with the 5% highest peak-to-peak amplitudes were rejected. For EEG recordings, the target stimulus modulation frequency of 40 Hz was adjusted to 39.0625 Hz such that each epoch contained an integer number of periods. Recording electrode Cz was used as the reference electrode. The response amplitudes were determined after a fast Fourier transform and Hotelling t^2 test, with significance set at $\alpha = .05$. Standard deviations across trials were used to calculate the noise floor. Only significant responses were considered for further analysis.

To investigate hemispheric effects, three electrode selections were used (see Figure 1), based on Van Eeckhoutte et al. (2016). In that study, these active electrodes were selected because significant response amplitudes were found in 80% of cases. For responses from
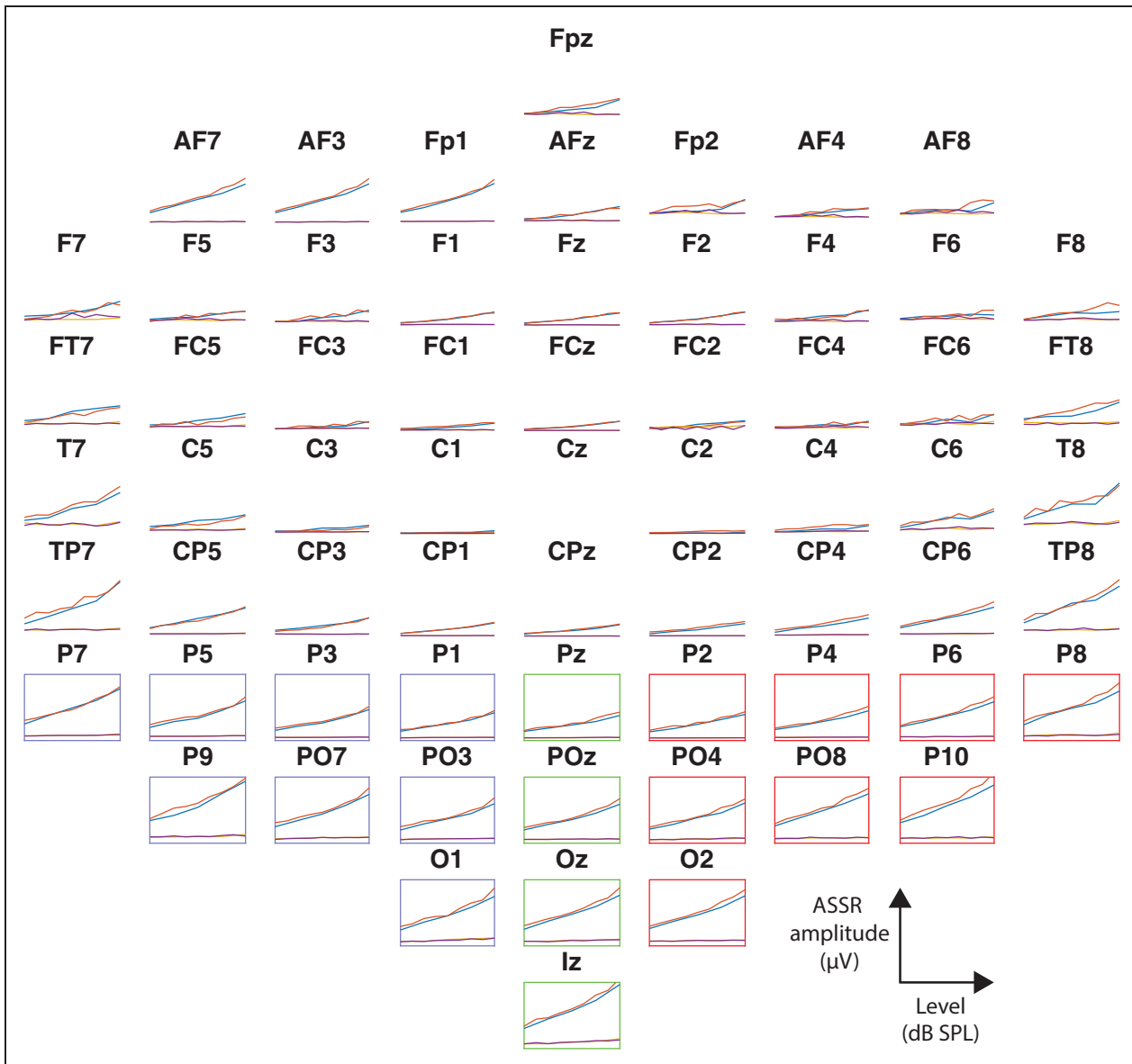
Figure 1. Electrode positions and corresponding ASSR amplitudes averaged across participants for 1000 Hz. Sixty-four Biosemi recording electrodes were mounted on the head. The left electrodes, blue in the colored version, were used for the analysis of responses for the left hemisphere, and the right electrodes, red in the colored version, were used for the analysis of responses for the right hemisphere. The midline electrodes, green in the colored version, were added to the blue and red electrodes for the analysis of "both hemispheres". Cz was always used as the reference electrode. Similar results were found for 500 and 2000 Hz.

both hemispheres, as well as midline electrodes, electrodes P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, PO7, PO8, PO3, PO4, O1, O2, Iz, Oz, POz, and Pz were used, hereafter referred to as electrode selection "both hemispheres." When investigating responses from the RH, electrodes P2, P4, P6, P8, P10, PO8, PO4, and O2 were used, and when investigating responses from the LH, electrodes P1, P3, P5, P7, P9, PO7, PO3, and O1 were used. An average of the amplitudes of the selection was used as the ASSR amplitude for further investigation. An additional investigation included only the

mastoid electrodes P9 and P10, which are frequently used in clinical practice.

Data analysis. The ASSR amplitudes as a function of level were fitted using a second-order polynomial, and this fitted function was used in all further analyses, using R version 3.3.1 (2016, R Core Team).

First, to rule out any behavioral errors and assuming that the NH participants had purely symmetric hearing across the ears, the ratio was calculated between the ASSR amplitudes for the right and left ear (for a

rationale for this see Mckay, 2012), for corresponding stimulation levels, as we hypothesized finding equal ASSR amplitudes at balanced loudness. A ratio of 1 would indicate the same ASSR amplitude at the right and left ears.

Next, the balanced levels were predicted based on the ASSR amplitude evoked by left ear stimulation with a fixed level, as shown in Figure 2 for participant NH11. The difference was calculated between the *reference level* of the left ear, for example, 60 dB, and the level leading to the right ASSR amplitude with the same magnitude as the left ASSR amplitude at this reference level, for example, 62.8 dB, giving a difference of −2.8 dB. We will refer to these levels as the *ASSR-predicted balanced levels*.

Furthermore, we also calculated the difference between the balanced level in the right ear found using *behavioral loudness balancing* (e.g., 64.5 dB in the example of Figure 2) and the balanced level in the right ear predicted from the left ASSR amplitudes, as described earlier (e.g., 62.8 dB), leading to a difference of 1.7 dB.

Hemispheric asymmetries were quantified using the laterality index, defined as the difference in amplitude of the RH and the LH, normalized by the sum of the amplitudes of the two hemispheres:

$$\text{Laterality Index} = \frac{\text{RH} - \text{LH}}{\text{RH} + \text{LH}} \tag{1}$$

A laterality index of +1 indicates a totally asymmetrical response toward the RH, 0 indicates a perfect symmetrical response, and −1 indicates a totally asymmetrical response toward the LH.
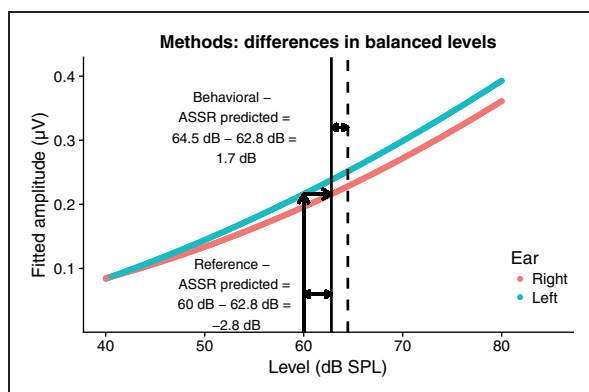
For statistical testing, Wilcoxon rank-sum tests were used to investigate whether the ratios in ASSR amplitudes were significantly different from a ratio of 1, and whether the differences between the predicted and actual loudness balanced levels, and the values of the laterality index were significantly different from zero. Moreover, linear mixed-effects models were used with the random factor *Participant* and fixed effects of *Ear of stimulation* or *Hemisphere* (depending on research question) and *(Reference) level* set as repeated measures, with $\alpha = .05$.

Results

Behavioral Loudness Balancing

Figure 3 shows the levels at the right ear that were judged to be loudness balanced to the reference levels at the left ear across all participants. Interquartile ranges were between 3 and 6 dB. Most differences between the balanced levels found with the "Up track" and the "Down track" were less than 5 dB (84% of all values, across participants, carrier frequencies, and levels). Table 1 presents the minimum, maximum, and median loudness balanced values for each condition.

ASSR Amplitude Growth Functions

Figure 4 shows the ASSR amplitude growth functions for the right and left ears of the participants who were tested using the 1000-Hz carrier frequency and for the electrode selection "both hemispheres," For most participants, the ASSR amplitude growth functions for the right and left ears were similar, but discrepancies occurred for participants NH1, NH7, NH13, and NH18. Similar results were obtained for the 500-Hz and 2000-Hz carrier frequencies as well as for the RH and LH electrode selections.

Across-Ear Ratios in ASSR Amplitude

The across-ear ratios in ASSR amplitudes are shown in Figure 5 for all participants. Across all stimulus levels, carrier frequencies, and electrode selections, the median right–left ear ASSR amplitude ratio was close to 1. However, clear deviations were observed.

Wilcoxon rank-sum tests indicated that the ratios for each combination of carrier frequency, electrode selection, and level were all not significantly different from 1 (p values > .05, after Holm correction), with the exception of the 1000-Hz condition at 40 dB SPL.

An additional analysis using only the mastoid recording electrodes P9 and P10 showed a tendency across all levels and carrier frequencies of larger ASSR amplitudes with right ear stimulation, especially for P10 (RH). However, statistical analysis showed no significant
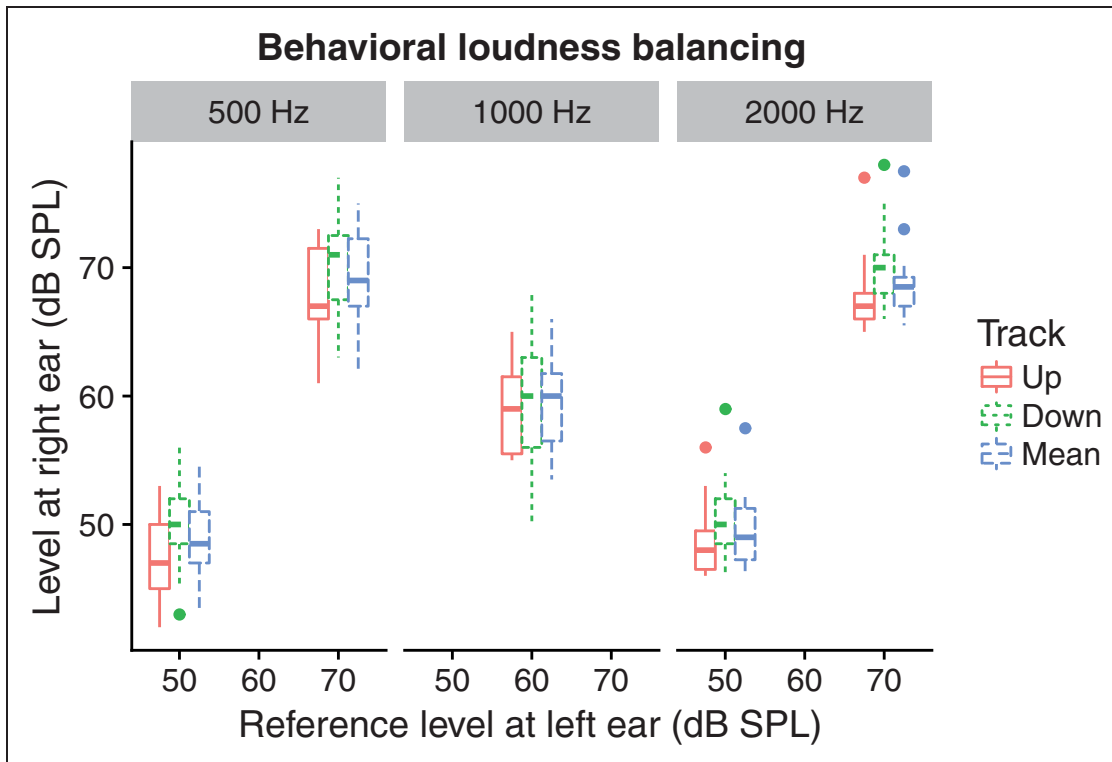
Figure 2. Example of the method to calculate the differences in balanced levels for participant NH11, who was tested using the 1000-Hz carrier frequency with a reference level of 60 dB SPL in the left ear. The balanced level in the right ear, predicted from the ASSR amplitudes, was 62.8 dB (continuous vertical line). The balanced level in the right ear as measured using behavioral loudness balancing was 64.5 dB (dashed line).

Figure 3. The results of the behavioral loudness balancing for all participants, for each reference level, and carrier frequency.

Table 1. Minimum, Maximum, and Median Loudness Balanced Values for Each Behavioral Condition.

Condition	Minimum (dB SPL)	Maximum (dB SPL)	Median (dB SPL)
500 Hz, 50 dB	43.5	54.5	48.5
500 Hz. 70 dB	62	75	69
1000 Hz, 60 dB	53.5	66	60
2000 Hz, 50 dB	46	57.5	49
2000 Hz, 70 dB	65.5	77.5	68.5

differences from a ratio of 1 across all conditions for 500 and 2000 Hz, while for 1000 Hz, significant differences from 1 were found for 40 dB and 80 dB using P10 and for 50 dB using P9 (which is at the LH). Thus, including the other electrodes from our selection leads to reduced hemispheric effects.

ASSR-Predicted Balanced Levels

The differences between the reference levels and the loudness balanced levels predicted from the ASSR amplitudes (the ASSR-predicted balanced levels) are shown in the top panel of Figure 6. The median differences were close to 0 dB. They were smaller than 5 dB for 54% of the data

points, and smaller than 10 dB for 87% of the data points, for all carrier frequencies, reference levels, and electrode selections. The outliers in the figure at a certain carrier frequency and level are from the same participant (e.g., the outliers seen for the right, left, and both hemispheres electrode selections at 70 dB SPL). For all conditions, Wilcoxon signed-rank tests indicated that the median differences were not significantly different from zero (all *p* values > .05).

Differences between the behaviorally found balanced levels and the ASSR-predicted balanced levels are shown in the bottom panel of Figure 6. These differences were again close to 0 dB and were smaller than 5 dB for 59% of cases and smaller than 10 dB for 85% of cases. Again, none of the Wilcoxon signed-rank tests were significant (all *p* values > .05).

Hemispheric Lateralization

Laterality index values are shown in Figure 7. The median values were always close to 0. Using linear mixed-effects models for each carrier frequency, the effect of ear of stimulation was never significant. A main effect of level was found only for 2000 Hz. Post hoc Wilcoxon rank-sum tests with Holm corrections indicated a significant asymmetry toward the RH at 40, 50, and 60 dB SPL, with median laterality index values of 0.06, 0.06, and 0.04, respectively.
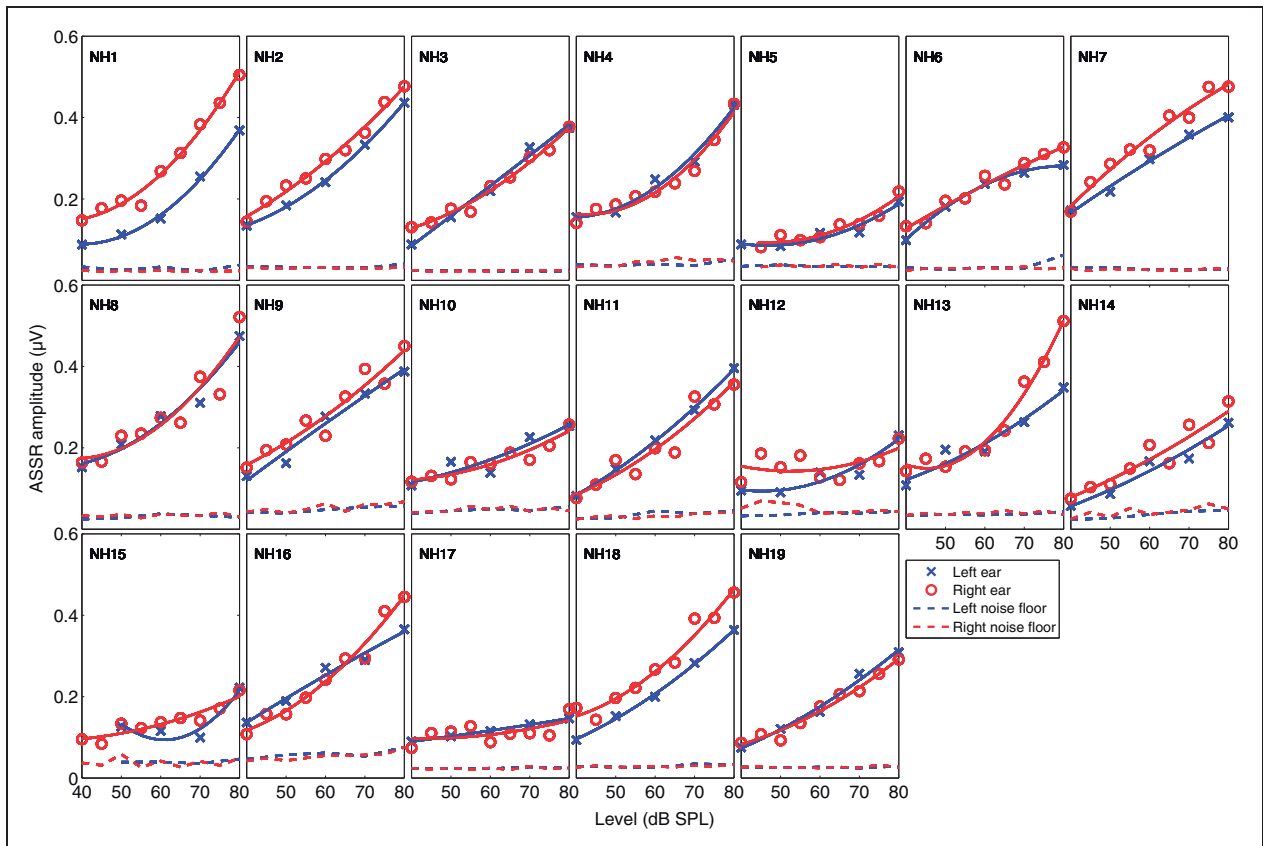
Figure 4. ASSR amplitude growth functions for right and left ear stimulation for participants tested using the 1000-Hz carrier frequency. The data were fitted using a second-order polynomial. The results are for the electrode selection "both hemispheres."
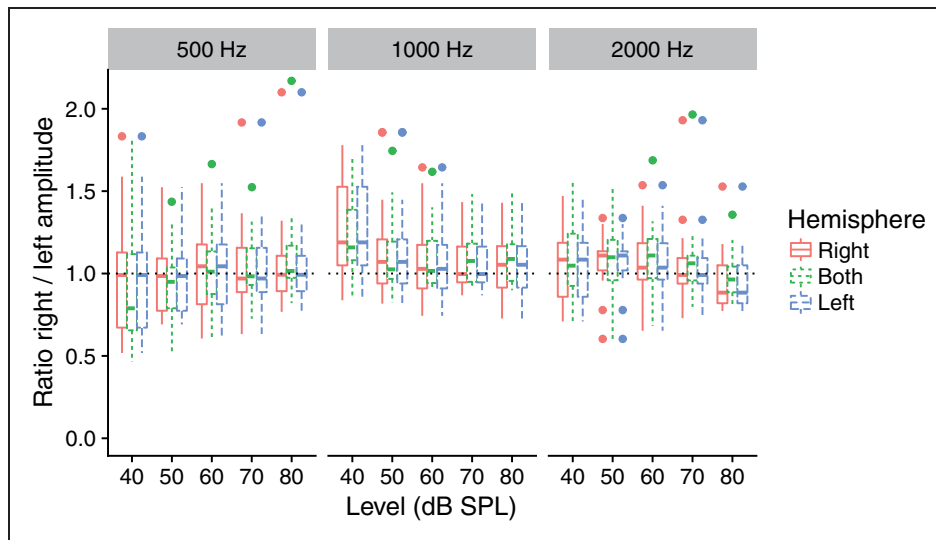

Figure 5. The ratios between the amplitudes of responses to the right and left ear signals, for each carrier frequency, electrode selection, level, and for all participants. A ratio of 1 indicates equal amplitudes for the right and left ears.
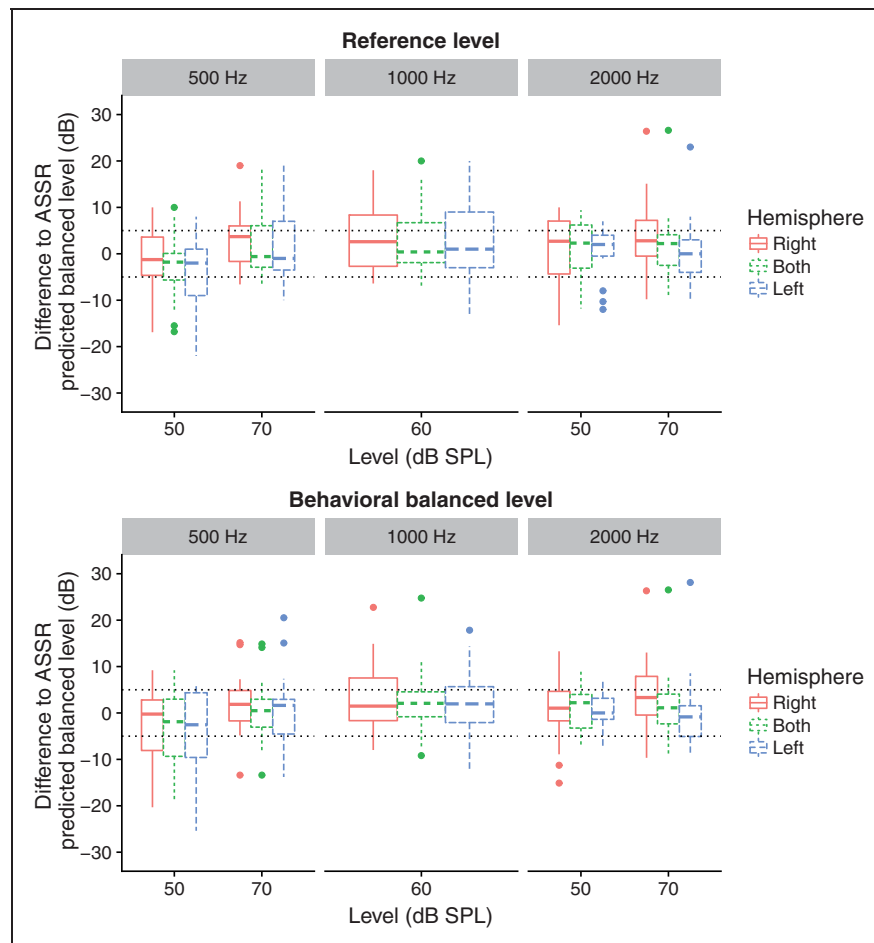
Figure 6. Top: The differences between the left ear reference level and the matching right ear level predicted from the ASSR amplitude, for each carrier frequency, electrode selection, level, and for all participants. Bottom: The differences between the right ear level that was behaviorally loudness balanced with the reference level, and the matching right ear level predicted from the ASSR amplitudes, for each carrier frequency, electrode selection, level, and for all participants.

Wilcoxon rank-sum tests did not indicate a significant difference from a laterality index of 0 at 70 and 80 dB SPL.

Discussion

ASSRs were evoked by stimuli presented to the left and right ears with different levels and carrier frequencies. Responses using different electrode selections were employed to investigate hemispheric lateralization. Behavioral loudness balancing was done for at least one fixed level in the left ear. Although other studies were interested in maturational or developmental differences (e.g., Poelmans, Luts, Vandermosten, Ghesquière, & Wouters, 2012; Vanvooren, Hofmann, Poelmans, Ghesquière, & Wouters, 2015), in this study, typical patterns were investigated for a population of young, NH individuals to assess the feasibility of using 40-Hz ASSR amplitudes for binaural loudness balancing.

As expected, ASSR amplitude growth functions were participant dependent, but within a given participant and for each carrier frequency, they were usually similar for the left and right ears, or when analyzed using electrode selections over the right and/or left hemispheres. The median ratios between ASSR amplitudes for the right and the left ears were close to 1. When comparing the reference levels and ASSR-predicted balanced levels, or when comparing the behaviorally found loudness balance levels and the ASSR-predicted balanced levels, in most cases (59%), the differences were less than 5 dB. This is a reasonable error, given that a 5 dB error is often accepted in audiology, such as for pure-tone audiometry using the Hughson–Westlake procedure. However, in 15% of cases, the error was greater than 10 dB. It should be noted that the error for the behavioral task could also go up to 10 dB (see Figure 1). When calculating the differences between the ASSR-predicted balanced levels and the behaviorally found balanced levels, large errors can also occur because of the
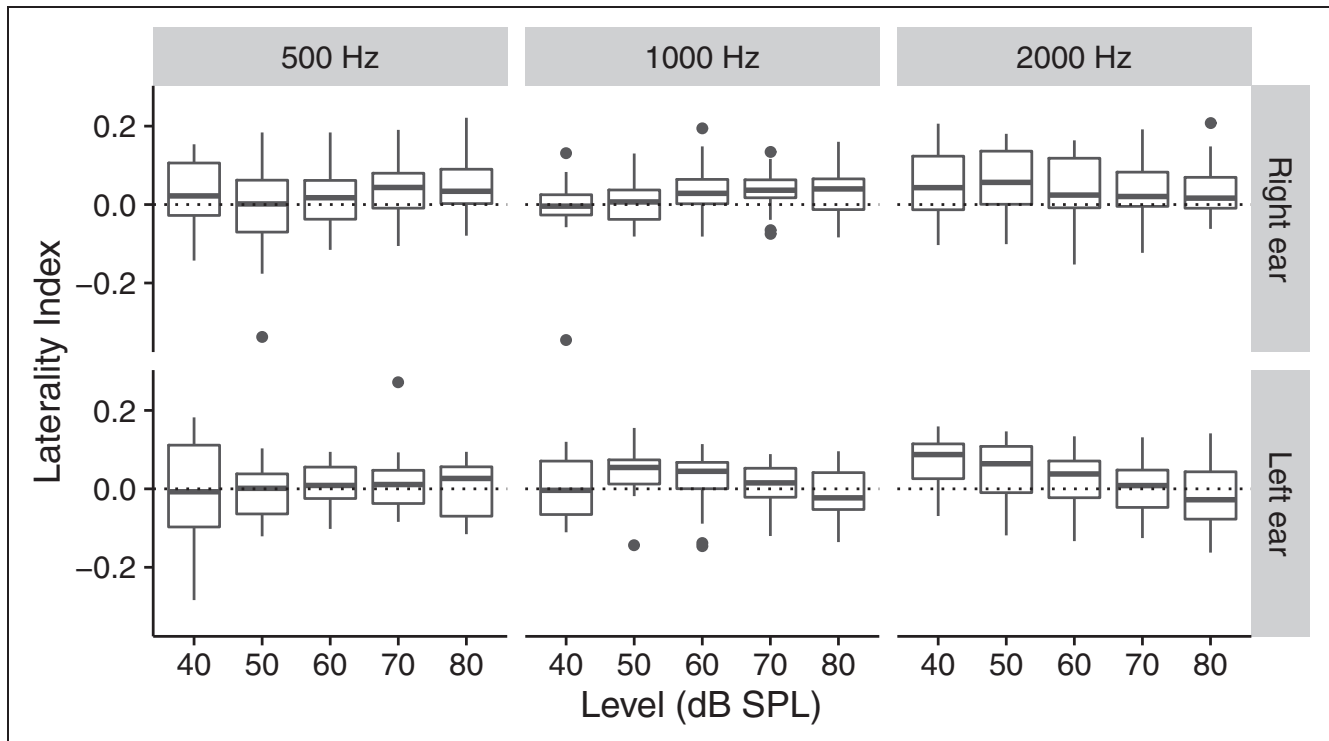
Figure 7. Laterality index values for each carrier frequency and level.

measurement errors for both tasks. For this study, ASSR measurements took around 5 min for each condition. If ASSR-predicted balanced levels would be used for clinical practice, only a few conditions could be tested or the ASSR test could be stopped once significance is reached.

Hemispheric Lateralization and Ear Advantage

Previous data on hemispheric lateralization of the 40-Hz ASSR reported either no hemispheric dominance (Gransier et al., 2017) or a slight dominance of the RH (Goossens et al., 2016; Ross et al., 2005; Yamasaki et al., 2005). Similar results were found in this study for multiple levels and carrier frequencies. There was a significant effect of level at 2000 Hz on the laterality index. For low levels (40, 50, and 60 dB SPL), the ASSR amplitude was larger for the RH than for the LH. However, median laterality indices were still close to 0 (0.06, 0.06, and 0.04, respectively).

Vanvooren et al. (2015) and Poelmans et al. (2012) found a gradual change from ipsilateral to right lateralization for ASSRs evoked by stimuli with modulation frequencies of 80, 20, and 4 Hz, and this tested with left and right monaural as well as bilateral stimulation in Poelmans et al. (2012). An ipsilateral response to 90 and 94 Hz ASSRs was also found by Van Der Reijden, Mens, and Snik (2005).

No clear effects of ear were found by Picton, Dimitrijevic, Perez-Abalo, and Van Roon (2005);

Picton, van Roon, & John (2007); and Picton, van Roon, & John (2009) using a vertex-neck electrode configuration for single and multiple 80 to 100 Hz ASSRs. Only small differences were described due to the differences in relative modulation frequencies or due to overall intersubject variance. Similar right- and left-ear 40-Hz ASSRs were found by De Vos, Vanvooren, Vanderauwera, Ghesquière, and Wouters (2017) using an electrode selection from both hemispheres and amplitude-modulated speech weighted noise at 70 dB SPL. However, Tiihonen, Hari, Kaukoranta, and Kajola (1989) found larger contralateral than ipsilateral steady-state magnetic fields over the RH using trains of 40-Hz click stimuli presented at 80 dB SPL. In this study, we did not find any clear effects of ear for 40-Hz single ASSR amplitudes, for participants who were mostly right handed (29/38) and had a right-ear preference (26/38), when using the electrodes indicated in Figure 1.

The differences in results across studies could be related to the different recording techniques, electrode selections, and stimulus parameters. For example, different brain sources are associated with different modulation frequencies, with clearly cortical sources for 4 and 20 Hz, and brainstem sources for 80-Hz modulation frequencies, while the 40-Hz ASSR has both cortical and subcortical sources (e.g., Herdman et al., 2002; Luke, De Vos, & Wouters, 2017; Rance, 2008; Reyes et al., 2005; Steinmann & Gutschalk, 2011).

In summary, we conclude that if there is any hemispheric asymmetry, it is small. The 40-Hz ASSR amplitudes may be slightly larger for the RH than for the LH, especially for low stimulation levels.

Conclusions

Median across-ear ratios in 40-Hz ASSR amplitudes were around 1 for a group of young, NH participants, but individual variability was also observed. The 40-Hz ASSR amplitudes could predict behaviorally found balanced levels within an error of 5 dB in 59% of cases and within an error of 10 dB in 85% of cases. No clear hemispheric lateralization was found for the 40-Hz ASSR amplitude, with the exception of a right-hemispheric lateralization for 40 to 60 dB SPL stimuli at 2000 Hz.

Note

1. The questionnaire was slightly adjusted to modern times. Instead of using Question 14 "Into which ear would you place the earphone of a transistor radio?" we used "In which ear would you place a phone if you want to answer a phone call?"

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