Effect of Stimulus Rate on Subcortical Auditory Processing in Children

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Abstract

Temporal processing that utilized the Auditory Brainstem Response audiometry (ABR) responses recorded at different rates have not studied the developmental changes during childhood. Aim of the present study: *The primary aim of the present study was to investigate the interactions between auditory temporal processing and stimulus complexity by examining the effects of stimulus rate on speech and click-evoked ABR and Frequency following responses (FFR) in children. The secondary aim was to develop a data base regarding how the non-speech stimulus and the speech stimulus coded at brainstem during early developmental period. A total of fifty seven (57) subjects participated in the study. Subject's age between 5 to 10 years were selected. All the participants were then divided into five groups.ABR and FFR were recorded using Biologic Navigator Pro evoked potential systems (Version-7.0). Results showed that there was no effect of repetition rate on latency and amplitude of click evoked ABR within group and across groups. Significant interaction was seen on the latency of speech evoked ABR and FFR within group, however it did not show significant interaction across groups. There was no significant interaction was seen on the amplitude of speech evoked ABR, but there was significant interaction on amplitude of FFR and F1 amplitude within group, but there was no significant interaction for F0 and F2. However there was no significant interaction for speech evoked ABR, FFR, F0, F1 & F2 latency & amplitude across groups. Developmental time course of speech encoding in the brainstem of neural maturation occur at the age of 5 years). Peripheral mechanism responsible for encoding temporal aspects of the acoustic signal appeared to be well developed in young listeners (4-5years) and this may be the reason for no difference was not noticed across age. Hence to study the temporal processing latency of speech evoked ABR and FFR waves should be considered. Amplitude of any wave is not a good parameter to study the rate effect.*

Key words: *Temporal processing, fundamental frequency, myelinization.*

Introduction

The neural encoding of sound stimulus begins at auditory nerve and continues till the cortex via auditory brainstem. Brainstem responses to simple stimuli are well defined and used widely in the clinical practice in the evaluation of the auditory pathway integrity (Moller, 1999; Starr & Don, 1988). The role of brainstem in processing a complex signal varying in many acoustic dimension continuously over time, such as a speech syllable have recently become popular among audiologist as it can be easily recorded with the help of conventional auditory techniques. The ABR is ideally suited for evaluating difficult to test patients because it passively elicits neurophysiological response to auditory stimuli and does not require the patient to actively attend or respond to the stimulus.

The click-evoked ABR is used widely by clinicians to evaluate hearing and the integrity of the auditory brainstem in certain populations such as, infants or neurologically impaired patients (Starr & Don, 1988). Speech syllables are being used to record evoked potentials as they have got the potential to understand neural processing of speech stimuli. ABRs recorded to speech reflect the acoustics with such accuracy that when the evoked response is played back as an auditory stimulus, it is perceived as intelligible speech (Galbraith, Arbagey, Branski, Comerci & Rector, 1995).

Temporal processing is critical to a wide variety of everyday listening tasks including speech perception and perception of music (Hirsh, 1959). Temporal processing is one of the functions necessary for the discrimination of subtle cues such as voicing and discrimination of similar words. Auditory temporal processing is not a unitary construct and temporal phenomena present in acoustic stimuli manifest themselves in different ways depending on the task (Green, 1984) and also based on the relevant timescales and the presumed underlying neural mechanisms. According to Klein (2002), temporal processing deficits could involve a hierarchy of temporal information-processing functions ranging from the perception and identification of stimuli to individualizing and perceiving multiple stimuli presented in the correct sequences.

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Early studies of the ABR used simple stimuli such as clicks and sinusoidal tones to tap and maximize these transient and sustained ABRs. Although clicks and tones have been instrumental in defining these basic response patterns, they are poor approximations of the behaviorally relevant sounds that we encounter outside the laboratory (e.g., speech and music, non-speech vocal sounds, and environmental sounds). Therefore there is a need to study the processing of speech sound at the brainstem level.

In children it is difficult to get the behavioral responses. Speech evoked ABR is an electrophysiological test which does not require the co-operations from the client and gives the information about brainstem encoding of speech sounds. Speech evoked ABR has been found very useful in the diagnosis of children with learning disability (Johnson, Nicol & Kraus, 2005; Kraus & Nicol 2005; Banai, Abrams, D & Kraus, 2007). Secondly, the processing of speech and speech sounds is potentially more "meaningful" with respect to psychological and linguistic issues, than the processing of clicks. Speech-evoked ABR recordings may have diagnostic and management implications to help screen or identify patients with abnormal speech processing or perhaps those with auditory processing disorders (Khaladkar, Kartik, & Vanaja, 2005*)*. Thus, there is a need to study processing of speech sound in normal children.

Temporal processing that utilized brainstem auditory evoked responses recorded at different rates by Cunningham, Nicol, Zecker, Bradlow and Kraus, (2001); King, Warrier, Hayes, and Kraus, (2002). Wible, Nicol and Kraus, (2004) done study in children with specific language impairment age between 4 to 11 years in 11 children and age matched control group was taken to compare the data. However, subject in the control group was not categorized into different groups to observe developmental changes. Thus, there is need to study how temporal processing is limited during developmental changes in normal hearing children.

Aim of the study

The primary aim of the present study was to investigate the interactions between auditory temporal processing and stimulus complexity by examining the effects of stimulus rate on speech and click-evoked ABR and FFR in children & secondary aim of the present study was to develop a data base regarding how the non-speech stimulus and speech stimulus coded at the brainstem during early developmental period.

Method

A total of fifty seven subjects participated in the study. Age of the subjects was between 5 to 10 years. All the participants were then divided into the following five groups based on their age.

Group I: 5 years to 5 years 11 months, (10 children)
Group II: 6 years to 6 years 11 months, (11 children)
Group III: 7 years to 7 years 11 months, (13 children)
Group IV: 8 years to 8 years 11 months, (13 children)
Group V: 9 years to 9 years 11 months, (10 children)
These groups were made to observe the developmental change.

The behavioral thresholds of all subjects were within 15 dBHL at octave frequencies from 250 Hz to 8 kHz and 250 Hz to 4 kHz for air conduction and bone conduction respectively in both ears. All had type a tympanograms with normal acoustic reflex thresholds in both ears. All of them passed the screening checklist for auditory processing (SCAP) developed by Yathiraj and Mascarenhas (2004) indicating absent auditory processing disorder. None of them reported to have any history of neurological or otological problems. No illness on the day of testing was reported by the subjects. They did have normal click-evoked ABR at lower (11.1/sec) and higher (90.1/sec) repetition rate, indicating absence of retrocochlear pathology (RCP).

Test Stimulus

A 40 ms duration is a synthesized /da/ stimulus generated using KLATT synthesizer (Klatt, 1980) available in the Biologic Navigator Pro-AEP system was used to record FFR.

Test Procedure

All the tests were carried out in a well illuminated air conditioned rooms which was acoustically treated. The noise levels were within the permissible levels as recommended by ANSI-S.3 (1991).

ABR and FFR were recorded using Biologic Navigator Pro evoked potential systems (Version-7.0). The non-inverting electrode was placed on forehead, the inverting electrode was placed on test ear and the ground electrode was placed on non-test ear respectively. ER-3A insert ear phones were used to present the stimuli. The parameters used to record ABR are given in Table 1.

For all the three repetition rates the latency and amplitude of wave V were calculated. Speech evoked ABR and FFR were also recorded at 3 repetition rate. In the present study latency and amplitude of transient

Table 1: Parameters used to record click and speech evoked ABR

Parameters	Click ABR	Speech ABR
	Acquisition Parameters	
Band-pass filter	100-3000 Hz	100-3000 Hz
Analysis time	10 ms	64 ms which included a prestimulus time of 10 ms
Notch filter	50 Hz	50 Hz
Gain	100000	100000
No. of channels	Single	Single
	Stimulus Parameters	
Stimulus	Click (100µs)	/da/ (40 ms)
Polarity	Alternate	Alternate
Repetition rate	6.9, 10.9 & 15.4	6.9, 10.9 & 15.4
Intensity	80 dBSPL	80 dBSPL
Total number of stimulus	2000	2000

as well as sustained responses were evaluated. Transient response consists of peak V and A latency whereas the sustained responses consists of peaks D, E, F, and O. For measuring the latency of the sustained responses, the response waveform was shifted 7 ms to compensate for neural lag in the response**.**

Procedure to obtain F0, F1 and F2 amplitude

Speech-evoked ABR waveforms were first converted into "ASCII" format using the software called ‘AEP TO ASCII’. ASCII format data was then analyzed using ‘BRAINSTEM TOOLBOX’ developed a Northwestern University. This software runs on MATLAB platform and does the FFT of the waveforms and analyses the FFR.

Fourier analysis was performed on the 11.4–40.6 ms epoch of the FFR to extract the information regarding the coding of fundamental frequency (103– 121 Hz), first formant (454- 719 Hz) and the higher harmonics (721-1155 Hz) of the speech stimulus for all the subjects. A 2 ms on 2 ms off Hanning ramp was applied to the waveform to prevent the frequency splattering during the Fourier analysis. Zero-padding was employed to increase the number of frequency points where spectral estimates were obtained. If the quotient of the magnitude of the F0, F1 and higher harmonics frequency component of the FFR divided by that of the prestimulus period was greater than or equal to one, the response was deemed above the noise floor (Russo et al., 2004). The raw amplitude value of the F0, F1 and the higher frequency component of the FFR were then measured.

To check for temporal processing and also developmental changes in latency and amplitude of click evoked ABR, wave V were compared. Latency and amplitude of speech evoked transient and sustained waves were also compared. Extracted information regarding the coding of fundamental frequency, first formant frequency and higher frequency or F2 for speech evoked ABR at different repetition rates were also compared.

Results

Latency of click evoked ABR

The mean and the standard deviations of the wave V latency were calculated for the click evoked ABR recorded at three repetition rates (Table 2).

Table 2 shows that, as the repetition rate increased, there is an increase in latency of the wave V elicited by clicks. Figure- 1 shows a ABR waveform elicited by clicks at three repetition rates in a normal hearing subject.

To see the effects of repetition rates and age on latency of click evoked wave V, Mixed ANOVA (3 repetition rates & 5 groups) was done. The results of the Mixed ANOVA did not show any significant effect of group [$F(4, 52)=1.01$, $p>0.05$] and also there was no interaction (groups vs repetition rates) [$F(8, 104)=1.30$, $p>0.05$]. However, a significant interaction across the repetition rates [$F(2, 104)=8.75$, $p<0.05$] was observed. Bonferroni post hoc test was done to see in which two repetition rates wave V latency differed significantly from each other. Details of the Bonferroni post hoc test is shown in Table 3. Repeated measure ANOVA (3 repetition rates) was done within the group to see which group had significant difference in wave V latency across the repetition rates. Results showed that there is no significant difference across the three repetition rates for Group I [F(2, 18)=0.45, p>0.05], Group II [F (2, 20)=3.20, p>0.05], Group III [F (2, 24)=0.73, p>0.05] and Group V [F2, 18)=2.52, p>0.05]. However, the results showed that there is a significant difference across the three repetition rates for Group IV [F(2, 24)=4.44, p<0.05]. However, Bonferroni post hoc test did not show any significant difference between any two repetition rates.

Paired t-test was done as Bonferroni post hoc test did not show significant difference, though repeated measures ANOVA showed significant difference. The test results showed significant difference between wave V latency obtained at 6.9 and 10.9 [t(12)=2.55, p<0.05] and also between 6.9 and 15.4

Table 2: Mean and Standard deviations (S.D) of click- evoked wave V latency obtained at three repetition rates across the groups

Repetition rate	10.9	15.4
6.9	Not Significant, p>0.05	Significant p<0.05
10.9		Significant p<0.05

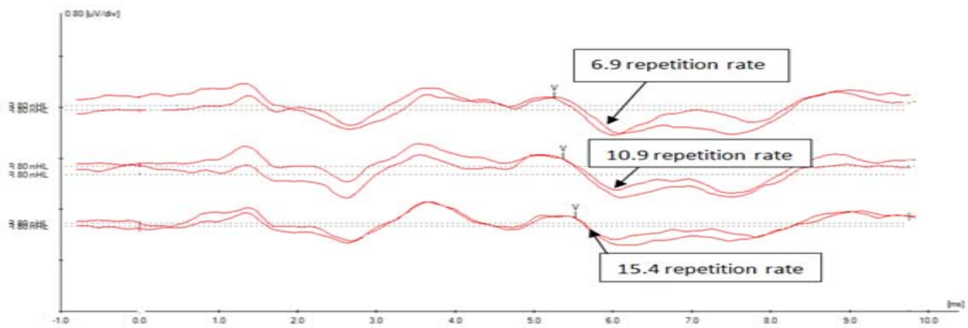

Figure 1: Click- evoked ABR recorded at three different repetition rates.

Table 3: Results for the Bonferroni Post Hoc Test showing pairwise comparison of click-evoked wave V latency in different repetition rates

Groups	Repetition rates					
	6.9		10.9		15.4	
	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D
5-5.11 years	5.31	0.23	5.31	0.23	5.32	0.25
6-6.11 years	5.22	0.27	5.22	0.27	5.27	0.21
7- 7.11 years	5.41	0.14	5.39	0.13	5.40	0.14
8-8.11 years	5.22	0.23	5.24	0.22	5.28	0.18
9-9.11 years	5.29	0.29	5.29	0.28	5.33	0.26

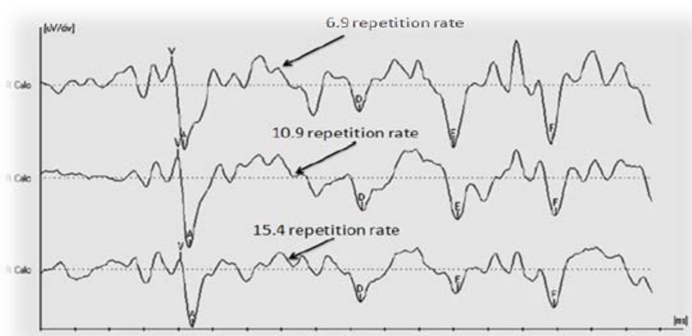

Figure 2: Speech evoked ABR and FFR recorded at three different repetition rates.

Table 4: Mean and Standard deviations (S.D) of different speech evoked ABR and FFR wave latencies obtained at three repetition rates across the groups

Wave Latency	Variable	df	F-value	Sig. level
Wave V	Repetition rate	(2, 104)	451.64	$p<0.05$
	Across age	(4, 52)	0.82,	$p>0.05$
	Rate & age	(8, 104)	1.37	$p>0.05$
Wave A	Repetition rate	(2, 104)	277.36	$p<0.05$
	Across age	(4, 52)	0.77	$p>0.05$
	Rate & age	(8, 104)	0.68	$p>0.05$
Wave D	Repetition rate	(2, 104)	104.02	$p<0.05$
	Across age	(4, 52)	0.92	$p>0.05$
	Rate & age	(8, 104)	0.86	$p>0.05$
Wave E	Repetition rate	(2, 104)	104.02	$p<0.05$
	Across age	(4, 52)	0.92	$p>0.05$
	Rate & age	(8, 104)	0.86	$p>0.05$
Wave F	Repetition rate	(2, 104)	63.97	$p<0.05$
	Across age	(4, 52)	0.77	$p>0.05$
	Rate & age	(8, 104)	1.26	$p>0.05$

Table 5: Degree of freedom, F-value and significance level of different speech evoked ABR and FFR wave latencies obtained at three repetition rates across the groups

Wave	Age Groups →	5-5.11 years		6-6.11 years		7-7.11years		8-8.11years		9-9.11 years	
	Repetition rates ↓	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D
V	6.9	5.98	0.30	6.11	0.32	6.11	0.21	6.11	0.25	6.19	0.20
	10.9	6.43	0.30	6.38	0.31	6.40	0.34	6.45	0.27	6.59	0.19
	15.4	6.69	0.33	6.68	0.34	6.73	0.33	6.76	0.33	6.93	0.20
A	6.9	6.80	0.23	6.92	0.47	7.09	0.42	6.95	0.31	7.07	0.20
	10.9	7.26	0.26	7.36	0.47	7.42	0.37	7.35	0.37	7.49	0.21
	15.4	7.64	0.29	7.71	0.44	7.75	0.32	7.78	0.32	7.81	0.15
D	6.9	21.62	0.31	22.10	0.59	22.11	0.55	21.82	0.84	22.11	0.60
	10.9	22.01	0.52	22.29	0.59	22.31	0.47	22.14	0.85	22.35	0.48
	15.4	22.18	0.51	22.48	0.64	22.56	0.47	22.33	0.85	22.56	0.47
E	6.9	30.30	0.47	30.44	0.54	30.56	0.67	30.57	0.51	30.67	0.38
	10.9	30.53	0.43	30.58	0.50	30.79	0.65	30.81	0.62	30.84	0.39
	15.4	30.69	0.37	30.72	0.40	31.15	0.80	30.96	0.60	30.92	0.35
F	6.9	38.85	0.30	38.95	0.46	38.97	0.35	38.99	0.30	38.77	1.29
	10.9	39.08	0.33	39.08	0.40	39.09	0.35	39.06	0.31	38.97	1.35
	15.4	39.29	0.44	39.17	0.43	39.32	0.35	39.28	0.32	39.24	1.36

[$t(12)=2.24$, $p<0.05$] repetition rates. However, it did not show significant difference between wave V latency obtained at 10.9 and 15.4 [$t(12)=1.83$, $p>0.05$] repetition rates.

Latency of speech evoked ABR and FFR waves

The mean and standard deviations of the different wave latencies were calculated for the speech evoked ABR and FFR recorded at three repetition rates (Table 4). It can be seen from the Table 4 that, as the repetition rate increased, there is an increase in latency of all the peaks. However, latency shift for transient response was more than the shift noticed for FFR waves.

Figure- 2 Shows syllable /da/ evoked ABR and FFR waveform at three repetition rates obtained from one of the normal hearing subject continuity with to see the effects of repetition rates and age on the latency of transient and sustain responses elicited by syllable /da/ Mixed ANOVA (3 repetition rates and 5 groups) was done. The results are given in Table 5.

The results showed a significant interaction between rate and age for all waves elicited by syllable /da/. Bonferroni post-hoc test was done to see which two repetition rates for wave V latency differ significantly. Details of the Bonferroni post-hoc test is shown in Table 6.

Repeated measure ANOVA was done within the groupto see significant different in data obtained across the repetition rates by considering data from all the groups.

As the repeated measure ANOVA showed significant difference across the repetition rates for all most all the groups, Bonferroni post-hoc test was done to see, which two repletion rates wave latency, differed significantly. The results obtained from Bonferroni post-hoc test results is shown in Table 8.

Effect of repetition rate and age on amplitude of click evoked ABR wave V

The mean and the standard deviations of the wave V amplitude were calculated for the click evoked ABR wave V recorded at three repetition rates (Table 9).

It can be seen from the Table 9 wave V amplitude did not show any specific trend with the change in repetition rate. However, most of the groups have shown a reduced wave V amplitude obtained at 15.4 rate, compared to that obtained at 6.9 repetition rate. To see the effects of repetition rates and age on amplitude of click evoked Wave V, Mixed ANOVA (3 repetition rates and 5 groups) was done. The results of the Mixed ANOVA did not show any significant interaction across the groups [$F(4, 52)=0.75$, $p>0.05$] groups and repetition rates [$F(8, 104)=1.23$, $p>0.05$] and also across the repetition rates [$F(2, 104)=2.56$, $p>0.05$].

Table 6: Bonferroni Post Hoc Test results for the /da/ evoked Wave V, A, D, E & F latency across the three repetition rates

Repetition rate	10.9	15.4
6.9	Significant p<0.05	Significant p<0.05
10.9		Significant p<0.05

Table 7: Repeated measure ANOVA results of different speech evoked ABR and FFR wave latencies obtained at three repetition rates across the groups

Wave	Group	df	F-Value	Sig. level
Wave V	I	(2,18)	90.22	p<0.05
	II	(2,20)	98.76	p<0.05
	III	(2,24)	52.79	p<0.05
	IV	(2,24)	126.34	p<0.05
	V	(2,18)	177.39	p<0.05
Wave A	I	(2,18)	50.38	p<0.05
	II	(2,20)	61.81	p<0.05
	III	(2,24)	28.14	p<0.05
	IV	(2,24)	113.20	p<0.05
	V	(2,18)	93.57	p<0.05
Wave D	I	(2,18)	20.57	p<0.05
	II	(2,20)	22.15	p<0.05
	III	(2,24)	18.88	p<0.05
	IV	(2,24)	26.44	p<0.05
	V	(2,18)	21.86	p<0.05
Wave E	I	(2,18)	31.64	p<0.05
	II	(2,20)	5.32	p<0.05
	III	(2,24)	31.29	p<0.05
	IV	(2,24)	19.40	p<0.05
	V	(2,18)	6.33	p>0.05
Wave F	I	(2,18)	26.04	p<0.05
	II	(2,20)	3.88	p<0.05
	III	(2,24)	11.65	p<0.05
	IV	(2,24)	8.73	p<0.05
	V	(2,18)	48.16	p<0.05

Table 8: Bonferroni Post hoc Test results for the latency of transient & sustained response across the group & across the three repetition rates

Wave/s	Group/s	Repetition rates	10.9	15.4
V	I, II, III, IV & V	6.9	S	S
		10.9	NC	S
A	I, II, III, IV & V	6.9	S	S
		10.9	NC	S
D	I, II, III, IV & V	6.9	S	S
		10.9	NC	S
E	I & III	6.9	S	S
		10.9	NC	S
	II	6.9	S	NS
		10.9	NC	NS
	IV	6.9	S	S
		10.9	NC	NS
F	I & IV	6.9	S	S
		10.9	NC	S
	II	6.9	NS	NS
		10.9	NC	S
	III & IV	6.9	NS	S
		10.9	NC	S

Note: S-$p<0.05$, NS-$p>0.05$, NC-Not compared

Table 9: Mean and Standard deviations (S.D) of wave V amplitude obtained at three repetition rates across the groups

Peak	5-5.11 years		6-6.11 years		7-7.11years		8-8.11years		9-9.11 years	
	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D	Mean (ms)	S.D
Wave V	0.19	0.10	0.18	0.08	0.24	0.13	0.22	0.9	0.24	0.11
	0.20	0.11	0.22	0.16	0.28	0.16	0.23	0.10	0.16	0.09
	0.13	0.10	0.21	0.07	0.18	0.06	0.20	0.13	0.18	0.09

Effect of repetition rate and age on amplitude of /da/ evoked transient, FFR waves, F0, F1 and Higher harmonics (F2) across groups.

The mean and the standard deviations of the different wave amplitude were calculated for the speech evoked ABR and FFR, recorded at three repetition rates (Table 10).

It can be seen from the Table 10 that, as the repetition rate increased, there is a decrease in amplitude of all most all the peaks of speech evoked transient and FFR waves in all the groups.

The mean and the standard deviations of the F0, F1 and higher harmonics amplitude were calculated for the speech evoked FFR recorded at three repetition rates (Table 11). It can be seen from the Table 11 that, as the repetition rate increased, there is a decrease in amplitude of the F0, F1 and also higher harmonics (F2) of speech evoked FFR. To see the effects of repetition rates and age on significantly from each other. Details of the Bonferroni post-hoc test is shown in Table 13.

Repeated measure ANOVA was done within the group to see significant difference in data obtained across the repetition rates as the Mixed ANOVA showed a significant interaction across the repetition rates by considering data from all the group.

Bonferroni post hoc test was done to see between which two repetition rates wave V amplitude, differed significantly. Details of the Bonferroni post hoc test results is shown in Table 15.

Table 10: Mean and standard deviations (S.D) of different speech evoked transient and FFR waves amplitude obtained at three repetition rates across the groups

Wave	Age Groups → / Repetition rates ↓	5-5.11 years Mean (ms)	5-5.11 years S.D	6-6.11 years Mean (ms)	6-6.11 years S.D	7-7.11years Mean (ms)	7-7.11years S.D	8-8.11years Mean (ms)	8-8.11years S.D	9-9.11 years Mean (ms)	9-9.11 years S.D
V	6.9	0.12	0.07	0.12	0.07	0.13	0.06	0.12	0.05	0.13	0.05
	10.9	0.09	0.06	0.10	0.05	0.11	0.06	0.09	0.04	0.08	0.04
	15.4	0.06	0.03	0.08	0.02	0.09	0.06	0.08	0.05	0.06	0.03
A	6.9	0.22	0.11	0.28	0.11	0.23	0.11	0.20	0.12	0.22	0.06
	10.9	0.24	0.06	0.24	0.11	0.20	0.09	0.23	0.11	0.23	0.05
	15.4	0.20	0.06	0.25	0.09	0.18	0.06	0.20	0.04	0.24	0.09
D	6.9	0.19	0.12	0.17	0.08	0.17	0.10	0.17	0.08	0.12	0.06
	10.9	0.17	0.07	0.18	0.05	0.16	0.06	0.18	0.09	0.13	0.07
	15.4	0.15	0.06	0.17	0.05	0.14	0.07	0.12	0.07	0.14	0.03
E	6.9	0.26	0.06	0.25	0.10	0.21	0.08	0.25	0.15	0.24	0.09
	10.9	0.22	0.05	0.20	0.13	0.19	0.08	0.21	0.11	0.19	0.08
	15.4	0.14	0.06	0.16	0.06	0.16	0.05	0.19	0.07	0.15	0.09
F	6.9	0.30	0.14	0.25	0.16	0.35	0.36	0.27	0.15	0.21	0.10
	10.9	0.25	0.11	0.26	0.11	0.19	0.07	0.24	0.13	0.18	0.13
	15.4	0.18	0.09	0.18	0.13	0.21	0.09	0.16	0.10	0.18	0.12

Table 11: Mean and Standard deviations (S.D) of F0, F1 and higher harmonics (F2) amplitude elicited by syllable /da/ obtained at three repetition rates across the groups

Peak	Age Groups → / Repetition rates ↓	5-5.11 years Mean (ms)	5-5.11 years S.D	6-6.11 years Mean (ms)	6-6.11 years S.D	7-7.11years Mean (ms)	7-7.11years S.D	8-8.11years Mean (ms)	8-8.11years S.D	9-9.11 years Mean (ms)	9-9.11 years S.D
F0	6.9	5.14	1.94	5.06	2.11	4.76	2.33	4.60	2.12	4.23	1.80
	10.9	4.58	1.37	5.40	2.03	4.73	2.23	3.53	1.66	3.51	1.05
	15.4	4.25	1.85	4.42	2.24	4.42	2.09	3.82	2.06	4.31	1.76
F1	6.9	0.70	0.26	0.60	0.28	0.59	0.21	0.65	0.28	0.64	0.22
	10.9	0.59	0.20	0.55	0.19	0.56	0.13	0.51	0.18	0.55	0.18
	15.4	0.65	0.20	0.60	0.20	0.55	0.16	0.59	0.24	0.53	0.15
F2	6.9	0.31	0.84	0.28	0.08	0.25	0.05	0.28	0.07	0.29	0.06
	10.9	0.28	0.07	0.28	0.07	0.28	0.08	0.27	0.08	0.27	0.07
	15.4	0.26	0.07	0.27	0.10	0.24	0.60	0.26	0.07	0.25	0.06

Table 12 : Mixed ANOVA result of wave V, E and F amplitude, across repetition rate, across age and rate and age

	Variable	df	F-value	Sig. level
Wav V	Repetition rate	(2, 104)	16.96	p<0.05
	Across age	(4, 52)	0.52	p>0.05
	Rate & age	(8, 104)	0.46	p>0.05
Wave A	Repetition rate	(2, 104)	0.96	p>0.05
	Across age	(4, 52)	0.93	p>0.05
	Rate & age	(8, 104)	1.07	p>0.05
Wave D	Repetition rate	(2, 104)	2.85	p>0.05
	Across age	(4, 52)	0.76	p>0.05
	Rate & age	(8, 104)	1.12	p>0.05
Wave E	Repetition rate	(2, 104)	35.78	p<0.05
	Across age	(4, 52)	0.21	p>0.05
	Rate & age	(8, 104)	1.02	p>0.05
Wave F	Repetition rate	(2, 104)	9.78	p<0.05
	Across age	(4, 52)	0.40	p>0.05
	Rate & age	(8, 104)	1.27	p>0.05
F0	Repetition rate	(2, 104)	1.50	p>0.05
	Across age	(4, 52)	1.05	p>0.05
	Rate & age	(8, 104)	0.61	p>0.05
F1	Repetition rate	(2, 104)	5.37	P<0.05
	Across age	(4, 52)	0.31	p>0.05
	Rate & age	(8, 104)	0.51	p>0.05
F2	Repetition rate	(2, 104)	2.84	p>0.05
	Across age	(4, 52)	0.35	p>0.05
	Rate & age	(8, 104)	0.50	p>0.05

Table 13: Bonferroni Post hoc Test results for the amplitude of wave V, E, F & F1 amplitude across the three repetition rates

Wave	Group	df	F-Value	Sig. level
Wave V	I	(2,18)	7.79	P<0.05
	II	(2,20)	1.82	p>0.05
	III	(2,24)	2.01	p>0.05
	IV	(2,44)	7.98	P<0.05
	V	(2,18)	9.13	P<0.05
Wave E	I	(2,18)	26.83	P<0.05
	II	(2,20)	7.00	P<0.05
	III	(2,24)	5.14	P<0.05
	IV	(2,26)	3.15	p>0.05
	V	(2,20)	7.38	P<0.05
Wave F	I	(2,18)	13.16	P<0.05
	II	(2,20)	4.51	P<0.05
	III	(2,24)	2.44	P>0.05
	IV	(2,24)	5.92	P<0.05
	V	(2,18)	1.56	P>0.05
F1	I	(2,18)	1.00	P>0.05
	II	(2,20)	0.59	P>0.05
	III	(2,24)	0.61	P>0.05
	IV	(2,24)	3.57	P<0.05
	V	(2,20)	1.45	P>0.05

Note: S-p<0.05, NS-p>0.05, NC-Not compared

Table 14: Repeated measure ANOVA results for wave V, E, F and F1 amplitude across the repetition rates

Wave/s	Repetition rate	10.9	15.4
V & E	6.9	S	S
	10.9	NC	S
F	6.9	NS	S
	10.9	NC	S
F1 amplitude	6.9	S	NS
	10.9	NC	NS

A paired t-test was done as Boneferoni post hoc test did not show any significant difference, though repeated measures ANOVA showed significant difference. A paired t-test results showed a significant difference between F1 amplitude obtained at 6.9 and 10.9 [t(12)=2.63, p<0.05] repetition rates. However, it did not show any significant difference between 6.9 and 15.4 [t(12)=1.07, p<0.05], and also between 10.9 and 15.4 [t(12)=1.64, p>0.05] repetition rates.

Discussion

Effect of repetition rate on latency of click evoked ABR, Speech evoked ABR, FFR, F0, F1 & F2

In the present study repetition rate did not show significant effect on the timing of the onset portion of the click evoked ABR, except for IV group. Present study supports the study by Fowler & Noffsinger (1983), where they reported no change in latency of click evoked ABR waves with increase in repetition rate between 2-20 Hz. Krizman, Skoe and Kraus (2010) also reported no change in latency of click evoked ABR with increase in repetition rate. However there are studies which report that there will be prolonged latency with increase in repetition rate in adults by Don, Allen & Starr (1977), Yagi & Kaga, (1979), Lasky, 1984;1997), Burkard & Hecox, (1983, 1987a, 1987b), Thornton & Coleman, (1975) as well as in children by Lasky, (1984, 1997). Basu, Krishnan and Weber Fox (2010) also observed longer latency of click evoked ABR components with the increase in repetition rate in children with specific language impairment and children with normal language. The difference in the results of the present study could be due to differences in rates used to recording of the click evoked ABR. However, it supports the earlier findings that repetition rate to 20/sec may not affect the latency of the click evoked ABR.

A significant effect was also noticed for the speech evoked transient response latency (wave V & A). The latency of onset response was increased with an increase in the repetition rates for all the five groups of children. Krizman, et al., (2010) reported that rate affects the timing of the onset of the speech-ABR in adults. Goncalves, Wertzner, Samelli & Matas (2011) also reported longer latency for wave V and A of speech evoked ABR in children with phonological disorders compared to normal children with age range of 7- 11 years. Wible, Nicol and Kraus (2004) also reported that onset of the speech sound /da/, wave V–A of the auditory brainstem response (ABR) had a significantly shallower slope in learning impaired children. This would suggests a closer relationship between brainstem neural maturity and rate effects. Delayed neural transmission due to incomplete myelinization and reduced synaptic efficiency is generally thought to produce greater latency changes with rate in infants and children (Pratt & Sohmer, 1976; Lasky 1984, 1997; Jiang, Brozi & Wilkinson, 1998).

Table 15: Bonferroni Post hoc Test results for the amplitude of transient & sustained response across the group & across the three repetition rates

Wave/s	Group/s	Repetition rate	10.9	15.4
V	I	6.9	NS	S
		10.9	NC	NS
	IV & V	6.9	S	S
		10.9	NC	NS
	II,III & V	6.9	NS	S
		10.9	NC	NS
E	I	6.9	NS	S
		10.9	NC	S
	I & IV	6.9	NS	S
		10.9	NC	S
F	I & IV	6.9	NS	S
		10.9	NC	S
	II	6.9	NS	NS
		10.9	NC	S
F1 amplitude	IV	6.9	S	NS
		10.9	NC	NS

Note: S-p<0.05, NS-p>0.05, NC-Not compared

A significant difference was seen in the latency of the peaks D, E, F with increase in rate in all the age groups except wave E latency for V Group. Krizman et al; (2010) reported that repetition rate had effect on sustained responses of the speech evoked FFR response.

No significant difference in the latency of click evoked ABR across the groups was noticed in the current study. Salamy (1984) reported that latency of click evoked ABR mature like adult by the age of 2 years. Gorga, Kaminski, Beauchaine, Jesteadt & Neely, (1989) reported that children, by the age of 3 years the latency of click evoked ABR will be same as adult. Johnson, Nicol, Zecker, & Kraus (2008) reported that there was no difference in the latency of click evoked ABR for younger children (3-5years) and older children (5-12 years). Thus, there was no difference seen on the latency of click evoked ABR across group of children as in the current study all the subjects were 5 years or above.

No significant difference seen in the latency of transient response of speech evoked ABR and FFR across the groups. Johnson et al., (2008) reported that development time course of speech encoding in the brainstem of neural maturation occur at the age of 5 years. Hall and Grose (1994) reported that peripheral mechanism responsible for encoding temporal aspects of the acoustic signal appeared to be well developed in young listeners (4-5 years). Thus, there was no difference seen on latency of speech evoked ABR and FFR across the groups of children as, in the current study all the subjects were 5 years or above.

Effect of repetition rate on amplitude of click evoked ABR, Speech evoked ABR, FFR, F0, F1 and F2

Repetition rate did not show significant effect on the amplitude of click evoked ABR within the group of children. However, most of the groups showed slight decrease in amplitude with increase repetition rates: Basu et al., (2010) reported a decrease in amplitude of wave V with an increase in the repetition rates in normal children. Pratt and Sohmer (1976) also observed similar effect on amplitude with increase in repetition rate. Fowler & Noffsinger (1983) did not observe any change in the amplitude of click evoked ABR with the increase in repetition rate between 2-20 Hz. However, the rate-related decrease in response amplitude observed for the ABR components may reflect an intensification of neural adaptation (producing a decrease in neural responsiveness) and/or reduced neural synchrony (rate-induced neural desynchronization) in the responding neural elements (Don et al., 1977; Fowler & Noffsinger, 1983; Burkard, Shi & Hecox, 1990; Lasky, Shi & Hecox, 1994) might have resulted in increase in latency.

No significant effect of repetition rate on the amplitude of transient response of speech evoked ABR was seen in the current study, though there was a decrease in wave V amplitude with the increase in the repetition rate for I, IV and V groups. Goncalves et al., (2011) also reported decrease in the wave V amplitude of speech evoked ABR with increase in repetition rate.

Repetition rate also showed significant effect on the amplitude of the E and F waves but did not show significant effect on wave D amplitude. Basu et al., (2010) reported that with an increase in repetition rate there was a decrease in FFR amplitude in normally language developed children.

No significant difference seen in the amplitude of F0 and higher harmonics (F2) across repetition rate within age group, whereas F1 showed significant difference across repetition for IV group. Wible et al., (2004) reported that amplitude of the FFR was significantly reduced among Language learning disability children in the frequency region of first formant (F1) evoked by /da/ stimulus. Krizman et al., (2010) also reported a similar finding in adult population.

No significant difference seen in the amplitude of click evoked ABR across the groups. Salamy (1984) reported that click evoked ABR mature like adult by the age of 2 years. Jiang, Wu and Zhang (1991) reported that there need not be any age effect on the amplitude of click evoked ABR with increase in rate in children (1-6 years) and Adults (22-36 years). Thus, there was no difference seen in the amplitude of click evoked ABR across group of children.

No difference seen in the amplitude of transient response of speech evoked ABR, FFR, F0, F1 and F2 across the groups. A similar result was also reported by Goncalves et al., (2011) that there were no significant differences in wave V and A between the groups with age range of 7-11 years. Johnson et al; (2008) reported that development time course of speech encoding in the brainstem of neural maturation occur at the age of 5 years. Hall and Grose (1994) reported that peripheral mechanism responsible for encoding temporal aspects of the acoustic signal appeared to be well developed in young listeners (4-5 years). Thus, there was no difference seen in the amplitude of speech evoked ABR, FFR, F0, F1, and F2 across the age group of children.

It can be concluded from the study that rate has significant effect on processing of speech evoked ABR and FFR. Transient component are more susceptible to change with rate but sustained responses may not show significant changes. This suggests that to assess the temporal processing of non-speech and speech stimulus with rate, one must consider transient response rather than sustained response evoked by speech stimulus. The current study also suggest that neural processing of temporal aspect of speech stabilizes before 5 years of age as age did not show any significant changes on any wave latency and amplitude of click evoked ABR, speech evoked transient response and FFR and also amplitude of F0, F1 and higher harmonics(F2).

Implications of the Study

Data obtained from the study can be useful as reference to study clinical population. The result obtained helped to understand how temporal aspects of non-speech and speech are processed at the nervous system at different repetition rates. It gives an idea about the parameters to be considered for further study (transient response) where repetition rates are used to assess temporal processing. It highlights the necessity for further study in clinical population.

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