Critical Review:
What evidence suggests that (Central) Auditory Processing Disorder is due to impairments in the descending auditory pathways?

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American Speech and Language Association (ASHA) states that (Central) Auditory Processing Disorder ((C)APD) is a deficit in neural processing of auditory stimuli that is not due to higher order language, cognitive, or related factors (Working Group on Auditory Processing Disorders, 2005). Assessment and treatment measures have been developed based on this definition. However, a recent study suggests that (C)APD is unrelated to auditory sensory processing, and could be a deficit in attention (Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010). If (C)APD has higher order etiologies, as audiologists we must refer to and collaborate with other professional perspectives. Therefore, we need to review the evidence that suggests that (C)APD is a top-down disorder. In order to guide future research and clinical practice, my research question asks: How do we determine that (C)APD is a top down auditory processing deficit, rather than a bottom up auditory processing issue? A critical challenge that will also be addressed, is how to determine if the deficits in higher order systems are not a result of deficits in sensory processing.

Introduction

(Central) Auditory Processing Disorder ((C)APD) has been an area of controversy since it was first recommended that central auditory function be assessed in children in 1954 by Helmer Myklebust (Working Group on Auditory Processing Disorders, 2005). (C)APD includes deficits in the auditory mechanisms that affect sound localization/lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, and auditory performance with degraded acoustic signals (Working Group on Auditory Processing Disorders, 2005). Currently, there is no standard protocol for clinicians to follow for assessment and treatment. The main reason for this is because there is still debate on the definition, as well as the causation of (C)APD. The American Speech and Language Association (ASHA) defines (C)APD as a deficit in neural processing of auditory stimuli that is not due to higher order language, cognitive, or related factors (Working Group on Auditory Processing Disorders, 2005). This panel of audiologists also specified that (C)APD may lead to or be associated with difficulties in higher order language, learning, and communication functions. This definition suggests that (C)APD is due to a bottom-up auditory processing deficit, but could also cause top-down auditory processing deficits. Therefore, in a position statement by ASHA, it states that treatment should incorporate both bottom-up processing and top-down processing, and is within the scope of practice of an audiologist (Working Group on Auditory Processing Disorders, 2005).

A recent study suggested that (C)APD is not due to auditory sensory processing, but could be a deficit in attention (Moore et al., 2010). In other words, (C)APD is due to a top-down processing deficit. If this prospective is true, then future assessment and treatment protocols should reflect this definition, and perhaps other professionals should be involved in assessment and management of (C)APD and suspected (C)APD.

It is difficult to separate these two perspectives. If all levels of processing are linked, it may not be clinically feasible to determine if a deficit in higher order systems are not a result of deficits in sensory processing, and vice versa.

One test that evaluates the integrity of the auditory efferent pathway is Transient Evoked Otoacoustic Emissions (TEOAE) suppression testing (Murdin & Davies, 2008). As mentioned previously, a symptom of (C)APD is a difficulty understanding speech in background noise. The medial olivocochlear bundle (MOCB) system has been suggested as a factor of hearing in noise ability. The MOCB function can be investigated by the TEOAE suppression testing in response to contralateral acoustic stimulation (Muchnik et al., 2004). It is hypothesized that those with (C)APD have a decreased suppression effect of TEOAE, which suggests poor efficacy of the MOCB and efferent auditory pathway.

This critical review examines the literature that suggests (C)APD is a top-down auditory processing matter, and whether it is possible to separate it from bottom-up processing. If the type of processing deficit can be determined, then treatment will be able to incorporate the level of processing difficulties, and will ultimately be more successful.

Objectives

The primary objective of this paper is to critically review the evidence that suggests (C)APD is due to impairments in the descending auditory pathways. A secondary objective that will be addressed is how to determine whether deficits in the higher order systems are a result of deficits in sensory processing.

Methods

<u>Search Strategy</u>
Databases that were utilized in this literature search included Google Scholar, PubMed, MedLine, SCOPUS, and CINAHL. The following search terms were used: (central auditory processing disorder) OR (auditory processing disorder) AND (top down processing) OR (efferent pathway) OR (descending pathway). No limitations were applied.

<u>Selection Criteria</u>
In addition to the Moore et al. (2010) study, articles that were selected were studies that examined the efferent pathways with TEOAE suppression testing in children under 12 years of age with (C)APD.

<u>Data Collection</u>
The literature search resulted in three additional studies (Burguetti & Carvallo, 2008; Muchnik et al., 2004; Sanches & Carvallo, 2006). One study was a single group series (post) test only cross sectional prospective (Moore et al., 2010), one study was a between groups nonrandomized cohort cross sectional prospective (Sanches & Carvallo, 2006), one was a mixed group nonrandomized cohort cross sectional prospective study (Burguetti & Carvallo, 2008), and one a between group nonrandomized case control cross sectional prospective study (Muchnik et al., 2004).

Results

Summary of Articles

Moore et al. (2010)
Moore and colleagues (2010) investigated the hypothesis that (C)APD is related to a sensory processing deficit. Invitation packs were sent to 8044 homes. A total of 1469 children from 44 primary schools in the United Kingdom, aged 6 to 12 years old were evaluated. Cases were stratified according to age, gender, and socioeconomic status. A socioeconomically representative sample was acquired. Inclusion criteria included English as the child's home language, and normal hearing screening results. Fifty-two children had special education needs, although these were not specified. Children completed a battery of audiometric, auditory processing, speech-in-noise, cognitive, and attention tests. Auditory processing tests included temporal, frequency, level, phase, and location properties of sound. Derived auditory processing tests, which were developed by the authors, were used as an attempt to separate sensory from nonsensory aspects of processing. This rationale assumed that the tests for frequency resolution and temporal resolution would make identical cognitive demands, and by subtracting the thresholds derived from each test would generate a pure index of sensory processing. For example, the temporal resolution result was found by subtracting the backward masking with a 50 msec gap (BM50) threshold from the backward masking with a 0 msec gap (BM0) threshold. Theoretically this subtraction should have eliminated memory related or other higher order task modulations of nonsensory performance.

Caregivers completed the Children's Communication Checklist 2 (CCC-2) and the Children's Auditory Processing Performance Scale (CHAPS) questionnaires. Multivariate regression analysis used a univariate general linear model. There were 96 variables input into the model and these accounted for 20 % of the variance. Different p values were used when calculating significance (0.001, 0.01, 0.05).

The authors found that (C)APD is unrelated to auditory sensory processing, but suggested that (C)APD could be an attention problem.

Burguetti & Carvallo (2008)
Burguetti & Carvallo (2008) evaluated the efferent auditory system in children aged 9 to 10 years old, who had been diagnosed with (C)APD. The study group consisted of 50 children with auditory processing disorder and the control group consisted of 38 children without auditory processing disorder, and had normal hearing thresholds, normal logaudiometry, and normal tympanometry. The efferent auditory system activity was evaluated using TEOAE with contralateral white noise suppression and ipsilateral acoustic reflexes with and without contralateral facilitating stimuli. The Wilcoxon and the Mann-Whitney tests were used for the statistical analysis of results with a significance level of statistical inference analysis of 0.05.

There was no statistically significant difference in the suppression effect between right ears and left ears in both groups, however right ear values were higher than left ear values in the control group. This suggests that there is a lack of right ear advantage in those with auditory processing disorders. There was no statistically significant difference in TEOAE suppression between genders in the control group, but in the study group there was a higher statistically significant difference in TEOAE suppression values for females. Between the groups, the TEOAE suppression values were higher for the study group, but this was not statistically significant. When comparing acoustic reflex sensitization among ears, the only statistically significant difference between the right and left ears was at 2000 Hz in the control group. Mean acoustic reflex sensitization values in females were higher than those in males, but this was not statistically significant. Between groups, the mean acoustic reflex sensitization values were higher in the study group than the control group at all frequencies except for 500 Hz, but this was not statistically significant.

Overall, this study found that the children with (C)APD had lower OAE suppression values than those without (C)APD, but this difference was not statistically significant.

Sanches & Carvallo (2006)
The authors evaluated children between the ages of 7 to 11 years. The children were divided into three groups: a control group which consisted of children with normal peripheral hearing and no auditory processing disorders (n =15), a group consisting of those with auditory processing disorder who scored low on a speech-in-noise test (n = 16), and a group consisting of those with auditory processing disorder who scored high on a speech-in-noise test (n = 20). Recruitment methods were not specified. The effect of contralateral white noise suppression of TEOAE under linear and nonlinear clicks was carried out in a quiet, but not acoustically treated room. A low-pass filter was used to reduce the effect of noise. ANOVA and a test for equality of proportions were used for statistical analysis, and the level of significance was set at $p<0.05$.

It was reported that not all ears in the group with (C)APD had present TEOAEs, therefore only 36 ears in the group with low speech-in-noise scores, and 28 ears in the group with high speech-in-noise scores were analyzed. All of the children in the control group had present TEOAEs. ANOVA was used to calculate the difference between test-retest, which resulted in no significant differences.

There were no significant differences found between the left and right ears in all groups. Statistically significant suppression effect differences were found between the groups with (C)APD and the control group. In other words, the percentage of ears presenting with no suppression was higher in both groups with (C)APD than the control group. However, there were no significant differences between the two (C)APD groups. These results suggest that the efficiency of the efferent auditory system, but more specifically the MOCB inhibitory function, is reduced in children with (C)APD. The authors stated that this could be an explanation of why children have difficulty hearing in background noise. Another important finding from this study is that the speech-in-noise behavioural test did not achieve a real separation within those with (C)APD. Therefore, the authors stated that this reinforces the lack of sensitivity and specificity of low redundancy tests, as well as the importance of electroacoustic tests, such as TEOAE suppression.

Muchnik et al. (2004)
The authors evaluated the suppression effect of TEOAE in children with (C)APD. The study group consisted of 15 children aged 8 to 13 years with auditory processing disorder. The control group was matched on a one-to-one basis by age and gender, with no history of speech or language impairments. Both groups were required to have normal hearing, normal tympanometry, present TEOAE, normal contralateral acoustic reflexes, and no neurologic or other medical disorders. In addition to these criteria, the study group was required to have normal auditory brainstem responses.

Both groups underwent behavioural testing, which included a speech-in-noise test, competing sentences test, and a threshold of interference test. The authors and names of these tests were not specified. TEOAEs were recorded in the nonlinear click mode, as well as the suppression effect with white noise in the contralateral ear. Pearson correlation coefficient was used to assess the reliability of the suppression measurements. Significance value of $p < 0.0001$ was used. To examine TEOAE values and suppression values, repeated measures ANOVA was conducted. Additional statistical measures included Fisher's exact test and paired t tests.

The most important abnormal behavioural test result was found to be the speech-in-noise test, for which 80% of those with (C)APD had an abnormal score. This corresponds with the main complaint in those with (C)APD having difficulty hearing in noise.

Results revealed that children with (C)APD demonstrated a statistically significant reduced TEOAE suppression effect, which suggests low activity of the MOCB system.

Critique of Articles

Moore et al. (2010) is classified as level III evidence (Dollaghan, 2007). Burguetti & Carvallo (2008), Sanches & Carvallo (2006), and Muchnik et al. (2004) are all considered level II evidence (Dollaghan, 2007). These levels of evidence are apprioriate for the type of research they are conducting, and the limited studies performed to date. However, as more evidence is gathered, future research should aspire to use randomized controlled trials to increase the level of evidence. Moore et al. (2010) methods, parameters of TEOAE suppression testing, sample size, and methods of statistical analysis will be reviewed from the previously mentioned articles in order to determine the strength of the evidence provided.

Moore et al. (2010) Methods

Moore et al. (2010) concluded that (C)APD was not a sensory disorder because of the derived auditory processing measures. The authors defended this method by stating that the cognitive influence could be eliminated by subtracting the results from carefully matched tests. The authors recognized that random variations in attention during the tests could not be completely removed. They noted that motivation, emotion, and fatigue were all assumed under the concept of attention. This method has yet to be reproduced, and therefore it can only be classified as suggestive evidence. Future research should evaluate the reliability of this method, and whether it is good assessment tool.

Parameters of TEOAE Suppression

It must first be determined if contralateral suppression of TEOAEs is a sufficient test to assess the integrity of the efferent descending auditory pathway. Assuming that it is a reliable and valid test, the parameters must also be best evidence based. Linear click stimuli was used in Burguetti & Carvallo (2008), nonlinear click stimuli was used with Muchnik et al. (2004), and both types of stimuli were used with Sanches & Carvallo (2006). When Sanches & Carvallo (2006) compared linear and nonlinear stimulus conditions, almost no differences were found, which suggests that both conditions are equally sensitive in identifying suppression. However, they noted that they had to vary the intensity levels when using the nonlinear stimulus to obtain responses from some subjects. This variation in intensity, suggests that linear clicks are the most appropriate stimulus when assessing children with (C)APD. It should also be noted that Sanches & Carvallo (2006) carried out their measurements in a quiet room, and not an acoustically treated room. Although a low pass filter was used to counteract the effects of possible noise, this method may not be ideal.

The contralateral suppressing stimulus used in the previous studies was broad band white noise. Burguetti & Carvallo (2008) used white noise at 60-65 dB, Sanches & Carvallo (2006) used white noise at 60 dB SPL, and Muchnik et al. (2004) used white noise at 40 dB SL.

The time window used varied in the studies addressed above. Burguetti & Carvallo (2008) used a 20 msec window, Sanches & Carvallo (2006) used a 2.5-20 msec window, and Muchnik et al. (2004) used two time windows. A time window if 2.5-20.48 msec was used, as well as a later time window of 8.0-20.48 msec was used. The authors stated that the first 2.5 msec were eliminated from analyses to avoid artifact. The later time window was used to evaluate a potentially enhanced suppression effect when removing the earlier portion of the response measurement due to external and middle ear properties. It was found that in the later time window, there was an increase in the mean values of the suppression effect in those with and without (C)APD, for both ears. The suppression enhancements were less noticeable in those with (C)APD than those without (C)APD, which parallels the finding that there is a reduced MOCB function in those with (C)APD.

Sample Size and Representation

All of the above studies did not report use of a power calculation to determine if there were a sufficient number of cases selected. Moore et al. (2010) used 1469 children who lived in a variety of postal codes in order to achieve a well-rounded representation. This appears to be a sufficient amount of cases. However, they did not identify children with auditory neuropathy, as well as did not account for children with already diagnosed learning disabilities, which both could have been confounding factors. Burguetti & Carvallo (2006) evaluated a total of 88 children. Results between genders were separately analyzed to assess if gender played a role in the results. Socioeconomic status was not taken into account, and therefore could have been a potential confounding factor. Sanches & Carvallo (2006) investigated a total of 51 children. Results between genders and socioeconomic status were not evaluated separately. It was not specified if learning disabilities, neurological disorders, or medical history were screened before the study. Recruitment methods were also not specified. All of these factors are limitations of the study, demonstrating only suggestive evidence. Muchnik et al. (2004) evaluated 15 children with (C)APD, who were age and gender matched with 15 other children who did not have (C)APD. All children had to meet the inclusion criteria, which accounted for neurologic and medical disorders, as well as having normal auditory brainstem responses. Although this study may not have as many participants as the other studies, it is a strong study because many confounding factors have been accounted for.

Statistical Analysis

Moore et al. (2010) used multivariate regression analysis to assess which factors accounted for the greatest variance. This is appropriate to help determine which components of processing influence (C)APD. Burguetti & Carvallo (2008) analyzed their data with the Wilcoxon and Mann-Whitney tests, which assesses two sample populations with a hypothesis. The significance value of p = 0.05 is a higher value than the other studies critiqued, but the results still did not show significance. This study demonstrates equivocal evidence due to the statistically insignificant results. Sanches & Carvallo (2006) used ANOVA to analyze the variance in their results, and a significance level of p = 0.05. This study demonstrated significance of their results with these statistical methods. The calculation of differences between test-retest revealed no significance, which suggests consistent reliability of the authors' methods. Muchnik et al. (2004) used a variety of statistical measures which attributed to the strength of these findings. Pearson correlation coefficient, repeated measures ANOVA, Fisher's exact test, and paired t tests were all appropriate analyses of the data. This study demonstrated strong significance using $p < 0.0001$, which suggests compelling evidence.

Discussion

The literature reviewed indicates that children with (C)APD have deficiencies in the efferent descending auditory pathway. Research conducted by Moore and colleagues (2010) used behavioural testing to diagnose (C)APD as cognitive problem, and not a sensory issue. This evidence was supplemented by objective measures, more specifically decreased TEOAE suppression values, completed by Burguetti & Carvallo (2008), Sanches & Carvallo (2006), and Muchnik et al. (2004). Future research should investigate whether top-down deficits are caused by bottom-up deficits, and vice versa. Moore and colleagues (2010) tried to separate these two types of processing by deriving auditory processing tests, but these should be replicated in order to make the evidence more compelling.

Another area of future research should be to determine a gold standard of parameters for TEOAE suppression testing. From the studies addressed, it appears that a linear stimulus with broad band contralateral suppression stimulus is appropriate for assessing children with (C)APD. Muchnik et al. (2004) suggested using a later time window, compared to the standard time window that the other two studied used. This should be further investigated.

Clinical Implications

The efferent auditory pathway should be part of the test battery when assessing, diagnosing, and treating suspected cases of (C)APD. This can help with differential diagnosis, as well as determine which type of professional should be involved. Moore and colleagues (2010) stated that attentional difficulties are still in the scope of practice for audiologists. However, if higher level etiologies are responsible for creating other auditory processing deficits, it can be argued that other professional opinions and practices should be collaborated.

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