Zagazig University Medical Journal
www.zumj.journals.ekb.eg
https://doi.org/10.21608/zumj.2024.234154.2873 Volume 30, Issue 6, Sept. 2024
Manuscript ID ZUMJ-2405-3418
DOI 10.21608/ZUMJ.2024.293709.3418
ORIGINAL ARTICLE.

Psychoacoustic and Electrophysiologic Auditory Neural Encoding in School-aged Children with Mild to Moderate Sensorineural Hearing Loss

Ahmed Mohamed El-Sayed Khater[1], Ola Abdallah Ibraheem[1], Fatma Ahmed Salem Eljetlawi[2],Dina Mamdouh Zein Elabdein[1]

[1]Audio-Vestibular Medicine, E.N.T. Department, Faculty of medicine,Zagazig university, Zagazig, Egypt

[2](M.B., B.C.H), Faculty of Medicine-Misurata University-Libya

Corresponding Author
Fatma Ahmed Salem Eljetlawi

Email fgetlawy@gmail.com

Submit Date 29-05-2024
Accept Date 02-06-2024

ABSTRACT

Background: Sensorineural hearing loss (SNHL) in children could impact speech processing along different levels of the auditory pathway; subcortical and cortical. The most frequently used psychoacoustic tests for temporal resolution and ordering evaluation are Gaps-In-Noise (GIN) and Pitch Pattern Sequence (PPS) tests. Moreover, speech-evoked auditory brainstem response (speech-ABR) represents an electrophysiologic test of brainstem speech processing.

Aim: To study the impactof mild to moderate SNHL on speech neural encoding in school-aged children, using psychoacoustic (GIN and PPS) and electrophysiological (speech-ABR) tests and to estimate the accuracy of the psychoacoustic and electrophysiological tests in the diagnosis of temporal processing deficit.

Methods: This observational, case-control study involved 30 school-aged children who were classified into; control group of normal-hearing children and study group of 20 children with mild to moderate SNHL. They were subjected to history-data reporting, basic audiological testing, and both psychoacoustic and electrophysiologic evaluation of the temporal auditory processing.

Results: In comparison to the control group,there were significantlyhigherapproximate threshold (APT) measure of GIN test in the moderate SNHL subgroups, lower total correct score measure of GIN test at a lower (mild) degree of SNHL, lower PPS scores as the hearing threshold increased above normal, and longer speech-ABR latency in the moderate SNHL subgroup. All the examined measures revealed a high accuracy with the APT measure of the GIN test showing the highest accuracy (92%).

Conclusions: The psychoacoustic and electrophysiologic evaluation provided evidence of temporal auditory processing impairment in children with SNHL.

Keywords: Children, Sensorineural hearing loss, Speech-evoked auditory brainstem response, Gaps-In-Noise test, Pitch Pattern Sequence test

INTRODUCTION

Sensorineural hearing loss (SNHL) constrains proper speech processing, especially in children. This presents as impaired audibility through hearing threshold elevation and restricted auditory processing abilities via imprecise coding of spectral and temporal acoustic cues **[1]**. The auditory temporal processing (ATP) is responsible for this spectral and temporal coding. Therefore, it is important to detect and discriminate syllables, phonemes, stress patterns, and speech in noise. ATP complements other central auditory processing functions in

speech processing. These functions involve discrimination, pattern recognition, and performance with acoustic interference. There are four subcomponents of ATP: temporal ordering, temporal resolution, temporal integration, and temporal masking **[2,3]**.

Temporal resolution refers to the minimum time required to segregate or resolve acoustic events **[4]**. It is closely related to the intelligibility of speech **[5]**. Furthermore, temporal ordering is a fundamental complex cognitive skill that allows one to perceive and organize sequences of events and actions **[6]**. Sensorineural hearing impairment, especially during childhood, could impair temporal resolution and ordering with a subsequent negative impact on acquired speech and language **[7]**.

As a consequence of the complex structure of the central auditory nervous system (CANS), peripheral auditory lesions (e.g. SNHL) may affect speech processing at different levels of the auditory pathway, subcortical and cortical. Consequently, a psychoacoustic and objective test battery is needed to evaluate speech processing within the auditory pathway in children with SNHL. Among the frequently used psychoacoustic tests are Gaps-In-Noise (GIN) and Pitch Pattern Sequence (PPS) tests that evaluate temporal resolution and ordering **[8,9]**. The electrophysiologic speech-evoked auditory brainstem response (speech-ABR) also evaluates speech processing at the subcortical level **[10]**.

The GIN test is an easily applied clinical measure that investigates temporal resolution with high accuracy **[11,8]**. Furthermore, the PPS test is a clinical measure that can be applied at different ages to evaluate temporal ordering that is responsible for properly recognizing, identifying, and sequencing auditory patterns **[12]**. Consequently, both GIN and PPS tests represent efficient tools in the diagnosis of temporal resolution and ordering deficits, respectively, in the pediatric population **[13]**. Moreover, speech-ABR is an objective, non-invasive test that can be used to assess temporal aspects of speech processing. It reflects neural activities of the auditory system at the subcortical level **[10]**. This test could complement the psychoacoustic test results in evaluating speech processing in children with SNHL.

The research is growing about the consequence of SNHL on neural encoding of speech in the pediatric population. Behavioral evaluation provides reasonable accuracy in evaluating ATP at a cortical level. However, it is challenging for very young children who are difficult to test behaviorally. Additionally, the outcomes of electrophysiological testing could provide a suitable approach to evaluate neural encoding of speech in very young children. Therefore, the current study attempts to 1) evaluate the effect of mild to moderate SNHL on cortical and subcortical auditory neural encoding in school-aged children, using psychoacoustic (GIN and PPS) and electrophysiological (speech-ABR) tests and 2) determine the accuracy of the psychoacoustic and electrophysiological tests in ATP deficit evaluation in this population.

METHODS

Participants

Thirty school-aged children, 6-12 years old, of both genders participated in this study. They were selected from children attending the Audio-Vestibular Medicine Unit, at Zagazig University and were categorized into control and study groups. The control group included 10 children with normal peripheral hearing sensitivity. The study group included 20 children with bilateral mild to moderate SNHL across the frequency range 250–8000 Hz. They were divided into two subgroups depending on the degree of hearing loss (10 with mild SNHL [Pure tone average (PTA: 21-30 dB)] and 10 with moderate SNHL [(PTA average: 31-55 dB)] **[14]**. All participants gave no history of neurologic illness or head trauma. They had no conductive, mixed, or syndromic hearing loss, with no medical, mental, or neurological illness.

Equipment

The audiological evaluation was performed using an immittancemeter, PATH medical SOD1100497; a diagnostic two-channel audiometer, Amplivox270+; and an auditory-evoked potential system, Duet Intelligent Hearing System. A cassette tape recorder and a CD player were connected to the audiometer and adjusted to deliver recorded material of GIN and PPS tests. A locally-made sound-

treated booth was used to implement audiometry and psychoacoustic testing.

Procedure

This observational, case-control study was conducted from June 2023 to December 2023, after obtaining approval from the Institutional Review Board of Zagazig University (ZU-IRB ID#:10801/17-5-2023). Written consents were obtained from the parents of all participants before testing. All children were subjected to full history taking, otoscopic examination to ensure intact external auditory canal and tympanic membrane, basic audiological testing, psychoacoustic ATP (PPS and GIN) tests, and electrophysiologic evaluation with speech-ABR. These examinations required about two hours to be completed for each child.

- **Basic audiological evaluation**

Pure-tone audiometry involved air conduction stimulation at the octave frequencies 250 Hz through 8000 Hz and bone conduction stimulation at 500 Hz through 4000 Hz. Speech audiometry encompassed the speech reception threshold (SRT) test using the Arabic Bisyllabic Words for children and the word recognition score (WRS) test using the Arabic Phonetically Balanced Kinder Garden Words for children **[15]**. Immittancemetery included tympanometry and acoustic reflex threshold determination that has been elicited using pure tones of 500, 1000, 2000, and 4000Hz.

- **Psychoacoustic ATP testing**

1- Gaps-In-Noise (GIN) test:

The GIN test involves a series of six broad-band noise segments, each containing zero to three silent gaps. The gap has 2, 3, 4, 5, 6, 8, 10, 12, 15, or 20 ms durations. Each is presented six times within a list. Four lists are available for testing **[8]**. Ten practice items precede the administration of the test. The test was delivered monaurally via headphones through one channel at 30-50 dB SL (referenced to SRT) (according to the child's tolerance and hearing level). The second channel was linked to a bone oscillator at a very low intensity (-10 dB SL) to alert the examiner about the gaps' incidence. The GIN test required about ten minutes in each ear to be completed. The child was instructed to count the gaps per each segment of noise correctly and elevate his fingers with each detected gap. Test scoring includes 1) the approximate threshold (APT) which represents the least gap duration indicated by the child four out of six times and 2) the total correct score (TCS) % out of the total number of gaps for each ear **[16]**.

2- Pitch pattern sequence (PPS) test:

The PPS test consists of a pattern of three tones. Tones are either of high (H: 1122 Hz) or low (L: 880 Hz) frequency, 150 ms duration each, with 200 ms intervals between them. The tones are arranged in one of six patterns: HHL, HLL, HLH, LLH, LHH, and LHL. Thirty sequences were presented monaurally at a level of 30-50 dB SL (referenced to SRT) (according to the child's tolerance and hearing level). Each child was asked to verbally label the three-tone pitch patterns, using the words high and low. A percent correct score is derived for each ear separately.

- **Electrophysiological evaluation (speech-ABR)**

The speech-ABR data for both ears were recorded in quiet. Children were instructed to stay relaxed while lying on a comfortable bed. An abrasive skin gel was used to decrease impedance and improve the conductivity and tracing. The electrode montage involved a non-inverting electrode placed on the upper forehead (Fpz), an inverting electrode on the ipsilateral mastoid, and a ground electrode on the contralateral mastoid, depending on the recording side. Electrode impedance was kept below 3 KOhms.

The /da/ stimulus (a CV syllable with 40 ms duration) was delivered via insert earphones with alternating polarity at a rate of 11.1/second. The stimulus was presented at 60 dB nHL for the control group and adjusted up to 80 dB nHL for the hearing loss group. The time window was 150 ms and the filter was 100-3000 Hz. Two traces, each containing 2000 sweeps, were obtained from each ear. Thereafter, the speech-ABR seven peaks and troughs (V, A, C, D, E, F, and O) were detected and marked. The latency and amplitude measures as well as the V–A complex measures (the V-A duration, interpeak amplitude, and slope [interpeak amplitude/duration]) of the speech-ABR waves were calculated and analyzed.

STATISCAL ANALYSIS

All data were collected, tabulated, and statistically analyzed using the IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.2015. Quantitative data were shown as mean ± standard deviation (SD), range, and 95% confidence limits (CL), whereas qualitative data were presented as numbers and percentages. As data were normally distributed, paired sample t-test compared ears' data, and One-Way-ANOVA test compared groups' variables. The least significant difference (LSD) of the post-hoc test determined which groups significantly differed from each other when an ANOVA test was significant. The chi-square test estimated the distribution of categorical variables. The validity of study tests was illustrated by calculating the sensitivity, specificity, positive predictive value, and accuracy measures. Moreover, the receiver operating characteristic (ROC) curve was displayed for a more effective assessment of accuracy. The significance level was set for *p* values < 0.05..

RESULTS

Personal and history-related criteria are presented in **Tables 1 and 2**. All children had bilateral type A tympanogram with preserved acoustic reflexes at 0.5, 1, 2, and 4 kHz in both ears of the control and the mild SNHL study subgroup. The reflexes were elevated or absent in the moderate SNHL subgroup. The mean pure tone thresholds at 0.25 through 8 kHz of the control and the two study subgroups exhibited significant differences ($p< 0.05$) in both ears **(Figure 1)**. Speech audiometry revealed SRT and WRS% that match the pure-tone average threshold.

Effect of SNHL on ATP

Table 3 shows a statistically significant elevation of APT measure in the moderate SNHL subgroup when compared to the control group and a statistically significant reduction of TCS measures in the mild and moderate study subgroups when compared to the control group. Additionally, PPS test scores become significantly poorer when the degree of hearing loss increases.On the other hand, the electrophysiologic evaluation reveals significantly longer speech-ABR waves' latency measures in the moderate SNHL group as compared to the control group and the mild SNHL subgroup **(Table 4)**. However, the amplitude measures did not differ among the three groups **(Table 5)**.

Accuracy of GIN, PPS, and speech-ABR (latency) tests in the evaluation of ATP in children with SNHL

A paired sample t-test was used to compare data between the right and left ears and revealed a statistically non-significant difference ($p>0.05$) in the three tests. Therefore, data from both ears was combined to estimate the validity. Validity measures **(Table 6)** and ROC curve analysis demonstrate a sensitivity of GIN test measures (APT and TCS) of 100%. The specificity of APT is 85% and that of TCS is 75%. The APT measure of GIN test shows the best accuracy (92%) **(Supplementary Figure 1)**. The sensitivity of PPS test is found to be 60%, while the specificity is 80%, with an accuracy of 82% **(Supplementary Figure 2)**. The sensitivity of speech-ABR latency measures ranges from 75% to 100% while the specificity ranges from 60% to 90%. The best accuracy is for wave F then C, D, E, and then V, A, O latencies, and V-A duration, with an accuracy range of 80%-88% **(Supplementary Figure 3).**

Table 1: Mean age and gender distribution of both groups.

Demographic data		Control group (n=10)	Study group		Test value	*p*-value
			Mild SNHL (n=10)	Moderate SNHL (n=10)		
Age (years)	**Mean ±SD**	9.90±1.79	10.00± 1.94	10.70±1.16	**0.68***	0.51
	Range	7-12	6-12	9-12		
Gender [n (%)]	**Females**	4(40%)	4(40%)	4(40%)	#	-
	Males	6(60%)	6(60%)	6(60%)		

*F- value of One-Way-ANOVA; # X^2 -value of Chi-square test.
***Abbreviations*:** SD = standard deviation.

Table 2: History-related data of the study subgroups.

History-related variables		Study group	
		Mild SNHL (n=10)	Moderate SNHL (n=10)
Family history [n (%)]	**Positive**	5(50%)	4(40%)
	Negative	5(50%)	6(60%)
Hyperbilirubinemia [n (%)]	**Positive**	1(10%)	4(40%)
	Negative	9(90%)	6(60%)
Low birth weight [n (%)]	**Positive**	1(10%)	1(10%)
	Negative	9(90%)	9(90%)
Fever [n (%)]	**Positive**	2(20%)	2(20%)
	Negative	8(80%)	8(80%)
Age of onset of hearing loss (years)	**Mean ±SD**	6.40±1.43	7.00±2.16
	Range	3-8	4-10
Duration of hearing loss (years)	**Mean ±SD**	3.50±1.78	3.90±1.59
	Range	1-6	1-7

***Abbreviations*:** SD = standard deviation.

Table 3: Comparison of Psychoacoustic (GIN and PPS) tests' outcomes in the control and the two study subgroups.

Control and study subgroups			GIN test measure				PPS test measure	
			APT (ms)		TCS (%)		PPS score (%)	
			Rt	Lt	Rt	Lt	Rt	Lt
Control group (n=10)	Mean ±SD Range		4.50±0.53 4-5	4.51±0.53 4-5	76.63±2.37 73.3-81.66	76.79 ±2.69 71.6-81.66	86.69±3.85 80-93.33	85.63±4.48 80-93.33
	95% CL	L	4.11	4.10	74.91	74.92	83.94	82.42
		U	4.92	4.91	78.33	78.71	89.45	88.83
Mild SNHL (n=10)	Mean ±SD Range		5.11±0.74 4-6	5.03±0.67 4-6	68.53±8.38 53-77	68.86±7.93 53-77	79.33±4.66 73.33-86.66	79.5±4.56 73-86.66
	95 % CL	L	4.63	4.52	62.50	63.21	76.00	76.3
		U	5.62	5.54	74.53	74.52	82.66	82.83
Moderate SNHL (n=10)	Mean ±SD Range		6.81 ± 1.03 6-8	6.60±0.97 6-8	57.95±4.0 53-63.33	60.97±1.15 60-63.33	74.83±3.34 70-80	73.93±4.1 70-80
	95 % CI	L	6.14	5.91	55.12	61.10	72.44	70.99
		U	7.52	7.32	60.81	61.82	77.22	76.87
F			22.63	21.82	28.62	26.31	٢٢.55	17.78
p-value			**< 0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
LSD			P1= ٠.257 **P2٠<.001 P3٠<.001**	P1= ٠.337 **P2<٠.001 P3<٠.001**	**P1<0.011 P2<0.001 P3<0.001**	**P1 = 0.005 P2<0.001 P3٠=.005**	**P1= 0.001 P2 < 0.001 P3 <0.0٥**	**P1< 0.05 P2< 0.001 P3< 0.0٥**

***Abbreviations*:** GIN test = Gaps-in-noise test; APT = approximate threshold; TCS% = Total correct scores%;PPS = Pitch Pattern Sequence test; Rt = Right; Lt = Left;SD = Standard deviation; 95%CL = 95% confidence limits; L= lower limit; U= upper limit; LSD = least significant difference.

(***P1: compare control group and mild SNHL), (P2: compare control group and moderate SNHL), (P3: compare mild SNHL and moderate SNHL).***

Table 4:Comparison of speech-ABR waves' latency measures (ms) in the control and the two study subgroups.

Speech-ABR waves' latency measures (ms)				Control group (n=10)	Study group		F	*p*-value	LSD
					Mild SNHL (n=10)	Moderate SNHL (n=10)			
V	Rt	Mean ±SD Range		6.96±0.5 6.33-7.65	7.64±0.55 6.47-8.25	8.32±0.86 7.4-9.7	10.8	**<0.001**	P1= 0.09 **P2 <0.001** P3= 0.08
		95%CL	L	6.61	7.22	7.72			
			U	7.32	8.00	8.93			
	Lt	Mean ±SD Range		7.63±0.41 6.53-7.75	7.02±0.49 6.25-7.65	8.21±0.64 7.65-9.6	16.73	**<0.001**	P1= 0.99 **P2 <0.001** **P3 <0.001**
		95%CL	L	6.77-	6.67	7.75			
			U	7.36-	7.37	8.67			
A	Rt	Mean ±SD Range		7.95±0.77 6.35-8.85	9.15±1.62 7.35-11.85	10.85±0.82 9.3-11.44	16.43	**<0.001**	P1= 0.08 **P2< 0.001** **P3 =0.009**
		95%CL	L	7.40	7.99	10.27			
			U	8.50	10.31	11.44			
	Lt	Mean ±SD Range		7.98±0.61 6.57-8.75	8.26±0.93 7.47-9.6	10.62±2.04 8.55-13.2	11.68	**<0.001**	P1= 0.89 **P2 <0.001** **P3 =0.002**
		95%CL	L	7.54	7.60	9.16			
			U	8.42	8.93	12.08			
V-A duration	Rt	Mean ±SD Range		1.1 ±0.32 0.8-1.68	1.08±0.35 0.6-1.68	2.55±0.97 1.41-4	7.545	**0.002**	P1= 0.99 **P2<0.001** **P3 <0.001**
		95%CL	L	0.87	0.83	1.9			
			U	1.33	1.33	3.2-			
	Lt	Mean ±SD Range		1.04±0.34 0.70-1.65	0.97±0.36 0.6-1.64	2.26±1.36 0.75-4	6.985	**0.004**	P1=0.99 **P2<0.001** **P3<0.001**
		95%CL	L	0.789	0.71	1.29			
			U	1.28	1.23	3.23			
C	Rt	Mean ±SD Range		18.64±0.79 17.55-19.8	19.45±2.33 17.55-22.95	21.87±2.07 19.8-24.75	8.24	**0.002**	P1 = 0.63 **P2 =0.002** **P3 = 0.02**
		95% CL	L	18.07	17.78	20.39			
			U	19.21	21.11	23.36			
	Lt	Mean ±SD Range		18.69±1.29 16.15-21.42	18.39±1.76 16.15-21	21.61±1.58 20.3-24.3	13.14	**< 0.001**	P1= 0.91 **P2 < 0.001** **P3 < 0.001**
		95% CL	L	17.76	17.124	20.49			
			U	19.612	19.65	22.74			
D	Rt	Mean ±SD Range		23.31±2.45 20.55-28.55	23.86±5.03 20.45-31.95	29.95±3.99 24.45-34.4	8.63	**0.001**	P1 =0.95 **P2= 0.004** **P3 =0.008**
		95%CL	L	21.55	20.26	27.09			

		L	U	25.06	27.46	32.80			
	Lt	Mean ±SD Range		23.02±2.44 20.4-28.95	22.74±2.17 20.42-25.85	29.33±4.29 23.44-35.55	14.32	<0.001	P1 = 0.98 P2 <0.001 P3 <0.001
		95%CL	L	21.27	21.19	26.26			
			U	24.77	24.29	32.397			
E	Rt	Mean ±SD Range		30.55 ±3.01 28.05-38.55	32.82±5.16 28.75-41.75	38.47±4.34 32.4-42.55	9.17	0.001	P1 = 0.50 P2 = 0.001 P2 = 0.022
		95%CL	L	28.39	29.13	35.37			
			U	32.71	36.503	41.58			
	Lt	Mean ±SD Range		30.29 ±1.77 27.45-33.6	31.26±2.63 27.45-35.95	38.18±4.56 32.25-43.95	18.00	< 0.001	P1= 0.798 P2 < 0.001 P3< 0.001
		95%CL	L	29.03	29.38	34.92			
			U	31.57	33.14	41.44			
F	Rt	Mean ±SD Range		39.12 ±2.98 37.3-47.35	41.13±4.11 37.95-47.95	47.63±4.24 40.35-51.6	13.60	< 0.001	P1= 0.51 P2 < 0.001 P3 = 0.003
		95%CL	L	36.99	38.19	44.61			
			U	41.26	44.07	50.67			
	Lt	Mean ±SD Range		38.4 ±0.84 37.35-39.65	41.34±3.96 37.35-47.95	46.425±3.00 41.35-50.1	19.44	< 0.001	P1= 0.10 P2< 0.001 P3 = 0.002
		95%CL	L	37.80	38.50	44.28			
			U	39.00	44.17	48.57			
O	Rt	Mean ±SD Range		47.30±4.84 37.12-57.35	50.41±4.48 46.5-57.45	57.01±4.54 49.35-61.5	11.59	< 0.001	P1=0.34 P2 < 0.001 P3 = 0.01
		95%CL	L	43.85	47.20	53.80			
			U	50.76	53.62	60.29			
	Lt	Mean ±SD Range		47.16 ±3.25 38.2-49.99	50.31±5.51 39.01-57.95	56.26±3.76 47.9-59.7	11.79	< 0.001	P1= 0.34 P2 < 0.001 P3 =0.01
		95%CL	L	44.84	46.09	53.57			
			U	49.49	53.97	58.95			

***Abbreviations*:** SD = Standard deviation; 95%CL= 95% Confidence limits; Rt = right; Lt = left; L = lower limit; U = upper limit; Speech-ABR = speech-evoked auditory brainstem response; LSD = least significant difference.

(P1: compare control and mild SNHL), (P2: compare control and moderate SNHL),* (*P3: compare mild HLand moderate SNHL).

Table 5: Comparison of speech-ABR waves' amplitude measures (μV) in the control and the two study subgroups.

Speech-ABR amplitude measures (μV)				Control group (n=10)	Study group		F	*p*-value
					Mild SNHL (n=10)	Moderate SNHL (n=10)		
V-A amplitude	Rt	Mean ±SD Range		0.26±0.05 0.21-0.37	0.26±0.03 0.21-0.3	23.00±0.04 0.13-0.27	2.01	0.15
		95%CL	L	0.23	0.24	0.23		
			U	0.30	0.28	0.26		
	Lt	Mean ±SD Range		0.21±.06 0.15-0.36	0.2±0.03 0.15-0.25	0.18±0.03 0.13-0.23	1.15	0.24
		95%CL	L	0.17	0.18	0.15		
			U	0.26	0.22	0.20		
V-A slope	Rt	Mean ±SD Range		0.24±0.08 0.13-0.37	0.27±0.31 0.13-1.2	0.17±0.08 0.1-0.32	2.82	0.08
		95%CL	L	0.19	0.14	0.11		
			U	0.30	0.59	0.22		
	Lt	Mean ±SD Range		0.21±0.07 0.1-0.32	0.27±0.26 0.12-1	0.17±0.08 0.1-0.31	2.67	0.10
		95%CL	L	0.17	0.19	0.11		
			U	0.26	0.55	0.22		
C	Rt	Mean ±SD Range		0.11±0.05 0.07-0.2	0.13±0.08 0.06-0.32	0.09±0.01 0.07-0.1	1.87	0.17
		95%CL	L	0.08	0.08	0.08		
			U	0.15	0.19	0.09		
	Lt	Mean ±SD Range		0.13±0.04 0.08-0.21	0.12±.06 0.04-0.22	0.09±0.01 0.07-0.1	2.71	0.09
		95%CL	L	0.10	0.08	0.08		
			U	0.13	0.16	0.09		
D	Rt	Mean ±SD Range		00.18±0.04 0.13-0.24	0.17±0.021 0.13-0.19	0.15±0.02 0.1-0.18	2.82	0.08
		95%CL	L	0.16	0.13	0.13		
			U	0.21	0.15	0.17		
	Lt	Mean ±SD Range		0.19±0.05 0.14-0.26	0.17±0.06 0.08-0.26	0.15±0.03 0.1-0.19	2.24	0.13
		95%CL	L	0.16	0.13	0.13		
			U	0.23	0.21	0.17		
E	Rt	Mean ±SD Range		0.28±0.09 0.19-0.42	0.28±0.09 0.2-0.42	0.23±0.04 0.13-0.25	2.66	0.07
		95%CL	L	0.22	0.24	0.16		
			U	0.34	0.37	0.24		
	Lt	Mean ±SD Range		0.25±0.03 0.22-0.29	0.23±0.06 0.16-0.35	0.21±0.04 0.13-0.24	2.01	0.16
		95%CL	L	0.23	0.19	0.16		
			U	0.27	0.28	0.23		
F	Rt	Mean ±SD Range		0.28±0.07 0.18-0.39	0.26±0.09 0.11-0.35	0.24±0.06 0.1-0.3	2.88	0.08
		95%CL	L	0.23	0.16	0.11		
			U	0.33	0.29	0.25		
	Lt	Mean ±SD Range		0.22±0.04 0.16-0.29	0.20±0.03 0.13-0.23	0.18±0.06 0.1-0.29	1.25	0.12

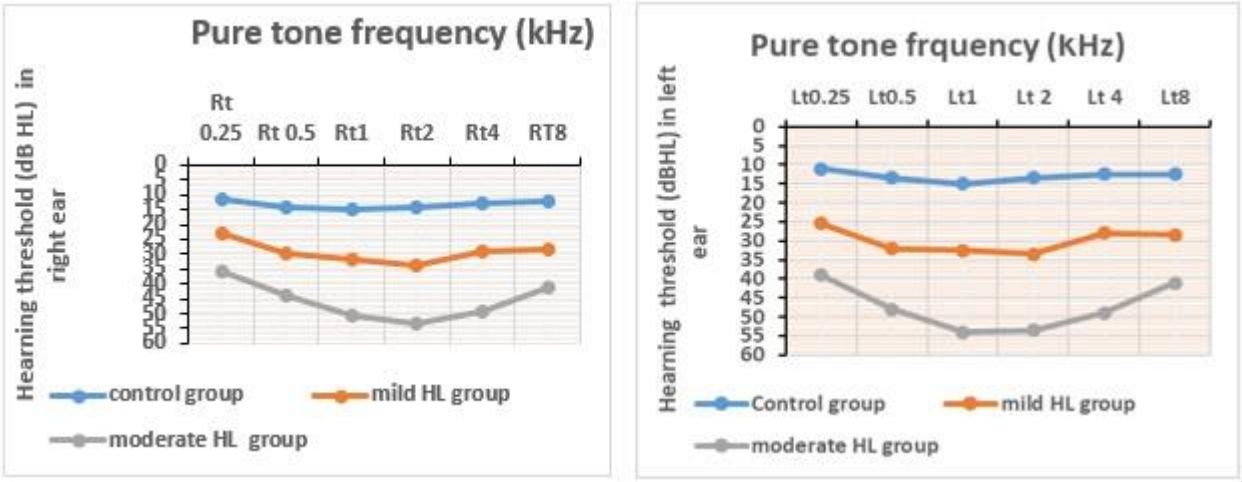
		95%CL	L	0.19	0.15	0.11		
			U	0.25	0.20	0.21		
O	Rt	Mean ±SD Range		0.22±.08 0.11-0.31	0.22±0.07 0.13-0.3	0.19±.05 0.08-0.23	1.87	0.11
		95%CL	L	0.16	0.18	0.11		
			U	0.27	0.28	0.21		
	Lt	Mean ±SD Range		0.18±0. 05 0.09-0.27	0.17±0.05 0.12-0.24	0.14±0.03 0.1-0.17	2.56	0.10
		95%CI	L	0.14	0.14	0.12		
			U	0.22	0.20	0.16		

***Abbreviations*:** Rt = right; Lt = left; SD = Standard deviation; 95% CL = 95% confidence limits; L= lower limit; U= upper limit; Speech-ABR = speech-evoked auditory brainstem response.

Table (6):Validity of psychoacoustic (GIN and PPS) and electrophysiologic (speech-ABR [latency measures]) tests in the evaluation of temporal auditory processing deficit in the study group.

Test		Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Accuracy (%)
GIN	APT (ms)	100%	85%	80%	92%
	TCS (%)	100%	75%	80%	83%
PPS	PPS score (%)	60%	80%	75%	82%
Speech-ABR latency measures (ms)	Wave V	95%	60%	70.4%	85%
	Wave A	85%	90%	93.9%	85%
	V-A duration	75%	85%	83.3%	80%
	Wave C	100%	70%	76.9%	87%
	Wave D	100%	70%	76.9%	87%
	Wave E	100%	70%	76.9%	85%
	Wave F	100%	70%	76.9%	88%
	Wave O	85%	65%	70.8%	85%

Abbreviations: GIN test = Gaps-in-Noise test; APT = Approximate threshold; TCS = Total correct score %; PPS = Pitch Pattern Sequence test; Speech-ABR = speech-evoked auditory brainstem response.



***Abbreviations*:** Rt = Right, Lt = Left.

Figure 1:Comparison of the mean value of pure-tone thresholds (in dB HL) at the audiometric frequency range in the control and study groups.

DISCUSSION

Early detection and proper management of SNHL are essential for the development of normal language and psychosocial functioning. One main objective of the current study was to study the effect of mild to moderate SNHL on ATP at different levels of the auditory pathway in school-aged children.We started the psychoacoustic evaluation with the GIN test that was adopted in literature to easily and reliably examine temporal resolution ability in children **[8,1].** Two indices of the GIN test were obtained: APT and TCS. Appropriate presentation levels were applied for GIN stimuli to abolish the impact of impaired audibility. An important finding in this study was the reduced performance in the GIN test measures, especially the TCS markedly reduced even with a mild degree of hearing loss. This could be attributed to the calculation method of TCS that involves all gaps detected, even when they are lower than APT **(Table 3).**

These findings agree with that of **Ismaail et al. [1]** who examined 30 children with moderate to moderately severe SNHL, aged 6-16 years old. They demonstrated significantly poorer temporal resolution ability [(APT: Rt= 9.86±2.67, Lt= 10.30± 2.61; TCS: Rt= 47.22 ± 12.71, Lt= 45.69 ± 12.58)] than children with normal hearing. The outcomes of **Ismaail et al. [1]** are even poorer than our results. This could be related to the older age of children and the higher degree of SNHL in their study with the presence of dead regions in some cases. Poorer temporal resolution ability in children with SNHL suggests central auditory changes caused by SNHL due to alteration of both membrane properties and synaptic transmission throughout the CANS **[17]**.

Another psychoacoustic test used in this study is the PPS test which examines the ability to properly recognize, identify, and sequence auditory patterns. **Musiek and Chermak [18]** found the PPS test as an excellent tool to use with young children aged 8 years and older. In the current study, the PPS test exhibited lower scores in both ears of the SNHL subgroups as compared to the normal-hearing children **(Table 3)**. These findings follow those of **Shabana et al. [19]**. Their study evaluated the frequency discrimination ability in 60 school-aged children with mild to moderate SNHL using the PPS test. They demonstrated poor performance with impaired PPS score %, reflecting poorer temporal ordering in children with SNHL in comparison to children with normal peripheral hearing.

Moreover, **Ji et al. [20]** examined the PPS test in 34 preschool children (mean age: 5.4± 0.9 years) with minimal and mild hearing loss (MMHL) of the sensorineural type. They denoted no difference between their control and study groups as regards PPS scores. They explained the non -significant differences between the two groups by presenting stimulus in a sound field environment, that evaluated both ears simultaneously where one ear could be of normal hearing. Thus, the functional status of the better ear may have resulted in insignificant differences. Additionally, the younger age and lower degree of hearing loss (as compared to the current study) could be a factor.

Overall, it can be stated that the presence of cochlear hearing loss has been found to have a detrimental effect on temporal resolution at the cortical level. Specifically, poor outcomes in the GIN and PPS tests have indicated this, with even worse results observed at higher degrees of hearing loss. This is due to decreased audibility caused by elevated hearing thresholds and impaired processing of auditory information due to imprecise encoding of temporal and spectral acoustic features.

Additionally, speech-ABR appears to be a very promising electrophysiologic measure to investigate the brainstem temporal encoding of speech at the subcortical level. The present study evaluated the speech-evoked potentials in children with mild to moderate SNHL to identify speech-processing deficits in such individuals. Therefore, the evaluation was performed in audible and comfortable stimulus intensity for the patients.

A comparison of speech-ABR latency measures showed comparable outcomes between the control group and the mild SNHL subgroup. However, the latency measures showed a significant delay in the moderate group **(Table 4)**. On the other hand, the amplitude measures were comparable among the studied groups **(Table 5)**.

In the literature, there were relative variabilities in the outcomes of speech-ABR among children with SNHL. The main causing factor could be differences in the age and the degree and configuration of hearing loss. In this respect, **Jalaei and Zakaria [21]** examined speech-ABR using 40-ms /da/ syllable at 30 dB SL, in 17 children (4-9 years old) with bilateral moderate-to-severe sloping SNHL. Following our findings, they reported delayed latencies in children with SNHL for

onset peaks (V and A) and transition portion (peak C) as compared to age-matched normal-hearing children. However, in contrast to our results, latencies of the sustained components (peaks D, E, and F) and offset peak (O) were not affected by SNHL, whereas the VA inter-peak amplitude was smaller and the VA slope was steeper in the SNHL group.

The variable outcomes between the two studies could be related to the younger mean age of the children (7.1± 1.8 years) in **Jalaei and Zakaria [21]** and different degrees and configurations of hearing loss. Their higher degree of hearing loss especially in the high-frequency region would alter the high-frequency consonant perception. However, in the current study, the hearing loss exhibited a flat configuration, affecting both high and low-frequency regions of the cochlea, thereby affecting latency measures of all components of speech-ABR. Moreover, the lower degree of hearing loss in this study did not significantly impact the neural synchronization to an extent that could affect the amplitude measures.

Similarly, **Ji et al. [20]** investigated speech-ABR, using /da/ syllable as a stimulus, presented at 80 dB SPL to 34 preschool children (4-6 years old) with MMHL. There were delayed latencies of wave A, C, E, and O and smaller amplitude of wave A in the study group as compared to the age-matching, normal hearing control group. The relative differences between **Ji et al. [20]** and the present study could be attributed to methodological variabilities (different ages and degrees of hearing loss).

The electrophysiologic results of the current study showed that speech-ABR latencies are more sensitive to mild to moderate SNHL than amplitude measures. Moreover, latency abnormalities involved all components of speech-ABR, involving transient, transitional, and sustained portions. This delayed subcortical neural timing and signal transmission could suggest that the brainstem's temporal encoding of speech sounds, including stop consonants and vowels, is markedly impaired in children with SNHL. This impaired speech encoding may be a factor in the decreased ability of children with hearing loss to understand conversations in their everyday lives.

Another objective of this study was to estimate the accuracy of the psychoacoustic tests and speech-ABR in the assessment of ATP in children with SNHL. The sensitivity of GIN test measures was found to be 100%. The specificity of APT was 85% and that of TCS was 75%. The APT measure of GIN test outcomes showed the best accuracy (92%). In addition, the sensitivity of the PPS test was found to be 60% while the specificity was 80% with an accuracy of 82% **(Table 6)**.

Likewise, **Fillipini et al. [22]** demonstrated GIN test consistency among different neurological cases. GIN test showed good sensitivity and specificity rates. It was overall accurate in differentiating patients with neuro-auditory lesions from norms. Among the available studies, sensitivity rates of the GIN test varied from 40% to 94%, whereas specificity rates ranged from 65% to 97%. Moreover, the accuracy of the PPS test in estimating frequency pattern recognition and temporal ordering has been studied. The cut-off point for young people with normal hearing was ≥76% **[23].** Therefore, GIN and PPS tests are denoted to be clinically effective measures that provide insight into the integrity of CANS and may aid in the clinical diagnosis of impaired ATP in pediatrics with SNHL.

Based on validity statistics and ROC curve analysis, the sensitivity of speech-ABR latency measures ranged from 75% to 100% while the specificity ranged from 60% to 90%, with an accuracy range of 80%-88% **(Table 6)**.In this regard, **Rocha-Muniz et al. [24]** estimated the sensitivity and specificity in 25 children (6-12 years) with APD, for speech-ABR wave latencies. The sensitivity ranged between 36% to 84%, whereas the specificity ranged between 48% and 80%. The higher accuracy was for wave A latency (74%). The relatively higher accuracy values for speech-ABR latencies in the current study could be attributed to the SNHL in our pediatric participants, while those of **Rocha-Manz etal. [24]**had normal hearing. Therefore, the results revealed that speech-ABR could be used to identify neural encoding deficits in children with SNHL with high accuracy.

Limitations and difficulties

The sample size was relatively small and possibly more favorable outcomes would be obtained if more children could be involved. Speech-ABR test was challenging in some children due to frequent activity or distress, requiring additional sessions. Furthermore, the data were gathered from children of a limited age range (6 to 12 years) and different study outcomes might be obtained if different age groups are tested. Accordingly, it is of interest to see how the brainstem encoding of speech cues is affected by SNHL in younger and/or older children.

Conclusion

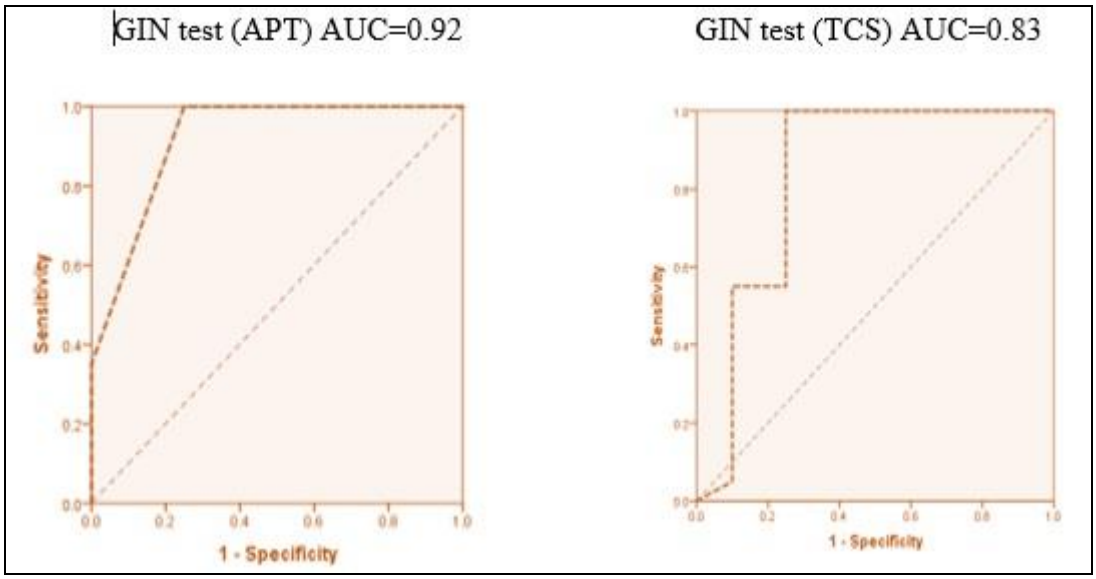
Psychoacoustic (GIN and PPS) and

electrophysiologic tests have an important role in the evaluation of ATP in children with SNHL. The APT measure of the GIN test showed the best accuracy (92%). However, other measures gave an appropriate accuracy that raises their importance in detecting ATP deficit. Consequently, combined administration of psychoacoustic and electrophysiologic tests would provide a thorough evaluation of speech neural encoding at different levels of the CANS with reasonable accuracy.

REFERENCES

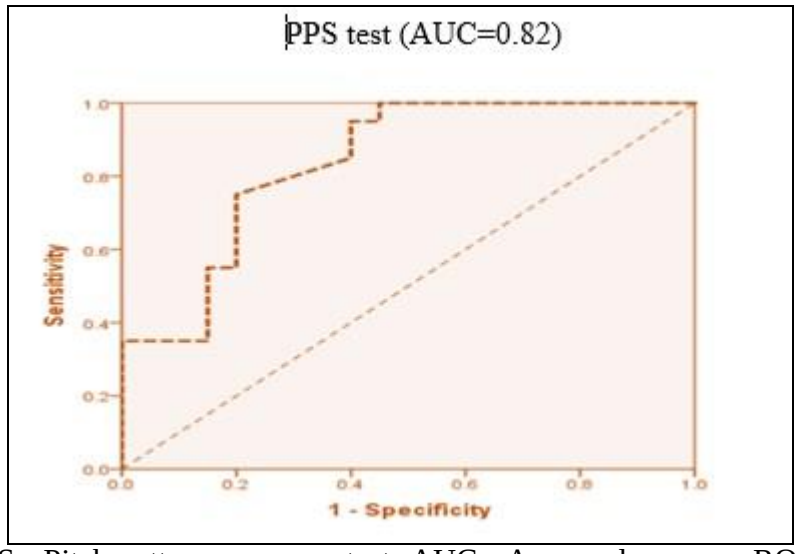
1. **Ismaail NM, Shalaby AA, Ibraheem OA, Elsayed AA E.** Temporal Resolution in School-Age Children with Cochlear Dead Regions. JAAA. 2019; DOI: 10.3766/jaaa.18004.
2. **American Speech–Language–Hearing Association**. Central auditory processing disorders [technical report] 2005. Available from: http://www.asha. org/docs/html/TR2005-00043.html.
3. **American Academy of Audiology**. American Academy of Audiology Clinical Practice Guidelines. Guidelines for the diagnosis, treatment and management of children and adults with central auditory processing disorder 2010. Available from: www.audiology.org.
4. **Shinn J.** Temporal processing: the basics. The Hearing Journal 2003; 56(7): 52.
5. **Eggermont J.** Neural responses in primary auditory cortex mimic psychophysical, across-frequency-channel, gap-detection thresholds. J. Neurophysiol. 2006; 84(3):1453-63.
6. **Toplak M, Dockstader C, Tannock R**. Temporal information processing in ADHD: Findings to date and new methods. J. Neurosci. Methods. 2006; 15(1): 15–29.
7. **Moore B**. Dead regions in the cochlea: Diagnosis, perceptual consequences, and implications for the fitting of hearing aids. Trends in Amplification 1998; 5: 1–34.
8. **Musiek F, Shinn J, Jirsa B, Bamio D, Baran J, Zaidan E.** GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. Ear and Hearing 2005; 26(6): 608-18.
9. **Musiek F, Pinheiro M.** Frequency patterns in cochlear, brainstem, and cerebral lesions. Audiology. 1989;6: 78-88.
10. **Koravand A., Al Osman R., Rivest V, Poulin C.** Speech-evoked auditory brainstem responses in children with hearing loss. Int. J. Pediatr. Otorhinolaryngol. 2017; 99: 24-9.
11. **Chermak G, Lee J**. Comparison of children's performance on four tests of temporal resolution. JAAA. 2005; 16:554–63.
12. **Emanuel DC, Ficca KN, Korczak P:** Survey of the diagnosis and management of auditory processing disorder. Am. J. Audiol. 2011.Available from: https://doi.org/10.1044/1059-0889(2011/10-0019).
13. **Shinn J, Chermak G, Musiek F.** GIN (Gaps-In-Noise) Performance in the Pediatric Population. JAAA. 2009; 20:229–38.
14. **Soliman S, El-Mahallawy T.** Simple speech test material as a predictor for speech reception threshold in preschool children 1984; Unpublished Master Thesis, Ain Shams University, Egypt.
15. **World Health Organization**. Childhood hearing loss: strategies for prevention and care 2016. Available from: http://www.who.int/iris/ handle/ 10665/ 204632.
16. **Jennifer BA**. Temporal processing tests: In: Musiek FE, Chermak GD, eds. Handbook of central auditory processing disorder: Auditory neuroscience and diagnosis. vol. 1, 2nd edition, chapter 15. Plural Publishing: San Diego; 2013: 414-745.
17. **Wang Y, Manis PB**. Temporal coding by cochlear nucleus bushy cells in DBA/2J mice with early onset hearing loss. JARO. 2006; 7, 412-24.
18. **Musiek FE, Chermak GD**: Psychophysical and behavioral peripheral and central auditory tests. In: Michael JA, François B, Dick FS, eds. Handbook of clinical neurology. vol. 129, chapter 18. Elsevier;2005: 313-32.
19. **Shabana MI, Shalaby AA., Dabbous AO, Emara AA. EM.** Does reduced frequency selectivity in children with mild to moderate sensorineural hearing loss affect frequency discrimination in Mismatch Negativity and Pitch Pattern Sequence Tests? Audiol. Med. 2012;10(1), 40-49.
20. **Ji H, Yu X, Xiao Z, Zhu H, Liu P, Lin H. et al.** Features of cognitive ability and central auditory processing of preschool children with minimal and mild hearing loss. JSLHR. 2023; 66(5), 1867-88.
21. **Jalaeia B, Zakariab MN**. Speech-evoked auditory brainstem response in children with sensorineural hearing loss. GJO. 2019; 20(4), 71-80.
22. **Filippini R, Wong B, Schochat E, Musiek F**. GIN test: a meta-analysis on its neurodiagnostic value. JAAA. 2010;31(02), 147-57.
23. **Delecrode CR, Cardoso ACV, Frizzo ACF, Guida HL.** Pitch pattern sequence and duration pattern tests in Brazil: literature review. Revista CeFAC 2014; 16, 283-93.
24. **Rocha-Muniz CN, Befi-Lopes DM, Schochat E.** Sensitivity, specificity and efficiency of speech-evoked ABR. Hear. Res. 2014; 317, 15-22.

Supplementary data



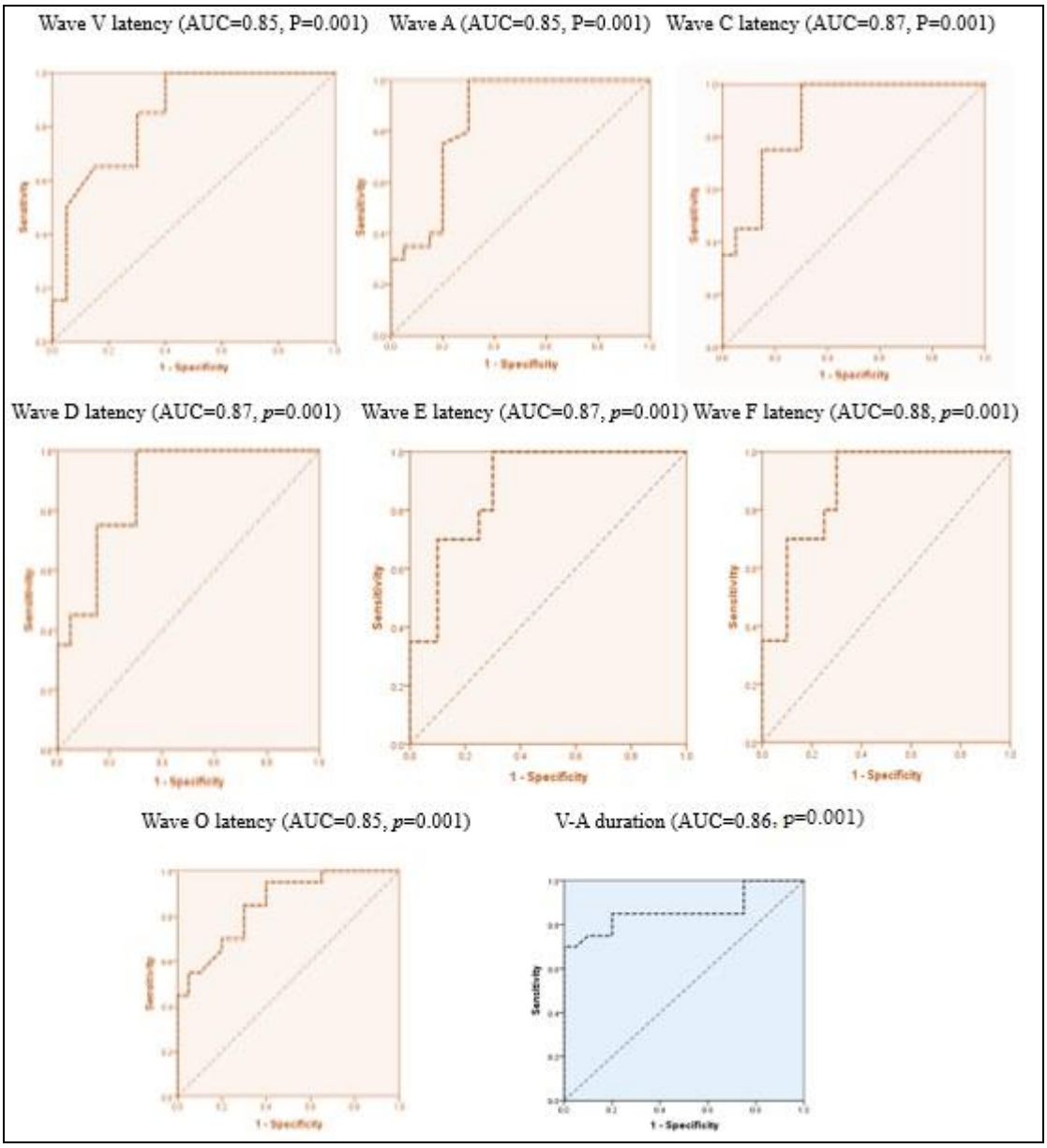
Abbreviations: GIN test =Gaps-in-noise test; APT = approximate threshold; TCS% = Total correct scores%; AUC= Area under curve; ROC curve= Receiver operating characteristic curve.

Supplementary Figure (1): ROC curve analysis of the validity of the GIN test (APT and TCS) in predicting temporal auditory processing deficit in children with SNHL.



Abbreviations: PPS= Pitch pattern sequence test; AUC= Area under curve; ROC curve= Receiver operating characteristic curve.

Supplementary Figure (2): ROC curve analysis of the validity of the PPS test in predicting temporal processing deficit in children with SNHL.



Abbreviations: AUC= Area under curve; ROC curve= Receiver operating characteristic curve.

Supplementary Figure (3): ROC curve analysis of the validity of speech-ABR latency measures in predicting temporal processing deficit in children with SNHL.

Citation:

Khater, A., Ibraheem, O., Eljetlawi, F., Zein Elabdein, D. Psychoacoustic and electrophysiologic auditory neural encoding in school-aged children with mild to moderate sensorineural hearing loss. *Zagazig University Medical Journal*, 2024;2392 (2392-2406): -. doi: 10.21608/zumj.2024.293709.3418