The Egyptian Journal of Hospital Medicine (April 2022) Vol. 87, Page 2064-2071

Evaluation of Auditory Efferent System using Speech Auditory Brainstem Response with Contralateral Noise

Dalia Helal Galhom, Ebtessam Hamed Nada, Hagar Ahmed Elsayed Ahmed, Nadia Mohamed Elnabtity
Audio-vestibular Medicine ENT Department, Faculty of Medicine, Zagazig University Hospitals, Egypt
***Corresponding author:** Hagar Ahmed Elsayed Ahmed, **Email:** hagarahmedoo660@gmail.com

ABSTRACT
Background: Speech auditory brainstem response (ABR) is an electrophysiological auditory test using speech stimuli, reflecting neural activities of the efferent system at subcortical level. Adding noise to the test can be an effective way to assess the upper portion of the auditory efferent system because the efferent system is more active in noisy conditions. **Objective:** To evaluate the auditory efferent pathway in adults with normal hearing and others with sensorineural hearing loss (SNHL) by using speech ABR.
Patients and Methods: This study included 69 subjects aged 20-50 years, divided into 2 groups: Control group: 46 adults with normal hearing sensitivity and study group: 23 adults with mild to moderate SNHL. All participants were subjected to: full history taking, otoscopic examination, basic audiological examination, speech in noise test, dichotic digits test and speech ABR.
Results: Regarding the behavioral tests, speech in noise (SPIN) test, there was highly statistically significant difference between the control and study groups as well as the Dichotic Digits Test (Version I and Version II). On the other hand, the electrophysiological results showed that the speech ABR in quiet, there were statistically significant differences between the control and study groups regarding latencies of V, A, F, and O waves and amplitudes of D, F and O waves.
Conclusions: Higher levels of the auditory efferent system in the brainstem, specifically the rostral part, play an important role in high-level auditory challenging situations like speech perception in noise and dichotic listening situations.
Keywords: Auditory efferent pathway, Dichotic Digits Test, Speech-ABR, Speech in noise test.

INTRODUCTION
An integrated afferent and efferent auditory pathway is the foundation of the hearing system. The efferent system shows that auditory input is modulated before it reaches the brain through a parallel arrangement of auditory reciprocal descending projections from the brain to the cochlea. Noise-induced cochlear damage protection, hearing development, and complex auditory signal processing all appear to be aided by the efferent system **(1)**.

Auditory processing depends on the integrity of both afferent and efferent auditory pathways. The efferent system is responsible for the central control of cochlear amplification, as well as selective attention. People with hearing loss have a hard time distinguishing speech from background noise, also selective attention is compromised, pointing to involvement of the efferent system **(2)**.

Because of its complex neural cycles, the auditory efferent system has received less attention than the auditory afferent system, which has been tested subjectively and objectively by behavioural and electrophysiological methods. The medial olivary cochlear bundle at the brainstem's base is the only part of the auditory efferent system typically examined in research by otoacoustic emission (OAE) suppression. Only the path from medial olivocochlear bundle (MOCB) to the outer hair cells is examined in this test. Since the upper efferent system is not included, these findings cannot be extrapolated **(3)**.

Efferent activity in the brainstem level can be measured using the speech auditory brainstem response (S-ABR), which is an electrophysiological, objective, non-invasive auditory test that uses speech stimuli to measure neural activity **(4)**. As the efferent system is more active when the environment is noisy, this may be a good way to study the performance of the rostral (top) auditory efferent system, which is less studied **(3)**.

To assess the efferent auditory system, tests such as the speech in noise (SPIN) and dichotic digits can be used subjectively. The efferent system is involved in these behavioral tests. Embedding speech in a background of noise is how the SPIN test works. It shows deficits in the ear that is on the other side of the hemisphere that is affected by auditory cortex. It is possible to evaluate the ability to focus on specific sounds using the dichotic digits test **(5)**.

Correlations between results of S-ABR in different conditions and auditory behavioural test scores aim to provide an objective tool for diagnosing difficulties of auditory processing in young children or poor cooperation adults and for monitoring the efficacy of treatment/rehabilitation methods, as well**(3)**.

Aim of the present study was to evaluate the auditory efferent pathway in adults with normal hearing and others with SNHL by using speech ABR.

PATIENTS AND METHODS
At Zagazig University Hospitals' ENT Department, we conducted a case-control observational study in the Audio-vestibular Unit.

Sixty nine patients were included in the study that were divided into 2 groups: Control group included 46 patients with normal hearing and age

Received: 19/11/2021
Accepted: 17/01/2022

range (20-50) years old and study group, which included 23 patients with mild to moderate sensorineural hearing loss. Both groups were matched as regards genders and age.

Subjects and/or patients with history of noise exposure, any systemic diseases (e.g. neurological diseases, hypertension, diabetes mellitus, ototoxic drug intake…), otorhinolaryngologic disease (otitis media, Eustachian tube dysfunction, nasal obstruction, etc.) or severe to profound sensorineural hearing loss were excluded from the study.

All subjects went through; otoscopic examination to ensure normal and intact tympanic membrane, pure tone audiometry at frequencies from 0.25-8KHz and bone conduction thresholds were tested from 0.5-4KHz and speech audiometry including speech reception threshold testing (SRT) and word discrimination testing (WD%) and immittancemetry including both tympanometry and acoustic reflex thresholds to ensure normal middle ear function.

Arabic Speech in noise Test (SPIN) was conducted to all subjects using Arabic Phonetically Balanced (PB) words recorded in a background of cafeteria noise. It consisted of 8 lists each of 25 monosyllabic words. The speech test materials and noise were delivered monaurally to each ear through headphones. The patient was asked to repeat the words and ignore the noise. The stimulus was presented at a level of 45-50 dB SL with three signal to noise ratios (SNR) (+10, 0, -10). Scoring was done by calculating the number of % correct words out of the total [6].

Dichotic digits test a 50-dB sensation level (SL) was used to administer the recorded Arabic digits. Twenty items were presented at a 50-dB SL level for the first subtest, while the second subtest contained only 10 items (referenced to SRT). First, there were 20 items with two digits presented simultaneously, one for each ear, in the first subtest, and only four digits were used in the second, with one pair of digits being presented simultaneously for both ears in the second. The percentage of correct answers for each ear was used to calculate a score. The subject was told to repeat everything in both ears, regardless of the order in which it was presented [7].

Speech evoked auditory brainstem response:

ER-3, Etymotic Research, Elk Grove Village, IL, USA) was used to deliver the speech stimulus /da/ (a 40-ms-long synthesised syllable) at a rate of 7.9/s using alternating polarity and a loudness of 40 dBSL or the study group's preferred level. With a band-pass filtering range of 150 to 1500 Hz, we were able to capture this signal in just 75 ms of time. Participants were instructed to remain calm and undisturbed as they were sat in a comfortable chair for the duration of the recording. The S-ABR data for both ears were recorded in quiet and in three contralateral signals to noise ratios (SNR) (+10, 0, −10 dB). The traces were recorded by Interacoustics, model Eclipse 25.

Ethical consent:

The Zagazig Faculty of Medicine's Research Ethics Committee approved this research with approval code 6708. After a thorough explanation of the test procedures, every patient signed an informed written consent for acceptance of participation in the study. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical analysis

The collected data were coded, processed and analyzed using the SPSS (Statistical Package for the Social Sciences) version 22 for Windows® (IBM SPSS Inc, Chicago, IL, USA). Data were tested for normal distribution using the Shapiro Wilk test. Qualitative data were represented as frequencies and relative percentages. Chi square test (χ^2) was used to compare qualitative variables. Quantitative data were expressed as mean ± SD (Standard deviation), median, and interquartile range (IQR). Independent samples t-test was used to compare between two independent groups of normally distributed variables (parametric data) and Mann Whitney test was used to compare nonparametric data. P value < 0.05 was considered significant.

RESULTS

The study involved two groups of both gender ranging in age from 20 to 50. Study and control groups were not statistically different in terms of age and gender distribution.

Table (1): Demographic characteristics of the control and study groups

Variable	Control group (n=46)	Study group (n=23)	*P* value
Age (years) Mean± SD	36.73±12.01	40.87±14.98	0.080
Variable	**No (%)**	**No (%)**	
Sex			
• Female	26 (56.5)	14 (60.9)	0.626
• Male	20 (43.5)	9 (39.1)	

Study and control groups differed significantly in pure-tone average (PTA) thresholds and SRT **(Figure 1).**

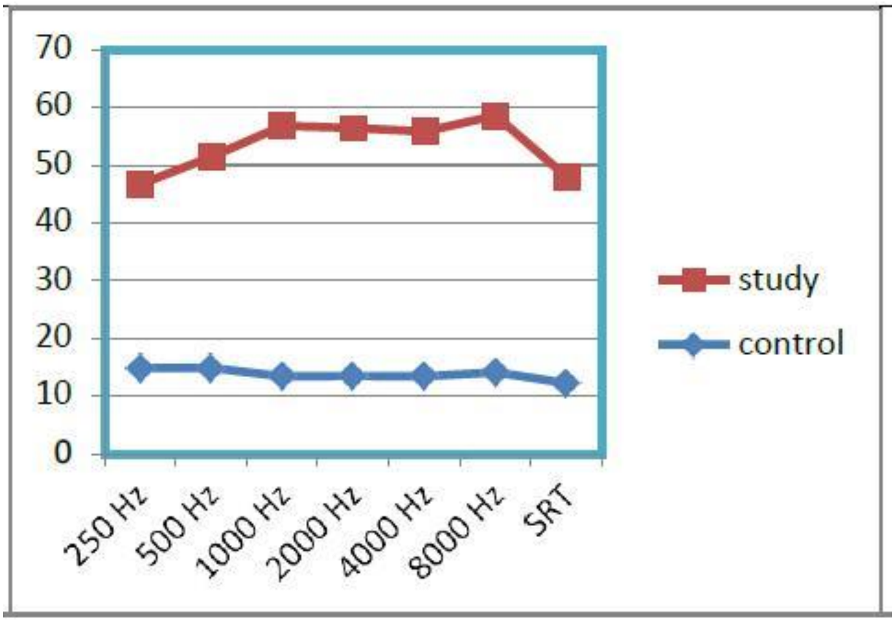

Fig. (1): Comparison of the results of pure tone threshold and SRT between the control and study groups

The results of comparison between right and left ears as regards pure tone threshold, acoustic reflexes (ipsilateral and contralateral), speech ABR, dichotic digits test and SPIN test did not differ significantly from each other, hence, we did not separate our results based on the ear and data from both ears were added together. The SPIN test showed a statistically significant difference between the control and study groups in regard to behavioural tests **(Table 2).**

Table (2): Comparison of Dichotic Digits Test between the control and study groups

Variable	**Control group (n=92)** Mean±SD	**Study group (n=46)** Mean±SD	***P***
Version I	96.57±4.5	86.85±4.98	<0.001
Version II	89.97±6.62	76±8.99	<0.001

A statistically significant difference was found between the control and study groups in the dichotic digits test (versions I and II) regarding SPIN test **(Table3).**

Table (3): Comparison of SPIN test between the control and study groups

Variable		**Control group (n=92)**	**Study group (n=46)**	***P***
Mean ±SD	**SNR= +10**	99±1.74	85.73±6.67	<0.001
	SNR= 0	98.35±2.07	84.09±6.67	<0.001
	SNR= -10	97±3.12	79.9±7.42	<0.001

Speech ABR in quiet was found to have statistically significant differences between control and study groups in terms of latencies, as demonstrated by electrophysiological results (V, A, F, O waves). Also there was statistically significant difference between the control and study groups as regard amplitudes of **(**D, F and O waves**) (Table 4).**

Table (4): Comparison of S-ABR waves in quiet between the control and study groups

speech ABR		**Control group**	**Study group**	***P***
Quiet				
V Mean±SD	Latency	5.79±0.99	7.46±1.13	**<0.001**
	AMP Median (IQR)	0.44±0.43 0.27 (0.13-0.65)	0.27±0.17 0.25(0.14-0.39)	0.200
A Mean±SD	Latency	6.94±0.99	8.99±1.28	**<0.001**
	AMP. Median (IQR)	-0.46±0.34 -0.32(-0.54-0.12)	-0.29±0.21 -0.21(-0.48-0.11)	0.423
C Mean±SD	Latency	19.92±0.25	20.95±2.98	0.072
	AMP. Median(IQR)	-0.55±0.24 -0.35 (-0.52-0.28)	-0.45±0.36 -0.34 (-0.7-0.21)	0.283
D Mean±SD	Latency	30.86±3.95	31.35±4.12	0.501
	AMP. Median(IQR)	-0.72±1.57 -0.45 (-0.61-0.33)	-0.33±0.29 -0.35 (-0.45-0.17)	**0.001**
E Mean±SD	Latency	39.63±3.56	40.51±5.43	0.258
	AMP. Median(IQR)	-0.47±0.38 -0.38(-0.61-0.28)	-0.37±0.31 -0.34 (-0.52-0.11)	0.086
F Mean±SD	Latency	46.11±2.86	50.02±5.79	**<0.001**
	AMP. Median(IQR)	-0.47±0.30 -0.45 (-0.63-0.27)	-0.30±0.33 -0.28(-0.45-0.11)	**0.001**
O Mean±SD	Latency	51.02±1.8	58.82±5.78	**<0.001**
	AMP. Median(IQR)	-0.65±0.39 -0.62 (-0.85-0.34)	-0.36±0.28 -0.34 (-0.55-0.14)	**<0.001**

In the study group, the comparison of the latency of S-ABR waves in quiet and at different SNR, there were statistically significant differences for S-ABR waves V, A, and O **(Table 5),** whereas on comparing amplitudes of S-ABR waves in quiet and at all SNR ratios, there were statistically significant differences for waves A, and O only **(Table 6).**

Table (5): Comparison of latencies of S-ABR in quiet, SNR=+10, SNR= 0, and SNR=-10 in the study group

Variables	Quiet (n=46)	SNR=+10 (n=46)	SNR=0 (n=46)	SNR=-10 (n=46)	Tests		
					Test value	*P* value	*Post hoc*
V (Latency) Mean±SD	7.45±1.13	9.05±1.9	9.02±2.2	9.84±1.9	13.839	<0.001	**P1=<0.001** **P2=<0.001** **P3=<0.001** P4=1.000 P5=0.158 P6=0.135
A (Latency) Mean±SD	8.99±1.3	10.77±1.9	10.79±2.06	11.33±2.1	13.471	<0.001	**P1=<0.001** **P2=<0.001** **P3=<0.001** P4=1.000 P5=0.487 P6=0.523
C (Latency) Mean±SD	20.95±2.9	21.26±2.6	21.25±2.8	22.11±3	1.427	0.237	P1=0.956 P2=0.962 P3=0.209 P4=1.000 P5=0.475 P6=0.459
D (Latency) Mean±SD	31.36±4.1	32.32±3.1	32.19±2.5	32.8±3	1.527	0.209	P1=0.481 P2=0.603 P3=0.160 P4=0.997 P5=0.912 P6=0.829
E (Latency) Mean±SD	40.5±5.4	41.9±4.95	41.9±4.95	41.33±3.8	0.892	0.446	P1=0.494 P2=0.494 P3=0.845 P4=1.000 P5=0.935 P6=0.935
F(Latency) Mean±SD	50.02±5.8	51.6±5.8	52.03±4.5	51.12±4.1	1.316	0.271	P1=0.460 P2=0.236 P3=0.727 P4=0.974 P5=0.973 P6=0.829
O (Latency) Mean±SD	58.82±5.7	60.37±5.2	60.38±4.8	62.18±4.3	3.361	0.020	P1=0.460 P2=0.456 **P3=0.010** P4=1.000 P5=0.324 P6=0.328

P1= quiet Vs. SNR+10, P2= quiet Vs. SNR 0, P3= quiet Vs. SNR-10,
P4= SNR+10 vs. SNR 0, P5= SNR+10 vs. SNR -10, P6= SNR 0 vs. SNR-10

Table (6): Comparison of amplitude of S-ABR in quiet, SNR=+10, SNR= 0, and SNR=-10 in the study group

Variables	Quiet (n=46)	SNR=+10 (n=46)	SNR=0 (n=46)	SNR=-10 (n=46)	Tests		
					Test value	***P* value**	***Post hoc***
V (AMP.) Mean±SD Median(IQR)	0.47±0.38 0.3(0.2-0.7)	0.44±0.43 0.27(0.1-0.7)	0.42±0.3 0.38(0.19-0.6)	0.41±0.37 0.26(0.1-0.5)	1.632	0.652	P1=0.349 P2=0.797 P3=0.502 P4=0.245 P5=0.779 P6=0.504
A (AMP.) Mean±SD Median(IQR)	-0.51±0.4 -0.4(-0.8-0.1)	-0.49±0.38 -0.4(-0.7-0.2)	-0.36±0.3 -0.3 (-0.5-0.1)	-0.33±0.4 -0.2(-0.4-1)	8.741	0.033	P1=0.199 P2=0.166 P3=0.163 **P4=0.012** **P5=0.018** P6=0.981
C (AMP.) Mean±SD Median(IQR)	-0.63±0.4 -0.6(-0.8-0.4)	-0.61±0.46 -0.4(-0.7-0.4)	-0.56±0.2 -0.4(0.5-0.3)	-0.54±0.3 -0.5(-0.8-0.3)	5.466	0.141	P1=0.399 P2=0.079 P3=0.022 P4=0.642 P5=0.283 P6=0.437
D (AMP.) Mean±SD Median(IQR)	-0.72±1.6 -0.5(-0.6-0.3)	-0.53±0.3 -0.5(-0.8-0.3)	-0.49±0.28 -0.5(-0.6-0.3)	-0.49±0.4 -0.5(-0.6-0.2)	0.525	0.913	P1=0.713 P2=0.978 P3=0.642 P4=0.628 P5=0.579 P6=0.648
E (AMP.) Mean±SD Median(IQR)	-0.51±0.3 -0.5(-0.6-0.4)	-0.47±0.4 -0.4(-0.6-0.3)	-0.46±0.35 -0.4(-0.6-0.3)	-0.44±0.4 -0.3(-0.7-0.1)	3.300	0.348	P1=0.211 P2=0.988 P3=0.437 P4=0.087 P5=0.196 P6=0.642
F (AMP.) Mean±SD Median(IQR)	-0.53±0.35 -0.4(-0.8-0.3)	-0.48±0.4 -0.4(-0.7-0.2)	-0.46±0.3 -0.4(-0.6-0.3)	-0.34±0.3 -0.3(-0.6-0.2)	6.968	0.073	P1=0.037 P2=0.606 P3=0.867 P4=0.017 P5=0.102 P6=0.359
O (amp.) Mean±SD Median(IQR)	-0.65±0.4 -0.6(-0.9-0.3)	-0.5±0.37 -0.4(-0.6-0.2)	-0.48±0.5 -0.4(-0.6-0.2)	-0.45±0.3 -0.4(-0.6-0.3)	9.118	0.028	**P1=0.008** **P2=0.010** P3=0.045 P4=0.788 P5=0.696 P6=0.514

P1= quiet Vs. SNR+10, P2= quiet Vs. SNR 0, P3= quiet Vs. SNR-10,
P4= SNR+10 vs. SNR 0, P5= SNR+10 vs. SNR -10, P6= SNR 0 vs. SNR-10

Moreover, there were no significant correlations between the dichotic digits test and S-ABR **(Table 7).**

Table (7): Correlation between Dichotic Digits Test and S-ABR waves in study group

S-ABR		Dichotic Digits Test Version 1		Dichotic Digits Test Version 2	
		R	P	R	P
V	latency	0.02	0.9	-0.02	0.88
	Amplitude	0.05	0.76	0.03	0.86
A	latency	-0.03	0.82	-0.18	0.23
	Amplitude	0.02	0.89	0.14	0.35
C	latency	0.1	0.87	-0.06	0.67
	Amplitude	0.3	0.83	0.15	0.33
D	latency	-0.08	0.61	-0.06	0.71
	Amplitude	0.74	0.13	0.09	0.53
E	latency	-0.26	0.08	-0.08	0.64
	Amplitude	0.26	0.08	0.04	0.77
F	latency	-0.09	0.53	-0.27	0.07
	Amplitude	0.30	0.76	0.25	0.09
O	latency	-0.11	0.45	-0.19	0.22
	Amplitude	0.16	0.28	0.01	0.92

DISCUSSION

When compared to healthy individuals, people with the SNHL have a lower ability to hear speech in noisy environments. These findings are in accordance with those of **Abd El Hai *et al.*** **[8],** who found that individuals with hearing loss, even those with mild hearing loss, are more difficult to hear in noisy environments than their hearing-impaired peers.

Comparison of S-ABR waves amplitudes and latencies between control and study groups revealed statistically significant differences primarily in the onset waves (V, A), wave (F), and offset wave (O). These results are in agreement with numerous studies[8-10]. **Ghannoum *et al.***[10] found that waves V, A, and F were significantly delayed in the study group compared to their controls. Wave F amplitude was statistically significantly reduced in both ears of the test group compared to the controls. The amplitudes of waves D and E were statistically significantly lower than their controls. It was concluded that abnormalities in speech signal encoding in the brainstem are reflected in Speech-ABR response parameters affection [10]**.**

Moossavi *et al.* [11] reported that speech ABR had been recorded with reduced amplitude and increased latency of waves, in people with SNHL. The effects of sensorineural hearing loss were more pronounced by increasing latency of initiating and transient parts of the response and lower changes reported in the frequency following response (FFR) part. However, patients with central auditory processing disorder had changes in the onset, the consonant-vowel (CV) transition and the sustained part, which suggested the possibility that this test can be used to diagnose and monitor the rehabilitation outcomes of the patients with central auditory processing disorder.

Complex signals (such as speech) are processed differently by hearing-impaired people than they are by hearing-normal people. Cochlear, eighth nerve, brainstem, and/or auditory cortex abnormalities may be to blame for processing difficulties. The auditory nervous system changes depending on the severity and duration of hearing loss. Neuronal responses must be synced to accurately encode the spectro-temporal structure of speech. To better understand the neural basis of speech perception, evoked responses depend on synchronous activation. One of the most promising audiological techniques for studying the brainstem temporal encoding of speech is Speech-ABR (S-ABR) [12]**.**

Ahadi *et al.* [13] found that compared to control groups, musicians and rehabilitated individuals with musical exercises had better harmonic representation and lower onset wave latency. People who are bilingual or multilingual have better wave morphology than monolinguals, to be able to distinguish between the sounds of different objects in different languages, they require a more accurate representation of F0. Compared to monolinguals, bilinguals and multilinguals have stronger cortical to subcortical level connections in the presence of noise.

In the present study, we tried to describe the relationships between the neural encoding of speech in noise at subcortical level and behavioral measures in neural hearing (NH) and SNHL adults.

In the current study, better SPIN performance in

SNHL correlated with earlier response timing and larger response amplitude of S-ABR transition, FFR, and offset peaks. These results are in agreement with **Parbery-Clark *et al.*** [14] who found that better speech-in-noise performance using the hearing in noise test (HINT) correlated with earlier onset and earlier transition peak response timing of S-ABR. Subcortical encoding and speech-in-noise perception have a strong correlation. Key neural aspects of speech perception in noise are provided by these electrophysiological events.

Additionally, the auditory efferent system plays a role in the allocation of cognitive resources for selective auditory attention. Selective attention tends to focus cognitive resources on one stimulus among several simultaneous non-target stimuli [3]**.** In this study, dichotic digits test was used as a valid behavioral tool for evaluating selective attention. The correlation between speech ABR and dichotic digits test revealed negative correlation with waves latency and positive correlation with waves amplitude.

CONCLUSIONS

The results suggest that Speech-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-up.

RECOMMENDATIONS

There is a need for further studies on different auditory disorders and different groups with higher auditory processing skills, such as musicians and multilinguals, to better understand the role of Speech-ABR in evaluating auditory excitation pathway evaluation.

Financial support and sponsorship: Nil.
Conflict of interest: Nil.

REFERENCES

1. **Di Girolamo S, Napolitano B, Alessandrini M *et al.* (2007):** Experimental and clinical aspects of the efferent auditory system. In Operative Neuromodulation. Springer, Vienna. Pp. 419- 424. https://ebin.pub/operative-neuromodulation-volume-2-neural-networks-surgery-1st-edition-9783211998861-3211998861.html
2. **Suthakar K (2017):** Changes to the Descending Auditory System in Hearing Loss: Focus on Auditory Efferents. Pp. 95-116. https://unsworks.unsw.edu.au/entities/publication/bec4c93e-cf7e-4312-bbb2-f45ca2296379/full
3. **Lotfi Y, Moossavi A, Javanbakht M *et al.* (2019):** Speech-ABR in contralateral noise: A potential tool to evaluate rostral part of the auditory efferent system. Medical Hypotheses, 132: 109355.
4. **Koravand A, Al Osman R, Rivest V *et al.* (2017):** Speech-evoked auditory brainstem responses in children with hearing loss. International Journal of Pediatric Otorhinolaryngology, 99: 24-29.
5. **Musiek F, Chermak G (2015):** Psychophysical and behavioral peripheral and central auditory tests. Handbook of Clinical Neurology, 129: 313-332.
6. **Tawfik S, Shehata W, Shalaby A (1992):** Development of Arabic speech intelligibility in noise test (Arabic SPIN). Ain Shams Medical J., 43: 10-12.
7. **Tawfik S, Abdel-Maksoud A, Weiheha, H. (2008):** Standardization of two binaural dichotic digits and dichotic rhyme tests on normal children. International Association of Logopedics and Phoniatric, 16: 416-19.
8. **Abd El Hai R, Elmahallawy T, Kolkaila E *et al.* (2017):** Studying the 'cocktail party problem' using subjective and neurophysiologic measures. Menoufia Medical Journal, 30(2):456-59.
9. **Musiek F, Chermak G (2015):** Psychophysical and behavioral peripheral and central auditory tests. Handbook of Clinical Neurology, 129:313-32.
10. **Ghannoum M, Shalaby A, Dabbous A *et al.* (2014):** Speech evoked auditory brainstem response in learning disabled children. Hearing, Balance and Communication, 12(3): 31-35.
11. **Moossavi A, Lotfi Y, Javanbakht M *et al.* (2019):** Speech-evoked auditory brainstem response: a review of stimulation and acquisition parameters. Auditory and Vestibular Research, 28(2):75-86.
12. **Kraus N, Nicol T (2005):** Brainstem origins for cortical ''what'' and ''where'' pathways in the auditory system. Trends Neurosci., 28:176–181.
13. **Ahadi M, Pourbakht A, Jafari A *et al.* (2014):** Effects of stimulus presentation mode and subcortical laterality in speech-evoked auditory brainstem responses. International Journal of Audiology, 53(4):243-9.
14. **Parbery-Clark A, Marmel F, Bair J *et al.* (2011):** What subcortical–cortical relationships tell us about processing speech in noise. European Journal of Neuroscience, 33(3):549-57.