Auditory Processing Abilities of Children who Stutter: Effect of Speech Therapy

Original Article

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ABSTRACT

Backround: Auditory processing difficulties are frequently reported among children who stutter.

Objective: This work aims to examine auditory processing abilities in children who stutter, before and after speech therapy, in order to assess the possibility of any improvement of their auditory processing after speech therapy.

Patients and Methods: Auditory processing abilities of 60 children, who stutter, in the age range of 8 – 14 years, have been examined before and after speech therapy, by fluency shaping program for three months. The performed tests included; Dichotic Digit Test (DDT), Pitch Pattern Sequence Test (PPST), Speech In Noise Test (children version) (SPIN), Gap In Noise Test (GIN) in addition to Speech-Auditory Brain Stem Response (s-ABR).

Results: Impaired auditory processing abilities as noticed in temporal ordering (PPST) and resolution (GIN), and auditory closure (SPIN), together with lack of / or reversed laterality (DDT). After submission to speech therapy, significant shift of laterality had been achieved (DDT) (*P value: 0.004*) with tendency to improvement of other abilities except PPST. Results of sABR showed impaired onset (waves V&A), offset (wave O), and transition response (wave C) with non-significant left ear preference (reversed laterality). Reevaluation after speech therapy revealed improvement in the amplitude of the offset (wave O) and transition response (wave C) with non significant tendency to right ear preference (restoration of laterality).

Conclusion: Enhancement of auditory processing abilities of children who stutter can be achieved by speech therapy.

Key Words: Auditory processing, fluency shaping, s-ABR, stuttering.

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INTRODUCTION

Stuttering dysfluencies are characterized by frequent repetitions, prolongations and/or blockages in the flow of speech (Shapiro, 2011)[1]. Plenty of theories and assumptions have been provided and extensively examined to explain the underlying etiology of stuttering. Apart from genetic predisposition, the neural auditory processing deficit is considered the most accepted theory (Jansson-Verkasalo *et al*., 2010)[2]. Developmental stuttering has a prevalence of 5% and a tendency toward recovery by adolescence to reach a prevalence rate of 1% in the adult population (Boyle, 2015)[3].

Radiological studies performed on individuals who stutter showed anomalous structure and function of the brain areas responsible for speech production and auditory processing (chang *et al*., 2008 and Etchell *et al*., 2018)[4&5] with impaired lateralization of speech function (Brown *et al*., 2005)[6]. These anomalies involves planum temporale (Foundas *et al*., 2004)[7] and multiple anomalous loci in the perisylvian speech-language areas (Jancke *et al*., 2004)[8]. Neuman *et al*. (2003)[9] explained the pathophysiology of stuttering by the neural breakdown between temporal lobe (responsible for auditory processing), left inferior frontal, premotor and motor cortices (responsible for articulatory programming and motor preparation), in addition to disconnection between premotor sensory area and motor language area.

The reduced prevalence of stuttering among hearing impaired population together with the importance of auditory feedback for ongoing correction of speech production and verbal fluency, have directed the researchers to investigate the auditory processing abilities of individuals who stutter (Villacorta *et al*., 2007)[10]. Difficulties in auditory processing abilities among individuals who stutter have been measured using behavioral and electrophysiological tests (Jansson-Verkasalo *et al*., 2014)[11]. Frequently used behavioral tests are; dichotic digit test (DDT) (Robb *et al*., 2013)[12] for sound localization and lateralization, gap in noise test (GIN) (Devaraju *et al*., 2019)[13] for

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auditory temporal discrimination and resolution, speech intelligibility perception in noise (SPIN) (Asal and Abdo, 2014)[14] for auditory closure, and pitch pattern sequence test (PPST) (Lotfi *et al*., 2020)[15] for temporal ordering or sequencing. Frequently used electrophysiological tests are cortical auditory evoked potentials (CAEPs) (Ismail *et al*., 2017)[16] and speech auditory brain stem response (sABR) (Mozaffarilegha *et al*., 2019)[17].

Therapy programs for stuttering were designed to modify symptoms of stuttering (stuttering modification) or to ameliorate them (fluency shaping). Stuttering modification techniques consider the moment of stuttering itself and the accompanying anxiety through loosely structured approach (Sidavi and Fabus, 2010)[18]. On the other hand, fluency shaping program adopts a highly structured approach that aims to establish fluency by gradually increasing fluent moments (Salihovikj *et al*., 2009)[19]. In the later approach, fluency enhancement is achieved by slowing speech rate and regulating breath stream to maintain easy phonation and breathy articulation (Ward, 2008)[20].

Moreover Kell *et al*. (2009)[21] used fMRI to study the neural activity of individuals who stutter after recovery, whether they received speech therapy or not. They declared that the impaired neural activity could improve with recovery of stuttering. They also postulated that developmental plasticity would help the unassisted recovery from stuttering and intensive speech therapy had assisted in the peri-anomalous reorganization of the affected brain areas.

To date changes or improvement of auditory processing abilities after speech therapy have not been examined.

The aim of this work is to examine auditory processing abilities in children who stutter, before and after speech therapy, in order to assess the possibility of any improvement of their auditory processing after speech therapy.

PATIENTS AND METHODS:

This study was performed on 120 child in the age range of 8-14 years (to avoid contamination of the sample by cases with physiological dysfluencies).Sixty child with variable degrees of stuttering severity and sixty fluent child as a control group for tests of central auditory processing. They were selected conveniently from patients who visited the Phoniatric outpatient clinic in Al Zahraa University Hospital in the period from March 2017 through February 2020.

Children who underwent previous speech therapy for stuttering, children with phonological or language impairment, and children with neurological, otological and/or audiological disorders that may interfere with central auditory processing were excluded from the study.

All children underwent full history taking andauditory perceptual assessment of the child's speech and language, visual assessment of associated movements and/or reactions, measuring speech rate (number of words per minutes) and assessment of stuttering severity using Arabic stuttering severity instrument (ASSI) (Rifaie, 1999)[27], psychometric evaluation using the Stanford Binet Intelligence Scale (4th ed.) (Melika, 1998)[39], basic audiological evaluation, and behavioral and electrophysiological central auditory processing evaluation.

Behavioral Central Auditory processing (CAP) tests: The child was seated in the sound treated room. Each test was presented by TDH-39 headphones and CD for each test was used and connected to two channels audiometer Piano Plus (Inventis) using Dell laptop. Four central tests were done as follows: Dichotic Digit Test (DDT) (Musiek, 1983)[22] which involves the simultaneous presentation of different digits to each of the two ears (2 digits in version I; 4 digits in version II). Pitch Pattern Sequence Test (PPST) (Musiek FE, Pinheiro,1989)[23] contains 60 frequency patterns presented monaurally. The pattern is composed of three tones of different combinations,where there are always two similar tones and a different one. Thus, there are six possible combinations of three-tone sequence (LLH, LHL, LHH, HLH, HLL and HHLSpeech in Noise Test (children version) (SPIN). A list of 12 meaning Arabic sentences presented monaurally with ipsilateral speech noise, the signal to noise ratio (SNR) is 0 dB which indicates that sound pressure level of speech is equal to overall noise level (Tawfik and Shalaby, 1995)[24]. Finally, Gap in Noise Test (GIN), is composed of a series of six sec segments of broad band noise (Musiek *et al*., 2005)[25]. Each segment contains zero to three silent gaps per noise segment. The gap durations presented are 2, 3, 4, 5, 6, 8, 10, 12, 15 and 20 ms. The child was instructed tocount the gaps per each segment of noise correctly and elevate his fingers according to number of gaps that he can detect. All tests were presented at 50 dB SL. The numbers of correctly repeated responses for each test were counted and calculated as a percentage score for each ear.

Electrophysiological evaluation (s-ABR): Children were seated in a comfortable reclining chair with lights dimmed and removing other electrical devices to eliminate electrical artifacts. Children were asked to relax with their eyes closed to reduce muscle artifacts, but in awakening state. Skin over the forehead and mastoids was cleaned by abrasive gel to reduce electrode impedance. Four disposable electrodes were fixed according to the EP25 (Interacoustics) manual specification. The sweep number used is 3000 sweeps with recording time window 75 ms (-15 to 60 ms) and band pass filters from 150-1500 Hz. Consonant-vowel (CV) da/ stimulus was used with the stimulus intensity 80 dB nHL and repetition rate was 7.4 per second(Skoe and Kraus, 2010)[26]. The stimuli were presented monaurally through insert earphones ER-3A.

Analysis of the Response:At least two recordings of s-ABR responses were obtained for each ear to determine high replicability. Afterwards, the responses were manually exported from Eclipse EP 25 (Interacoustics) as XML files, which were exchanged to M files using 1024 digital sampling points of the response. M files were applied on Brainstem Toolbox 2010 and analyzed using MATLAB 2017a (version 9.2, MathWorks Inc., Natick, MA, US) (Figure 1).

Responses were analyzed into prominent waves/peaks, latencies and amplitudes, transient measures, sustained measures (frequency following response), root mean square and cross correlations (stimulus to response correlation).

Seven prominent waves were identified: One positive peak (wave V) and six negative peaks (waves A, C, D, E, F and O). Absolute latency and amplitude of each peak was detected. Transient response is composed of waves V, A, C and O. Transient response includes onset (waves V, A and probably C) and offset responses (wave O). Further analysis of the onset response, included V/A complex (latency, amplitude, area and slope) was done.

Frequency following response (FFR) was analyzed in terms of magnitude of F0 and F1.

All the participants had received speech therapy for 3 months, using Arabic fluency shaping program (Rifaie *et al*, 2016)[41], and were reevaluated by central auditory tests.

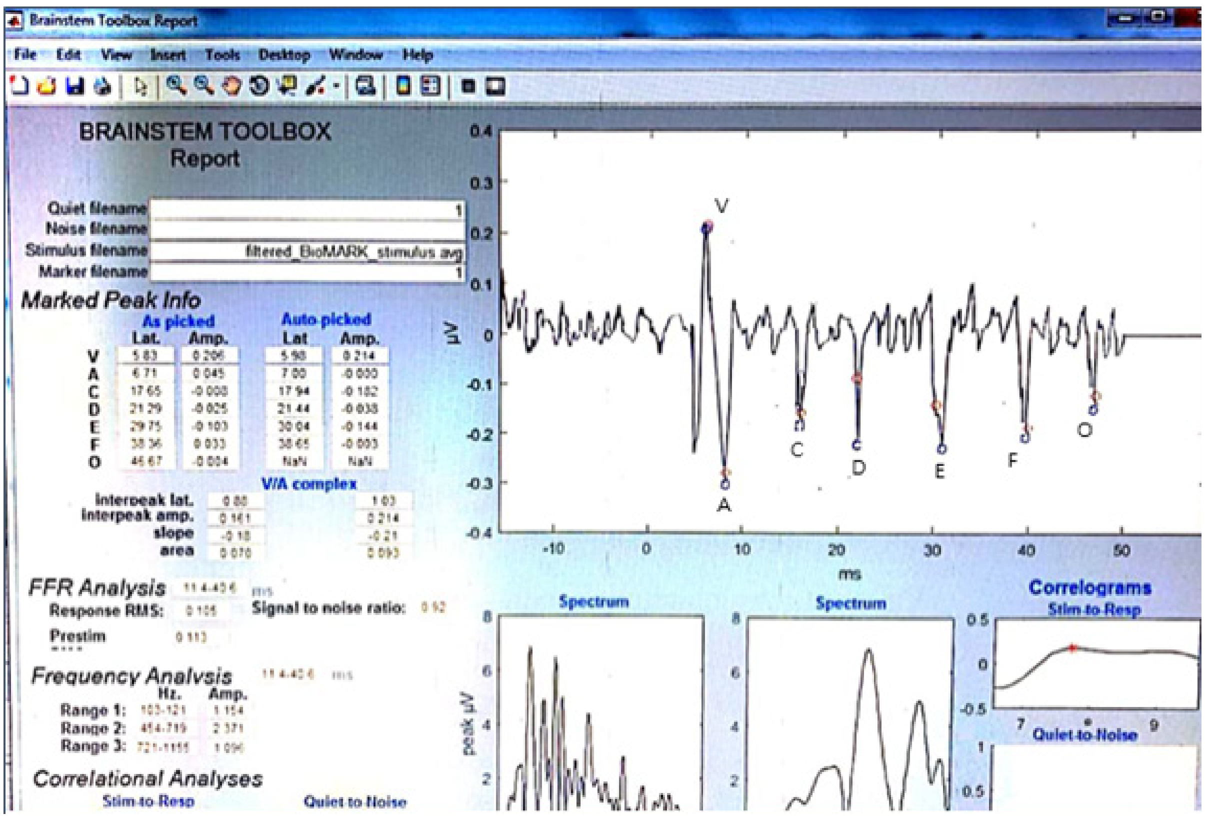

Fig. 1: Matlab analysis of s-ABR

RESULTS:

Table (1): Demographic data of study group:

There were no statistically significant differences as regard age, gender and handedness distribution among study and control groups.

Table (2): DDT scores:

There was no statistically significant difference in DDT version I and II scores of study (Pre therapy) versus control groups in both ears.

Table (3): PPST scores:

There was statistically significant difference in PPST score of study group (Pre) therapy versus control in both ear.

Table (4): SPIN test scores:

There was no statistically significant difference in SPIN score of study Pre therapy versus control group in both ears.

Table (5): GIN test thresholds and scores:

There were statistically significant differences in GIN test score and threshold in study group (Pre) therapy versus control group.

After speech therapy, denote a tendency to improvement but did not reach a statistically significant level, when compared to pre therapy evaluation in all behavioral central tests

Right versus left ear (Pre therapy): There were statistically significant differences, in right versus left ear responses, in all the behavioral central tests in study group.

Right versus left ears post therapy: the differences between the right and left ear, denote a tendency to improvement after speech therapy but did not reach a statistically significant level, when compared to pre therapy evaluation in all behavioral central tests except PPSTwhich showed statistically significant difference in right versus left ear scores after speech therapy.

Table (6): Detectability of s-ABR waves (C and O):

There were highly statistically significant differences in waves C and O detectability of study group Pre therapy versus control group. The differences in waves C and O detectability after speech therapy denote a tendency to improvement after speech therapy. Although,they did not reach a statistically significant level.

Table (7): Absolute latencies of s-ABR waves (ms) in study (Pre therapy) versus control groups:

There were statistically significant differences in waves V and A latencies of study group (pre therapy) than control groupin both ears. There were statistically significant differences of waves C and O latencies in both ears in study group (Pre therapy) versus control.

Table (8): Absolute amplitudes of s-ABR (μv) in study group (Pre therapy) versus control: There were statistically significant differences in waves C and O amplitudes in both ears of study group (Pre therapy) versus control.

Table (9): Absolute latencies of s-ABR waves (ms) in study group Pre versus Post therapy:

The differences in latencies, of all waves, denote a tendency to improvement after speech therapy. Although, they did not reach a statistically significant level.

Right versus left ears: The differences in latencies, between right and left ears, did not reach a statistically significant level after speech therapy when compared to pre therapy levels.

Table (10): Absolute amplitudes of s-ABR (μv) in study group Pre versus Post therapy:There were statistically significant differences in waves C and O amplitudes in both ears of study group after speech therapy when compared to pre therapy.

Right versus left ears: There was statistically significant difference in wave C amplitude in right versus left ears after speech therapy when compared to pre therapy.

Table (11): VA complex of s-ABR:

There were statistically significant differences in duration, amplitudes, slope and area of VA complex in study group (Pre therapy) than control in both ears.

Right versus left ears:There were statistically non-significant differences in VA complex of right versus left ears in study group Pre therapy andcontrol group.

The differences in duration, amplitudes, slope and area of VA complex denote a tendency to improvement after speech therapy. Although, theydid not reach a statistically significant level.

Table (12): Advanced analysis of s-ABR:

The differences in stimulus to response correlation SNR, fundamental envelope (F0), RMS amplitude and fine temporal structure (F1) after speech therapy denote a tendency to improvement after speech therapy. Although, they did not reach a statistically significant level.

Right versus left ears: The differences between right and left ears, after speech therapy did not reach a statistically significant level when compared to pre therapy.

Table 1: Demographic data of study and control groups:

Item	Study (n = 60)		Control (n = 60)		Test of significance	*P value*
	No.	%	No.	%		
Age (years)						
Min. – Max.	8.0 14.0 –		8.0 14.0 –			
Mean ± SD.	11.27 ± 2.31		12.27 ±2.52		t = 0.876	0.543
Gender						
Male	44	73.3	41	68.3	X^2= 0.531	0.452
Female	16	26.7	19	31.7		
Handedness						
Right	56	93.3	60	100	X^2= 0.766	0.453
Left	4	6.7	0.0	0.0		
Family history						
Negative	40	66.7				
Positive	20	33.3				
Consanguinity						
Negative	44	73.3				
Positive	16	26.7				

No: numbers of children in each item, **%:** percent of detectability, n: number of children in each group, **Min:** minimum, **Max.:** maximum. **SD:** standard deviation, **t:** Paired t-test, **X^2** = Chi square test, *P> 0.05* statistically insignificant,***:** statistically significant *P<0.05*, ****:** highly statistically significant *P<0.01*.

Table 2: DDT scores: in study group (Pretherapy) versus control group and in study group pre and post therapy:

DDT	Side	Study Group (Pretherapy)	Control	t test	*p*
Version I	Right	90.83 ± 3.25	93.67 ± 4.42	0.240	0.871
	Left	91.82 ± 3.03	92.0 ± 3.87	0.356	0.663
	Rt vs Lt: p1	0.380	0.622		
Version II	Right	85.73 ± 1.25	91.67 ± 4.42	0.123	0.654
	Left	88.81 ± 1.3	90.0 ± 3.87	0.393	0.345
	Rt vs Lt: p1	0.004*	0.651		
DDT	Side	Study group		t test	*P value*
		Pre therapy	Post therapy		
Version I	Right	90.83 ± 3.25	92.83 ± 5.34	0.407	0.873
	Left	91.82 ± 3.03	91.73 ± 3.25	0.407	0.643
	Rt vs Lt: p_1	0.380	0.681		
Version II	Right	85.73 ± 1.25	89.63 ± 5.28	0.407	0.062
	Left	88.81 ± 1.3	88.82 ± 5.34	0.407	0.074
	Rt vs Lt: p_1	0.004*	0.672		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, **Rt:** right ear, **Lt:** left ear, **p1:** *p value* of student t test for detecting significance between both ears,***:** Statistically significant at *p ≤ 0.05*, ****:** highly statistically significant *P<0.01*, all values were displayed as mean and standard deviation

Table 3: PPST scores in study group (Pre) therapy versus control group and in study group (Pre) versus (Post)therapy:

PPST	Study Group (Pre)	Control	t test	*P*
Right	65.17 ± 2.63	84.22 ± 2.66	4.571*	0.003*
Left	69.0 ± 4.41	83.22 ± 2.34	3.437*	0.02*
Rt v-s Lt: p_1	0.04*	0.435		
PPST	Study group		t test	*P value*
	Pre therapy	Post therapy		
Right	65.17 ± 2.63	65.18 ± 3.59	0.950	0.342
Left	69.0 ± 4.41	69.1 ± 4.52	0.407	0.512
Rt vs Lt: p_1	0.04*	0.041*		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, Rt: right ear, **Lt:** left ear, **p1:** *p value* of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, values were displayed as mean and standard deviation

Table 4: SPIN test scores: in study group (Pre) therapy versus control group and in study group (Pre) versus (Post) therapy

SPIN	Study Group (Pretherapy)	Control	t	*P*
Right	85.0 ± 2.51	97.33 ± 3.72	0.579	0.762
Left	85.0 ± 3.84	95.23 ± 3.72	0.459	0.361
Rt vs Lt: p1	0.456	0.342		
SPIN	Study group		t test	*P value*
	Pre therapy	Post therapy		
Right	85.0 ± 2.51	89.0 ± 5.84	0.407	0.167
Left	85.0 ± 3.84	87.0 ± 3.02	0.407	0.263
Rt vs Lt: p_1	0.456	0.059		

t: student t test for comparing between both groups, **p:** p value of student t test for detecting significance between both groups, **Rt:** right ear, Lt: left ear, **p1:** p value of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, values were displayed as mean and standard deviation

Table 5: GIN test thresholds and scores:in study group (Pre) therapy versus control group and in study group (Pre) versus (Post) therapy

GIN	Side		Study Group (Pretherapy)	Control	t test	*p value*
Threshold	Right	Mean ±SD.	7.33 ± 0.69	4.33 ± 0.69	3.412*	0.042*
	Left	Mean ±SD.	7.60 ± 0.61	4.60 ± 0.61	4.517*	0.03*
	Rt vs Lt: p1		0.042*	0.212		
Total score	Right %	Mean ±SD.	20.47 ± 1.87	30.37 ± 3.81	5.434*	0.004*
		33.27 ±1.45	50.77 ± 4.45	4.407*	0.007*	
	Left %	Mean ±SD.	23.47 ± 1.95	28.47 ± 3.95	3.841*	0.005*
		36.77±1.91	48.77 ± 4.91	4.831*	0.006*	
	Rt vs Lt: p1		0.008*	0.248		
GIN	Side		Study group(Pre therapy)	Post therapy	t test	*p value*
Threshold	Right	Mean ± SD.	7.33 ± 0.69	7.32± 0.59	0.412	0.445
	Left	Mean ± SD.	7.60 ± 0.61	7.58 ± 0.52	0.517	0.437
	Rt vs Lt: p1		0.042*	0.052*		
Total score	Right %	Mean ± SD.	20.47 ± 1.87	20.77 ± 4.95	0.232	0.432
		33.27 ±1.45	33.37 ±3.41	0.677	0.637	
	Left %	Mean ± SD.	23.47 ± 1.95	23.41 ± 6.95	0.465	0.155
		36.77±1.91	36.21±2.56	0.512	0.687	
	Rt vs Lt: p1		0.008*	0.008*		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups,Rt: right ear, **Lt:** left ear, **p1:** *p value* of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, SD: standard deviation

Table 6: Detectability of s-ABR waves (C and O) : in study (Pre therapy) and control groups and in study group (Pre versus Posttherapy):

Detectability	Study group Pre therapy				Control group				X^2 test	*P value*
	Right (n=60)		Left (n=60)		Right (n=60)		Left (n=60)			
	No.	%	No.	%	No.	%	No.	%		
Wave C										
Absent	28	46.7	24	40	0.0	0.0	0.0	0.0	4.948^{*}	$<0.001^{**}$
Present	32	53.3	36	60	15	100	15	100	4.823^{*}	$<0.001^{**}$
Wave O										
Absent	16	26.7	12	20	0.0	0.0	0.0	0.0	4.731^{*}	$<0.001^{**}$
Present	44	73.3	48	80	15	100	15	100	4.342^{*}	$<0.001^{**}$
Detectability	Study group								X^2 test	*P value*
	Pre therapy				Posttherapy					
	Right (n=60)		Left (n=60)		Right (n=60)		Left (n=60)			
	No.	%	No.	%	No.	%	No.	%		
Wave C										
Absent	28	46.7	24	40	28	46.7	24	40		
Present	32	53.3	36	60	32	53.3	36	60		
Wave O										
Absent	16	26.7	12	20	13	21.7	10	16.7	0.123	0.988
Present	44	73.3	48	80	47	78.3	50	83.3	0.123	0.988

No: numbers of children, **%:** percent of detectability, **n:** number of children in each group, X^2= Chi square test, **p:** *p value* of student t test for detecting difference significance between both groups.

Table 7: Absolute latencies of s-ABR waves (ms) in study (Pre therapy) versus control groups:

Wave	Side	Study Group (Pre therapy)	Control	t test	P value
V	Right	6.82 ± 0.05	6.64 ± 0.06	2.855^{*}	0.006^{*}
	Left	6.80 ± 0.26	6.65 ± 0.07	3.190^{*}	0.002^{*}
	Rt vs Lt: P1	0.621	0.128		
A	Right	7.88 ± 0.11	7.61 ± 0.06	2.487^{*}	0.003^{*}
	Left	7.85 ± 0.11	7.63 ± 0.07	2.805^{*}	0.003^{*}
	Rt vs Lt: P1	0.137	0.438		
C	Right	18.69 ± 0.16.	18.11 ± 0.05	3.864	$<0.001^{**}$
	Left	18.65 ± 0.16	18.22 ± 0.06	2.647	0.022^{*}
	Rt vs Lt: P1	0.177	0.128		
D	Right	23. 29 ± 0.27	23.29 ± 0.29	0.677	0.768
	Left	23. 30 ± 0.26	23.30 ± 0.29	0.511	0.778
	Rt vs Lt: P1	0.612	0.743		
E	Right	30. 68 ± 0.27	30. 68 ± 0.24	0.346	0.678
	Left	30. 70 ± 0.25	30. 70 ± 0.24	0.518	0.788
	Rt vs Lt: P1	0.437	0.768		
F	Right	40. 30 ± 0.23	40. 30 ± 0.28	0.731	0.567
	Left	40. 32 ± 0.23	40. 32 ± 0.28	0.702	0.768
	Rt vs Lt: P1	0.347	0.732		
O	Right	48.83 ± 0.14	48.34 ± 0.09	5.446^{*}	$<0.001^{**}$
	Left	48.70 ± 0.15	48.36 ± 0.09	2.159^{*}	0.004^{*}
	Rt vs Lt: P1	0.671	0.762		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, **Rt:** right ear, **Lt:** left ear, **p1:** p value of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, all latencies were displayed as mean and standard deviation

Table 8: Absolute amplitudes of s-ABR (μv) in study group (Pre therapy) versus control:

Wave	Side	Study Group (Pre therapy)	Control	t test	*P value*
V	Right	0.29 ± 0.02	0.37 ± 0.02	0.255	0.191
	Left	0.32 ± 0.01	0.36± 0.02	0.271	0.138
	Rt vs Lt: p_1	0.234	0.214		
A	Right	0.28 ± 0.02	0.37 ± 0.02	0.234	0.352
	Left	0.32 ± 0.03	0.35 ± 0.04	0.434	0.434
	Rt vs Lt: p_1	0.561	0.463		
C	Right	0.16 ± 0.02	0.37 ± 0.04	2.74*	<0.004*
	Left	0.18 ± 0.02	0.35 ± 0.05	2.97*	<0.003*
	Rt vs Lt: p_1	0.342	0.324		
D	Right	0.34 ± 0.12	0.39 ± 0.04	0.530	0.123
	Left	0.36 ± 0.02	0.37 ± 0.02	0.918	0.423
	Rt vs Lt: p_1	0.034	0.342		
E	Right	0.44 ± 0.03	0.49± 0.04	0.437	0.067
	Left	0.46 ± 0.04	0.48 ± 0.02	0.753	0.061
	Rt vs Lt: p_1	0.565	0.341		
F	Right	0.47 ± 0.04	0.53 ± 0.04	0.427	0.067
	Left	0.49 ± 0.03	0.51 ± 0.03	0.191	0.476
	Rt vs Lt: p_1	0.551	0.121		
O	Right	0.33 ± 0.04	0.47 ± 0.04	2.47*	<0.003*
	Left	0.35 ± 0.05	0.44 ± 0.05	2.94*	<0.004*
	Rt vs Lt: p_1	0.234	0.237		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, **Rt:** right ear, Lt: left ear, **p1:** *p value* of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, all amplitudes were displayed as mean and standard deviation

Table 9: Absolute latencies of s-ABR waves (ms) in study group Pre versus Post therapy:

Wave	Side	Pre therapy	Post therapy	t test	*p value*
V	Right	6.82 ± 0.05	6.68 ± 0.05	0.856	0.06
	Left	6.80 ± 0.26	6.68 ± 0.06	0.464	0.07
	Rt vs Lt : p_1	0.621	0.712		
A	Right	7.88 ± 0.11	7.77 ± 0.12	0.407	0.123
	Left	7.85 ± 0.11	7.77 ± 0.11	0.588	0.432
	Rt vs Lt : p_1	0.137	0.453		
C	Right	18.69 ± 0.16.	18.60 ± 0.14	0.798	0.654
	Left	18.65 ± 0.16	18.60 ± 0.13	0.583	0.431
	Rt vs Lt : p_1	0.177	0.342		
D	Right	23. 29 ± 0.27	23.29 ± 0.26	0.530	0.641
	Left	23. 30 ± 0.26	23.30 ± 0.27	0.841	0.342
	Rt vs Lt : p_1	0.612	0.056		
E	Right	30. 68 ± 0.27	30. 68 ± 0.25	0.530	0.765
	Left	30. 70 ± 0.25	30. 70 ± 0.26	0.132	0.451
	Rt vs Lt : p_1	0.437	0.231		
F	Right	40. 30 ± 0.23	40. 30 ± 0.21	0.407	0.124
	Left	40. 32 ± 0.23	40. 32 ± 0.22	0.416	0.231
	Rt vs Lt : p_1	0.347	0.235		

O	Right	48.83 ± 0.14	48.70 ± 0.13	0.874	0.086
	Left	48.70 ± 0.15	48.60 ± 0.12	0.910	0.096
	Rt vs Lt : p_1	0.671	0.077		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, Rt: right ear, **Lt:** left ear, **p1:** *p value* of student t test for detecting significance between both ears,*: Statistically significant at $p \leq 0.05$, **: highly statistically significant $P<0.01$, all latencies were displayed as mean and standard deviation.

Table 10: Absolute amplitudes of s-ABR (μv) in study group Pre versus Post therapy:

Wave	Side	Pre therapy	Post therapy	t test	*P value*
V	Right	0.29 ± 0.02	0.35 ± 0.03	0.285	0.090
	Left	0.32 ± 0.01	0.35± 0.02	0.211	0.038
	Rt vs Lt: p_1	0.234	0.234		
A	Right	0.28 ± 0.02	0.34 ± 0.05	0.211	0.342
	Left	0.32 ± 0.03	0.34 ± 0.02	0.425	0.234
	Rt vs Lt: p_1	0.561	0.461		
C	Right	0.16 ± 0.02	0.38 ± 0.02	2.64*	0.004*
	Left	0.18 ± 0.02	0.28 ± 0.01	2.94*	0.003*
	Rt vs Lt: p_1	0.342	0.004*		
D	Right	0.34 ± 0.12	0.37 ± 0.03	0.130	0.023
	Left	0.36 ± 0.02	0.37 ± 0.02	0.998	0.453
	Rt vs Lt: p_1	0.034	0.345		
E	Right	0.44 ± 0.03	0.48 ± 0.04	0.407	0.082
	Left	0.46 ± 0.04	0.48 ± 0.03	0.752	0.065
	Rt vs Lt: p_1	0.565	0.481		
F	Right	0.47 ± 0.04	0.50 ± 0.04	0.407	0.023
	Left	0.49 ± 0.03	0.50 ± 0.02	0.091	0.432
	Rt vs Lt: p_1	0.551	0.471		
O	Right	0.33 ± 0.04	0.45 ± 0.04	2.27*	0.003*
	Left	0.35 ± 0.05	0.45 ± 0.05	2.91*	0.004*
	Rt vs Lt: p_1	0.234	0.067		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, **Rt:** right ear, **Lt:** left ear, **p1:** *p value* of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, all amplitudes were displayed as mean and standard deviation.

Table 11: VA complex of s-ABR in study group (Pre therapy) versus control group and in study group Pre versus Post therapy:

VA Complex	Side	Study Group (Pre therapy)	Control	t test	*P value*
Latency (Duration)	Right	1.18 ± 0.09	0.75 ± 0.04	6.738*	0.041*
	Left	1.16 ± 0.07	0.88 ± 0.09	6.697*	0.043*
	Rt vs Lt: p_1	0.652	0.122		
Amplitude	Right	0.16 ± 0. 04	0.23 ± 0. 04	3.095*	0.039*
	Left	0.19 ± 0.02	0.22 ± 0.02	2.939*	0.045*
	Rt vs Lt: p_1	0.352	0.431		
Slope (amp/dur)	Right	0.64 ± 0.04	1.54 ± 0.03	4.036*	0.043*
	Left	0.73 ± 0.04	1.51± 0.04	3.078*	0.034*
	Rt vs Lt: p_1	0.422	0.212		
Area (dur X amp)	Right	0.73 ± 0.03	1.45 ± 0.02	5.465*	0.032*
	Left	0.75 ± 0.02	1.23 ± 0.05	6.893*	0.043*
	Rt vs Lt: p_1	0.451	0.403		

VA Complex	Side	Pre therapy	Posttherapy	t test	*P value*
Latency (Duration)	Right	1.18 ± 0.09	1.12 ± 0.21	0.338	0.932
	Left	1.16 ± 0.07	1.14 ± 0.20	0.325	0122
	Rt vs Lt: p_1	0.652	0.058		
Amplitude	Right	0.16 ± 0. 04	0.22 ± 0.01	0.345	0.965
	Left	0.19 ± 0.02	0.20 ± 0.01	0.363	0.452
	Rt vs Lt: p_1	0.352	0.308		
Slope (amp/dur)	Right	0.64 ± 0.04	1.27 ± 20.74	0.312	0.432
	Left	0.73 ± 0.04	1.18 ± 18.01	0.334	0.674
	Rt vs Lt: p_1	0.422	0.238		
Area (dur x amp)	Right	0.73 ± 0.03	0.9 ± 0.01	0.317	0.732
	Left	0.75 ± 0.02	0.86 ± 0.02	0.677	0.233
	Rt vs Lt: p_1	0.451	0.126		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, **Rt:** right ear, **Lt:** left ear, **p1:** p value of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, all values were displayed as mean and standard deviation. **dur.:** duration, **amp.:** amplitude

Table 12: Advanced analysis of s-ABR:

Analysis	Side	Study Group (Pre therapy) (n = 60)	Study Group (Post therapy) (n = 60)	t test	*P value*
F0 amplitude	Right	1.41 ± 0.25	1.46 ± 0.25	0.298	0.076
	Left	2.09 ± 2.95	2.15 ± 2.94	0.407	0.981
	Rt vs Lt: p_1	0.079	0.078		
F1 amplitude	Right	0.74 ± 0.13	0.77 ± 0.13	0.365	0.065
	Left	0.71 ± 0.14	0.74 ± 0.14	0.147	0.235
	Rt vs Lt: p_1	0.245	0.165		
Correlation coefficient (SRr)	Right	0.61 ± 0.04	0.71± 0.04	0.425	0.255
	Left	0.71± 0.03	0.7 ± 0.04	0.745	0.626
	Rt vs Lt: p_1	0.045	0.069		
RMS amplitude	Right	1.49 ± 0.16	1.51 ± 0.15	0.371	0.185
	Left	1.47 ± 0.16	1.48 ± 0.16	0.299	0.465
	Rt vs Lt: p_1	0.215	0564		

t: student t test for comparing between both groups, **p:** *p value* of student t test for detecting significance between both groups, **SRr:** stimulus response correlation, RMS: root mean square, **Rt:** right ear, **Lt:** left ear, **p1:** *p value* of student t test for detecting significance between both ears,***:** Statistically significant at $p \leq 0.05$, ****:** highly statistically significant $P<0.01$, all values were displayed as mean and standard deviation.

DISCUSSION

Studies of sensorimotor adaptation proved that intact auditory feedback is crucial for developing a repertory of feed forward speech motor commands (Purcell and Munhall, 2006)[40]. The aforementioned studies support the importance of intact processing of auditory input for the production of fluent speech output.

In the current study, auditory processing abilities of children who stutter have been examined before and after 3 months of speech therapy using fluency shaping program. Auditory processing abilities have been examined through behavioral and electrophysiological tests.

Results of behavioral auditory central tests have shown impaired auditory processing abilities as noticed in the lower scores of the study group (Pre therapy) versus control group in both ears for temporal ordering (PPST), resolution (GIN), and auditory closure (SPIN), together with lack of / or reversed laterality (DDT). Penaloza *et al*., (2008)[28] declared that stutterers had showed deficits in temporal ordering ability which might lead to impaired speech prosody such as rhythm, accentuation and intonation. Fox *et al*., (2000)[29] assumed that stutterers' temporal resolution deficits presents as difficulty in processing rapidly presented speech. Higher auditory cortex particularly left temporal lobe dysfunction has been correlated with low GIN scores in stuttering. Lotfi *et al*., (2020)[15] found poor GIN scores in stutterers with in creased threshold. Temporal inaccuracy in speech perception or decreased processing skills might lead to moments of dysfluency and inability to maintain fluent speech.

There was higher left ear scores than right ear as regard behavioral auditory central tests in study group before therapy. In control group, there was statistically non-significant higher right ear scores than left ear). Asal and Abdou, (2014)[14] supposed that lower right ear scores came from left hemispheric deficits in children who stutter.

On the other hand, after submission to speech therapy, significant shift of laterality had been achieved (DDT). Apart from temporal ordering (PPST), tendency to improvement of other abilities have been noticed but did not reach a statistically significant level. Arcuri *et al*., (2016)[30] found that adults who stutter had good SPIN test performance after speech therapy. Kell *et al*., (2009)[21] found that fluency shaping might improve pitch perception in stuttering, however, that improvement might not be dramatic if auditory processing deficit was prominent That speech therapy might improve auditory processing abilities but need more than three months' speech therapy to be more noticed. Improving auditory central areas activities would give better auditory perceptual function.

Results of sABR showed that onset (waves V&A), offset (wave O), and transition response (wave C) were the most affected parts of sABR (Figure 2a) with non significant left ear preference (reversed laterality). The use of /da/ stimulus, among other speech stimuli, was recommended by Cummingham *et al*. (2001)[38]. Its spectral complexity helps in determining minor neural asynchrony in brain stem responses prior to other components of ABR. Reevaluation after speech therapy revealed improvement in the amplitude of the offset (wave O) and transition response (wave C) (Figure 2b) with non significant tendency to right ear preference (restoration of laterality).

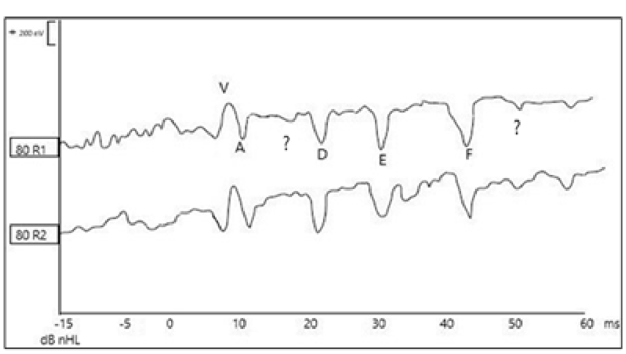

Fig. (2a): s-ABR in child who stutter from the study group Pre therapy (right ear).

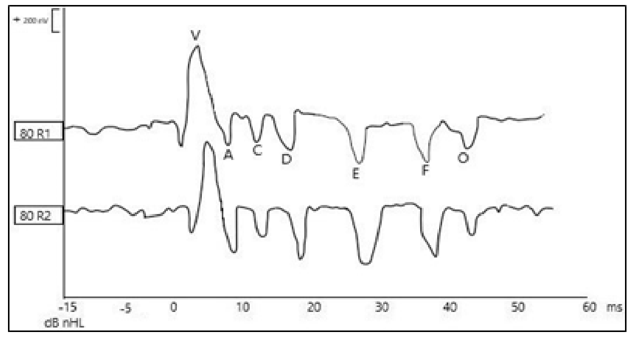

Fig. (2b): s-ABR in child who stutter from the study group Post therapy (right ear).

Tahaei *et al*. (2014)[31] explained that impaired auditory processing in children who stutter may be due to impaired influences of cortical and subcortical speech processing (top down mechanism) or brain stem timing deficit (bottom up mechanism). Top down influence had been also examined electrophysiologically in other studies. Ismail *et al*. (2017)[16] used CAEPs (cortical auditory evoked potentials) and found that auditory processing abilities, in children who stutter, were impaired at the level of early perceptual auditory cortex. The enhancement effect of both mechanisms is established, but the debate between which mechanism provokes the other is still strong. In addition, none of these studies examined the effect of speech therapy on auditory processing.

Fluency shaping program is a principal behavioral readjustment therapy included in evidence-based practice, with a high degree of efficacy and effectiveness (Thomas and Howell, 2001)[32]. Euler and Wolf von Gudenberg (2000)[33] stated that its ability to enhance fluent responses could lead to reduction in the percent of stuttered syllables to reach only 1%.

Functional MRI studies of recovered individuals who stutter after fluency shaping therapy showed reduced right hemisphere over activation and restoration of normal or near normal activation of basal ganglia and left hemisphere (Neumann *et al*., 2005 and Giraud *et al*., 2008)[34&35]. Unfortunately, studies that examined auditory processing abilities of individuals who stutter hadn't involve recovered individuals and hence hadn't provide any information regarding auditory processing abilities after recovery from stuttering.

The current study provides an evidence of improvement of lateralization of auditory processing abilities after recovery from stuttering. Its major limitation is the short period of therapy. We assume that longer period of therapy would have helped individuals who stutter to achieve more significant improvement. Similarly, Song *et al*. (2008)[36] declared that short term experiences can improve time dependent brain stem responses (V, A, and O waves) even after short periods of therapy. Moreover, Krishnan *et al*. (2005)[37] noted that pitch differences and gap detection require either long periods of therapy or specific auditory training programs to improve. On the other hand, Kell *et al*. (2009)[21] figured up that lateralization may be temporary in relapsing cases.

CONCLUSION AND RECOMMENDATIONS

Enhancement of auditory processing abilities of children who stutter can be achieved by speech therapy. The combination of central auditory training program with longer periods of speech therapy are expected to improve the results.

CONFLICT OF INTEREST

There are no conflicts of interest.

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