The effects of Singing Lessons on Speech Evoked Brainstem Responses in Children With Central Auditory Processing Disorders

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Résumé

Cette étude a examiné l'impact de cours de chant sur le traitement auditif sous-cortical chez les enfants atteints d'un trouble du traitement auditif (TTA). Onze enfants de 7 à 11 ans ont participé à cette étude. Les potentiels évoqués auditifs du tronc cérébral (PEATC) ont été enregistrées en utilisant un stimulus auditif non verbal (clic) et un stimulus de parole (phonème /da/), avant et après six mois de cours de chant. Les leçons comprenaient un programme spécialement conçu pour remédier aux déficits de perception de la tonalité et du rythme observés chez les enfants ayant un TTA. Les résultats obtenus ont révélé des latences allongées chez les enfants présentant un TTA avant et après les leçons de chant par rapport aux valeurs normatives établis sur des enfants ayant une audition normale. Cependant, aucune différence de latence significative n'a été observée après six à huit mois de cours de chant. Des amplitudes significativement plus grandes ont été observées pour l'onde A et la pente VA après un entraînement musical. Une tendance vers une amplitude supérieure a également été observée pour l'onde O. Les expériences auditives enrichies ont une influence profonde sur la façon dont le son est traité dans le cerveau. Les données de cette étude suggèrent que l'efficacité des leçons de chant peut être quantifiée grâce aux PEATC enregistrés avec un stimulus de parole chez les enfants atteints de TTA. Après six à huit mois de formation musicale, l'amplitude de l'*onset* et de l'*offset* de la réponse physiologique s'est améliorée. L'amplitude des réponses sous-corticales pourrait donc être plus sensible que la latence pour démontrer l'effet positif des leçons de chant. Toutefois, cette durée reste insuffisante pour révéler une amélioration de la synchronisation neurale (latence).

Mots clefs : potentiels évoqués auditifs sous-corticaux ; potentiels évoqués auditifs du tronc cérébral avec stimuli verbaux ; trouble de traitement auditif, plasticité, intervention spécialisée, cours de chant

Abstract

This study investigated the effects of formal singing lessons on subcortical auditory responses in children with central auditory processing disorders (CAPD). Eleven school aged children (7-11 years old) participated in the study. Auditory brainstem responses (ABRs) were recorded using click and speech stimuli (/da/) before and after 6 months of singing lessons. The lessons included curriculum specifically designed to address deficits in pitch and timing perception as seen in children with CAPD. Results revealed delayed latencies in CAPD children before and after singing lessons compared to the normative data developed for children with normal auditory function. However, no significant latency differences were observed after the six to eight months of singing lessons. Significantly larger amplitudes were observed for Wave A and the VA slope after musical training. A trend for larger amplitude was also observed for Wave O. Enriched auditory experiences have a profound influence on how sound is processed in the brain. The data of the present study suggest that efficacy of formal singing lessons can be demonstrated by speech-ABR in children with CAPD. The magnitude of the onset and off-set of the speech-ABR response improved after the six to eight months of formal auditory (music) training. Subcortical response amplitude could be more sensitive than latencies to demonstrate the positive effect of singing lessons. However, this duration would be insufficient to reveal an improvement for the neural timing (latency).

Keywords: central auditory processing disorders, sub-cortical auditory evoked potentials, speech-ABR, plasticity, specific intervention, singing lessons

1 Introduction

An~auditory~centered~dysfunction,~a~prevailing~central auditory processing disorder (CAPD), has been outlined as a perceptual disorder which should be distinguished from peripheral hearing loss, cognitive, psychological and/or learning problems that are not auditory specific [1-4]. According to the Canadian Guidelines on Auditory Processing Disorder in Children and Adults (2012) [4], CAPD is defined as a persistent limitation in the performance of auditory activities. Children with CAPD have difficulties

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processing, tolerating, filtering and listening to sounds in background noise [1, 4]. Consequently, children with CAPD experience challenges in daily living which can make their school experiences extremely challenging and tiring [1, 4]. CAPD prevalence is not precisely known due to the lack of agreement about a ‘universal standard’ diagnostic test [5]. However, CAPD prevalence in the school-aged children is estimated to be between 2 and 3%, worldwide [6]. Besides high co-morbidity between CAPD and attention disorders [2], reading impairments [7], and language disorders [7], the behavioral test battery may be easily influenced by non-auditory factors like memory [8] or attention [9].

Research on therapeutic interventions specifically for CAPD is emerging [10-12], however, there is still much work to be done to identify evidence-based approaches which have demonstrable success as the results of the existing research have been limited. A meta-analysis by Fey et al. (2011) [13] explored the efficiency of several auditory and language interventions, such as Dichotic listening, Fast ForWord, Earobic, modified auditory integration, comprehension in noise training and other specific interventions, in school-aged children with CAPD (for more information and details about the interventions, see [13]). Based on the meta-analysis results, there was little evidence to support the effectiveness of existing intensive interventions [13]. Kraus and Banai (2007) [14] also noted that existing interventions generally do not show remarkable improvements. As such, there is currently little direction for clinicians working with children with CAPD and there is a marked need for deficit-specific interventions.

Given the impact that CAPD-related deficits can have on the daily life of children and the limited results of existing interventions, the need to explore possible interventions for CAPD is pressing. Preliminary studies on the use of music as auditory processing training show promising results in improving functions across several domains, such as enhancements in speech perception [11, 15], reading acquisition [11], socialization and emotional self- regulation [16, 17], numeracy and general attainment [18]. Moreover, changes in the brain become evident after mere months of music training, especially in children [11, 15]. The indirect benefits of music training have also been observed in special populations, including children with learning difficulties [19]. Music-making can improve general auditory function [11] and language processing [14, 20]. Studies show that there is a link between musical perception, phonological awareness and early reading development [15] and between perception of musical meter and phonological development [21]. Specific music training has also been shown to improve neural differentiation in speech sounds [11], and phonological awareness and auditory memory [15]. While music training has not been shown to provide an advantage in clinical speech-in-noise tests [22, 23], there is significant evidence of improved pitch perception and processing in musicians versus nonmusicians as seen in both behavioural and electrophysiological measures [23- 27]. The promise shown in these preliminary explorations of the effect of music on CAPD-related deficits encourage further research on music-related interventions.

Several studies investigated whether certain electrophysiological tests could be used as an objective and non-invasive neurophysiological tool to explore the impact of specific auditory intervention, such as music training, in diverse clinical populations [10, 11, 28, 29]. Recording auditory brainstem responses (ABRs) to nonverbal sounds such as a click has long been established as a valid and reliable clinical tool to assess the integrity of the neural transmission of acoustic stimuli [30]. The ABRs are auditory subcortical evoked responses originating from the distal portion of the eighth nerve and extending up to the auditory brainstem [31, 32]. ABRs consist of five distinct positive peaks (I to V) originating from the brainstem; the first peak, wave I, occurring 1.5 to 2 ms, and together IV and V form normally the largest peak, occurring about 5.5-6 ms after the onset of a click stimulus [30, 32]. Although the clinical ABR evoked by nonverbal stimuli, click or tone burst provides information regarding hearing sensitivity, it would not provide specific information regarding auditory processing.

Additional methods have been developed to analyze ABR information obtained from the presentation of speech stimuli such as /da/ that are spectrally and temporally more complex than click stimuli [33]. As described in Skoe and Kraus (2010) [34], ABRs recorded from presentation of a 40 ms stimuli to a stop consonant-vowel /da/ are composed of seven evoked waves (peaks); V and A are related to the onset response corresponding to the burst release of the stop consonant, peak C is the transition from consonant to vowel, peaks D, E, and F correspond to the speech-evoked frequency following responses (FFR) and peak O is the response to the stimulus offset.

ABRs evoked by speech stimuli were used in several clinical populations, such as children with hearing loss and/or reading difficulties, with the aim of finding neurophysiological markers [29, 35- 38]. For example, Strait et al. (201l) [29] tested 42 participants ages 8 to 13 years with different reading abilities. The objective was to define common biological underpinnings for music and reading abilities. Auditory working memory, attention, musical aptitude, reading ability, neural sensitivity to acoustic regularities, and auditory brainstem measures were investigated. The authors concluded that the multimodal quality of musical training promoted neuroplasticity and the enhancement of specific mechanisms such as auditory discrimination or temporal processing – pitch, timing or rhythm – essential abilities in speech processing. Therefore, biological markers and shared qualities promote the positive correlations between literacy and music, positioning the latter as a forthcoming reading – improvement approach [29].

Based on reviewed investigations, music training would improve auditory functioning and there would be a possibility that music training could be a viable option for CAPD intervention. This would fill the noted gap in effective interventions for CAPD. The purpose of this study was to explore this possibility by developing and delivering a music training intervention that targeted specific deficits seen in CAPD. We hypothesized that music-based intervention would be an effective intervention for CAPD. As playing a musical instrument requires intense coordination of skills, we opted to remove the challenge of motor coordination and focus purely on auditory skills by using singing lessons as the vehicle of training. We also sought to explore the clinical value of speech-evoked ABR, and potentially increase evidence for its use as part of the test battery required to diagnose CAPD.

2 Method

The experiment was conducted at the APD Ottawa clinic and at Lotus Centre for Special Music Education. All procedures were approved by the Office of Research Ethics and Integrity at the University of Ottawa.

2.1 Participants

Data were collected from 11 Canadian English-speaking school-age children (8 boys and 3 girls) that were between the ages of 7 and 12 years (mean age: 9 years, 11 months; SD: ±1 year and 3 months). Hearing threshold was within normal limits (pure tone thresholds ≤ 15 dB HL for octave frequencies from 250 to 8000 Hz and tympanometry was normal as well (admittance curve with a single peak between +50 to -100 daPa using a 226 Hz probe).

The participants were recruited from the APD Ottawa clinic in Ottawa, Canada and were diagnosed with auditory processing difficulties before enrolling in the present study. The diagnosis was given independently from the study. Since there are no universal criteria for the diagnosis of CAPD, the Canadian Guidelines on Auditory Processing Disorder in Children and Adults [4] were followed by APD Ottawa's audiologists to establish diagnosis. Within the parameters of these guidelines, children have a hypothesis or working diagnosis of CAPD when their performance is at least two standard deviations below the mean on a minimum of two tests. The test battery included the following tests: Staggered Spondaic Words [39], the Dichotic Digits Test [40], Pitch Pattern Test [41], Random Gap Detection Test [42] the Filtered Words test [43] and the Bamford-Kowal-Bench Speech-in-Noise Test [44-46] or Quick Speech-in-Noise Test [47]. To be part of the present study, the participants were required to have failed the Pitch Pattern Test [41] and the Random Gap Detection Test [42], as well as the other mentioned criteria (See Table 1).

2.2 Materials

Stimuli

Click stimuli and the speech syllable /da/ were used to elicit the auditory brainstem responses. All the responses were elicited and collected using a BioMARK system (Biological Marker of Auditory Processing, BioMARK software, NavigatorPro AEP system, Bio-logic Systems Corp.). The stimuli used was a five-formant speech syllable /da/ (provided with the BioMARK) comprised of an initial noise burst and a formant transition between the vowel and the consonant (for more information about the formant, see [34]).

Table 1: Results of eleven participants with Auditory Processing Difficulties on six tests evaluating the key functions of the central auditory system in two different moments. The age of the participants at the first singing session is also indicated.

CAPD	Gender	Age at the beginning of singing lessons (yr; month)	Specific information	Tests failed 1st evaluation	Tests failed 2nd evaluation
1	M	7;11	Diagnosed with: learning disability -difficulty reading	SSW, BKB-SIN, PPST, RGDT, FS, ACPT (borderline)	SSW, BKB-SIN FS:LE,
2	F	10;1	Difficulties in school consistent with apraxia and short attention span	SSW, BKB-SIN, DD, PST, PPST, RGDT, CST	SSW, BKB-SIN, DD, PST, PPST, RGDT
3	M	8;9	-Intellectual functioning in the upper end of the average range with great variability	FS:LE, PST, PPST, RGDT	N/A
4	M	8;9	-Diagnosed with: speech disorder	SSW, PPST, RGDT, CST:LE ACPT, DD:LE (borderline)	N/A
5	M	7;7	Difficulties with ocular function and challenges with overall motor skills	SSW, PPST, RGDT, DD:LE, CST :LE, BKB-SIN :LE and ACPT (borderline)	N/A
6	M	7;9	Concerns with attention and focus	SSW, PPST, RGDT, FS:RE	None
7	M	8;4	Difficulties in school	SSW, FW, CST:LE PPST, RGDT, DD, FS:RE	N/A
8	F	10;10	Difficulty with reading comprehension	SSW, PPST, RGDT, Quick SIN, PST, FS, DD:LE, CST :LE ACPT (borderline)	None
9	F	8;4	-Difficulties with reading	SSW, RGDT, PPST, PST, CST, FS, DD:LE	N/A
10	M	7;4	-History of non-verbal learning disability and ongoing school difficulties	SSW, PPST, RGDT, DDT=LE, FW= LE, CST= LE	N/A
11	M	11;6	-Diagnosed with ASD	SSW, PPST, RGDT, PST, CST, DD:RE	SSW, PST, TCS, CST:LE, DD:RE Quick-SIN,

Legend: SSW = Staggered Spondaic Word test, BKB-SIN (Bamford-Kowal-Bench) Speech-in-Noise Test, PPST = Pitch Pattern Sequence Test, RGDT = Random Gap Detection Test, FS = Filtered Speech, ACPT = Auditory Continuous Performance Test, *DD* = Dichotic Digits, PST = Phonemic Synthesis Test, CST = Competing Sentence Test, FW = Filtered Words, Quick SIN = *Quick* Speech in Noise *test*, *TCS* = Time-Compressed Speech *Test*, RE = Right Ear, LE = Left Ear, N/A = not applicable (not tested yet)

The speech syllable was 40 ms synthesized at a sampling rate of 10 kHz.

2.3 Procedures

A consent form was reviewed and signed by the parents, and the children also agreed to participate in the study. The study was conducted in three distinct steps over the course of six to eight months. The first and third steps were respectively the pre- and the post-test via electrophysiological recordings. The second step was the singing lesson intervention.

Electrophysiological recordings

Participants were seated comfortably with closed eyes during the recordings and the experimenter was in the room. The stimulus was delivered to the right ear through a Bio-logic® small foam insert earphone. The left ear was kept non-occluded for the entire recording. The single channel montage consisted of three disposable adhesive scalp electrodes (Natus Medical Inc, Mundelein, IL, USA): an active Cz (vertex), a reference (ipsilateral earlobe), and a grounded electrode (contralateral earlobe). The clicks were presented with rarefaction polarity at a rate of 13.3 clicks/sec. Two blocks of 1500 sweeps were collected from the right ear and were averaged using a 10.6 ms time window, band-pass filtered on-line from 80 to1500 Hz using a 12 dB/octave filter roll-off. The /da/ syllable was presented at alternating polarities at a rate of 10.9 cycle/sec. A total of 4000 artifact-free responses (two sub-averages of 2000 sweeps) were collected and averaged using an 85.33 ms (including a 15-ms pre-stimulus time window) band-pass filtered on-line from 100-2000 Hz. For the click and /da/ recordings; electrical impedances at each electrode tended to be ≤ 5 kΩ and did not exceed a 2 kΩ difference between electrodes throughout the recordings. Trials with an artifact exceeding ±23.8 µV indicating movement artifacts and baseline noise contamination were excluded from the average. The total recording time lasted between 30 and 45 minutes, including the time required for electrode placement.

Singing lesson intervention

Participants received 24 lessons of 30 minutes each, once per week, which were completed within a six to eight-month range. All participants attended 24 lessons by the end of the intervention period, which was sometimes interrupted by holidays or participant vacation.

A preparatory singing lesson curriculum was used as the intervention, with specific activities designed to develop rhythmic abilities, pitch awareness and discrimination, and auditory memory. The curriculum was specially designed for this investigation based on prior research in vocal instruction [48] and was adapted by the researchers of this study to target specific deficits in participants with auditory processing disorder. The curriculum was developed to be accessible to music educators and not as a comprehensive therapeutic approach. The objective was to determine whether singing lessons with targeted rhythm and pitch development activities delivered by music educators could be an effective intervention in improving CAPD-specific deficits. For this reason, the progress of each participant was allowed to flow naturally and the instructor was encouraged to follow the curriculum in a way that was participant-led and would be replicable by music educators. An identical lesson structure was used for each participant, however individual progress was encouraged, meaning that students progressed through the lesson material at individual rates. The lessons were collaborative and involved active participation from both the participant and the teacher providing the intervention. This removed the rigidity that would be present in traditional therapeutic interventions, but as the goal here was to explore the effectiveness of singing lessons that would be delivered by a music educator, the intervention was allowed to proceed in a natural manner that would reflect typical music lessons while providing activities to improve student deficits that could be implemented by any experienced music educator.

The singing lesson plan was highly structured and followed the same set of activities in the same order in each lesson. The lessons first activity was an introductory song to create structure and develop rote-learning skills. The song was led by the instructor and echoed by the student. It also involved rhythmic movement in the form of waving to reinforce the musical beat.

The second activity aimed to achieve rhythmic accuracy through full-body movement. A medium-sized ball was rolled between the instructor and participant to the predetermined tempo set on a metronome. This required attention to and awareness of the tempo. The tempo increased incrementally at and between each lesson, beginning at 40 beats per minute and capping off at 180 beats per minutes. The rate at which the tempo increased was individual based on the development of each participant.

The third activity served the purpose of developing pitch awareness, pitch differentiation, and intonation (ability to sing in tune). It also aimed to foster creativity and musical improvisation skills, as well as the exploration of a wide range of pitches. The instructor and student took turns playing single to double note patterns on a glockenspiel. Participants chose any pitch between a predetermined range appropriate for his/her voice, as determined by the teacher. After playing and listening to the pattern once, participants sang his/her name, word of choice, or solfege syllable to the pitch(es) of choice.

The fourth activity was vocal warmups to prepare for the repertoire. Warm-ups included repetitive melodic patterns that increased in length and range throughout the intervention in accordance with each participant's musical development and progress. Freedom was given to the instructor when determining the specifics of each warm-up, particularly to address vocal technique issues specific to the student. The final step of the warm-up involved participants using solfege syllables in a call-and-response activity using three-note melodies sung to a specific rhythmic pattern with simple, chorded piano accompaniment.

The fifth step of the lesson was to apply the above skills to larger-scale repertoire. The repertoire was selected from a compilation of preparatory-level voice repertoire prepared by the Royal Conservatory of Music, Resonance: A Comprehensive Voice Series [49]. The pieces were introduced to each participant in a predetermined sequence, however the pacing was individualized. The process of learning the repertoire was the same for every participant, starting first with reading reading the text; second, speaking the text to rhythm; third, singing the melody on a pure vowel; fourth, singing the melody with the text; finally, singing the song in its entirety with piano/CD accompaniment.

The final portion of the lesson was a rhythm activity for learning rhythmic notation and developing rhythmic accuracy. The instructor and student reviewed notated rhythm by using colour-coded and sized rhythm cards, and then worked together to build rhythmic patterns that increased in complexity as the lessons progressed. The participant practiced clapping the rhythm both with and without a metronome. The lesson concluded with a good-bye song to the same melody as the introductory song.

3 Results

All statistical analyses were completed using IBM SPSS Statistics software (Version 25) (SPSS, Inc. Chicago, IL). For each dependent measure, one-way analyses of variance ANOVA were used for pre- and post singing training. In all cases, p-values reflect two-tailed tests ($p \leq 0.05$). Levene's test was used to ensure homogeneity of variance for all measures.

All waves of the click and speech-ABR were identified and marked manually. Click-ABR waves (I, III and V) and Speech-ABR waves (V, A, C, D, E, F and O) were replicated twice and visually marked.

3.1 Electrophysiology measurement

Electrophysiological recordings

No significant differences were observed between the two pre- and post singing training sessions test conditions for ABR wave latencies ($p \geq 0.05$) and amplitudes ($p \geq 0.05$) in response to click stimuli. For the speech-ABRs, dependent measures included timing (i.e., the latencies in ms) and the magnitude (amplitude in uV) of waves V, A, C, D, E, F, O and VA slope).

Figure 1 illustrates the participants' grand average responses to speech stimuli recorded in the two pre- and post singing training sessions. No significant differences were found between the two conditions for speech ABR neural timing (peak latencies) of any of the waves ($p \geq 0.05$). However, the neural magnitude (amplitude) revealed somewhat different results. Significant differences were found between the two conditions for the speech ABR wave peak amplitude: A (on-set): [$F(1, 19) = 5.4$, $p = 0.03$, $\eta p2 = 0.22$] and VA slope (on-set): [$F(1,19) = 6.5$, $p = 0.02$, $\eta p2 = 0.25$]. A trend was observed for peak amplitude O (off-set) [$F(1,19) = 3.4$, $p = 0.08$, $\eta p2 = 0.15$]. The peak (A, O) amplitudes and VA slope were bigger post- singing lessons compared to the pre-lesson session.

Participant individual data

In order to have a better understanding of the pattern of results in relation to wave amplitude, the individual data of participants with CAPD was explored. Three categories were identified: A) noticeable amplitude changes for almost all waves after singing training; B) a mixed pattern of noticeable changes for some waves and no remarkable changes for other waves; and C) minor amplitude changes for the several of the speech-ABR waves after singing training. Twenty per cent of the participants were classified in category A; twenty in category B; and sixty per cent of participants were included in category C (See Figures 2, 3 and 4).

4 Discussion

The goal of this study was to evaluate the degree to which neurophysiological subcortical response morphology, timing and magnitude would be modulated by a 6-month block of singing lessons for children identified with CAPD. The main neurophysiological findings of the present study suggest that the magnitude (amplitude) of several subcortical responses demonstrated a positive effect from the music training.

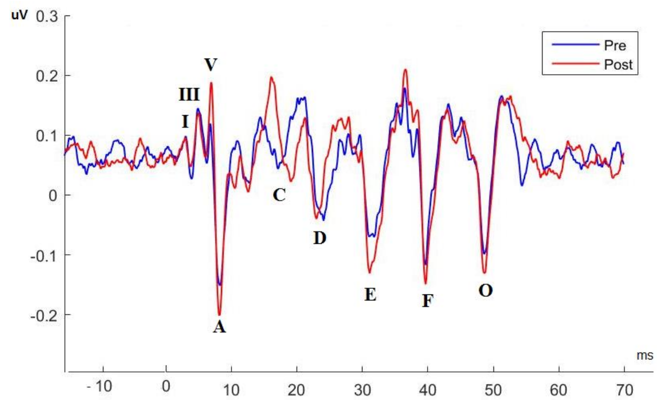

Figure 1: Grand average of subcortical responses (speech-ABR) obtained from children with auditory processing difficulties recorded before and after singing lessons (Pre, presented in bleu, and Post, presented in red). Click-evoked ABR peaks (I, III, and V) and the major speech- ABR peaks V, A, C, D, E, F, and O are labeled

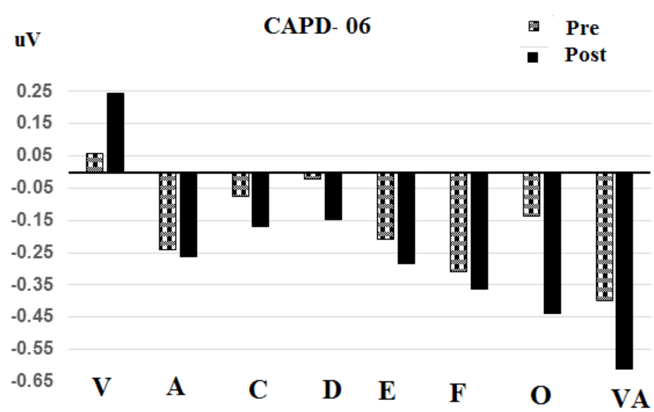

Figure 2: Category A. subcortical responses (speech-ABR) obtained from a participantparticipant with auditory processing difficulties (CAPD 6) recorded before and after singing lessons (Pre and Post). The amplitude of the six waves (V, A, C, D, E, F, O) and the VA slop were improved after the singing training.

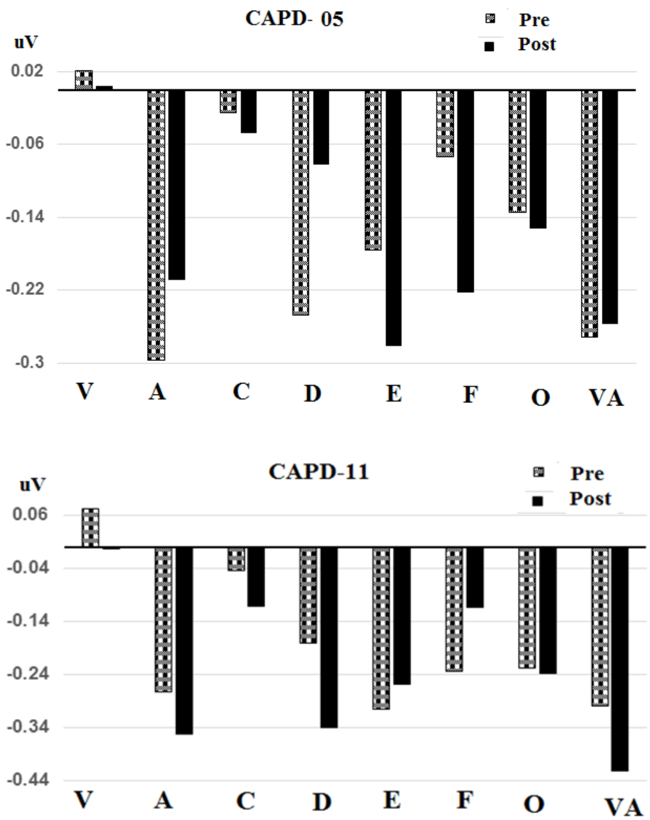

Figure 3: Category B. subcortical responses (speech-ABR) obtained from two participants with auditory processing difficulties (CAPD 05 and 11) recorded before and after singing lessons (pPre and pPost). The amplitude of waves C, E, F and O was improved for CAPD 05 and the amplitude of waves A, C, D and VA slop was improved for CAPD 11 after the singing training.

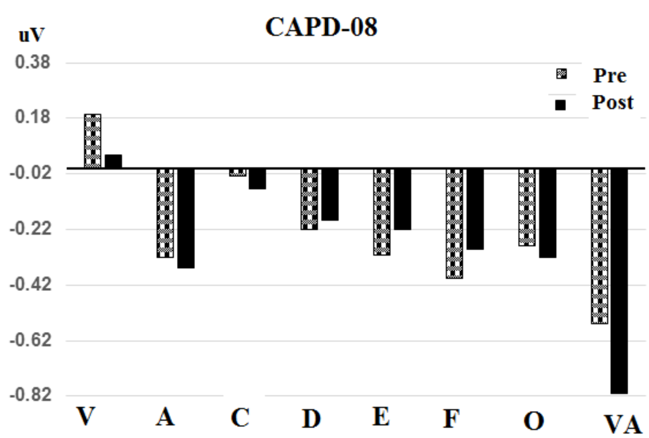

Figure 4: Category C. subcortical responses (speech-ABR) obtained from a participantsparticipant with auditory processing difficulties (CAPD 8) recorded before and after singing lessons (Pre and Post). The amplitude of majority waves (V, C, D, E, F, O) were not changed after the singing training, except VA slop which improved after the training.

The amplitude representation of several waves improved with singing lessons; at the early processing stage, onset level, and to the certain extent at the end of processing (offset). The larger amplitude responses could be a sign of more efficient auditory processing as a result of the singing lessons intervention. The amplitude of a waveform represents the magnitude of processing by the central auditory system [50]. Although the exact mechanisms of auditory learning – related plasticity remain unclear, the amplitude increase of some subcortical responses could indicate changes in the number of contributing neurons (such as synaptic density).

Musical training would shape the central auditory system [17, 51] and neuronal plasticity is the idea that neural pathways can be strengthened through repetitive use [52]. As noted by Ohl & Scheich (2005) [53], the effect of learning can be observed at different regions of the central auditory system from subcortical to cortical. Moreover, an increased amplitude of the physiological responses to the trained sound would be one of the learning manifestations in animal and in humans [53]. However, it remains puzzling that significant changes related to the training were not observed for all waves. How does the positive effect of singing lessons manifest mainly at the on-set and the offset (two waves A, VA slop and some trend on O) and not at the FFR region (Waves D, E, F)? Little is still known about the specific generator of the ABRs evoked by speech stimuli and the underlying neural mechanisms of these responses.

Since significant group results may not imply clinical significance, individual data of participant with CAPD for waves amplitude were explored in the present study. The examination demonstrated that the participants had different individual responses to the auditory (singing) training. The most revealing results showed that a fifth of the participants exhibited changes documented by neurophysiological recording. However, some of the participants had similar results before and after the training, showing no measurable benefits with the tests used. The majority of the participants demonstrated a larger amplitude for some neural responses. This could be due to heterogeneous characteristics of the CAPD participants in that they did not all demonstrate the same large amplitude patterns for the neural responses.

Children with auditory processing difficulties from a similar age group were tested with speech-evoked ABR before and after singing lessons and showed different amplitude patterns based on the individual data. Speech-ABR could therefore provide insight into a precision-assessment approach for CAPD individuals pre – and post – singing lessons. However, even children of the same age group diagnosed with auditory processing difficulties may present heterogenous results after singing lessons as a "reflection" of the differently altered auditory abilities. A recent review by Joshi and Light (2018) [54] proposed using an umbrella trial paradigm instead of a basket trial paradigm for individuals with schizophrenia. Generally, basket trials evaluate the effectiveness of a potential drug based on the mechanism of the disease. On the other hand, umbrella trials would take a more precise approach in which an intervention would be tailored to nuanced patient factors [54]. Authors proposed a tailored umbrella method for treating the cognitive impairment in schizophrenia (candidate illness) and the electroencephalogram measure of mismatch negativity as the candidate biomarker for identifying the patients' particularities [54]. Although the umbrella method has not been explored in audiology and/or in the CAPD domain, it would be worth exploring the potential of this method. By having a larger sample size and using ABRs evoked by speech stimuli (as a biomarker), it might be possible to identify CAPD children who would benefit from singing lessons.

Regarding the neural processing timing (latency) of the subcortical responses, these latencies continued to be delayed both before and after the training in participants when compared to the norm developed by Russo, Nicol, Masacchia and Kraus (2004) [55]. In other words, the speech-ABR waves for the children identified with auditory processing deficiencies had longer latencies than the norm. However, contrary to our hypothesis, neural timing was not improved after six to eight months of singing lessons. Although musical experience could shape the central auditory system [15, 17, 51-53], the exact training duration or form of the training remains unclear. This lack of change in latency could be interpreted as an insufficient duration of training, or that our investigation tool, speech-ABR, was not sensitive enough to show changes after the short training period. Moreover, a study by Kraus and Banai (2007) [14] demonstrated no latency changes in any peaks of speech-ABR responses after auditory training. In another example, speech-ABR was recorded in school age children before musical training, after one year, then again after two years [11]. No changes were observed after one year of training. However, results demonstrated a difference after two years of training. Authors explained that the number of hours of lessons after one year was not sufficient to produce a neurophysiological change [11]. When the duration of music lessons increased from two to four hours per week and was more focused on a single instrument, the positive effect of musical training was measurable by speech-ABR [11].

It should be emphasized that the children in the present study also failed several behavioral CAPD tests including timing processing (PPT, RGDT). Although the timing of the subcortical representation of speech in participants with CAPD did not show improvement with musical training, these children might have needed longer musical training, or more intensive repetition, instead of once per week, in order to observe timing changes at the subcortical level. Moreover, the small participant sample could explain this unexpected finding, to a certain degree.

Study limitations and future directions

A major limitation of the current study was the small sample size, which prohibits making any strong conclusions based on the obtained results. However, to the best to our knowledge, this is the first study showing preliminary data on the effect of singing lessons on subcortical auditory responses in children with auditory processing difficulties. We aim to present the results from a larger cohort in the future since these disorders are heterogeneous and characterized by overlapping symptoms. A larger sample size will also allow the examination of any correlation between behavioural and electrophysiological results. Moreover, a study with a larger sample size would help to determine the sensitivity and the specificity of the present auditory training protocol in order to identify which children would benefit from this type of training. Another limitation of the study was the absence of a control group; the latency data were compared only to the norm. It would be interesting to compare the results pattern between children with and without auditory processing difficulties. Moreover, it might be important to have an active control group of children with APD who do some other type of activity that matches the singing training in time and in interaction with another person.

5 Conclusion

The present study explored the capacity of the central auditory system to change through musical training in children with identified auditory processing difficulties. This study demonstrates that children with auditory processing disorders exhibit abnormal timing of subcortical responses to speech stimuli. Six to eight months of auditory training through singing lessons was shown to improve the magnitude, though not the timing of some subcortical responses in these children. Additionally, ABRs evoked by speech stimuli offers a method for objectively monitoring the neurophysiological effects of auditory training programs.

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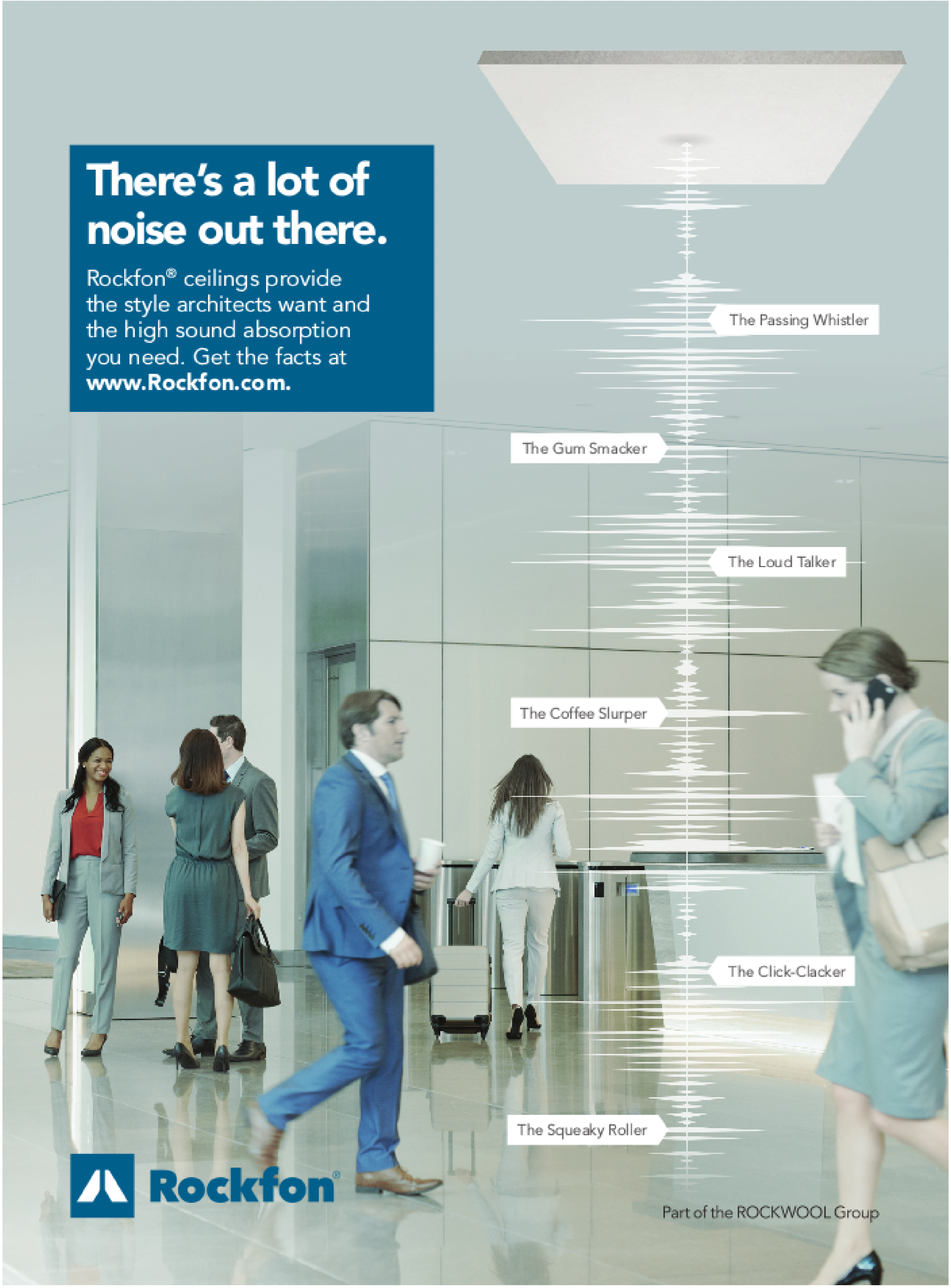
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