Auditory Lateralization Training Effects on Binaural Interaction Component of Middle Latency Response in Children Suspected to Central Auditory Processing Disorder

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Abstract Many children with central auditory processing disorder (C)APD suffer from spatial processing disorder and benefit from binaural processing training including auditory lateralization training. There are subjective tests for evaluating auditory training effects in children with (C)APD but they rely on patient's attention and cooperation so there is a need for appropriate objective tests. The aim of present study was investigating effects of auditory lateralization training on binaural interaction component (BIC) of middle latency response (MLR). This study was an analytical interventional study. Sixty children suspected to (C)APD (40 boys and 20 girls) were selected based on inclusion criteria and were divided into two groups: control and training group. Auditory lateralization training included 12 formal sessions under headphone by using interaural time difference and performed as a game. MLR (monaural right ear, monaural left ear and binaural) and monaural selective auditory attention test (mSAAT) tests were performed in all the cases. BIC was calculated by subtracting binaural response from summed monaural responses. Covariance test showed that BIC latency decreased and BIC amplitude increased significantly and mSAAT score increased significantly in training group after auditory lateralization training (p value ≤ 0.001). In

present study BIC of MLR had potential to show underlying neurophysiologic changes after auditory lateralization training in children suspected to (C)APD objectively. It is in agreement with behavioral improvements after training (mSAAT improvements).

Keywords Auditory training · Binaural interaction · Spatial hearing · Middle latency response

Introduction

One of the most vital functions of auditory system is sound source localization. Horizontal localization is mainly dependent on binaural hearing [1, 2]. In addition, sound localization enable us to detect and separate sound sources in the space and can help to differ one source of speech from other simultaneous speech sources (noise) [3, 4]. Therefore it is one of the significant auditory system functions for perceiving target speech in everyday listening tasks [5]. Speech perception in noise is better if desired speech and competing signal arrive from different spatial directions [6, 7] and auditory localization in humans is one of the bases for cocktail party phenomenon [4, 8].

Central auditory processing disorder (C)APD is defined as a disorder in auditory neural processing [9] and early identification and intervention in children with (C)APD may prevent poor educational performance and improve everyday listening functions [10]. Spatial processing disorder (SPD) is one of the difficulties in children with (C)APD [11–13]. Dillon and Cameron showed SPDs are prevalent among these children and this may cause sound source segregation problems and speech understanding difficulties in presence of competing sound sources [14, 15] and may lead to poor educational performance [16]. Some

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studies have shown that auditory lateralization training leads to speech understanding improvement in noise [14, 17–19]. Lotfi et al. [19] showed that auditory lateralization training improves auditory behaviors of children with suspected (C)APD including mSAAT (monaural selective auditory attention test) score and spatial WRS (word recognition score) in noise.

There are fewer studies about auditory evoked potentials in children with (C)APD. SPD is a type of binaural processing disorder so binaural processing evaluations are crucial in children with (C)APD [20, 21]. Subjective (behavioral) binaural processing tests like localization and speech in noise [22] tests can be easily affected by non-auditory factors including reduced attention and lack of cooperation. So there is a need for objective evaluation of binaural processing [23]. An alternative to behavioral binaural evaluations is binaural interaction component (BIC) in auditory evoked potentials. Binaural processing is extent of interaction between two ears. If there is no binaural interactions, binaural processing is facing a problem [24].

The aim of present study was investigating effects of auditory lateralization training on BIC of MLR. BIC of MLR was selected because it has larger amplitude than BIC of ABR and is not affected by attention as much as BIC of LLR (late latency response) [25].

Methods

In this analytical interventional study, sixty children suspected to (C)APD (40 boys and 20 girls) were selected based on inclusion criteria and were divided into two groups: thirty children in the control group (mean age 9.07 ± 1.25 years; 10 females and 20 males) and thirty children in the training group (mean age 9.00 ± 1.28 ; 10 females and 20 males). Both groups were match in terms of gender and age.

Inclusion criteria included normal PTA (pure tone audiometry; auditory threshold less than 20 dBHL in 500–4000 Hz frequency range) in both ears; symmetric hearing (PTA difference less than 5 dBHL between two ears); normal middle ear function (A type tympanogram); 85 or higher Wechsler IQ score, monolingualism (Persian language); no history of ADHD (attention deficit/hyperactivity disorder), seizures, behavioral or developmental disorders; not being on any central nervous system medications; poor academic performance; abnormal results in Dichotic Digit Test (DDT), Pitch Pattern Sequence Test (PPS) and monaural Selective Auditory Attention Test (mSAAT) test battery. If a child had scores less than two standard deviations from established norms in this test battery, he/she was highly suspected to (C)APD.

As there is not a single gold standard test for (C)APD diagnosis, DDT [26]/PPS [27]/mSAAT [28] tests were selected based on MAPA (multiple auditory processing assessment) test battery [29, 30]. MAPA study showed that DDT/PPS/mSAAT test battery can provide 90% sensitivity and 100% specificity in (C)APD diagnosis [9, 29]. Results were compared to establish norms for Persian-version of DDT (free recall), mSAAT-Persian version and PPS test [19].

Auditory lateralization training was performed based on Lotfi et al. [19] method and included 12 formal sessions (two 45-min sessions in each week) in the training group and performed as a game (giving a reward to correct child's response). A high pass and a low pass noise with 2 kHz cutoff point, with 250 ms duration and 20 ms rise and fall times were used. Stimuli were presented through headphones with 880, 660, 220, zero, – 220, – 660, – 880 microseconds ITDs at 50 dBHL, and the children had to point to the perceived location of sound source [19, 31]. There were 7 pictures of loudspeakers, in – 90°, – 60°, – 30°, 0°, + 30°, + 60°, + 90° around children [19].

MLR test (monaural right ear, monaural left ear and binaural) was performed in all the cases and BIC was calculated by subtracting binaural response from summed monaural responses. MLR was recorded by click stimuli, 70 dBHL, 7.1/s rate, and rarefaction polarity. Stimuli were delivered via insert phone. Patients were awake and lied down on bed in an acoustic room. Electrodes were placed on the right and left mastoids (inverting), on the forehead Fpz (ground), and at the vertex CZ (non-inverting). Impedance of each electrode was less than 5 k Ω for all subjects and inter-electrode impedance was less than 2 k Ω . BIC of MLR and mSAAT tests was conducted once before auditory lateralization training and once after that. In control group, BIC of MLR test was performed twice for comparison with training group. Second evaluation was performed 2 months after first evaluation.

Written consent was received from children's parents for evaluations and for rehabilitation program. All tests were non-invasive. Control group received auditory rehabilitation after research. Patients' information were kept private. All ethical protocol was followed. This study was approved by ethical committee of the related university with registration number of 892503003.

Data analysis was performed by using SPSS version 21.

Results

Sixty children suspected to (C)APD (mean age 9.02 ± 1.25 years) were divided to control and training group. BIC of MLR was derived in both groups before auditory lateralization training. BIC of MLR was tested after auditory lateralization training in training group and

Table 1 BIC latency and amplitude in control and training group

	1st evaluation	2nd evaluation
BIC latency (ms)		
Training group	29.36 ($\pm$ 0.96)	24.00 ($\pm$ 1.72)
Control group	29.01 ($\pm$ 0.96)	29.05 ($\pm$ 1.32)
BIC amplitude (μ v)		
Training group	0.33 ($\pm$ 0.01)	0.37 ($\pm$ 0.03)
Control group	0.32 ($\pm$ 0.01)	0.31 ($\pm$ 0.01)

after 2 months from the first evaluation in control group. Summary of results can be found in the Table 1.

Covariance test showed that BIC latency decreased and BIC amplitude increased significantly in training group after auditory lateralization training (p value $\leq$ 0.001).

Covariance test showed that mSAAT score in right and left ear (p value $\leq$ 0.001) improved significantly after lateralization rehabilitation. Table 2 shows mSAAT score (percent) in right and left ear in training group after lateralization rehabilitation and in control group after 2 months from first evaluation.

Komogrov–Smirnov test showed that BIC latency and amplitude had a non-normal distribution therefore Wilcoxon test was used for comparing results within groups. Wilcoxon showed that BIC latency (p value = 0.77) and amplitude (p value = 0.62) has not change significantly in control group but there is a significant increase in BIC amplitude and significant decrease in BIC latency in training group after auditory lateralization training (p value $\leq$ 0.001).

Kolmogorov–Smirnov test showed that mSAAT data had non-normal distribution in training and control groups (p value $\leq$ 0.001). Wilcoxon test was used for comparing results. In control group mSAAT score in right ear did not show any significant changes after 2 months (p value = 0.05) but left ear showed significant decline (p value = 0.03). In training group mSAAT score in both ears showed significant improvement after lateralization rehabilitation (p value $\leq$ 0.001).

Discussion

In present study, auditory lateralization training could make significant changes in mSAAT score BIC latency and amplitude in MLR. Therefore in addition to behavioral

improvements in children suspected to (C)APD, there is a change in electrophysiologic response. To our knowledge there is not any other research about effects of auditory training on BIC of MLR.

After lateralization rehabilitation, mean mSAAT score improved significantly (p value $\leq$ 0.001). This finding generally is in agreement with other studies [15, 17]. It appears that high proportion of children with CAPD has speech in noise/competition problems [15]. Lateralization training was able to improve children's ability to understand speech in presence of competition. This finding was seen in another research conducted by the authors [19].

Schochat et al. [32] studied 30 children with (C)APD and 22 normal children without (C)APD in 8–14 years of age. They wanted to show auditory training effects on MLR. They used four central processing tests to determine children with (C)APD: the pediatric speech intelligibility (PSI) test, speech-in-noise test (SIN), staggered spondaic word test (SSW), dichotic digits test (DDT), and a dichotic nonverbal test. All subjects tested twice. Subjects with (C)APD tested once before starting the auditory training program and once 1 month after completion of auditory training. Subjects in control group tested at the same time as children with (C)APD but they did not received any intervention. The (C)APD group received auditory training for 2 months. They were retested 1 month after finishing the training. The auditory training consisted of 50-min sessions, once a week. Training lasted for over 8 weeks. Formal training sessions included frequency training, Intensity training, temporal training, dichotic interaural intensity difference (DIID), localization and speech perception. The results of this study showed an improvement in the MLR after the auditory training. Although subjective tests of central auditory processing can be used to measure auditory training effects, auditory evoked responses are objective and sensitive tools for underlying neurophysiologic changes related to training. They maintained that there is a lack of data on MLR and (C)APD and generators of the MLR are neurons in the thalamo-cortical areas of the brain, which can be involved in (C)APD [32].

Gopal and Pierel [22] used BIC of ABR in nine children at risk for (C)APD (based on SCAN test) and nine normal children. Results indicated a significant reduction in the amplitude of the BIC of ABR (auditory brainstem

Table 2 mSAAT score (percent) in training and control group in 1st and 2nd evaluation (mean $\pm$ SD)

	Score in right ear		Score in left ear	
	1st evaluation	2nd evaluation	1st evaluation	2nd evaluation
mSAAT in control group	60.20 ($\pm$ 2.36)	64.66 ($\pm$ 2.09)	62.23 ($\pm$ 2.00)	63.01 ($\pm$ 2.23)
mSAAT in training group	62.11 ($\pm$ 2.42)	83.21 ($\pm$ 2.86)	63.83 ($\pm$ 2.02)	83.91 ($\pm$ 2.87)

response), in the CAPD group. They showed that BIC of ABR can be an objective response for determining children with (C)APD. They did not investigate auditory training effects on BIC [22]. Delb et al. [11] introduced BIC as a valuable objective test for diagnosing (C)APD as there is a high prevalence of binaural processing difficulties in these children. They explained that behavioral tests for binaural processing have limitations because they need active response from children and none-auditory factors like lack of attention and cooperation can easily confound the results. They studied BIC of ABR in 17 children at risk for CAPD and 25 normal children. They used absence of clear BIC as an index for diagnosing CAPD. They found that BIC has a sensitivity and specificity of 76% for differentiating children with (C)APD from normal children. They did not study effects of any auditory training on BIC [11].

In present study it was shown that BIC of MLR can be potentially an index for showing auditory training effects in children with (C)APD. To our knowledge it is the first study in this area and further researches are recommended.

Conclusion

In present study BIC of MLR had potential to show neurophysiologic changes after auditory lateralization training in children suspected to (C)APD objectively. BIC of MLR showed changes in parallel to behavioral improvements (mSAAT improvements). It can be indicative of binaural processing changes at thalamocortical areas. BIC test has the benefit of being objective so it is not dependent on children's attention and cooperation. BIC can show training effects and ensure the clinicians that they are making auditory processing improvements may be even before they be able to see these improvements subjectively. Further studies are needed to generalize these findings.

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