Medical Hypotheses 132 (2019) 109355

Contents lists available at ScienceDirect

Medical Hypotheses

journal homepage: www.elsevier.com/locate/mehy

Speech-ABR in contralateral noise: A potential tool to evaluate rostral part of the auditory efferent system

Yones Lotfi[a], Abdollah Moossavi[b], Mohanna Javanbakht[a,*,1], Soghrat Faghih Zadeh[c]

[a] Department of Audiology, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran
[b] Department of Otolaryngology, School of Medicine, Iran University of Medical Sciences, Tehran, Iran
[c] Department of Biostatistics and Epidemiology, Zanjan University of Medical Science, Zanjan, Iran

A R T I C L E I N F O

Keywords:
Speech evoked auditory brainstem response
Auditory efferent system
Speech in noise
Dichotic
Lateralization

A B S T R A C T

In parallel with the auditory *afferent* system, the auditory *efferent* system is active in all parts of the auditory pathways from auditory cortex to the cochlea. The auditory efferent system has two main segments: the rostral and the caudal parts. The rostral part, which starts from the cortical centers to thalamic nuclei and continues into collicular pathways in rostral brainstem, which sends its neural fibers to the main collicular nuclei especially inferior colliculus. The caudal part includes the olivocochlear bundle, which originates from the superior olivary complex and terminates on the cochlear hair cells. Most studies about the auditory efferent system have focused only on the caudal part using otoacoustic emission suppression test. Speech-evoked auditory brainstem response (S-ABR) as an electrophysiologic test that uses speech stimuli to simulate real-life auditory conditions, reflects the performance of rostral brainstem centers, so structurally seems to be an appropriate candidate to examine the rostral part of the auditory efferent system. Our hypothesis is that S-ABR in noisy condition, a typical condition for stimulating the auditory efferent system, has the potential to be used as an objective noninvasive electrophysiologic test for studying the rostral auditory efferent system in diagnosis and treatment/rehabilitation follow-ups. In addition, S-ABR can potentially reflect higher-order auditory functions and the effects of their dysfunctions on the lower brainstem. This characteristic makes S-ABR even more suitable tool for evaluation of the efferent system. To evaluate our hypothesis, Eighteen normal hearing subjects in the age range of 18–25 were tested in a pilot study for S-ABR in quiet mode and three signal to noise ratios of +10,0 and −10 for both ears. Then we checked the correlation between the results of S-ABR in different conditions and scores of auditory behavioral tests that auditory efferent system is involved in them: Consonant-Vowel perception in noise, dichotic Consonant-Vowel-Consonant and sound lateralization in noise. The results of our pilot study showed a significant correlation between S-ABR changes in noise with the scores of the behavioral tests in noisy or dichotic situations. Findings of the current study suggest that S-ABR with specific contralateral noise can be an appropriate option for evaluating the performance of rostral part of the auditory efferent system and may be suitable for top-down auditory training follow-ups, although the generalization of these results needs further studies in different groups with different auditory processing abnormalities or skills.

Introduction

Various functions have been proposed for the auditory efferent system, which its fibers have been identified in parallel to auditory afferent fibers throughout the neural pathway of the auditory system [1,2]. The auditory *afferent* system has been tested subjectively and objectively by various behavioral and electrophysiological methods from the most peripheral to its most central levels, while less attention has been paid to the assessment of auditory *efferent* system due to the neural cycles and complexity of its' loops and chains [2]. Since the

Abbreviations: ABR, Auditory brainstem response; S-ABR, Speech evoked ABR; S-ABR/coN, Speech evoked ABR with contralateral noise; ADHD, Attention deficit hyperactivity disorder; IC, Inferior colliculus; CV, Consonant-vowel; CVC, Consonant-vowel-consonant; SNR, Signal to noise ratio; ITD, Interaural time difference; IID, Interaural intensity difference; SD, Standard deviation; ECochG, Electrocochleography; AMLR, auditory middle latency response; ALL, Rauditory late latency response; TEOAE, Transient evoked otoacoustic emission

* Corresponding author at: Department of Audiology, the University of Social Welfare and Rehabilitation Sciences, Tehran, Iran.
E-mail addresses: m.javanbakht@yahoo.com (M. Javanbakht), s.faghihzadeh@zums.ac.ir (S. Faghih Zadeh).
[1] ORCID: 0000-0002-2876-3208.

https://doi.org/10.1016/j.mehy.2019.109355
Received 27 June 2019; Received in revised form 1 August 2019; Accepted 7 August 2019
0306-9877/

anatomical presence of the efferent cycles from the cortex to the rostral auditory brainstem parts like inferior colliculus (IC) is confirmed through last studies [3], limitation of access to the objective test for this part of auditory system evaluation becomes more tangible.

Many studies have shown that the auditory efferent system is involved in many auditory skills such as speech perception in noise, dichotic hearing tasks and sound localization in noise [4–6] and it is suggested its role as one of the reasons for superior performances of musicians and bilinguals in some auditory tests [7–9]. The pathways of speech perception in noise, dichotic hearing tasks and sound localization in noise are partly related to top-down processes and contribution of the efferent auditory system [9–22,33,34]. Clinically, the defect of these skills have been reported in central auditory processing disorder (CAPD) [10], attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorder [11], dyslexia and specific language impairment (SLI) [12].

Most studies in the field of the auditory efferent system such as otoacoustic emission (OAE) suppression are only limited to the examination of the medial olivary cochlear bundle (MOCB) at the low brainstem or caudal part of the efferent system [13–19]. The use of OAE suppression has inherent clinical and theoretical limitations. One of the most important clinical limitations of OAE suppression test is its dependency on middle ear function. Middle ear pathology can corrupt OAE recordings. This test examines only the pathway from MOC to the outer hair cells. Therefore, according to the cycles in the auditory efferent pathway [2], the results of the OAE suppression test cannot be generalized to the upper parts of the efferent system. Objective assessment and access to different parts of this system is as important as the electrophysiological assessments carried out for different levels of the auditory afferent pathway i.e. ECochG, ABR, AMLR, and ALLR.

Although there are some objective tests like the AMLR, ALLR and P300 which can express to some extent the function of the rostral parts of the auditory efferent system. However, there are many confounding factors that interfere with their results such as, attention, memory and other cognitive skills of higher levels can interfere with the results of these tests [20]. Regarding the considerable efferent fibers entering to the IC and the upper levels of the auditory brainstem, it seems possible to study the rostral auditory efferent system with minimal cognitive interference at the level of IC using speech evoked ABR (S-ABR) [21]. S-ABR as an objective, non-invasive auditory test using speech stimuli, can accurately simulate the performance of the auditory brainstem in real-life conditions compared to conventional click ABR test. Studies on S-ABR show that it can display the effects of the auditory abnormalities or auditory skills on the lower-level responses [22–29]. Since noisy conditions make the efferent system more active, we hypothesized that adding noise to the test can actually be an appropriate option to study the performance of the less studied rostral auditory efferent system. It is expected that the activity of auditory efferent system at the IC and upper brainstem can be shown with the speech evoked ABR in the presence of contralateral noise (S-ABR/coN). To verify the validity of this hypothesis through a noninvasive method in normal human samples, we tried to find the correlation between the S-ABR/coN with the behavioral tests, which are partly related to the auditory efferent system function.

Introducing a valid objective test for the rostral auditory efferent system is necessary for the diagnosis of auditory processing difficulties in young children or poor cooperation adults and for monitoring the efficiency of treatment/rehabilitation methods. The speech perception in noise, sound lateralization in noise and dichotic hearing test are three auditory behavioral tests, which are partly related to the performance of the auditory efferent system and are selected for the current study. We used this model for the examination of our hypothesis in a pilot group.

Hypothesis examination method

Eighteen subjects (10 females) aged 18 to 25 years (22.50 ± 3.40) participated in the current pilot study, two participants were excluded from the study, due to the poor S-ABR reproducibility. The participants had bilaterally normal thresholds of < 20 dB in the frequency octaves of 250 to 8000 Hz audiometry (AC40, Interacoustic, Denmark)and type An tympanogram with ipsilateral acoustic reflexes in 500, 1000 and 2000 Hz (AT235, Interacoustic, Denmark). with at least 1 dB suppression of TEOAE amplitude (evoked by 1024 sweeps of 60 dB peSPL click stimuli in each ear with 70 dB peSPL broadband contralateral noise) to approved normal function of MOCB through OAE suppression option of ILO288 system (Echoport ILO 288, Otodynamic Company, UK). Normal click-evoked ABR morphology and latencies that were recorded by 80 dBnHL rarefaction click stimuli with 10.3 stimuli per second rate in 10 ms time window through Biologic Navigator Pro system (Navigator Pro; Bio-Logic Systems Corp, Mundelein, IL, USA) was last inclusion criteria. Click ABR was recorded to approve normal function of the brainstem in click stimuli processing and as a prerequisite for S-ABR test. Auditory brainstem peaks had absolute latencies of 1 ms, 3 ms and 5 ms with ± SD respectively for waves I, III and V. Inter-peak latencies of I-III, III-V, and I-V of each ear are in normal clinical limit and the interaural wave V latency was < 0.2 ms difference between ears. Just right-handed volunteers (based on Edinburgh Handedness Questionnaire) that were Farsi monolinguals without any music training, participate in this study. The participants were selected through a convenient sampling of Tehran universities students that had entry criteria and none of them had a current or past history of neurological disorders. All procedures were approved by the research committee of the *University of Social Welfare and Rehabilitation Sciences (IR.USWR.REC.94.293)* and complied with the Declaration of Helsinki. Written informed consent was obtained from all for two sessions of electrophysiological and behavioral assessments. After meeting inclusion criteria, subjects underwent the evaluation of the S-ABR in quiet and in the presence of contralateral noise with Biologic system (BioMark of Navigator Pro; Bio-Logic Systems Corp, Mundelein, IL, USA). Finally, behavioral evaluations including consonant-vowel (CV) in noise test, Dichotic consonant-vowel-consonant (CVC) and sound lateralization in noise were conducted through the calibrated laptop (Sony, Vaio S series) and headphone (SHP6000, Philips).

Electrophysiological measures

The S-ABR data for both sides were recorded in quiet and in three contralateral signal to noise ratios (SNR) (+10, 0, −10 dB). During the recording, subjects were seated in a comfortable chair and were instructed to watch a silent wildlife movie. They were asked to stay awake, relax and without any movement during recordings. All S-ABR traces were recorded by the Biologic Navigator Pro System (BioMark of Navigator Pro; Bio-Logic Systems Corp, Mundelein, IL, USA). Three electrodes in the vertical array were used. The non-inverting electrode was placed on Cz, inverting one on the ipsilateral earlobe (or mastoid in some cases) and ground on the forehead with electrode impedances below 3 KOhms. The /da/ stimulus was delivered with alternating polarity through insert earphones (ER-3, Etymotic Research, Elk Grove Village, IL, USA) at 80 dB SPL with the rate of 10.9/s. A band-pass filter was set to 100–2000 Hz. In the first step, two blocks (/da/) each containing 3000 sweeps were delivered to each ear. In the next step, speech stimuli were delivered with contralateral white noise in three SNRs (+10 dB, 0 dB, and −10 dB, respectively). Two blocks of 3000 sweeps were collected in each SNRs and added to make a sum of 6000 artifact-free S-ABR traces. These responses were recorded for each one of the four-stimulus situations (Quiet mode and three SNRs) in both ears. During the recording procedure, 15 to 20 min of rest was considered for participants. Default stimulus for speech evoked ABR in BioMark apparatus is a synthesized syllable /da/ with 40 ms duration [30]. In final

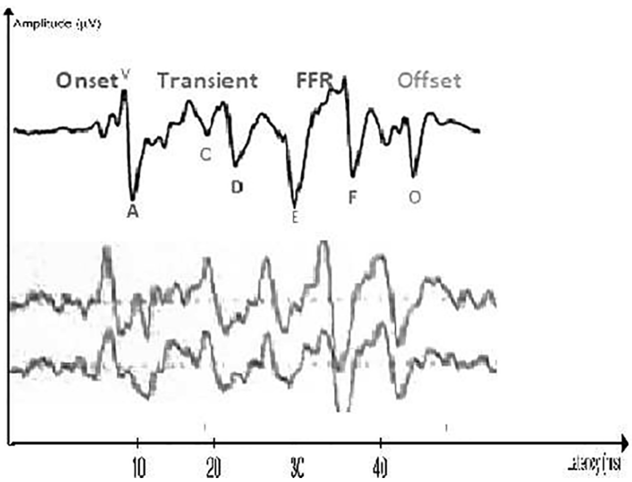

Fig. 1. sample of the current study S-ABR record in response to /da/ syllable in quiet in comparison with norms of 18–28 years old S-ABR (Norm response from Moossavi A, et al. 2019 [33]).

recorded traces, S-ABR peaks (V-A-C-D-E-F-O) were marked (Fig. 1). Since studies including the present pilot have shown that the transient parts of response are the most sensitive components to the noise [31,32]] the difference of latency and amplitude of V and A onset peaks and O offset peak were calculated and analyzed between quiet (only target stimuli without noise or S-ABR) and noise conditions (S-ABR/coN). The correlations between the results of auditory behavioral tests and efferent system activation at the upper brainstem in auditory challenging situations were studied and the S-ABR/coN validity for evaluation of the rostral part of the auditory efferent system was checked.

Selected Behavioral measures

Speech perception in noise

One of the most important functions of the auditory efferent system is detecting the target signal like speech in the presence of background noise [1,20,34,35]. Among the conventional speech perception in noise tests, CV in noise test was used in the current study since its' materials (CVs) have more similarity to the S-ABR stimuli (/da/) and also in comparison with the word or sentence stimuli, cognition and memory are less involved in CVs perception. The version of CV in noise test that was used in this study, consists of 25 single-syllable items, including explosive consonants and long vowels in the presence of background white noise [36]. Separate equivalent lists were used for quiet and −6 SNR level. The test scores were recorded as the percentage of correct responses to stimuli in each presented mode (Quiet and −6 signal-to-noise ratio).

Dichotic listening

One of the confirmed functions of the auditory efferent system at brainstem level is its role in selective attention [22]. Dichotic listening tasks are valid behavioral tools for evaluation of selective attention [37–39]. To create the most difficult and challenging dichotic condition and to minimize the probability of prediction of stimuli by participants, the dichotic CVC test was used in this study. This test consists of 25 items in two lists include meaningless single-syllable CVCs that are presented to both ears in dichotic mode [40]. The test was done in selective attention mode focusing on one ear at a time. At first for the instruction, the participants were asked to repeat test items that were presented monaurally, and then they were asked to carefully track the stimuli in the target ear and repeat it while ignoring the simultaneous

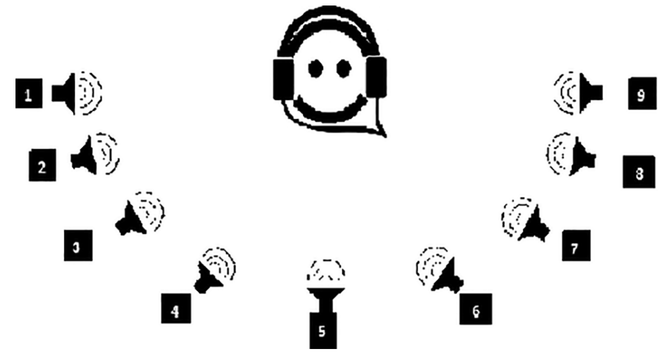

Fig. 2. Schematic diagram of the imaginary sound source position under the headphone in sound lateralization test.

stimuli in the opposite ear (noise stimulus). The test scores were recorded as the percentage of the correct stimuli in each step and ear.

Sound lateralization in noise

Lateralization in noise as a challenging condition with auditory efferent system involved [9] was tested in the current study. Since sound lateralization test can be carried out under the headphone [41,42], this technique was used in our study. We evaluated the subjective lateralization skill in quiet and in background noise situation to mimic real life. Lateralization test was implemented under headphone by applying interaural time difference (ITD) cues for low pass filtered noises with the cut off frequency of 2000 Hz. In the ITD task, the stimuli were presented binaurally. The interaural time delay varied in 220 µs steps towards left and right to produce −880, −660, −440, −220, 0, +220, +440, +660, +880 µs time difference, respectively (negative and positive symbols correspond to preponderance towards the left and right and 0 represents center position) making 9 different locations. By these interaural cues, 9 imaginary positions were simulated in the horizontal plane in front of the subject (Figs. 1 and 2). Participants were instructed to point to the imaginary spatial position of the sound source for test signals. The task was performed according to a two-alternative forced-choice (2AFC) method. After lateralization test in quiet, the same test was performed with high pass filtered continuous noise in −5 dB signal to noise ratio, without any interaural time or intensity differences (ITD and IID). The number of correctly detected locations in quiet and noise were counted and used in statistical analysis.

Statistical analysis

Statistical analyses consisted of descriptive statistics including mean and standard deviation of S-ABR latencies and amplitudes, CV in noise, dichotic listening and lateralization tests. Normal distribution of data was assessed by the Kolmogorov-Smirnov test. Then, the paired *t*-test was used for comparison of two-mode lateralization and CV in noise scores in quiet and noise, which showed normal distributions. The Wilcoxon test was used for evaluation of effects of different noise levels on peak latencies and amplitudes of S-ABR (lack of normal distribution). At the last step, the Spearman correlation was employed to measure the degree of association between changes of behavioral test scores and the S-ABR latency and amplitude secondary to applying noise. All the analyses were conducted using version 19 of the Statistical Package for the Social Sciences (SPSS). The significance level adopted was 0.05 (5%), with confidence intervals of 95%.

Results

The results come in three parts including *S-ABR and S-ABR/coN* findings*, auditory behavioral tests* findings*, and the correlation between*

Table 1
Descriptive statistics of dichotic CVC scores in Quiet and Noise mode.

Ear	Participants (Num)	Minimum score (Percent %)	Maximum score (Percent %)	Mean (SD)
Right	16	53	93	66.3 (± 12.4)
Left	16	46	80	62.75 (± 8.96)

changes of these two types of evaluations.

S-ABR and S-ABR/coN findings

The latencies of V, A and O peaks significantly increased after contralateral noise presentation in all SNR values (P-value < 0.05) which was more significant in lower SNRs i.e. 0 and −10.

Auditory behavioral tests findings

In Auditory Behavioral measures, Paired T-test revealed a significant decrease of CV perception scores in a noisy situation in comparison with Quiet in both ears (P-values < 0.05). Tables 1 and 2 shows the mean and standard deviations of dichotic CVC scores in selective attention mode for both ears and lateralization in quiet and in noise which revealed a significant decrease of lateralization score in the noisy situation in comparison with quiet mode (P-values < 0.05).

Correlation of S-ABR/coN with auditory behavioral tasks in noise

Table 3 reveals the correlation between latency changes for V, A, and O in different SNRs with changes in the score of three behavioral tests. With reducing SNR, correlation coefficients between latency changes with behavioral tests scores changes were increased V and A waves. As it is summarized in Table 3, the lowest SNR i.e. −10 showed the highest significant negative correlation between latency of S-ABR/coN onset peaks and score of behavioral tests in noisy or dichotic. This means that in cases with more changes in behavioral test scores in noise or dichotic presentation (decrease scores), showed more changes in V and A peaks' latency of S-ABR/coN (Increase latency) and cases with more resistance to noise, showed less reduction in behavioral scores and less latency increase. The correlations between V and A latency changes and dichotic CVC score were not significant in −10 SNR for *left* ear in left attention mode only. For offset peak i.e. O latency, no uniform changes with SNR decrease and no significant correlation with none of the behavioral test score changes in any SNRs.

A high positive correlation was seen between the changes in the amplitude of the transient components of S-ABR/coN and changes in all three behavioral test scores only in −10 SNR for the right ear (Table 3). Although inter-subject and intra-subject high amplitude variability of S-ABR peaks were seen in the current study, generally these results revealed that cases with more reduction in behavioral tests scores, showed more decrease in the amplitude of the transient S-ABR/coN which was statistically significant in −10 SNR for right ear (in all three behavioral tests). Correlation between S-ABR/coN transient peaks in -SNR 10 and CVC dichotic test was not statistically significant in the left ear but correlations were significant for CV in noise and lateralization in noise tests in both ears. The findings in other SNRs showed an unspecific model in comparison with the changes in the behavioral test scores.

Discussion

The present study was conducted based on our hypothesis about use of S-ABR/coN for rostral auditory efferent system evaluation. In this study we examined the performance of the rostral part of the auditory efferent system by means of speech evoked ABR in contralateral noise (S-ABR/coN) and its correlation with CV in noise test, dichotic CVC test and lateralization in noise as behavioral tests which partly evaluate the efferent system function, indirectly. The main efferent pathway in the rostral part of the auditory system has been defined from contralateral thalamocortical level to IC and to show its performance, we used contralateral noise during S-ABR recording. Introducing noise to S-ABR test had more effects on the onset and offset peak latencies and amplitudes, which is in line with other studies [31,32,43].

Correlation analysis between electrophysiological with behavioral measures revealed a high correlation between electrophysiologic changes of transient onset V and A peaks of S-ABR with the degree of changes in selected behavioral tests.

By introducing noise, a significant decrease was seen in the CV in noise test scores, such a result is in accordance with the findings of Lotfi et al. and de Boer et al. [36,44]. Lotfi et al. confirmed behaviorally performance improved as SNR increased without the comparison of any correlation with objective tests or performance of the auditory efferent system [35]. De Boer et al. determined not only improved CV in noise perception with SNR increase but also reported the correlation between CV in noise scores with OAE suppression that was opposite to the antimasking hypothesis. They report that individuals with stronger OAE suppression tended to show greater noise-masking effects on CV processing. The current results indicate that reflexive MOC activation is not always beneficial to speech-in-noise processing and higher levels control on this reflexive pathway is the key for antimasking effects of this part of the auditory efferent system [43]. In this study, we examine this correlation between CV in noise perception (in different SNRs) with rostral parts of auditory brainstem through S-ABR/coN. Significant negative correlations were seen between the changes of V and A peak latencies in S-ABR/coN and CV in noise scores, meaning that more decreases of CV in noise scores accompanied with more latency increases in S-ABR/coN onset peaks. This finding is in accordance with the de Boer et al. findings for CV evoked ABR with use of ipsilateral noise in higher selected SNRs(+20, +10). These high correlations in our study were seen in most difficult test situation i.e. −10SNR perhaps it's due to the dominance of contralateral neural pathway in the auditory efferent system. We selected contralaterally pathway based on the previous study of Schochat et al. in 2012 [20]. We propose the necessity of investigating the difference between the noise presenting in the ipsilateral, contralateral and bilateral manner for future studies in this field.

Because of complex multi-factor relations and interactions in process of speech perception in noise and as other factors besides the efferent system function have a contribution, so the correlation between S-ABR changes with two other auditory behavioral tests that partly were dependent on efferent system function was considered to analyze.

Another confirmed function of the auditory efferent system is its role in selective auditory attention. Selective attention is a mechanism that leads to the allocation of cognitive resources and the focus on specific stimulus among several simultaneous non-target stimuli [37,38]. In this study, dichotic CVC test with the meaningless items was used as a valid behavioral tool for considering and evaluating selective

Table 2
Descriptive statistics of Lateralization scores in Quiet and Noise mode.

Participants (Num)	Lateralization mode	Minimum score	Maximum score	Mean (SD)
16	Quiet	5	11	8.00 (± 1.78)
16	Noise	2	8	4.13 (± 1.89)

Table 3
Correlation Coefficients (P-value) of S-ABR transient waves *Latency* and *Amplitude* changes with changes in behavioral test scores (Right and Left Ear).

	CV in noise **Latency / Amplitude** Correlation Coefficients (P-value)	**Dichotic CVC** **Latency / Amplitude** Correlation Coefficients (P-value)	**Lateralization** **Latency / Amplitude** Correlation Coefficients (P-value)
SNR= +10			
Wave V	0.25 (0.36) / 0.29 (0.32) 0.15 (0.55) / 0.38 (0.14)	0.13 (0.63) / 0.10 (0.68) 0.23 (0.39) / 0.28 (0.28)	0.08 (0.77) / 0.43(0.93) 0.20 (0.43) / 0.03 (0.89)
Wave A	0.32 (0.22) / 0.02 (0.91) **0.54 (0.02) / 0.52 (0.03)**	0.25 (0.33) / 0.31 (0.23) 0.05 (0.83) / 0.46 (0.06)	0.29 (0.27) / 0.01 (0.92) **0.65 (0.00) / 0.51 (0.04)**
Wave O	**0.65 (0.00 / 0.75 (0.00)** **0.73 (0.00)** / **0.66 (0.00)**	0.41 (0.11) / 0.41 (0.10) 0.20 (0.44) / 0.46 (0.06)	**0.65 (0.00) / 0.75 (0.00)** **0.84 (0.00)** / **0.54 (0.03)**
SNR= 0			
Wave V	0.49 (0.05) / **0.51 (0.04)** **0.63 (0.00)** / 0.13 (0.62)	0.33 (0.20) / **0.63 (0.00)** 0.31 (0.23) / 0.37 (0.15)	0.49 (0.05) / 0.41 (0.11) **0.69 (0.00)** / 0.25 (0.34)
Wave A	**0.54 (0.02) / 0.80 (0.00)** **0.52 (0.03)** / **0.77 (0.00)**	**0.58 (0.01)** / 0.41 (0.10) 0.10 (0.69) / 0.19 (0.46)	**0.53 (0.03) / 0.65 (0.00)** **0.55 (0.02)** / **0.76 (0.00)**
Wave O	0.35 (0.18) / 0.19 (0.47) **0.86 (0.00) / 0.53 (0.03))**	0.19 (0.46) / 0.12 (0.63) 0.21 (0.44) / 0.25 (0.33)	0.31 (0.24) / 0.06 (0.81) **0.69 (0.00)** / **0.73 (0.00)**
SNR= -10			
Wave V	**0.86 (0.00) / 0.57 (0.01)** **0.88 (0.00) / 0.81 (0.00)**	**0.59 (0.01)** / **0.61 (0.01)** 0.38 (0.23) / 0.27 (0.30)	**0.85 (0.00) / 0.59 (0.01)** **0.83 (0.00) / 0.83 (0.00)**
Wave A	**0.58 (0.01) / 0.85 (0.00)** **0.68 (0.00)** / **0.79 (0.00)**	**0.60 (0.01)** / **0.50 (0.04)** 0.17 (0.52) / 0.32 (0.22)	**0.63 (0.00) / 0.77 (0.00)** **0.73 (0.00)** / **0.80 (0.00)**
Wave O	0.28 (0.27) / **0.86 (0.00)** 0.41 (0.11) / **0.68 (0.00)**	0.27 (0.31) / **0.63 (0.00)** 0.07 (0.77) / 0.27 (0.30)	0.09 (0.97) / **0.82 (0.00)** 0.08 (0.76) / **0.81 (0.00)**

Significant r and p-values are shown with the highlight-bold font.

attention. Our findings showed a significant correlation between the changes of latency and amplitude of onset transient peaks of S-ABR/coN (V, A) with the changes found in the scores of dichotic listening in selective attention versus divided attention mode which potentially shows the effects of the rostral auditory efferent system. These findings were only seen in the right ear and in the most difficult situation i.e. the lowest SNR value (−1 0). It seems that auditory efferent system at rostral brainstem levels becomes operational after all other facilitative options used in easier situations i.e. higher SNRs (0, + 10). The other important finding in this part is S-ABR/coN correlation with right ear scores in the dichotic test, which suggests that rostral auditory efferent system might be one of the reasons for right ear advantage, which usually see in dichotic tests. More studies with different methods seem necessary to understand the effects of the auditory efferent system on selective listening and dichotic tasks. Brainstem role in selective auditory attention was reported previously [45,46] but not about the efferent system. Our findings also support a hypothesis of a relation between more central and more peripheral auditory lateralities based on corticofugal control pathways as Markevych et al. found that those with greater MOC strength were better at using the top-down corticofugal skill in attend to the selective ear in dichotic tasks [7].

Since little knowledge is available about the laterality and details of the auditory efferent system structures especially at the rostral part, more evidence is needed to find a better side of stimulation in S-ABR/coN.

Help to the identification of the signal in challenging conditions, such as the presence of background noise is one of the well-known functions of the auditory efferent system and as humans need to localize sound sources in challenging noisy conditions for following target stimulus, therefore localization/lateralization in noise was taken into account in the current study. Andeol et al. reported a significant correlation between localization scores in noise and OAE suppression, therefore, suggested a facilitative role for caudal part of the auditory efferent system for localization in noisy conditions [9]. Our findings revealed that the decrease of lateralization behavioral scores in noisy conditions had a significant negative correlation with the latency increase of the S-ABR/coN transient peaks. Decrease of V and A amplitudes of S-ABR/coN also showed a significant positive correlation with the decrease of lateralization scores in a noisy situation. Since S-ABR reflects the performance of rostral parts of the brainstem, according to these findings we conclude that there is a facilitative role of the rostral auditory efferent system for lateralization at least in low SNR values such as −10.

Conclusion

The findings of the current study revealed that in high challenging auditory situations, like speech perception in noise, dichotic hearing situations and auditory lateralization in noise, rostral part of the auditory efferent system at upper brainstem levels plays a special role, especially in low SNRs. Our findings, obviously support that S-ABR/coN provide a useful tool for examining the rostral auditory efferent system and gives a screenshot of the collaboration between auditory afferent and efferent systems for processing complex auditory stimuli in the noisy situation at the level of upper brainstem. S-ABR/coN as an objective, noninvasive tool for evaluation of rostral auditory efferent system also is expected to be suitable for monitoring the outcome of top-down auditory training and controlling their effects on the auditory efferent system.

The generalization of the results needs further studies with an extended sample size on different auditory disorders groups and different groups with higher auditory processing skills like musicians and multilinguals.

Declaration of Competing Interest

This study was a part of the Ph.D. dissertation project in audiology that was supported by the University of Social Welfare and Rehabilitation Sciences.

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgement

This study was a part of the PhD dissertation project in audiology that was supported by the University of Social Welfare and Rehabilitation Sciences. The authors gratefully thank the research subjects who voluntarily took part in this study and from Rofeideh rehabilitation hospital clinical research development center.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mehy.2019.109355.

References:

[1] Pickles J. An introduction to the physiology of hearing. Brill; 2013.
[2] Ryugo DK. Introduction to efferent systems. Auditory and vestibular efferents. Springer; 2011. p. 1–15.
[3] Winer JA, Chernock ML, Larue DT, Cheung SW. Descending projections to the inferior colliculus from the posterior thalamus and the auditory cortex in rat, cat, and monkey. Hear Res 2002;168(1–2):181–95.
[4] Kumar UA, Vanaja C. Functioning of olivocochlear bundle and speech perception in noise. Ear Hear 2004;25(2):142–6.
[5] de Boer J, Thornton ARD. Neural correlates of perceptual learning in the auditory brainstem: efferent activity predicts and reflects improvement at a speech-in-noise discrimination task. J Neurosci 2008;28(19):4929–37.
[6] Garinis A. Efferent control of the human auditory system. Braz J Otorhinolaryngol 2008.
[7] Markevych V, Asbjørnsen AE, Lind O, Plante E, Cone B. Dichotic listening and otoacoustic emissions: shared variance between cochlear function and dichotic listening performance in adults with normal hearing. Brain Cogn 2011;76(2):332–9.
[8] Kerber IS, Seeber IBU. Sound localization in noise by normal-hearing listeners and cochlear implant users. Ear Hear 2012;33(4):445.
[9] Andéol G, Guillaume A, Micheyl C, Savel S, Pellieux L, Moulin A. Auditory efferents facilitate sound localization in noise in humans. J Neurosci 2011;31(18):6759–63.
[10] Weihing J, Musiek FE. An electrophysiological measure of binaural hearing in noise. J Am Acad Audiol 2008;19(6):481–95.
[11] Danesh AA, Kaf WA. DPOAEs and contralateral acoustic stimulation and their link to sound hypersensitivity in children with autism. Int J Audiol 2012;51(4):345–52.
[12] Canale A, Dagna F, Favero E, Lacilla M, Montuschi C, Albera R. The role of the efferent auditory system in developmental dyslexia. Int J Pediatr Otorhinolaryngol 2014;78(3):455–8.
[13] Rasmussen GL. The olivary peduncle and other fiber projections of the superior olivary complex. J Comp Neurol 1946;84(2):141–219.
[14] Khalfa S, Bougeard R, Morand N, Veuillet E, Isnard J, Guenot M, et al. Evidence of peripheral auditory activity modulation by the auditory cortex in humans. Neuroscience 2001;104(2):347–58.
[15] Collet L, Kemp DT, Veuillet E, Duclaux R, Moulin A, Morgon A. Effect of contralateral auditory stimuli on active cochlear micro-mechanical properties in human subjects. Hear Res 1990;43(2–3):251–61.
[16] Perrot X, Ryvlin P, Isnard J, GuÈnot M, Catenoix H, Fischer C, et al. Evidence for corticofugal modulation of peripheral auditory activity in humans. Cereb Cortex 2005;16(7):941–8.
[17] Guinan Jr JJ. Olivocochlear efferent function: issues regarding methods and the interpretation of results. Front Syst Neurosci 2014;8:142.
[18] Guinan Jr JJ. Olivocochlear efferents: anatomy, physiology, function, and the measurement of efferent effects in humans. Ear Hear 2006;27(6):589–607.
[19] Berlin C, Hood L, Wen H, Szabo P, Cecola R, Rigby P, et al. Contralateral suppression of non-linear click-evoked otoacoustic emissions. Hear Res 1993;71(1–2):1–11.
[20] Schochat E, Matas CG, Samelli AG, Carvallo RMM. From otoacoustic emission to late auditory potentials P300: the inhibitory effect. Acta Neurobiol Exp 2012;72(3):296–307.
[21] Skoe E, Kraus N. Auditory brainstem response to complex sounds: a tutorial. Ear Hear 2010;31(3):302.
[22] Forte AE, Etard O, Reichenbach T. The human auditory brainstem response to running speech reveals a subcortical mechanism for selective attention. Elife 2017;6:e27203.
[23] Musacchia G, Sams M, Skoe E, Kraus N. Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. Proc Natl Acad Sci 2007;104(40):15894–8.
[24] Parbery-Clark A, Strait DL, Anderson S, Hittner E, Kraus N. Musical experience and the aging auditory system: implications for cognitive abilities and hearing speech in noise. PLoS ONE 2011;6(5):e18082.
[25] Anderson S, Kraus N, editors. Neural encoding of speech and music: implications for hearing speech in noise. Seminars in hearing. NIH Public Access; 2011.
[26] Krizman J, Marian V, Shook A, Skoe E, Kraus N. Subcortical encoding of sound is enhanced in bilinguals and relates to executive function advantages. Proc Natl Acad Sci 2012;109(20):7877–81.
[27] Banai K, Hornickel J, Skoe E, Nicol T, Zecker S, Kraus N. Reading and subcortical auditory function. Cereb Cortex 2009;19(11):2699–707.
[28] Banai K, Abrams D, Kraus N. Sensory-based learning disability: insights from brainstem processing of speech sounds. Int J Audiol 2007;46(9):524–32.
[29] Anderson S, Skoe E, Chandrasekaran B, Zecker S, Kraus N. Brainstem correlates of speech-in-noise perception in children. Hear Res 2010;270(1–2):151–7.
[30] Moossavi A, Lotfi Y, Javanbakht M, Faghihzadeh S. Speech-evoked auditory brainstem response: a review of stimulation and acquisition parameters. Auditory Vestibular Res 2019:75–86.
[31] Russo N, Nicol T, Musacchia G, Kraus N. Brainstem responses to speech syllables. Clin Neurophysiol 2004;115(9):2021–30.
[32] Cunningham J, Nicol T, King C, Zecker SG, Kraus N. Effects of noise and cue enhancement on neural responses to speech in auditory midbrain, thalamus and cortex. Hear Res 2002;169(1–2):97–111.
[33] Moossavi A, Lotfi Y, Javanbakht M, Faghihzadeh S. Speech-evoked auditory brainstem response: a review of stimulation and acquisition parameters. Auditory Vestibular Res 2019;28(2):75–86.
[34] Kawase T, Delgutte B, Liberman MC. Antimasking effects of the olivocochlear reflex. II. Enhancement of auditory-nerve response to masked tones. J Neurophysiol 1993;70(6):2533–49.
[35] Winslow RL, Sachs MB. Single-tone intensity discrimination based on auditory-nerve rate responses in backgrounds of quiet, noise, and with stimulation of the crossed olivocochlear bundle. Hear Res 1988;35(2–3):165–89.
[36] Lotfi Y, Kargar S, Javanbakht M, Biglarian A. Development, validity and reliability of the persian version of the consonant-vowel in white noise test. J Rehabil Sci Res 2016;3(2):29–34.
[37] Lehmann A, Schönwiesner M. Selective attention modulates human auditory brainstem responses: relative contributions of frequency and spatial cues. PLoS ONE 2014;9(1):e85442.
[38] Gazzaley A, Nobre AC. Top-down modulation: bridging selective attention and working memory. Trends Cogn Sci 2012;16(2):129–35.
[39] Bryden M, Munhall K, Allard F. Attentional biases and the right-ear effect in dichotic listening. Brain Lang 1983;18(2):236–48.
[40] Ghanbari N, Loi Y, Nazeri AR, Bakhshi E, Moossavi A, Mehrkian S, et al. Developing and evaluang validity and reliability of persian version of “Dichoc Fused Rhymed Word Test”. Rehabilitation 2015;16(3).
[41] Moosavi A, Hosseini Dastgerdi Z, Lotfi Y, Mehrkian S, Bakhshi E, Khavar Ghazalani B. Auditory lateralization ability in children with (central) auditory processing disorder. Iran Rehabil J 2014;12(1):31–7.
[42] Lotfi Y, Moosavi A, Abdollahi FZ, Bakhshi E, Sadjedi H. Effects of an auditory lateralization training in children suspected to central auditory processing disorder. J Audiol Otology 2016;20(2):102–8.
[43] Chandrasekaran B, Kraus N. The scalp-recorded brainstem response to speech: neural origins and plasticity. Psychophysiology 2010;47(2):236–46.
[44] de Boer J, Thornton ARD, Krumbholz K. What is the role of the medial olivocochlear system in speech-in-noise processing? J Neurophysiol 2011;107(5):1301–12.
[45] Galbraith GC, Arroyo C. Selective attention and brainstem frequency-following responses. Biol Psychol 1993;37(1):3–22.
[46] Giard M-H, Fort A, Mouchetant-Rostaing Y, Pernier J. Neurophysiological mechanisms of auditory selective attention in humans. Front Biosci 2000;5(1):84–94.