UTILITY OF ACOUSTIC CHANGE COMPLEX AS AN OBJECTIVE TOOL TO EXAMINE DLI IN HEALTHY INDIVIDUALS AND INDIVIDUALS WITH AUDITORY PROCESSING DISORDERS

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LIST OF ABBREVIATION

ACC- Acoustic Change Complex

AEPs- Auditory Evoked Potentials

BLST- Bankson language screening test

CAEPs-Cortical Auditory Evoked Potentials

(C)APD- Central auditory processing disorder

DLI- Differential Limen of Intensity

(DLI_b) - Behavioral DLI

(DLI_o) -ACC DLI

DPOAE- Distortion Product Otoacoustic Emission

ERPs-Event Related Potentials

ERS- Early reading skills

GDT-Gap Detection Threshold

MATLAB-Matrix Laboratory

MLD-Masking Level Difference

MLP- Maximum Likelihood Procedure

MMN-Mismatch Negativity

MMSE-Mini-mental state examination

PB-Phonemically Balanced

PTA- Pure tone audiometry

RMS-Root Mean Square

SCAP- Screening checklist for auditory processing

SPIN- Speech in noise

SRT- Speech reception threshold

STAP- Screening test for auditory processing

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Abstract

Previous literature has reported usefulness of Acoustic Change Complex (ACC) to assess correlation between behavioral and electrophysiological measures in normal hearing individuals. If ACC is to be considered a valid tool to investigate the ability of an individual to detect a minimum amount of change in the acoustic intensity (difference lime for intensity- DLI) within an ongoing stimulus, it must be used in the clinical population that are known to have deficiency in this aspect like Central Auditory Processing Disorder [(C)APD]. It is likely that the use of ACC will reflect the intensity discrimination deficits as shown behaviorally in children with (C)APD. The present study is aims at investigating the utility of ACC as an objective measure of DLI in children with (C)APD and compared with normal children. Forty children in the age range of 8 to 14 years participated in the study. They were divided into two groups i.e. control (normal children) and clinical [(C)APD] group. Children with (C)APD were identified from different English medium schools of Mysuru city, Karnataka. They were labeled (C)APD based on screening (SCAP and STAP) and diagnostic CAPD tests (Gap detection test, Dichotic CV test and Speech in noise test). Differential limen for intensity (DLI_b) was carried out using Psycon 2.18 software installed in personal laptop. ACC was recorded for 6 intensity differences (+1, +3, +4, +5, +10 & +20 dB) and a standard stimulus (no change in intensity) using the above generated 1000 Hz pure-tone. The lowest intensity change that produced ACC was considered objective DLI (DLI_o). Result showed that children with (C) APD have larger (poorer) DLI_b and DLI_o compared to normal children. Independent 't' test showed that DLI_b in normal children was significantly smaller (better) than DLI_b in children with (C)APD. Similarly, Mann-Whitney U test showed significantly smaller (better) DLI_o in normal children compared to children with (C)APD. This probably indicate problem in physiological processes accountable for intensity discrimination skill. Spearman's correlation showed statistically significant correlation between DLI_b and DLI_o in normal as well as children with (C)APD. Thus, outcome of the study provides evidence for the clinical use of ACC as an objective tool for examining DLI in children with central auditory processing disorder.

Key Words: ACC; CAPD; DLI

Introduction

Auditory evoked potentials (AEPs) are defined as small changing voltages which are elicited using auditory stimuli. These potentials are divided into various categories based on the latency, amplitude and the origin of the potentials. The cortical event related potentials (ERPs) are “slow” and “late” auditory potentials that occur at least 40-50 ms after the onset of auditory stimuli (Katz, 2009). These responses have been mainly used for studying maturation (Martin, Shafer, Morr, Kreuzer, & Kurtzberg., 2003; Wunderlich, Cone, & Shepherd; 2006), and aging process (Cooper, Todd, McGill, & Michie., 2006; Martin & Jerger, 2005). Cortical Auditory Evoked Potentials (CAEP’s) are also used to assess auditory system in clinical population such as in sensory neural hearing loss (Korczak, Kurtzberg & Stapells., 2005; Oates, Kurtzberg & Stapells., 2002), and cochlear implants (Sharma, Dorman, & Spahr, 2002; Gordon, Tanaka, & Papsin., 2005). Acoustic Change Complex (ACC) is a type of CAEPs which is recorded in response to the change(s) in the ongoing stimuli in terms of frequency, intensity, duration, amplitude modulation and frequency modulation (Jerger & Jerger, 1970; Naatanen & Picton, 1987; McCandless & Rose, 1970; Yingling & Nethercut, 1983; Han & Dimtrijevic, 2015) or changes in any other aspect during a sustained speech sound (Kaukoranta, Hari & Lounasmaa, 1987). It is this nature of the ACC that has attracted the attention of various scientists who are interested in identifying an objective test that can be reliable and useful in evaluating the ability of an individual to discriminate between two portions of a stimulus or a change like the presence of a gap within a sustained stimulus. ACC is a negative-positive complex that is elicited by changes that occurs within an ongoing acoustic stimulus which shows discrimination at the level of the auditory cortex and provides insight into the brain’s capacity to process the acoustic features of speech (Ostroff, Martin & Boothroyd, 1998; Martin & Boothroyd, 1999). As waveform reflects the acoustic change contained in the stimuli, the response was termed as acoustic change complex by Martin and Boothroyd (1999). As reported by various studies, ACC has been studied in various population such as children (Juneja, 2011; Spoorthy, 2012), adults (Ganapathy, Narne, Kalaiah, & Manjula, 2013; Shetty & Manjula., 2012), individuals with auditory neuropathy (Srikar, 2011), hearing aid users (Jobish, 2012) and cochlear implant users (Brown, Etler, He, O'Brien, Erenberg, Kim, & Abbas, 2008). The main advantages of the ACC over other potentials like mismatch negativity (MMN) and P300 is that ACC can be obtained even in the absence of attention, and requires relatively less number of sweeps to record a response with a better signal-to-noise ratio (Martin & Boothroyd, 1999). In addition, the ACC can be evoked consistently in individuals with good test-retest reliability, stability of the ACC, and the feasibility with which it can be recorded. ACC has potential application to the investigation of neural processing of speech in individuals with hearing loss, hearing aids, or cochlear implants. Ostroff et al in 1998 reported ACC may have importance in the assessment of speech perception capacity in young children with hearing impairment. Martin and Boothroyd in 1999 also reported acoustic change complex as sensitive sign of the neural processing of changes in periodicity, though the acoustic change complex has an advantage in terms of amplitude. The results of their study support the possible utility of the acoustic change complex as a clinical tool in the evaluation of peripheral speech perception ability.

Based on the neuronal maturation, Juneja (2011) investigated ACC in children with normal hearing with three different age groups (7 to 9.11, 10 to 12.11, & 13 to 15.11 years) and found that younger subjects had longer latency and lesser amplitude than older subjects. Systematic changes were observed in N1-P2 and N2-P3 complexes. Similarly, Small and Werker in 2012 also investigated that it is possible to record an ACC in young infants and provide a starting point for further investigation of the infant ACC and its utility as an index of discrimination. Martinez, Eisenberg and Boothroyd in 2013 investigated ACC in adults and young children evoked using the changes in height of vowel (/u/-/a/) and place of the vowel /u/-/i/ contrasts. The participants were normal hearing adult, normal hearing children and children with mild-to-moderately severe hearing loss. The children with hearing impairment were using amplification device (hearing aid). The age range of children was 2 years to 6 years, whereas, for adults the age range was 44 to 55 years. For adults, P1-N1-P2 responses were present, whereas, only P1-N2 response was found for children with hearing impairment. These finding suggested that ACC can be an objective tool to assess auditory resolution in young children. Spoorthy (2012) obtained the correlation between behavioral measure and acoustic change complex and the results showed a positive correlation between amplitude measures and speech in noise scores, which indicates that as speech-in-noise score, increases the amplitude of ACC increases. They also observed significant negative correlation between latencies and speech-in-noise score, indicating as the speech-in-noise score increases latencies decreases. They concluded that acoustic change can be an objective tool to quantify behavioral measures.

Need for the study

The key aspect in the production of ACC is the presence of a change in an ongoing stimulus and the ability of the auditory system to detect this change. This seems to suggest that it has the potential for studying the discrimination between two components of a stimulus like a sudden change in periodicity, frequency or intensity within a stimulus. In fact, Martin and Boothroyd (1999) demonstrated that ACC could be elicited by a change of spectral envelope alone or by a change of periodicity alone when the root mean square amplitude was held constant. Martin and Boothroyd in 1999 were performed ACC with change in intensity level from -5 dB to +5 dB in 1 dB steps on adults with normal hearing. Outcome of the study showed that ACC was detectable to amplitude changes of +2 to +5 dB and -3 dB to -5 dB. In a subsequent study, Harris, Mills and Dubno (2007) also reported that change of 2-3 dB at 500 Hz and 2-4 dB at 3000 Hz is adequate to evoke ACC in younger adults with normal hearing. However, these studies were conducted in healthy individuals with normally functioning auditory system. Spoorthy (2012) found correlation between speech-in-noise score and different measures of ACC. They reported significant correlation between amplitude and latency measures with speech in noise scores. Similarly, earlier studies have also investigated correlation between electrophysiological and behavioral measures (Michalewski, Starr, Nguyen, Kong & Zeng, 2005; Dimitrijevic, Starr, Bhatt, Michalewski, Zeng & Pratt, 2011; He et al., 2015). Michalewski et al., 2005 obtained strong positive correlation between gap detection thresholds measured behaviorally and electrophysiologically in both normal hearing individuals and individuals with auditory neuropathy. In a another study, Dimitrijevic et al., in 2011 investigated correlation between speech perception scores and N100 measures (latency and amplitude) to frequency changes in ongoing stimulus. However, there is dearth of literature where ACC has been used to measure differential limens of intensity in clinical population like (C)APD. If ACC is to be considered a valid tool to investigate the ability of an individual to detect a minimum amount of change in the acoustic intensity (difference lime for intensity- DLI) within an ongoing stimulus, it must be used in the clinical population that are known to have deficiency in this aspect. An auditory processing disorder is a kind of disorders in which psychoacoustic studies have shown the presence of intensity discrimination deficit (Bellis, 2006). Since difficulties in behavioral discrimination have been shown to be reflected in neurophysiological representation of the same stimuli using auditory electrophysiological measures (Kraus, McGee, Carrell, Zecker, Nicol &

Koch, 1996), it is likely that the use of ACC will reflect the intensity discrimination deficits as shown behaviorally in individuals with APD. However, there is no study to the best of our knowledge that has explored the utility of ACC to show such differences in the DLI in children with (C)APD.

Aim of the study

The present study is aims at investigating the utility of ACC as an objective measure of DLI in normal children and children with (C)APD.

Objectives of the study

1. To find the DLI using behavioural test (DLI_b) and ACC (DLI_o) in typically developing children.
2. To find the DLI using behavioural test (DLI_b) and ACC (DLI_o) in children with (C)APD.
3. To find the correlation between the DLI obtained using behavioural measures (DLI_b) and ACC (DLI_o) in typically developing children.
4. To find the correlation between the DLI obtained using behavioural measures (DLI_b) and ACC (DLI_o) in children with (C)APD.

Methods

Participants

Forty children in the age range of 8 to 14 years participated in the study. They were divided into 2 groups of 20 children each based on the outcomes of the audiological tests i.e. Group I (control group) consisted of 20 children with normal hearing sensitivity as ensured by pure-tone average ≤ 15 dBHL, 'A' type tympanograms with presence of acoustic reflexes, presence of normal results on auditory brainstem responses and presence of transient evoked otoacoustic emissions. To rule out the presence of (C)APD in this group, screening checklist for auditory processing (SCAP) developed by Yathiraj and Mascarenhas (2003) and screening test for auditory processing (STAP) developed by Yathiraj and Maggu (2012) were administered, which revealed normal results.

Group II (clinical group) consisted of 20 children with (C)APD in the age range of 8 to 14 years. They were taken from different English medium schools of Mysuru city, Karnataka. The diagnosis of (C)APD was ascertained upon completion of three stages of evaluation process. In the first stage, 782 children studying in grade 3 to 7 from three different English medium schools were screened. The screening for the risk for (C)APD was performed by using SCAP. Of 782 children, 136 children demonstrated scores of >6 on SCAP. They were further screened using STAP. Of these 136 children, 48 failed in one or more sub-test of STAP (GDT, SPIN, Dichotic CV test, and auditory memory test). Following this, these 48 children underwent detailed diagnostic evaluations (SPIN, Gap Detection Test, & Dichotic CV) and 33 were diagnosed as having (C)APD. In addition, early reading skill test, Bankson Language screening test (Bankson, 1977) and modified mini-mental scale for cognitive function (Teng & Chui, 1987) was used for ruling out deficits in reading, language and cognition skills on these 33 children. Further, these children had normal hearing sensitivity (pure tone average ≤ 15 dBHL) across frequency range from 250 Hz to 8000 Hz and normal middle ear function revealed by tympanometry and reflexometry. Out of 33 children with (C)APD, 5 children were excluded as they were having deficit in either reading, language or cognition skills. Later, among 28 children with (C)APD, 20 were randomly selected for the present study. Written consent was taken from parents/caregivers of all the children participated in the study. The study was approved by ethical committee of All India institute of Speech and Hearing, Mysore.

Instrumentation

A calibrated two channel diagnostic audiometer, MAICO MA-52 with TDH-50 headphones, was used for assessing the air conduction thresholds at octave frequencies between 250 Hz and 8000 Hz. The bone conduction thresholds were estimated at octave frequencies between 250 Hz to 4000 Hz using Radioear B-71 bone vibrator coupled to the same audiometer. Speech audiometry was done for estimation of speech recognition as well as speech identification scores. A calibrated middle ear analyzer (GSI-tympstar) was used to obtain tympanogram and acoustic reflex thresholds. The probe tone used was 226 Hz and Ipsilateral as well as contralateral acoustic reflex thresholds were measured at octave frequencies between 500 Hz and 4000 Hz. STAP was carried out with CD using personal laptop (intelCOREi3) with a set of calibrated supra-aural headphones (Pulse 5) to screen for risk of (C)APD. Gap detection test (GDT) was carried out using Maximum likelihood procedure toolbox of the MATLAB version R2011a platform loaded in the personal computer. Standardized Dichotic CV test (Yathiraj et al., 2012) was performed by routing the laptop's output through the audiometer mentioned above at most comfortable level. Behavioral Differential limen for intensity (DLI_b) was carried out using

Psycon 2.18 software installed in personal laptop. Acoustic change complex were recorded using Neuro ScanSyn Amps[2] data acquisition system for recording the EEG and Neuro Scan Stim2 (Ver 4.4) for stimulus presentation.

Test Environment

Audiological evaluation and administration of psychophysical as well as electrophysiological tests were carried out in sound treated room with the ambient noise levels within permissible limits (ANSI 1991). Audiometric testing was done in double room situation. However, psychophysical and electrophysiological tests were done in single room situation.

Procedures

SCAP (Screening Checklist for Auditory Processing)

SCAP consists of 12 ‘Yes/No’ questions which are answered by parents or teachers. Each ‘yes’ gives a score of 1 and each ‘no’ gives a score of 0. A score of ≥6, as recommended by the developers of the test, considered for identifying children at risk for (C)APD. All the teachers who answered the questions in the present study were familiar with the children for over 3 years.

STAP (Screening Test for Auditory Processing)

STAP consists four subsections (speech-in-noise test, dichotic consonant vowel test, gap detection test and auditory memory test) to tap different aspects of auditory processing. STAP was administered using personal laptop with headphone at most comfortable loudness level on children who obtained ‘refer’ result on SCAP.

Modified mini-mental scale for cognitive function in children (MMSC).

Modified mini-mental scale for cognitive function in children assesses orientation, attention-concentration, registration, recall and language in a single set of questions (Teng & Chui, 1987). In the present study, this tool was administered for those children who had 'refer' results on both SCAP and STAP.

Bankson Language Screening Test (BLST)

BLST consists of a battery of 17 nine-items subtests organized into five subtests namely, semantic knowledge, morphological rules, syntactic rules, visual perception and auditory perception (Bankson, 1977). The test is designed to assess expressive language skill, and it is on this aspect of language that scoring is primarily based. In the current study, this test was administered for those children who failed on both SCAP and STAP. Children who failed in this test were excluded from the study.

Early reading skill (ERS).

ERS was used to evaluate the reading ability of the school going children from grade 1 to grade VIII (Loomba, 1995). This test was performed to exclude those children had reading and writing difficulty.

Dichotic CV test.

Dichotic CV Test for was used for assessment of binaural integration. Two different consonant-vowel (CV) syllables were presented to the two ears with a 0 ms lag between them and the task for children was to identify the CV syllables irrespective of the ear.

Gap detection test (GDT).

GDT was assessed using maximum likelihood procedure (MLP) toolbox implemented using MATLB. Gap detection threshold was calculated using 750 millisecond of Gaussian noise with a gap in center. Here, gap duration was varied according to subject performance using MLP. The noise used here had 0.5 millisecond cosine ramps at the starting and end of the gap. Three alternative forced choice method was used where reference stimulus was always a 750 ms white noise (without gap), whereas the variable stimulus consisted of a gap. Children's task was to identify the noise token that had gap.

Pure-tone and speech audiometry

All participants underwent air-conduction and bone-conduction pure-tone audiometry to verify normal hearing thresholds. Pure-tone thresholds were obtained using modified Hughson and Westlake procedure (Carhart & Jerger, 1959) at octave frequencies from 250 Hz to 8000 Hz for air-conduction and between 250 Hz to 4000 Hz for bone-conduction audiometry. Speech recognition threshold (SRT) was assessed using the standardized paired word list in Kannada and it showed fair agreement between with pure-tone average. Speech identification score (Vandana, 1998) was obtained at 40 dBHL above the SRT using the standardized phonemically balanced (PB) word lists in Kannada.

Immittance evaluation

Tympanometry and reflexometry were done for all participants to check their middle ear functioning. This involved the use of probe tone frequency of 226 Hz at 85 dB SPL and changing the air pressure in the external ear canal from +200 to -400 daPa. The acoustic reflex thresholds were measured for octave frequencies between 500 Hz and 4000 Hz for both ipsilateral and contralateral reflexes.

Distortion product otoacoustic emissions (DPOAE)

DPOAEs were measured using DP Echoport ILO (Version 6). A standard DPOAE probe tip was positioned in participant's ear canal. The ratio of the frequencies (f2/f1) was kept constant at 1.22. The stimulus intensity levels were also held constant 65 and 55 dBSPL for f2 and f1 respectively. The level of the 2f1-f2second order distortion product) DPOAE were depicted as a function of frequency from 1000 Hz to 6000 Hz. DPOAEs were considered present when signal-to-noise ratio was ≥3 dB (Moulin et al., 1993).

Auditory Brainstem Response (Site of Lesion)

To rule out retrocochlear pathology, auditory brainstem response (site of lesion) was done for all children participated in the study.

Acoustic Change Complex

Stimulus generation

The stimulus used in the study was a 500 ms pure-tone of 1000 Hz which was generated through Aux Viewer v1.38 (64 bit) program. The amplitude changes were created with Adobe Audition 3.0 in which the root mean square (RMS) amplitude was increased by different amounts at approximately the mid-point of the stimulus (at 250 ms). A total of 7 stimulus tokens were created, with each having the amplitude change by a different amount (0, 1, 3, 4, 5, 10 or 20 dB). In order to avoid the spectral splatter, the stimuli were gated using a raising cosine function with a rise/fall time of 10 ms. The stimuli were digitized at 16 bits using a sampling rate of 48000 Hz. Intensity calibration was done for all stimulus tokens using Bruel & Kjaer 2270 SLM. Intensity of the initial 250 ms stimulus was calibrated to 80 dBSPL for all stimulus tokens. Stimuli were presented monaurally via ER-3A insert ear phones of the AEP recording system after the analog-to-digital conversion.

Recording of ACC

ACC was recorded in an acoustically treated room using Neuro Scan Syn Amps^2 data acquisition system for recording the EEG and Neuro Scan Stim2 (Version 4.4) for the stimulus presentation. Participant was seated comfortably in a reclining chair and was instructed to minimize the head and body movements. The electrode sites were cleaned with Nu-prep abrasive gel. Disc type Ag–AgCl electrodes were placed at the recording sites using 10-20 conduction paste. The non-inverting electrode was placed at Cz reference/inverting electrode at the ipsilateral mastoid and ground electrode on the contralateral mastoid. Additionally, one bipolar ocular channel was used for detection of eye blinks so that the traces containing blinks could be avoided when averaging. These electrodes were placed above and below left eye. The absolute and inter-electrode impedances were maintained below 5 kΩ and 2 kΩ respectively. ACC was recorded for 6 intensity differences (+1, +3, +4, +5, +10 & +20 dB) and a standard stimulus (no change in intensity) using the above generated 1000 Hz pure-tone. The intensity of standard tone was kept constant at 80 dBSPL.

Online recording of EEG

The raw EEG output of the electrode was recorded in the acquired module of the Scan 4.5 suite interfaced by a Synamps^2 pre-amplifier. Online EEG was recorded at an analog-to-digital sampling rate of 1000 Hz. EEG was band-pass filtered online from 0.1 to 100 Hz (12 dB/octave roll off) and all channels were amplified by a factor of 2010. For each recording, the stimuli were being presented 150 times. While recording ACC, the participants were instructed to watch a muted movie played through a battery operated lap-top computer kept at a distance of 2 meters. This was done to ensure cooperation from participants. Breaks were provided whenever requested.

Offline data analysis

The recorded EEG was analyzed offline. Ocular artifact reduction was performed using linear regression (Semlitsch, Anderer, Schuster & Presslich, 1986) implemented in Compumedics Neuroscan instrument. Continuous EEG data were epoched over a time window of 1100 ms with a pre-stimulus duration of 100 ms and a post-stimulus duration of 1000 msec. Epoched responses were baseline corrected and off-line band-pass filtered from 0.1 to 30 Hz (12 dB/octave roll-off, zero phase-shift FIR filter). Epochs that were greater than ±100 µV were excluded from averaging. All evoked waveforms were analyzed from electrode site Cz. All responses were then averaged to obtain the final ACC waveform. Waveforms were evaluated by two experienced audiologists for presence of ACC and excellent agreement between them was found (Kappa analysis, K = 0.95).The lowest intensity change that produced ACC was considered objective DLI (DLI_o).

Behavioral DLI (DLI_b)

DLI_b was obtained using Psycon 2.18 software installed in a personal laptop (Lenovo, G560, intel COREi3) with calibrated headphones (Pulse 5). The sound card of the laptop was calibrated and volume was set to 70% to yield a maximum of 80 dBSPL. Pure-tone signal of

1000 Hz (500 ms duration, rise and fall time of 10 ms; same parameters as stimuli used for ACC) was used for DLI_b. Adaptive procedure was used with 2 down and 1 up procedure to achieve 70.7% response on the psychometric function (Levitt, 1971). A three alternate forced choice (3IAFC) method was used in descending direction with step size of 5 dB shift was used for first 5 reversals and then narrowed down to 2 dB for the last 4 trials. The session was limited to 100 trials, out of which final four reversals were considered to obtain the mean score and standard deviation. If the standard deviation was more than 2.5 dB, the run was repeated. The inter-stimulus interval was set to 500 ms. Two practice trials were given to each participant for familiarization. The instruction given was "Three blocks will be appearing on the screen and you will be hearing three tones sequentially. One among them will be higher in intensity while other two would be similar. You have to select the block which has a lesser intensity (less loudness) among the three blocks presented or three tones heard". The absolute DLI (ΔI) was noted as minimum difference in intensity between the standard and variable tone which could be discriminated (DLI_b).

Statistical analyses

In the present study, Shapiro-Wilk's test was used to check normal distribution of the data. The data collected of DLI_b revealed normal distribution in normal children group ($p>0.05$) and children with (C)APD ($p>0.05$), whereas the data collected of DLI_o showed non-normal distribution in normal children group ($p<0.05$) and children with (C)APD ($p<0.05$). So, Independent 't' test was used to compare DLI_b between normal children and children with (C)APD. Whereas, Mann-Whitney U test was used to compare DLI_o in normal children and children with (C)APD.

Results

Present study aimed to investigate the utility of ACC as an objective tool to measure DLI in normal children and children with (C)APD. To analyze the data collected to fulfill different objectives from normal children and children with (C)APD, descriptive statistics, Independent 't' test, Mann Whitney U test and Spearman correlation test was done. Frequency of occurrence of ACC at different change in intensity level in normal children and children with (C)APD is shown in table 1.

Table 1: Frequency of occurrence of Acoustic Change Complex at different changes in intensity levels.

Changes in intensity levels	Normal Children (Number of individuals in which ACC was present) (N=20)	(C)APD Children (Number of individuals in which ACC was present) (N=20)
1 dB Change	3	0
3 dB Change	17	5
4 dB Change	20	16
5 dB Change	20	19
10 dB Change	20	20
20 dB Change	20	20

From the table 1 it can be observed that at +1 dB change in intensity, ACC was present in only 3 normal children (15%) and none of the children with (C)APD. Similarly at +3 dB change in intensity, ACC was present in 17 normal children (85%) and 5 children with (C)APD (25%). At +4 dB change in intensity, ACC was present in 100% normal children however only 80% of children with (C)APD showed responses. Similarly, at +5 dB change in intensity, ACC was present in 100% normal children but only 95% children with (C)APD showed responses. Result showed that at +10 dB and +20 dB change in intensity, ACC was present in 100% both normal children and children with (C)APD. Figure 1 to 7 shows grand mean average waveform of ACC for different changes in intensity levels (0, 1, 3, 4, 5, 10, & 20 dB) in normal children (black color) and children with (C)APD (red color).

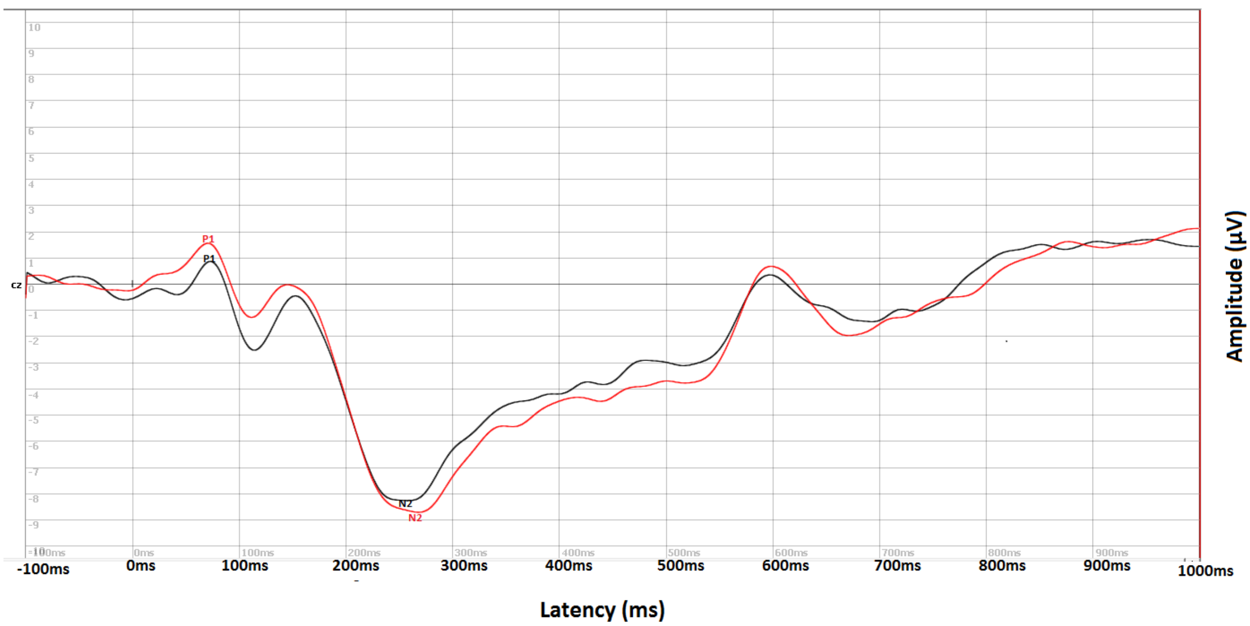

Figure 1: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) at no change in intensity level.

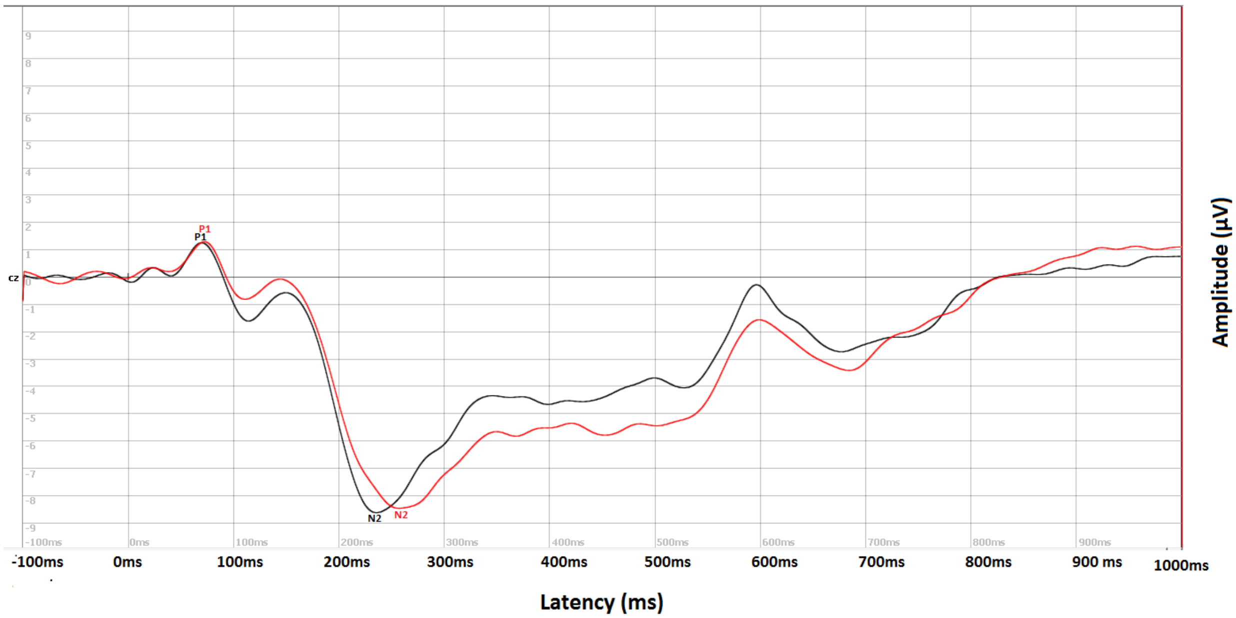

Figure 2: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) for 1 dB change in intensity level.

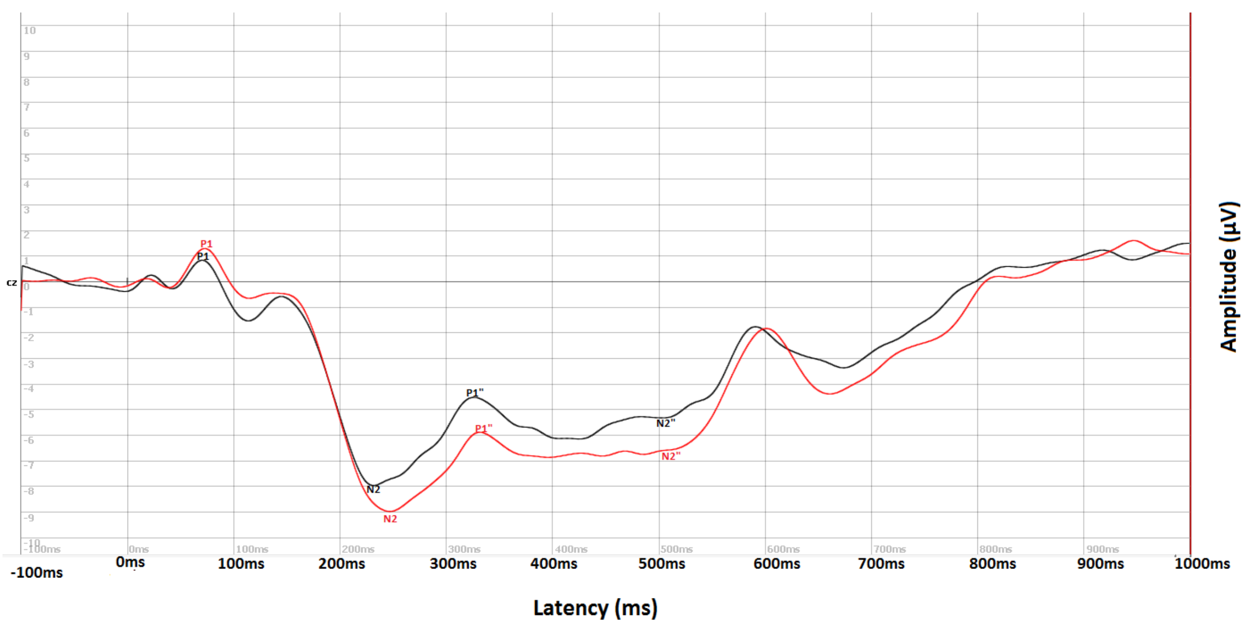

Figure 3: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) for 3 dB change in intensity level.

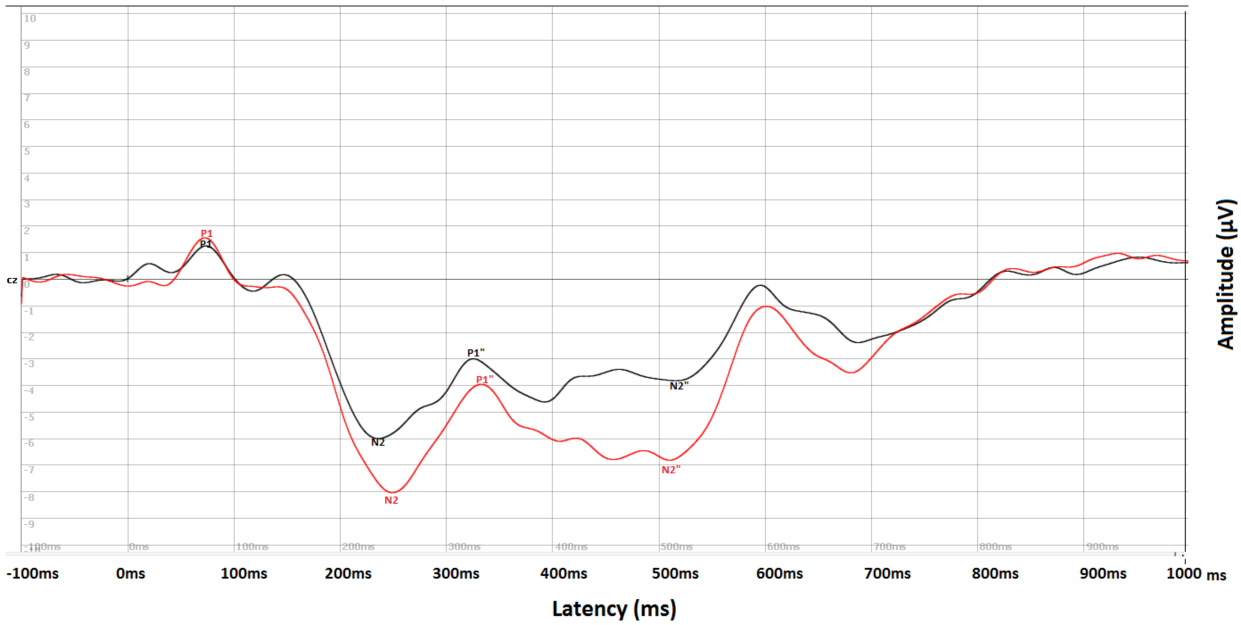

Figure 4: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) for 4 dB change in intensity level.

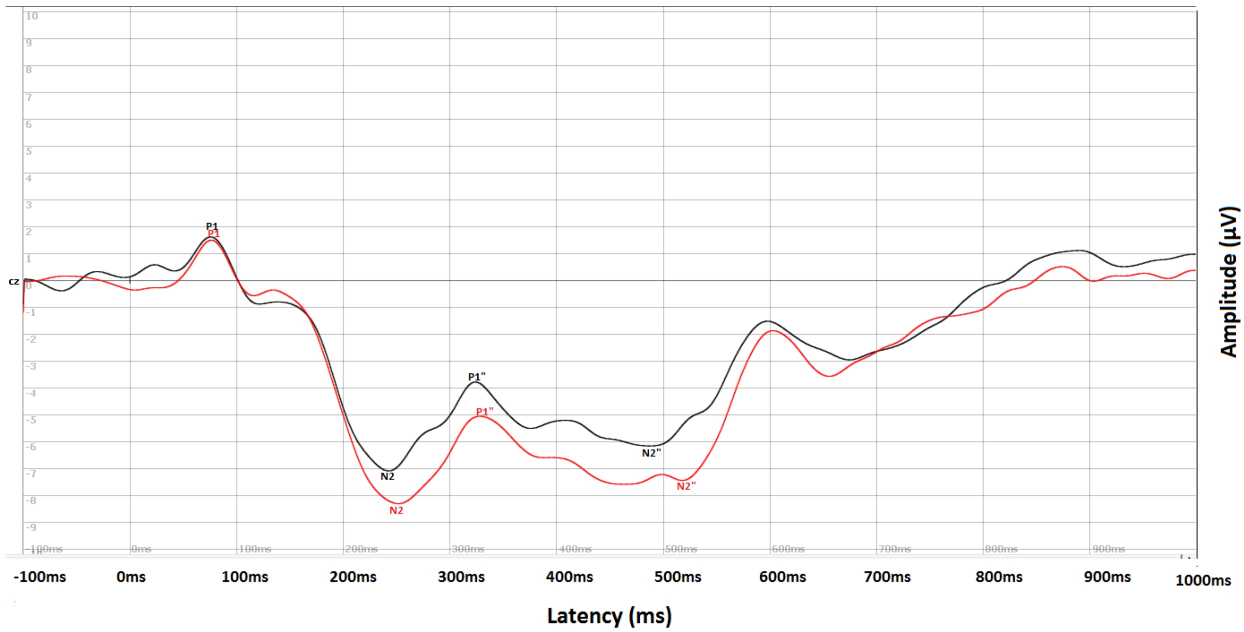

Figure 5: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) for 5 dB change in intensity level.

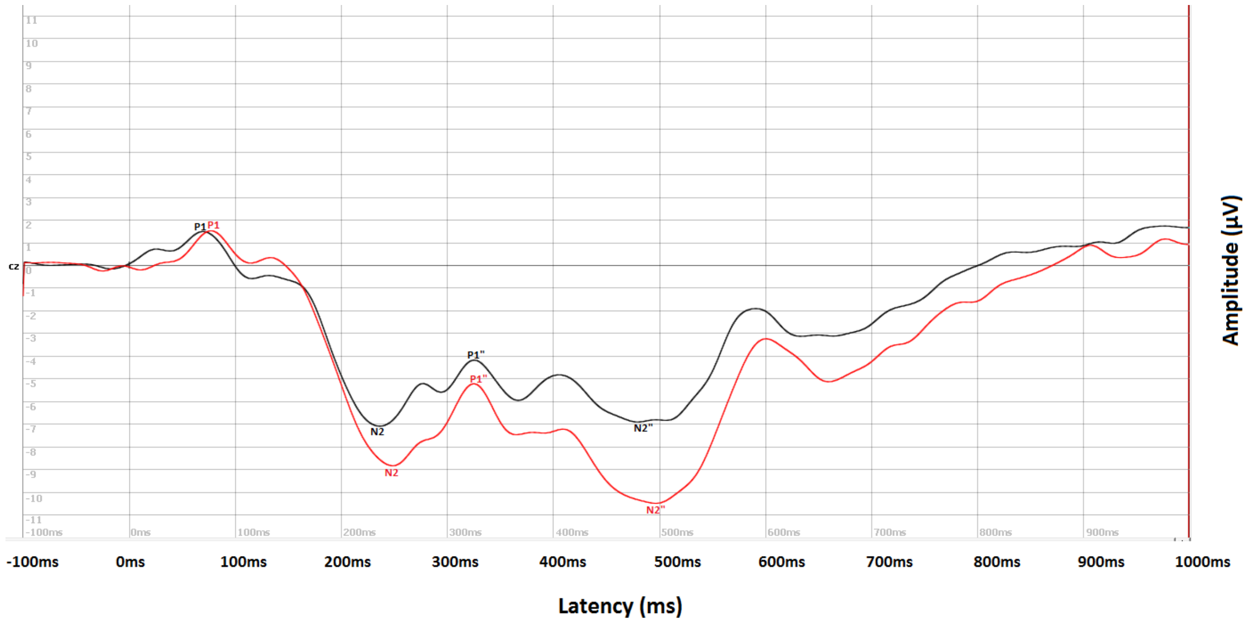

Figure 6: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) for 10 dB change in intensity level.

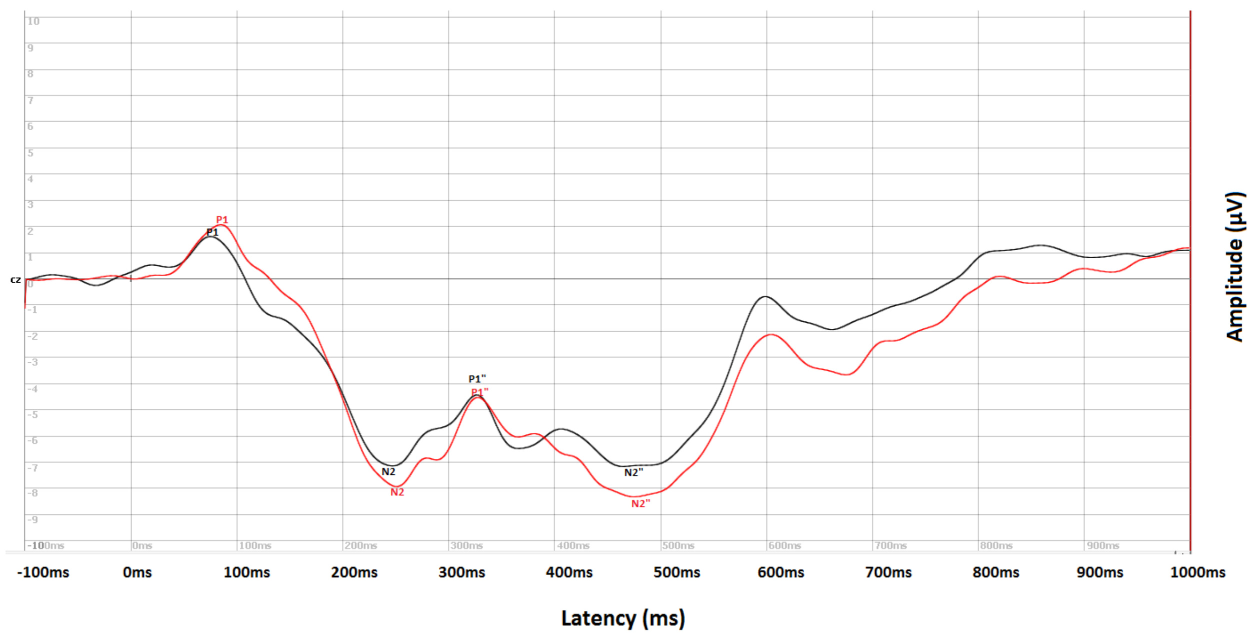

Figure 7: Grand mean average waveform of normal children (black color) and children with (C)APD (red color) for 20 dB change in intensity level.

Table 2: Mean and standard deviation (SD) of DLI using behavioral (DLI_b) and ACC test (DLI_o).

	Groups	N	Mean	SD
DLI_b^{**}	Normal	20	2.12	0.80
	(C)APD	20	3.92	1.10
DLI_o^{**}	Normal	20	2.85	0.87
	(C)APD	20	4.20	1.50

$^{**}p<0.001$; SD: standard deviation

Outcome of DLI_b and DLI_o

Table 2 represents mean and standard deviation (SD) of DLI using behavioral (DLI_b) and ACC test (DLI_o). From table 2, it can be observed that children with (C)APD have larger (poorer) DLI_b and DLI_o compared to normal children. The result showed that DLI_b in normal children was significantly smaller (better) than DLI_b in children with (C)APD ($t=-5.88$, $df=38$, $p<0.001$). Mann-Whitney U test showed significantly smaller (better) DLI_o in normal children compared to children with (C) APD [$Z=-3.91$, $p<0.0001$].

Spearman's correlation test was done to find correlation between DLI_b and DLI_o in both the groups i.e. normal children and children with (C)APD. Spearman's correlation showed statistically significant moderate positive correlation between DLI_b and DLI_o in normal children ($\rho = 0.43$, $p<0.05$). Similarly, Spearman's correlation showed statistically significant strong positive correlation between DLI_b and DLI_o in children with (C)APD ($\rho = 0.62$, $p<0.05$).

The result of the present investigation revealed poorer DLI in children with (C)APD compared to normal children in both behavioral and objective measures. The finding of present study also showed correlation between objective and behavioral DLI.

Discussion

The present study aimed to examine the utility of Acoustic change complex as an objective measure of Difference limens intensity in typically developing children and children in with (C)APD. Difference limens intensity was measured using both electrophysiological ($DLI_{o)}$ and behavioral test ($DLI_{b)}$. The behavioral DLI test was done using the Psycon 2.18 software, and electrophysiological measurement of DLI was done using ACC in both typically developing children and in children with (C)APD. The present study also explored the correlation between DLI_b and DLI_o in typically developing children and children with (C)APD.

DLI_b and DLI_o in typically developing children and children with (C)APD

In the present study, the threshold of behavioral DLI was between 2-3 dB in typically developing children and 3-6 dB in children with (C)APD. Similar results were reported by other researchers (Maxon & Hochberg, 1982; Jensen & Neff, 1993).The current study also showed electrophysiological DLI between 1 to 3 dB in typically developing children and 3 to 5 dB in children with (C)APD. These results are in agreement with other studies. Further DLI_b were increased (poorer) for children with (C)APD when compared against typically developing children. These results indicates that children with (C)APD required larger change in stimulus to perceive the presence of an alteration behaviorally. This indicates a problem in physiological processes accountable for intensity discrimination skill. Belin, McAdams, Smith, Savel, Thivard, and Samson in 1998 stated that discrimination of sound intensity involves two different cortical networks, i.e., a supra-modal right fronto-parietal network accountable for distribution of sensory attentional resources, and a region of secondary auditory cortex specifically involved in sensory computation of sound intensity difference. It might be that delayed maturation of the central auditory nervous system (is a reason for larger (poorer) DLI_b and DLI_o in children with (C)APD (Liasis, Bamiou, Campbell, Sirimanna, Boyd & Towell, 2003). The discrimination ability of intensity changes has been documented to be poorer in children with (C)APD than the control peers (Bellis, 2006). Similar DLI_o results were seen in children with (C)APD. The DLI required for (C)APD children were higher than the typically developing children. The DLI_o and DLI_b both showed increased scores, thus implying the use of objective test to assess the children with (C)APD.

Correlation between DLI_b and DLI_o

In typically developing children, the correlation analysis showed a moderate positive correlation between DLI_b and DLI_o, whereas, in children with (C)APD it showed a strong positive correlation between DLI_b and DLI_o. As discussed above the usefulness of electrophysiological test to assess the DLI, these correlation results point out the clinical utility of the objective tests in assessing difficult to test individuals. There is no previous literature explaining the relationship between DLI found using behavioral measures and ACC in children with (C)APD. However several studies have pointed out that ACC can be reliably recorded with good test-retest reliability not only from listeners with normal hearing but also from individuals with hearing loss, hearing aids, and cochlear implants (Martinez et al., 2013; Friesen & Tremblay, 2006; Tremblay & Burkard, 2006). Further ACC can be obtained even in the absence of attention and requires relatively few stimulus presentations to record response with a good signal-to-noise ratio. The outcome of the current study has shown that acoustic change complex can be used as an objective tool to substitute or to complement the behavioral DLI.

Many studies have shown a positive correlation between behavioral and electrophysiological tests. Michalewski et al (2005) also reported a strong positive correlation between gap detection thresholds measured behaviorally and electrophysiologically (ABR) in both normal hearing individuals and individuals with auditory neuropathy. Bush, Jones, and Shinn (2008) suggested that a diagnostic relationship exists between behavioral and auditory brainstem response (ABR) thresholds. The current study, also points out that ACC can be used as a tool to understand processing problems in children with (C)APD.

Conclusions

Present study aimed to investigate usefulness of ACC as an objective tool to measure DLI in normal children and children with (C)APD. A total of 40 children in the age range of 8 to 14 years participated in the study. There were divided into control (typically developing children) and clinical (children with (C)APD) group based on detailed audiological investigation. Difference limen for intensity (DLI_b) was obtained using Psycon 2.18 software installed in personal laptop. Acoustic change complex was recorded for 6 intensity differences (+1, +3, +4, +5, +10 & +20 dB) and a standard stimulus (no change in intensity) using the above generated 1000 Hz pure-tone. The lowest intensity change that produced ACC was considered objective DLI (DLI_o). Result showed that children with (C)APD have larger (poorer) DLI_b and DLI_o compared to typically developing children. Independent 't' test showed that DLI_b in typically developing children was significantly smaller (better) than children with (C)APD. Similarly, Mann-Whitney U test showed significantly smaller (better) DLI_o in typically developing children compared to children with (C)APD. Spearman's correlation showed statistically significant moderate positive correlation between DLI_b and DLI_o in typically developing children. Similarly, Spearman's correlation showed statistically significant strong positive correlation between DLI_b and DLI_o in children with (C)APD. The current study showed less frequent occurrence of ACC in children with (C)APD compared to normal children. Findings of the present study showed larger (poorer) DLI_b and DLI_o in children with (C)APD compared to typically developing children might be due delayed maturation of central auditory nervous system in children with (C)APD. This shows issues in physiological processes in children with (C)APD responsible for intensity discrimination skill. Although there are no previous studies explaining the relationship between DLI found using behavioral measure (DLI_b) and ACC (DLI_o), the finding of a significant positive correlation between them in the present study stands testimony to the assumptions of previous investigations, that ACC could be used for assessment of DLI in children with central auditory processing disorder.

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