Speech auditory brainstem response audiometry in adults with sensorineural hearing loss

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Received 21 December 2015; accepted 2 April 2016
Available online 17 June 2016

KEYWORDS
Speech auditory brainstem response (S-ABR); Sensorineural hearing loss (SNHL); Speech processing

Abstract Background: Listeners with sensorineural hearing loss (SNHL) have a reduced ability to use temporal fine structure cues due to broadening of the tuning curves. Auditory evoked potentials (AEPs) can be used to assess the functional consequences of auditory deprivation. Objectives: This work aimed to study the effect of mild to moderate SNHL on speech processing at brainstem levels. Subjects and method: This study included two groups: control group (GI) which consisted of 20 subjects with normal peripheral hearing adults and study group (GII) consisted of 40 patients with mild to moderate SNHL. Speech auditory brainstem response (S-ABR) was recorded in both groups using two speech stimuli: /da/ and /ba/. Results: In both groups, S-ABR in response to /ba/ showed statistically significant delayed latencies compared to /da/. On the other hand, there was no statistically significant difference as regards amplitudes between /da/ and /ba/ stimuli in both groups. Comparing both groups, there were statistically significant differences in the S-ABR onset latencies but not in FFR latencies for both stimuli in the SNHL group compared to the control group, while there was no statistically significant difference in amplitudes. Conclusion: SNHL affects speech processing at the level of brainstem.

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1. Introduction

Speech sounds are complex sounds with rich harmonic structures, dynamic amplitude modulations and rapid spectro-temporal fluctuations. This complexity is represented by an exceptionally precise temporal and spectral neural code within the auditory brainstem. It provides an ensemble of nuclei belonging to the efferent and afferent auditory systems.

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Peer review under responsibility of Egyptian Society of Ear, Nose, Throat and Allied Sciences.

Complex sounds, including voiced speech, consisting of many harmonics, are heard with a strong pitch at the fundamental frequency, even if energy is physically lacking at that frequency. The physiologic representation of the acoustic features of speech in the human brain depends on the periodicity, formant structure, frequency transitions, acoustic onsets and speech envelope. The articulation of a consonant or vowel produces multiple acoustic events or cues. These cues can be quite robust in guiding recognition (Primary cues) while others (Secondary cues); will be effective only when primary cues are altered. This is especially important for patients suffering from a considerable degree of hearing loss.
Hearing impaired individuals have compromised sound transduction, which in turn, will impair their hearing and speech comprehension. Speech comprehension is dependent on several factors including the acoustical characteristics of the words as well as suprasegmental features. Speech intelligibility relies on consonant sounds, which have a sound spectrum with frequencies above 2 kHz.10 Because consonants are sounds of lower intensity than vowels, they become more difficult to be detected, especially by individuals with high frequency sensorineural hearing loss.9

Auditory evoked potentials (AEPs) offer the opportunity to objectively examine neural timing and representation of important speech cues at subcortical and cortical levels of the auditory pathway.9 Speech evoked auditory brainstem response (S-ABR) appears to be a very promising technique for investigating the brainstem temporal encoding of speech. In recent studies, S-ABR has brought further insights in temporal encoding of amplitude modulations,10 speech,11,12 tonal language processing skills13,14 and to temporal acuity.10,15

S-ABR is composed of seven waves named (V, A, C, D, E, F and O). Waves V, A, C and O represent the transient component of the response with V, A and probably C called the onset component, whereas, wave O is called the offset component.11,16 The sustained component of S-ABR is called the frequency following response (FFR) which reflects phase locking to the fundamental frequency of the stimulus. It arises in response to the periodic information present in the vowel at the frequency of the sound source (i.e. the glottal pulse). Thus peaks D, E, and F of the FFR correspond to the fundamental frequency of the stimulus (F0), whereas the peaks between waves D, E, and F represent phase locking to the frequencies of the first formant (F1).16

2. Aims of the work

This work was designed to study speech processing at the brainstem level in healthy subjects and in patients with sensorineural hearing loss using ABR in response to speech stimuli.

3. Materials and methods

This study included 60 subjects with age range of 18–50 years. They were chosen from patients, volunteers from patients’ relatives or subjects coming for pre-employment evaluation at Audiology Unit, Tanta University Hospitals. Consents were taken from each subject in this study. The local ethics committee approved this study on 13/3/2012 with the approval code (948/01/12).

Subjects of this work were divided into two groups:

(1) Control group: It consisted of 20 subjects with bilateral normal peripheral hearing (hearing threshold level does not exceed 25 dB at any frequency of the range of 250–8000 Hz) and with no systemic diseases (e.g. any endocrinial, vascular, renal or neurological). Exclusion criteria were: subjects with any hearing complaints or history of otological diseases, general health problems (e.g. any endocrinial, vascular, renal or neurological complaints).

(2) Study group: It consisted of 40 subjects with bilateral symmetrical almost flat mild to moderate sensorineural hearing loss (hearing threshold does not exceed 60 dB even at single frequency in the frequency range of 250–8000 Hz). They had no systemic diseases or complaints (e.g. any endocrinial, vascular, renal or neurological). Exclusion criteria include cases with unilateral or asymmetrical hearing loss, conductive or mixed hearing loss, middle ear pathologies, or suspected cases with retrocochlear lesions.

All cases included in this study were subjected to: full audiological history, otological examination, basic audiological evaluation including: pure tone audiometry, speech audiometry (including both Speech Recognition Threshold (SRT) using Arabic spondee words18 and Word discrimination % (WD) tests) using Arabic phonetically balanced words19 and immittance (including Tympanometry, ipsilateral and contralateral acoustic reflex).

Auditory brainstem response (ABR) was recorded using two types of stimuli, click for click evoked-ABR (ABR) (to confirm presence of wave V) and speech for speech evoked ABR (S-ABR). For S-ABR, two types of speech stimuli were used: CV syllables /da/ of 206 ms duration and /ba/ of 114 ms duration. They were pronounced by a native Arabic male speaker, recorded and sent to Intelligent Hearing System Company (IHS) to be digitized and calibrated before using them. The two types of speech stimuli differ from each other at the place of articulation. Hence, they differ in the spectral information (spectra of the release bursts and the onsets and shapes of the formant transitions). They were characterized by energy at 3–4 kHz and the bilabials energy (/b/) is near 1 kHz.30 So, we expected them to give different responses.

Stimuli were presented at 50 dB SL or their most comfortable level (MCL), at repetition rate (RR) of 19.3/s click-ABR and 11.1/s for S-ABR using alternating polarity through monaural presentation via an ER3A insert-phone. Four disposable electrodes were fixed according to the Smart-EP manual specification as the following: one high frontal Fz (positive electrode), one low frontal Fpz (ground electrode). The last two electrodes were placed on the left and right mastoids (as negative electrode or reference electrode) depending on the recording side. Sweep number was 1024 sweeps and the analysis epoch (time window) was 0–12 ms for click-ABR and 0–75 ms for S-ABR with 150 Hz to 1500 Hz filtering.

3.1 Response analysis of S-ABR

For S-ABR, the response was identified by the presence of seven waves (V, A, C, D, E, F, G) using nomenclature previously established for the S-ABR.23,24 Beside the calculation of the absolute latency and amplitude of each wave, the measurement of VA amplitude, duration, area and slope was done according to Wible et al.11 Peak-to-trough slope was defined as peak-to-trough amplitude divided by peak-to-trough duration, while area was defined as peak-to-trough amplitude multiplied by peak-to-trough duration. Three blocks of 1024 artifact free sweeps were collected for each ear. The formerly mentioned calculations were done for both /da/ and /ba/ stimuli. Russo et al.23 had interpreted area measurements as the amount of...
activity that contributed to the wave generation while the slope was interpreted as the temporal synchronization of the response generators.

4. Statistical analysis

The collected data were organized, tabulated and statistically analyzed using SPSS software statistical computer package version 16. For qualitative data, comparison between two groups and more was done using Chi-square test ($X^2$). For comparison between means of two groups, parametric analysis ($t$-test) and non-parametric analysis ($Z$ value of Mann-Whitney $U$ test) were used. Significance was adopted at $P < 0.05$ for interpretation of results of tests of significance.

5. Results

This work included two groups: the control group (GI) consisted of 20 subject (2 males and 18 females). Their ages ranged from 19 to 50 years. Mean and standard deviation (SD) of pure tone thresholds were 10.56 ± 2.01 dB in the right ear and 10.44 ± 2.64 dB in the left ear. Word discrimination scores were 100 ± 0.00% for both right and left ears and 10.44 ± 2.64 dB in the left ear. Word discrimination scores were 95.8 ± 6.01% in the right ear and 96.41 ± 5.33% in the left ear. Acoustic reflex thresholds were within the expected values as regards hearing thresholds.

As regards the study group (GII), it consisted of 40 cases (19 males and 21 females) with the same age range as the control group. All cases had bilateral mild to moderate SNHL (27 subjects with mild SNHL and 13 subjects with Moderate SNHL). The duration of hearing loss ranged from one up to fifteen years. Mean and SD of pure tone thresholds were 39.71 ± 13.54 dB in the right ear and 40.11 ± 14.81 dB in the left ear. Word discrimination scores were 95.8 ± 6.01% in the right ear and 96.41 ± 5.33% in the left ear. Acoustic reflex thresholds were within the expected values as regards hearing thresholds.

The response was composed of onset response (waves V and A), frequency following response (FFR) (C, D, E, F) and offset response, (G). In this study, as we used long duration /da/ stimulus of 206 ms and /ba/ of 114 ms, we took only the part of the response that covered the consonant and the consonant vowel transition (60 ms) of the response.

5.1. In response to /da/

In the control group, all components of S-ABR waveform were detected in 100% of the cases except wave C which was detected in 90% in the left ear (18/20 ears). However, it was recorded in all right ears. There is no significant difference between right and left ears in this group as regards latency, amplitude, VA complex amplitude, duration, area and slope ($P > 0.05$) (Tables 1–3; Fig. 1).

In the SNHL group, all peaks of S-ABR were 100% detectable among all individuals in this group except wave C which was detected in 92.5% of the cases in right ears (37/40 ears) and 94.87% of the cases in left ears (37/39 ears). There was no significant difference between right and left ears in this group at all peak latencies. As regards peak amplitudes, there was also no significant difference between right and left ears except for wave A amplitude which was significantly smaller in left ears ($P = 0.032$). As regards VA complex amplitude, duration, area and slope, there is no significant difference between right and left ears (Tables 1–3; Fig. 2).

The comparison between the control and study groups showed significant delayed wave V latencies in the SNHL group (GII) in both right and left ears. Moreover, wave A and C latencies were delayed in group II in both ears, however, this delay was significant only in left ears. Moreover, the offset response (G) also showed no significant difference between right and left ears. As regards S-ABR amplitudes, VA complex amplitude, duration, area and slope, there is no statistically significant difference between both groups in either right or left ears ($P > 0.05$) (Tables 1–3 and Fig. 3).

5.2. In response to /ba/

In the control group, all components of S-ABR waveform were detected in all cases except wave C which was detected...
in 19/20 in both right and left ears (95% detectability). There was no significant difference between right and left ear latencies or amplitude of different components of S-ABR in the control group. As regards VA complex amplitude, duration, area and slope, there was no statistically significant difference between both ears ($P > 0.05$) (Tables 4–6; Fig. 1).

In the SNHL group, onset and F waves were detectable in all individuals in this group. The rest of FFR waves varied in their percentage of detectability. Wave C has the least detectability in 32/40 of right ears (80%) and 31/39 of left ears (79.5%). There was no significant difference between right and left ears as regards latencies or amplitude of different components of S-ABR as well as VA complex amplitude, duration, area and slope (Tables 4–6; Fig. 2).

The comparison between the control and SNHL groups showed statistically significant delayed wave V latency in both right and left ears in the SNHL group. Moreover, waves A and wave F latencies were significantly delayed in the left ear of the SNHL group when compared to the control group. The offset response (G) also showed no significant difference between right and left ears. As regards S-ABR amplitudes, VA complex amplitude, duration, area and slope; there was no statistically significant difference between both groups in either right or left ears ($P > 0.05$) (Tables 4–6; Fig. 3).

5.3. S-ABR in response to /da/ versus /ba/

In both groups, the latencies of all components of S-ABR were significantly longer on using /ba/ stimulus than for /da/ in all ears ($P > 0.05$). However, there was no significant difference as regards amplitudes of S-ABR between both stimuli in right and left ears ($P > 0.05$) (Tables 7 and 8; Figs. 2 and 3).

6. Discussion

Hearing impaired individuals presumably process complex signals (i.e., like speech) in a different manner from those with normal hearing. Processing deficits are likely present due to abnormal representation of complex speech signals at the cochlea, the eighth nerve, the brainstem, and/or the auditory cortex. Hearing loss causes changes in the auditory nervous system depending on its degree as well as its duration.

The complex spectro-temporal structure of speech signal requires a synchronized neural response for accurate encoding. Evoked responses depend on this synchronous activation and are ideal for studying the neural basis of speech perception. Speech-ABR (S-ABR) appears to be a very promising audiological technique to investigate the brainstem temporal encoding of speech. The present study was designed to evaluate the speech evoked potentials in adults with mild to moderate SNHL in order to identify speech processing deficits in such individuals.
In this study we keep the results of right and left ears separate as we decided to study the possibility of the presence of right ear advantage (REA) to some degree in speech processing. Latencies of different components of S-ABR showed no significant differences between the right and left ears for both types of stimuli (/da/ and /ba/). Comparing both groups also showed no significant difference. As regards amplitude, there was no significant difference between the right and left ears for both /da/ and /ba/ among and across the study groups except for amplitude of wave A of S-ABR which was smaller in the left ear compared to the right ear in the SNHL group in response to /da/ stimulus.

Our results agreed with the results of Vander Werff and Burns who did not find a REA in their work. However, Sinha and Basavaraj reported a REA that appeared in the form of earlier latencies or larger amplitudes of FFR in the right ear relative to left ear. Moreover, Hornickel et al. reported that the REA was manifested in the form of increased amplitude of the frequency encoding in the frequency ranges corresponding to the 1st formant but not the fundamental frequency in the right ear. Both studies suggested that left lateralization of acoustic element processing, which was important for discriminating speech, extended to the auditory brainstem.

6.1. In response to /da/

In the control group wave C for /da/ stimulus was the least detectable (90% of left ears). This agreed with the results of Vander-Werff and Burns. In the SNHL group, wave C was also the least detectable for /da/ where it was detected in 92.5% of right ears and in 94.87% of left ears. The morphology of S-ABR waveform was distorted in the SNHL subjects compared to the control group and this might be a result of impaired speech processing in patients with SNHL.

The /da/ stimulus used in this work was of relatively of long duration (206 ms) which might be similar to 170 ms duration /da/ stimulus used in other studies. Using such long duration stimulus resulted in about 3 ms shift in the onset response of the S-ABR response compared to that evoked by the short duration used in other studies.
be explained by Song et al.33 who reported a time difference in wave V latency in response to click and speech stimuli. Those authors suggested that the delayed wave V latency in S-ABR might be related to the stimulus itself. They reported that vowel following the consonant is a sustained periodic signal and is much louder than the consonant. Thus, that higher amplitude and longer portion of the stimulus might actually mask the brief consonant onset critical for eliciting the onset portion of the speech-evoked ABR. If we take this into consideration, we supposed that the longer the duration of the stimulus, the more the backward masking effect of the vowel onto the consonant. Hence the delayed latency of the onset of the long duration /da/ compared to the short duration /da/.32

In the SNHL group, there was a delay in peak latencies compared to the control group which was significant only for wave V in both right and left ears as well as waves A and C for left ear only. However, peaks D, E, F and offset response were similar in both groups. These results agreed with those of Khaladkar et al.25, who reported a significant delay in response were similar in both groups. These results agreed with Lipson34 who did not find a statistically significant delay in the latencies of all peaks of S-ABR in SNHL group when compared to control group.

Comparison between the waves’ latencies of S-ABR in response to /da/ and /ba/ stimuli in the control group (GI) in both Rt and Lt ears.

<table>
<thead>
<tr>
<th>(S-ABR)</th>
<th>GI</th>
<th>GII</th>
<th>#Z-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave V</td>
<td>R</td>
<td>13.53 ± 1.69</td>
<td>14.78 ± 2.41</td>
<td>2.092</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>15.22 ± 1.72</td>
<td>14.81 ± 2.44</td>
<td>2.592</td>
</tr>
<tr>
<td>Wave A</td>
<td>R</td>
<td>16.47 ± 1.67</td>
<td>17.53 ± 2.45</td>
<td>1.745</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>15.80 ± 1.96</td>
<td>17.91 ± 2.86</td>
<td>2.954</td>
</tr>
<tr>
<td>Wave C</td>
<td>R</td>
<td>27.95 ± 2.11</td>
<td>28.22 ± 1.62</td>
<td>0.514</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>28.66 ± 2.43</td>
<td>28.75 ± 1.86</td>
<td>0.156</td>
</tr>
<tr>
<td>Wave D</td>
<td>R</td>
<td>34.48 ± 2.19</td>
<td>34.95 ± 2.02</td>
<td>0.823</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>34.66 ± 2.33</td>
<td>35.02 ± 1.80</td>
<td>0.650</td>
</tr>
<tr>
<td>Wave E</td>
<td>R</td>
<td>42.35 ± 2.27</td>
<td>42.88 ± 2.24</td>
<td>0.867</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>42.69 ± 2.43</td>
<td>43.00 ± 2.06</td>
<td>0.513</td>
</tr>
<tr>
<td>Wave F</td>
<td>R</td>
<td>50.52 ± 2.10</td>
<td>51.18 ± 2.07</td>
<td>1.164</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>50.59 ± 2.30</td>
<td>51.70 ± 1.79</td>
<td>2.047</td>
</tr>
<tr>
<td>Wave G</td>
<td>R</td>
<td>58.59 ± 1.64</td>
<td>58.99 ± 1.63</td>
<td>0.880</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>58.20 ± 1.88</td>
<td>59.02 ± 1.46</td>
<td>1.833</td>
</tr>
</tbody>
</table>

Bold indicated the significant difference between both groups.

Results of S-ABR amplitudes showed similar results to those reported by Vander-Werff et al.9, and Song et al.30 The comparison of the control and SNHL groups showed no significant difference between both groups. Our results also agreed with Lipson34 who did not find a statistically significant difference as regards amplitudes between both groups.
The latencies of S-ABR peaks in response to /ba/ were significantly delayed in comparison to /da/ in both control and SNHL groups. This could be explained by the difference in the acoustics of both stimuli. In general, /ba/ and /da/ differ acoustically in the second formant frequency transition (it is rising for /ba/ and falling for /da/) and, to a smaller extent, in the frequency content of the stop release burst where /da/ contains somewhat higher frequency content. Johnson et al. and Hornickel et al. stated that the higher the F2 and F3 frequencies, the earlier the response. Another explanation is the cross phaseogram proposed by Skoe et al. Explanation is the cross phaseogram proposed by Skoe et al. The authors declared that there are no financial or other conflicts of interest that might bias their work.

### Table 8 Comparison between the waves’ latencies of S-ABR in response to /da/ and /ba/ stimuli in the studied cases (GII) in right and left ears.

<table>
<thead>
<tr>
<th>Wave</th>
<th>/da/</th>
<th>/ba/</th>
<th>t-test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>11.65 ± 2.27</td>
<td>14.78 ± 2.41</td>
<td>5.995</td>
<td>0.0001*</td>
</tr>
<tr>
<td>A</td>
<td>14.17 ± 2.30</td>
<td>17.53 ± 2.45</td>
<td>6.320</td>
<td>0.0001*</td>
</tr>
<tr>
<td>C</td>
<td>21.44 ± 1.96</td>
<td>28.22 ± 1.62</td>
<td>15.493</td>
<td>0.0001*</td>
</tr>
<tr>
<td>D</td>
<td>28.31 ± 1.89</td>
<td>34.95 ± 2.02</td>
<td>15.085</td>
<td>0.0001*</td>
</tr>
<tr>
<td>E</td>
<td>37.42 ± 1.72</td>
<td>42.88 ± 2.24</td>
<td>12.204</td>
<td>0.0001*</td>
</tr>
<tr>
<td>F</td>
<td>45.85 ± 1.84</td>
<td>51.18 ± 2.07</td>
<td>12.171</td>
<td>0.0001*</td>
</tr>
<tr>
<td>G</td>
<td>54.90 ± 2.17</td>
<td>58.99 ± 1.63</td>
<td>9.456</td>
<td>0.0001*</td>
</tr>
</tbody>
</table>

Bold indicated the significant difference between both groups.

Additionally, there was no statistically significant difference between the two groups as regards slope and area.

### 6.2 In response to /ba/

All components of S-ABR were 100% detectable in all normal individuals except wave C which was absent in one case only (detected in 19 out of 20) in both right and left ears. In the SNHL group, S-ABR morphology was distorted where wave C was detected in 32/40 in right ears (80%) and in 31/39 left ears (79.5%). We postulated that distortion in wave-form is mainly due to the affection of speech processing in patients with SNHL.

Up to our knowledge, only few studies had used /ba/ to evoke S-ABR. Example of these studies include Akhoun et al. and Johnson et al. As regards comparison between both groups: there was a significant delay in the SNHL compared to control group as regards wave V in both right and left ears as well as wave A in left ears. These results are similar to those of /da/ stimulus. However, in FFR, there was no significant difference between the studied groups except for F in the left ear which showed a statistically significant delay in the SNHL group compared to control. Meanwhile, S-ABR amplitude, slope and area were similar in both groups.

This work showed that S-ABR latencies are more sensitive to mild to moderate SNHL than amplitudes. This finding was pronounced in the onset response rather than the FFR. This indicated that the problem among the subjects with mild to moderate hearing loss was the impaired synchronization to the onset while, phase locking to the fundamental frequency and its harmonics was not affected.

### 6.3 Comparison between S-ABR in response to /da/ and /ba/

The morphology of S-ABR in response to /ba/ was more distorted than to /da/ with less detectability of waves in the SNHL group, however, we could not owe the reduced detectability of waves in response to /ba/ compared to /da/ to the sensitivity of the first to the SNHL due to relatively small sample size.

Speech ABR is acoustically similar to the stimulus and it provides a unique chance to evaluate the strength of subcortical processing of speech sounds. The onset response represents the neural conduction time required for speech processing and its delay indicates temporal processing deficits in patients with hearing loss. This work showed that onset response of S-ABR is more vulnerable than FFR or offset response. This indicated that the temporal discharge of auditory neurons in the upper midbrain (FFR) or the end of stimulus processing (offset response) are not affected with hearing loss.

In conclusion, S-ABR is affected with hearing loss which affects the latencies but not the amplitudes. This indicated that the synchronization to the response was early affected than the discharge rate. The onset response of S-ABR was more affected than the FFR. This indicated that the problem among the subjects with hearing loss was the less synchronization to the onset while, phase locking to the fundamental frequency and its harmonics was not affected. Finally, we concluded that speech processing was affected in individuals with mild to moderate SNHL at the level of brainstem.

Future studies should be done with large number of subjects with more severe degrees and different configurations of hearing loss and different duration of hearing loss in order to study the effect of SNHL on speech processing at the level of brainstem and auditory cortex.

### Declaration of interest

The authors declare that there are no financial or other conflicts of interest that might bias their work.
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