Otoacoustic emission suppression in children diagnosed with central auditory processing disorder and speech in noise perception deficits

Running Title: OAE suppression in children with CAPD

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Abstract

Objective: The present study was designed to test the hypothesis that medial olivocochlear system functionality is associated with speech recognition in babble performance in children diagnosed with central auditory processing disorder.

Method: Children diagnosed with central auditory processing disorder who specifically demonstrated speech in noise deficits were compared to children diagnosed with central auditory processing disorder without these deficits. Suppression effects were examined across 15 time intervals to examine variability. Analysis of right and left ear suppression was performed separately to evaluate laterality.

Study Sample: 52 children diagnosed with central auditory processing disorder, aged 6-14 years were divided into normal or abnormal groups based on SinB performance in each ear. Cut-off value was set at SNR=1.33 dB. Transient otoacoustic emissions suppression was measured.

Results: The abnormal Speech in Babble Right Ear group showed significant negative correlations with suppression levels for 7 of the 15 time intervals measured. No significant correlations with SinBR performance were observed for the remaining time intervals, as was the case for the typically evaluated R8-18 time interval and the Speech in Babble Left Ear.

Conclusions: Results indicate that suppression is influenced by the time window analysed, and ear tested, and is associated with speech recognition in babble performance in children with central auditory processing disorder.

Keywords

Speech Perception, Central Auditory Processing Disorder, Otoacoustic Emissions Suppression, Ear Advantage, Speech Recognition in Babble, Auditory Processing Disorder

Acronyms & Abbreviations

OAE=OtoAcoustic Emissions; MOC=Medial OlivoCochlear system; CAPD=Central Auditory Processing Disorder; SinBR= Speech in Babble Right ear; SinBL= Speech in Babble Left ear; TOAEs = Transient OtoAcoustic Emissions; DPOAEs= Distortion Product OtoAcoustic Emissions;DD= Dichotic Digits;PPS= Pitch Pattern Sequence test;DPS= Duration Pattern Sequence; RGDT= Random Gap Detection Test; GIN= Gaps-In-Noise; SNR=Signal to Noise Ratio; SinB=Speech in Babble; VOT=Voice Onset Time; OHC=Outer Hair Cells

1. Introduction

Otoacoustic emissions are the result of outer hair cell mobility of the inner ear and are measured in the external ear canal. Otoacoustic emissions (OAEs) reflect the integrity of the outer hairs cells (OHCs) of the cochlea that may not be detected by other procedures, such as conventional pure tone audiometry. Generation of OAEs is thought to reflect a combination of an active nonlinear distortion and a passive linear coherent reflection mechanism [1]. The active element is thought to be associated with the motility of the OHCs and the passive element with stereocilia stiffness. Usually evoked by incoming sounds, the two most often clinically used types of evoked OAEs are transient otoacoustic emissions (TOAEs) and distortion product otoacoustic emissions (DPOAEs), which differ on the basis of the stimulus. Clicks are used to evoke TOAEs, while two pure tones are used to evoke DPOAEs.

Otoacoustic emissions (OAE) suppression is a promising clinical tool for assessing central auditory system inhibitory efferent effects on cochlear function that may facilitate speech perception in demanding situations. This effect is mediated through the medial olivocochlear system (MOC) of the central auditory nervous system. In the normal auditory system, OAEs typically become suppressed (i.e., reduced in amplitude) when contralateral noise is introduced. This suppression effect results from activation of the auditory efferent system. Specifically, OAE suppression is a consequence of contralateral broadband noise and is an indirect index of the medial olivocochlear system functionality (MOC) [2, 3]. The MOC is formed of thick myelinated nerve fibers projecting predominantly to the contralateral cochlea and of fewer fibers projecting to the ipsilateral cochlea. Both projecting fibers, crossed and uncrossed, synapse with OHCs. The synaptic release of acetylcholine (which is the main MOC neurotransmitter) inhibits OHC mobility, reduces cochlear amplification gain, and decreases afferent auditory nerve fiber responses to incoming sound [4, 5]. MOC functionality may differ in the presence of background noise leading to an observed reduction of auditory perception in quiet and a perceptual improvement in continuous background noise [5, 6]. Hence, MOC function is posited as facilitating listening in noisy situations [7].

While children with central auditory processing disorder (CAPD) often show normal evoked OAEs in quiet, examination of emissions in the presence of contralateral broadband noise may have greater diagnostic utility. It has been hypothesized that the auditory efferent system, as reflected by OAE suppression, may be compromised in cases of CAPD. It is well established that the predominant symptom of CAPD is difficulty understanding speech in noise [8]. While some have hypothesized that poor speech in noise recognition is associated with reduced or absent OAE suppression effects, findings have been equivocal. An absence of a significant reduction of OAE suppression in CAPD has been documented by several researchers [9, 10], while others have failed to confirm the effect [11]. Additionally, while some studies have shown a relationship between speech in noise recognition and contralateral otoacoustic emission suppression [7, 12], others have reported a lack of statistical correlation between speech in noise recognition and otoacoustic emission suppression [13, 14]. It is clear that further research is needed to examine the possible link between CAPD and auditory efferent system dysfunction.

The present study examined whether MOC strength, as reflected by OAE suppression, facilitates listening in noisy situations in children with CAPD. The present study was designed to address limitations of prior studies. First, a more homogeneous participant sample was examined, comparing children diagnosed with CAPD who specifically demonstrated speech in noise deficits to those without these deficits. Despite the fact that speech in noise perceptual deficits are commonly seen in children diagnosed with CAPD, current guidelines (e.g., American Academy of Audiology-AAA [15] and the British Society of Audiology-BSA [16]) permit this diagnosis to be assigned even in cases where speech in noise recognition is within normal range. In such cases, the child's diagnosis is supported on the basis of other deficits (e.g., dichotic listening and/or temporal processing) in at least one ear. Second, unlike prior research in which suppression effects were examined at only one or two time intervals, we examined suppression effects across 15 partially overlapping time intervals to obtain a better understanding of variability. Finally, since some research has shown laterality in OAE suppression results, with higher values in the right ear in normal hearing subjects [17, 18] and in children with CAPD children [9], we analyzed right and left ear suppression separately.

The present study was designed, therefore, to test the hypothesis that MOC functionality (i.e., OAE suppression) is associated with speech recognition in babble performance in children diagnosed with CAPD. Specifically, we tested whether greater OAE suppression was significantly correlated with better speech recognition in babble performance as measured by signal-to-noise (SNR) thresholds. This relationship was examined at 15 time-intervals during the same visit, and analyzed for right and left ears to test for possible asymmetries. We also examined whether children diagnosed with CAPD with demonstrated speech recognition in babble deficits exhibited reduced OAE suppression relative to their similarly aged peers diagnosed with CAPD who presented normal speech recognition in babble performance.

2. Material and Methods

2.1. Participants

Participants were 52 children, aged 6-14 years (mean age=9.2 years, standard deviation 1.9 years), including 18 females and 34 males with a primary diagnosis of learning difficulties as determined by a multidisciplinary group (i.e., psychiatrist, speech pathologist, psychologist, educator) who were referred for central auditory processing testing. This study was carried out following written informed consent from the parents/legal guardians of all individuals tested. This is in accordance with the Declaration of Helsinki. The study was approved by the Ethics and Bioethics Committee of the Aristotle University of Thessaloniki. All 52 children (49 right handed and 3 left handed [2 males and 1 female with respective ages of 8, 9 and 8 years] were diagnosed with CAPD based on the following criteria: failure (at least two standard deviations below the mean) in at least one ear for two or more auditory processing tests, one of which used non-verbal stimuli [15, 16] . Participants were evaluated clinically for CAPD using test batteries comprised of three to six tests. All participants were administered a Greek speech recognition in babble test [SinB] [19, 20, 21]. The majority of the children also completed the Dichotic Digits (DD) test (86% of the sample) [20, 22, 23] , and a Pitch Pattern Sequence test [PPS](60% of the sample) [24]. The Duration Pattern Sequence (DPS) test was administered to 39% of the children [25] and one of two measures of temporal resolution was administered: 58% of the children received the Random Gap Detection Test (RGDT) [26] and 28% was administered the Gaps-In-Noise (GIN) test [27]. These tests were administered by an audiologist in a selective manner based on medical history, prevailing symptoms, and available time in the clinical setting; therefore, not all children were tested with exactly the same test battery. This is acceptable as the current guidelines for CAPD diagnosis are not specific as to the number or specific tests used. The guidelines do recommend the testing of different central auditory processes, as was done in the present study.

For several of the analyses reported below, participants were divided into one of two groups based on their SinB performance. Participants with abnormal SinB results were defined as those who scored 50% correct identification at SNR $\geq$ 1.33 dB. Those with normal SinB results scored 50% correct identification at SNR <1.33 dB. This criterion has been reported in clinical published data of the Clinical Psychoacoustics Lab of the 3rd Psychiatric Department of Aristotle University of Thessaloniki [21]. This criterion was applied separately by ear, yielding four groups: normal SinB right ear (SinBR) comprised of 28 children (12 girls), abnormal SinBR comprised of 24 children (6 girls), normal SinB left ear (SinBL) seen in 33 children (12 girls), and abnormal SinBL seen in 19 children (6 girls). Included in the two abnormal groups are 14 children with poor SinB results in both ears. The mean age of the normal SinBR group is 10 years old (±1.9), 9.9 (±1.9) for the normal SinBL group, 8.4 (±1.6) for the abnormal SinBR group, and (8.2 ±1.4) for the abnormal SinBL group.

2.2. Speech in Babble Test

The SinB test, developed at the Psychoacoustic Laboratory of the Aristotle University of Thessaloniki, was administered monaurally to the right and left ears in counterbalanced order. The SinB consists of two equivalent in quiet lists (one for each ear) of 50 phonetically balanced disyllabic words and background multitalker babble [19, 20, 28]. The number of words per list is sufficient for obtaining a reliable threshold in noise, as verified for two different languages (Wilson and Burks [29] for American English and Lagace´ [30] for French). The background multitalker babble was recorded in the university student cafeteria during a high demand time of day using a highly sensitive microphone directly to a personal computer with Cool Edit software (Adobe Systems, San Jose, CA). SNR varied within lists. Five SNRs (+7, +5, +3, +1, and -1) were used in a fixed order (i.e., each SNR was applied to ten words in each list). The children were instructed to repeat the word after each single presentation. The dependent variable or outcome measure was the SNR at which the child achieved 50% correct word identification on the SinB [31-33]. Higher SinB scores (measured in dB) correspond to poorer performance (i.e., higher SNR was required to achieve 50% word recognition ability). Performance was quantified using the basic Spearman–Karber formula: SNR of 50% correct speech identification=i + 1/2(d) - [(d) (number of corrects)]/w (where i is the initial presentation level in dB, d is the step size, and w is the number of items per decrement [per step]) [28]. Each child was tested with a list of 50 words in each ear beginning with the easiest listening condition (SNR +7), and ending with the most difficult listening condition (SNR -1). This test has been shown to be able to successfully separate children diagnosed with CAPD from typically developing ones in terms of listening difficulties [21].

2.3. Procedures

Each child's central auditory processing was assessed in a sound-treated room following confirmation of normal pure tone hearing sensitivity (<=15dB HL across all tested frequencies 250, 500, 1000, 2000, 4000 & 8000Hz) and tympanometry (> -150mm H_2O and compliance >.0.3 cc). All central auditory processing tests were administered at 50 dB SL re: PTA. OAEs, obtained in a separate session (2-5 days post CAPD diagnosis), included non-linear and linear transient otoacoustic emissions [TOAE]. Non-linear TOAE was recorded at 80dB SPL with the IHS SmartTOAE platform, at a rate of 49.1/sec. Passing criteria consisted of a SNR of at least 6 dB for every frequency band (1000Hz, 1500Hz, 2000Hz, 3000Hz and 4000Hz) and a correlation percentage of at least 90%. Subsequently linear TOAE was recorded at 60 dB SPL (2000 samples), followed by a second recording using the linear mode at 60dB SPL with simultaneous broadband noise stimulation (a white noise signal with a flat spectrum to 8KHz) delivered to the contralateral ear. Ear order was randomized both within and between subjects. Suppression was calculated on IHS SmartTOAE platform by subtracting the TOAE levels with contralateral broadband stimulation from TOAE levels obtained in the absence of contralateral noise. A total of 15 intervals of 10 msec each were obtained during the same visit. A variable depicting the mean OAE suppression across the 15 time windows was computed separately for the right and left ears. In addition, suppression was calculated separately for each time window and for right and left ears. Analysis of results per ear instead of per subject was elected in light of unilateral deficits of the auditory system showing functional and anatomical alterations of central auditory pathways [34]. Contralateral OAE suppression results for each ear was compared to SinB results for the same ear. It is outside of the scope of this study to explore within subject symmetry of suppression.

3. Results

Figures 1 through 4 show mean OAE suppression across the 15 time intervals for the normal SinB and abnormal SinB groups by ear. Suppression levels in the group with deficient SinBR were greater at earlier time intervals and gradually decreased across intervals, while suppression levels in the group with deficient SinBL were much smaller and gradually increased across intervals. The peak suppression level was numerically larger in the abnormal SinBL than in the abnormal SinBR. For the normal SinBR and normal SinBL groups, the trend of suppression gradually increasing across the 15 intervals was similar, though steeper for SinBR. The peak suppression level was numerically larger in normal SinBR than in the SinBL. Mean suppression levels were higher for the children with poorer speech in babble perceptual abilities (abnormal SinBR in figure 5 and abnormal SinBL in figure 6). The abnormal SinBL ear suppression levels (figure 6) run parallel to those with normal SinBL. The abnormal SinBR ear results (figure 5) show a steeper regression line when compared to the normal SinBR group.

Suppression and SinB results were found to be non-normally distributed based on skewness and kurtosis values [35, 36]; hence, nonparametric statistics were used. It should be noted that normal SinBR and normal SinBL groups include younger children (Mann-Whitney U=186.5, p=0.006) compared to pathological SinBR and pathological SinBL groups, possibly reflecting a contributing maturation factor. However, there are two factors that minimise any possible maturation effects. Firstly, the MOCB maturation is thought to be complete before the age of five [37] and secondly the presence of suppression laterality indicates full maturation [37]. As shown in Table 1a for the right ear and Table 1b for the left ear, there was no significant correlation observed between OAE suppression and SinB for any of the measurement intervals for the normal SinBR group; however, the abnormal SinBR group showed significant negative correlations (larger SNR required for 50% speech recognition reflecting poorer SinB performance associated with less suppression) for 7 of the 15 intervals tested. The remaining time intervals did not show significant correlation with SinBR performance and this was the same for the usually evaluated R8-18 time interval (table 1a). A significant correlation between SinBR performance and OAE suppression collapsed across all fifteen time intervals persisted following Bonferroni correction. Collapsing across normal and abnormal SinBR groups, only the R13 to 23 time windows were significantly correlation with SinBR. Neither the normal SinBL nor abnormal SinBL groups presented significant relationships between the SinB and OAE suppression (table 1b).

4. Discussion

4.1. Overview of Main Findings

The present study investigated the relationship between OAE suppression and speech recognition in babble in children diagnosed with CAPD, some with normal speech recognition in babble performance and others with abnormal speech recognition in babble. Children with abnormal speech in babble recognition showed enhanced OAE suppression for both abnormal SinBR and abnormal SinBL. In participants presenting abnormal speech in babble performance for the right ear (abnormal SinBR), the degree of OAE suppression increased linearly with improving speech in babble performance. This trend was seen as well for the abnormal speech in babble performance in the left ear (abnormal SinBL), but was less steep and lacked statistical significance. Conversely, there was no significant relationship between SinB and OAE suppression in children with CAPD with normal speech recognition in babble performance. To our knowledge, this is the first published report linking abnormal speech recognition in babble with greater OAE suppression in children with CAPD.

These findings may explain why some studies [7, 38, 39] reported support for the hypothesis that speech in noise perception is reflected in the otoacoustic emission suppression results, while others [13, 40] failed to document this relationship. Specifically, our results demonstrate that the relationship between OAE suppression and speech recognition in babble varies as a function of performance on this behavioral task. A significant relationship was observed between suppression and speech recognition in babble in children with CAPD, but only those evidencing abnormal speech recognition in babble performance. The group difference is only evident when TOAE suppression is monitored through a wide time frame using 10 msec windows and it may remain obscure if one 10msec window is selected for comparison, as is often the case with the most often monitored 8-18msec window.

It should be noted that a limitation of the present study is the different ratio between girls and boys in the sample analysed. This might have affected our results, as girls generally are found to have higher suppression levels. Matching for sex in the clinical audiology setting may be demanding, especially given the higher incidence of boys diagnosed with CAPD as opposed to girls. However, our results show that the mean suppression levels were higher for the children with poorer speech in babble perceptual abilities (SinBR & SinBL) even though there were more girls in the normal SiBR as compared to the abnormal SinBR group and the same was true for the normal SinBL and abnormal SinBL groups. If it was an issue of girls with higher suppression driving our results, then our findings should have been the other way round.

The present results also demonstrated that OAE suppression trends fluctuated in a completely different manner between children demonstrating abnormal speech recognition in babble performance and those with normal speech recognition in babble performance. Specifically for the right ear, the normal SinB group appeared to have a gradual increase in OAE suppression across time (in ms), reaching higher suppression levels, while the abnormal SinB group reached the highest degree of suppression (which was still less than that of the normal speech recognition group) much earlier (R5 to 15 msec), after which rapidly decreased suppression levels were observed. Although the MOC function time course shows heterogeneity and is not yet elaborately described in humans [41], it may be hypothesized that the unmasking effect of MOC efferent pathways leading to better speech recognition in babble performance requires a gradual and steady increase across a millisecond range. It should be noted that there is a documented [42, 43] gradual increase in adults with normal hearing sensitivity as measured for a smaller overall time window (4-18ms) than the one that was used in the present study. For the left ear, the normal SinB group presented small suppression levels with one of the largest suppression levels seen at 4-14 msec, whereas large suppression levels exceeding 2 dB were observed for the abnormal SinB group. When analyzing all CAPD diagnosed children together, greater levels of suppression were seen at earlier time windows (R5- 15 msec) and gradually increasing for the right ear, whereas left ear suppression levels were much smaller (<0.5dB), but increased robustly at L 14-24 msec time window, reaching 1dB, which was the highest suppression level observed for the right ear as well. A different quantification approach of suppression used in adults is based on a percentage change from the baseline amplitude on the premise to exclude inter-subject differences in magnitude of the otoacoustic emissions recording [44]. This approach is thought to normalise suppression measurement. As this approach has only be used in normal adult controls, using it in the present study would render it impossible for us to compare our findings with all other APD paediatric studies.

4.2. Comparison to Past Research

We examined the relationship between speech recognition in babble performance and otoacoustic emissions suppression as a step toward exploring OAE suppression as a potential objective measure of CAPD. Kumar and Vanaja [45] reported an improvement in a psychoacoustic task of speech in noise identification as a result of contralateral noise stimulation, and this improvement correlated with MOC suppression effects in normally hearing 10-12 year old children with typical reading skills. Muchnik et al. [9] measured contralateral otoacoustic emissions suppression in children diagnosed with CAPD. They reported smaller suppression for the right ears of children with CAPD as opposed to normal controls, and increased transient otoacoustic emission levels for the children with CAPD as opposed to a normal control group of children. These pediatric studies indicate that the MOC function plays a role for speech in noise performance in children. Suppression studies in adults may offer some further insights into this relationship. Garinis et al. [46] employed two different measurement approaches for suppression leading to two different results in active vs passive listening conditions: they found no differences in the OAE suppression values between active listening to background noise (+ speech) vs passive listening to noise conditions on the mean response amplitude of the overall waveform. However, the mean root mean square amplitude of the difference waveform of the OAE obtained in quiet minus the OAE obtained in noise and at 2ms intervals at the 6- to 18-ms post stimulus was significantly greater in the active vs the passive condition in normal hearing adults. They interpreted their findings as indicative of cortical, language specific effects on the auditory periphery of the MOC pathway that are also frequency specific. De Boer and Thornton [7] administered auditory training on a consonant–vowel phoneme-in-noise discrimination task in normal hearing adults and reported a significant increase in suppression levels following the training in the good learners on the discrimination task. They also found a negative correlation between initial suppression levels and training outcome. They concluded that the MOC bundle mediates a listening strategy that improves speech in noise perception. In a subsequent study, De Boer et al. [47] reported a negative correlation between consonant-vowel recognition and OAE suppression. They proposed that the MOC system's function depends on both attention allocation and experience.

Greater suppression levels found in our children with CAPD with abnormal speech recognition in babble performance relative to the children with CAPD with normal speech recognition in babble performance may thus indicate that the MOC attempts to compensate for the speech recognition difficulties. MOC is modulated by the corticofugal descending auditory system, which originates in the auditory cortex, while forming multiple feedback loops with the ascending auditory system. It has been argued that the auditory cortex acting through the MOC modulates the transduction of acoustic stimuli through the cochlea while changing active micromechanics of OHC and the initiation of auditory processing at the level of the cochlear nucleus [5]. Based on our results showing greater suppression levels in children with abnormal speech recognition in babble, it might be hypothesized that the antimasking effect [48, 49] due to MOC activation in noise did not lead to improved speech in noise perception due to excessively increased firing rates of the auditory nerve fibers, thereby resulting in increased suppression levels, in our participants with abnormal speech recognition in babble. This may have led to even greater inability to restore the effective dynamic range of nerve fibers and thereby increased auditory perceptual difficulties. Of interest, Sanches and Carvallo [10] studied suppression levels on a somewhat smaller group of children with CAPD group divided into two sub groups—one with low scores (<68%), in one or both ears on a speech in noise test (Portuguese version) and a second subgroup with normal scores (>68%). They reported no difference in suppression levels between the two groups. Considering speech in noise results of >68% to be within normal range may be including children with speech in noise difficulties, however the specific parameters (SNR administered) of the test are not described and the authors state that these are normal scores for Brazilian children. The difference in the results presented in the current study may be due to the analysis of fifteen 10 ms time windows, as opposed to one measure (2.5-20 ms) used by Sanches and Carvallo, and be consistent with the frequency specific effects of the MOC pathway as proposed by Garinis' et al. [42]. The somewhat larger number of 52 in the present study as opposed to 36 in the study by Sanches and Carvallo may also have played a role.

The absence of a typically developing group may be perceived as a limitation of this study. However, our aim was not to test if MOC functionality differs between APD and controls (other studies have addressed this—e.g., Muchnik et al, 2004 [9]). Our interest was to determine whether there is a correlation between MOC functionality as measured by OAE suppression and speech recognition in babble in children with CAPD. Answering our question did not require a control group, although it would be useful in the future to compare our present results in the APD paediatric group with normal controls.

4.3. Mechanism for Laterality Differences

It is of interest that significant effects were seen for the right ear, but not for the left ear. There are several considerations regarding why this trend might have been observed. The right ear advantage of the auditory system for right-handed listeners is well documented for a range of auditory tests including the audiogram [50], auditory-evoked potentials [51], and contralateral suppression of TOAEs, both in adults and children [18, 52, 53]. The suppression effect in particular has being proposed as a marker of peripheral auditory lateralization that is independent of TOAE strength [54].

The finding of a persistent right ear advantage in our group with abnormal speech recognition performance as well as the one with normal SinB shows normal lateralization in this pediatric group who experience communication difficulties due to abnormal central auditory processing. Of interest, a reverse ear advantage for TOAE suppression has been reported for adults with learning difficulties and a great variety of other diagnoses, including 3 of the adults with CAPD in 18 adults studied [55], as well as in children with dyslexia [12]. Of interest, in the Veuillet pediatric group, audiovisual training led to improved reading skills, and improved VOT perception, as well as restoration of the right ear suppression advantage [12]. It may well be that in a subgroup of participants with a range of communication difficulties, abnormal lateralization of the auditory pathway already evident at the early stages of the auditory pathway (i.e., medial olivocochlear bundle in the brainstem) is a biological marker of left hemisphere dysfunction. However, this is not evident in our study. The right ear advantage is not only persisting, but it is enhanced in the group of children with abnormal SinB, possibly indicating normal cerebral laterality and left-hemisphere specialization for speech and language processing in our group of children diagnosed with CAPD.

The finding of a correlation between suppression and speech in babble performance in the right ear only of the children with abnormal speech recognition in babble scores is similar to reports of a correlation between suppression and phonemic boundaries by Veuillet et al. [12] in their dyslexic, but not in their normal group. Veuillet et al. found correlation of right as well as left suppression with phonemic boundaries; however, phonemic boundaries were obtained binaurally in their study. It may be that children with CAPD rely more on effective frequency selectivity for speech in babble performance than do children with normal central auditory processing. The lack of correlation between left ear speech in babble and suppression in our study is similar to the findings of Bidelman and Bhagat [48] of the presence of a robust link in normal young adults between OAE suppression and speech in noise recognition performance for the right, but not for the left ear results. Their interpretation of the noise-degraded speech perception being influenced by initial cochlear processing, but in an ear specific manner, is plausible, although an ear suppression asymmetry was not observed in 15 children with CAPD tested by Muchnik et al [9], but was documented in the 36 CAPD children in Sanches and Carvallo [10], and in 52 CAPD children in the present study. Sample size or other methodological considerations such as the heterogeneity of pediatric populations with CAPD may explain this disparity in different studies' findings.

4.4. Clinical Implications

Different trends were seen in OAE suppression across multiple time windows between children with CAPD with abnormal speech recognition in babble performance in their right ear and those with the disorder but with normal speech recognition in babble performance. This indicates that suppression is influenced by time window analyzed, ear tested, and is associated with speech recognition in babble performance. Using TOAE suppression in the clinic, audiologists should not limit evaluation in the most often used 8-18msec time window. Given clinical time constraints, our results suggest that measuring right ear suppression may reveal more robust data than obtaining this information for the left ear. TOAE suppression may present in different ways within CAPD children based on their speech in babble performance and other variables such as past experience (e.g., auditory training) or suppression protocol aspects.

5. Conclusions

This is the first study demonstrating a correlation between abnormal speech recognition in babble performance and transient otoacoustic emissions suppression in children diagnosed with CAPD. By examining these effects in children diagnosed with CAPD and analyzing the relationships as a function of speech recognition in babble performance, we were able to sort out the relationships with greater clarity and begin to understand the disparate results reported by others examining this matter. Our findings revealed that our pediatric participants with CAPD and abnormal SinB performance exhibited a moderate correlation with suppression limited to the right ear. This relationship was not seen among our children with CAPD with normal SinB performance, nor was it observed when the correlation was run collapsed across all participants, those with normal SinB and those with abnormal SinB.

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Table 1a. Correlation analysis (spearman's rho) between speech in babble perception and transient otoacoustic emissions suppression in the normal SinBR CAPD diagnosed children, in the abnormal SinBR group and in all CAPD diagnosed children regardless of SinB performance. A distinct difference exists between the groups with abnormal SinBR showing significance correlation in multiple time windows as well as in the mean suppression level across all time windows. This correlation is not present in the R8 to 18 time window that is most often used to assess correlation between speech in noise performance and otoacoustic emissions suppression. Presence of asterisks denotes statistical significance.

		normal SinBR	abnormal SinBR	both normal & abnormal SinBR
SupR mean	**rho** **p**	-0.08 0.54	**-0.64*** **0.000**	-0.11 0.53
R1 to 11	**rho** **p**	-0.28 0.12	**-0.51*** **0.01**	0.04 0.79
R2 to 12	**rho** **p**	-0.25 0.17	**-0.46*** **0.02**	0.04 0.79
R3 to 13	**rho** **p**	-0.23 0.20	**-0.46*** **0.02**	0.03 0.85
R4 to 14	**rho** **p**	-0.22 0.20	-0.37 0.07	-0.003 0.98
R5 to 15	**rho** **p**	-0.19 0.29	-0.40 0.05	-0.23 0.87
R6 to 16	**rho** **p**	-0.19 0.29	**-0.41*** **0.04**	-0.1 0.48
R7 to 17	**rho** **p**	-0.22 0.22	-0.35 0.08	-0.14 0.31
R8 to 18	**rho** **p**	-0.28 0.11	-0.39 0.05	-0.19 0.16
R9 to 19	**rho** **p**	-0.23 0.20	-0.30 0.15	-0.25 0.07
R10 to 20	**rho** **p**	-0.16 0.37	-0.31 0.13	-2.43 0.08

		normal SinBR	abnormal SinBR	both normal & abnormal SinBR
R11 to 21	rho p	-0.04 0.83	-0.33 0.10	-0.27 0.05
R12 to 22	rho p	-0.008 0.96	-0.38 0.064	-0.27 0.05
R13 to 23	rho p	-0.064 0.73	**-0.43*** **0.04**	**-0.28*** **0.04**
R14 to 24	rho p	0.138 0.45	**-0.4*** **0.07**	-0.21 0.13
R15 to 25	rho p	0.041 0.82	**-0.52**** **0.009**	-0.28* 0.04

Table 1b. Correlation analysis (spearman's rho) between speech in babble perception and transient otoacoustic emissions suppression in the normal SinBL CAPD diagnosed children, in the abnormal SinBL group and in all CAPD diagnosed children regardless of SinBL performance. No significant correlation exists in each of the three groups.

		normal SinBL	abnormal SinBL	both normal & abnormal SinBL
SupL mean	**rho** **p**	-0.01 0.9	-0.21 0.39	0.06 0.66
L1 to 11	**rho** **p**	-0.11 0.52	0.14 0.57	0.22 0.12
L2 to 12	**rho** **p**	-0.10 0.52	0.08 0.75	0.22 0.12
L3 to 13	**rho** **p**	-0.09 0.60	0.09 0.71	0.18 0.18
L4 to 14	**rho** **p**	-0.08 0.64	-0.04 0.88	0.18 0.19
L5 to 15	**rho** **p**	-0.009 0.96	-0.08 0.72	0.19 0.17
L6 to 16	**rho** **p**	-0.06 0.7	-0.21 0.40	0.14 0.31
L7 to 17	**rho** **p**	-0.74 0.67	-0.27 0.26	0.16 0.25

		normal SinBL	abnormal SinBL	both normal & abnormal SinBL
L8 to 18	**rho** **p**	-0.05 0.77	-0.40 0.86	0.11 0.45
L9 to 19	**rho** **p**	-0.73 0.67	-0.37 0.12	0.05 0.74
L10 to 20	**rho** **p**	-0.43 0.80	-0.30 0.21	0.06 0.67
L11 to 21	**rho** **p**	0.06 0.71	-0.27 0.39	0.03 0.85
L12 to 22	**rho** **p**	0.08 0.63	-0.08 0.72	0.12 0.38
L13 to 23	**rho** **p**	-0.03 0.86	-0.02 0.93	0.17 0.21
L14 to 24	**rho** **p**	-0.006 0.71	-0.23 0.34	0.07 0.61
L15 to 25	**rho** **p**	0.04 0.81	-0.03 0.91	0.26 0.06

Figure Captions

Figure 1. Right ear OAE suppression following contralateral broadband stimulation as measured for different but partially overlapping time intervals for participants who score within normal limits on the SinB (normal group).

SinBR: Speech in Babble Right ear

OAE SuppressionR_Mean: Mean suppression otoacoustic emissions level in dB for the right ear

R1to 11: Right ear time interval (sub-item) between 1 and 11 msec

R2 to 12: Right ear time interval (sub-item) between 2 and 12 msec

R3 to 13: Right ear time interval (sub-item) between 3 and 13 msec

R4 to 14: Right ear time interval (sub-item) between 4 and 14 msec

Etc …

R15 to 25: Right ear time interval (sub-item) between 15 and 25 msec

Figure 2. Right ear OAE suppression following contralateral broadband stimulation as measured for different but partially overlapping time intervals for participants who score beyond normal limits on the SinB (pathological group).

SinBR: Speech in Babble Right ear

OAE SuppressionR_Mean: Mean suppression otoacoustic emissions level in dB for the right ear

R1to 11: Right ear time interval (sub-item) between 1 and 11 msec

R2 to 12: Right ear time interval (sub-item) between 2 and 12 msec

R3 to 13: Right ear time interval (sub-item) between 3 and 13 msec

R4 to 14: Right ear time interval (sub-item) between 4 and 14 msec

Etc …

R15 to 25: Right ear time interval (sub-item) between 15 and 25 msec

Figure 3. Left ear OAE suppression following contralateral broadband stimulation as measured for different but partially overlapping time intervals for participants who score within normal limits on the SinB (normal group).

SinBL: Speech in Babble Left ear

L1to 11: Left ear time interval (sub-item) between 1 and 11 msec

L2to 12: Left ear time interval (sub-item) between 2 and 12 msec

Etc…

L15 to 25: Left ear time interval (sub-item) between 15 and 25 msec

Figure 4. Left ear OAE suppression following contralateral broadband stimulation as measured for different but partially overlapping time intervals for participants who score beyond normal limits on the SinB (pathological group).

SinBL: Speech in Babble Left ear

L1to 11: Left ear time interval (sub-item) between 1 and 11 msec

L2to 12: Left ear time interval (sub-item) between 2 and 12 msec

Etc…

L15 to 25: Left ear time interval (sub-item) between 15 and 25 msec

Figure 5: As SinB right results improve (lower values in dB, perceiving 50% correct word identification at lower signal-to-noise ratio) otoacoustic emission suppression right ear levels (in dB) reach

higher amplitudes. This is correlation is statistically significant in the present study only for the abnormal SinB CAPD subgroup.

SinBR: Speech in Babble Right ear in dB HL, “O” denotes normal SinB, “1” denotes abnormal SinB

OAE suppressionR_mean: Mean otoacoustic emission suppression for the right ear in dB

Figure 6: SinB left ear results were not correlated with otoacoustic emission suppression in the abnormal SinB CAPD subgroup.

SinBL: Speech in Babble Left ear in dB HL, “O” denotes normal SinB, “1” denotes abnormal SinB

OAE suppressionL_mean: Mean otoacoustic emission suppression for the left ear in dB