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Effectiveness of a Novel Computer/Tablet-Based Auditory Training Program in Improving Dichotic Listening Skills in Children

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Abstract

Purpose: The purpose of this study was to examine the effectiveness of a novel computer/tablet-based dichotic listening training program (Zoo Caper Skyscraper, ZCS) in improving dichotic listening (DL) deficits of children identified as being at-risk educationally.

Method: Participants were 15 children identified both as exhibiting documented DL deficits and as being in the lowest 20% of educational achievers as compared to same-aged peers. Participants underwent two sets of pre-therapy DL measures using the Dichotic Digits test [1]. Following verification of a consistent DL deficit, all participants underwent the ZCS program. Following completion of training, participants' DL skills were retested.

Results: Results indicated that, although the two pre-treatment measures of DL did not differ from one another, a significant improvement was seen in DL following training, most notably for the left ear. Further, number of sessions required to complete the program did not correlate with degree of improvement, which underscores the need for individualization of treatment recommendations.

Conclusions: This study adds to the growing body of literature supporting the use of auditory training for improving DL skills. Results of this study also indicate that the ZCS program holds promise as a therapeutic tool for children with DL deficits.

Introduction

Dichotic listening (DL) is a term used when a listener is receiving a separate auditory signal to each ear simultaneously. DL has been the subject of discussion and investigation since the pioneering work of Broadbent and Kimura [2-4]. It is generally accepted that the auditory portion of the corpus collosum is required for the transfer of dichotic information between auditory cortical hemispheres based on lesion and MRI studies [5,6]. It is also accepted that other factors can influence the results of a DL task such as auditory memory and motivation to perform; however, under appropriate testing situations, these factors can be minimized. DL has also been associated with educational success and it has also been used in the diagnostic assessments of central auditory processing for more than two decades [7-12].

DL has also been investigated with regards to its impacts regarding linguistic and supralinguistic lateralization and attentional effects. That is, if a listener receives a standard dichotic speech signal in each ear, then the ear opposite to the primary language center (typically located in the left temporal lobe) will show an advantage (most commonly the right ear). In contrast, if the listener must listen to and identify the emotion of emotional-based speech in a dichotic fashion, then the ear opposite to the hemisphere that processes emotional content (typically located in the right temporal lobe) will show an advantage (most commonly the left ear). This is thought to be due both to the relative specialization of the hemispheres as well as to the ipsilateral pathways being suppressed when hearing dichotic stimuli [13-16].

When using dichotic speech stimuli, the ipsilateral pathways are suppressed and the majority of neural information is sent through the contralateral pathways. As such, the contralateral ear will have direct access to the primary (usually left) auditory cortex, whereas the stimuli delivered to the ipsilateral ear will need to cross the corpus callosum to reach the primary cortex to be processed. The opposite ear advantage is consistent in most individuals unless that individual has his or her attention directed during the testing to focus first on the non-advantaged ear, at which point the scores may reverse and the non-advantaged ear will have the better scores using some stimuli.

The effect of direct auditory training on DL has been examined in the literature. In both articles, Dichotic Listening Therapy (DLT) techniques were investigated employing intensity differences between ears, either using headphones or sound-field speakers placed to the right or left side of the listener. Both studies recruited children with known DL difficulties and had them participate in DLT sessions in which the intensity of the stronger ear was reduced until the poorer ear was able to successfully identify the stimulus; at times, the poorer ear also received an increase in stimulus levels. After success, the stronger-ear stimuli were increased systematically over time, leading to a more balanced intensity level between ears as the therapy progressed. Both studies indicated significant improvements in DL scores post-therapy compared to pre-therapy measures. Other areas of improvement were

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also noted in speech-language and academic performance, however direct attribution of these improvements to the auditory training cannot be drawn conclusively [18-20,22].

In addition to these two paradigms, Bellis [8] has described an informal approach to DLT that can be implemented in the home setting using devices such as iPods and recorded books. In this method, the target book is directed to the weaker ear (usually left, as identified by DL testing) and the competition (the same book at a different location, in order to avoid use of speaker cues) is directed to the opposite ear (usually right). Over time, the competition is raised to render the task consistently challenging. Effectiveness of this paradigm for improving both DL and hearing in noise has been demonstrated in children and adults with central auditory processing disorders (CAPD), including frank lesions of the cortex, as well as in other populations.

Musiek et al. [19] described a different approach to DLT. In this paradigm, an interaural timing difference, rather than an interaural intensity difference, was utilized. The authors conducted a pilot study which indicated significant improvements in DL abilities of the participants following treatment using the interaural timing difference paradigm.

In summary, DLT, in a variety of forms, has been shown to have promise in improving DL and concomitant hearing-in-noise abilities in individuals with DL and related deficits. In this paper, we will describe a novel computer/tablet-based dichotic listening program and provide the results of a pilot study regarding the effectiveness of this program in ameliorating DL deficits in children also identified to be at risk for educational difficulties [21-24].

Zoo Caper Skyscraper

Zoo Caper Skyscraper (ZCS, also known as Zoo Caper), created by Acoustic Pioneer, Ltd., is a DLT program that uses an interactive video game that can be played through stereo headphones using an Apple iPad app or through any internet browser using a standard computer. It uses interaural timing differences in a progressive algorithm. Because it is optimized for iPads, android tablets and personal computers, it can be implemented anywhere and, unlike other formal paradigms, does not require the use of an audiometer and ongoing clinician oversight. This allows the program to be implemented in a variety of locations, thus improving access to the therapy tool. Further, because ZCS is provided in a fun, game-like format with reinforcement, the engagement level of the individual undergoing the therapy may be increased. Finally, game progress can be monitored remotely by clinicians simply by signing into the clinician interface.

The training uses the interaural timing difference approach in which one ear initially receives the stimulus earlier than the other ear. Over time, the stimuli become closer and closer together while, at the same time, increasing in number, until such time as the stimuli are fully dichotic. Finally, in contrast to the paradigms discussed previously, ZCS uses a novel set of non-speech stimuli (animal noises), which allows for the program to be adapted to non-native English speakers.

ZCS requires the player to listen to animal sounds and identify which animal is associated with which sound. Once the player selects the correct animals, he or she then tries to stack the animals as high as possible, earning points as a motivator (Figure 1). ZCS becomes incrementally more difficult as the player achieves success. There are six levels of play. The first level begins with one sound in each ear separated in time. As the player progresses, both the number of stimuli and the degree of overlap increase, and the length of the stimuli decreases. By the sixth level, two 0.5 s stimuli are given per year in a fully overlapped (true dichotic) presentation. Players progress to subsequent levels only when they have demonstrated success at their current level. The definition of success differs depending on level of play; as higher levels are reached; more stimuli are given, leading to a higher accuracy requirement for progression to subsequent levels. This ensures that participants reach more challenging levels quickly when needed, and spend more time on gameplay levels that are at their individual challenge status. As a result, the program automatically individualizes itself to the participant's abilities. Within levels, the algorithm renders the activity more or less difficult depending on the success of the player. These levels are graphically depicted in Figure 2.

Figure 1: Screenshot of the ZCS app which targets dichotic listening deficits using an interaural timing difference between ears and incrementally increasing the difficulty of the task as the listener is successful.

After the initial program was created, small clinical trials were conducted with children who exhibited documented DL difficulties. Initial recommendations were that the child use the therapy game between 45-60 min, 5 days a week. It became apparent that the children's progress plateaued very quickly (e.g., soon after the second session of therapy) and their frustration level increased dramatically with some commenting that they did not want to proceed. Additional trials were then conducted in which the therapy was administered only twice per week and for no more than 20 min per session.

During these second trials, the children did not plateau even when they reached the same levels as the initial clinical trial group and frustration levels were not reported. Further, the children remained motivated to continue the therapy sessions. This shorter and less frequent regime of therapy was repeated with a slightly larger clinical trial group and again produced a favorable outcome. These trials resulted in the formal recommendation, as made on the acousticpioneer.com website that, for most children, the ZCS activity be engaged in twice per week, for 15-20 min per session; however, for participants who progress at slower rates, an increase in the frequency should be considered, or a cessation of therapy if frustrations are too high, perhaps returning after some time for neural maturation.

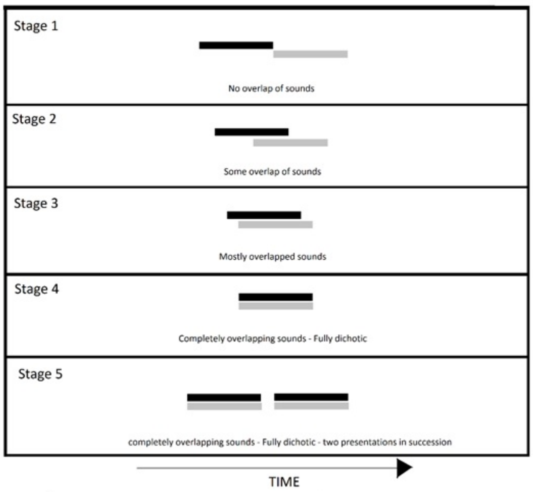

Figure 2: Visual representation of how the ZCS program algorithm progresses so that more overlap (smaller interaural timing difference) occurs with successful responses. Conversely, the degree of overlap decreases with unsuccessful responses. With each presentation, the ear receiving the signal first alternates. At the highest level of gameplay, stimuli are fully dichotic, with two stimuli presented per ear.

Depending on progress, the algorithm stops the game between 15 and 20 min after onset of gameplay, and a mandatory stand-down period of 12 h was incorporated. The present study was conducted using the final version of the program and these recommendations for duration and frequency.

Method

Following the preliminary trials, final recommendations for therapeutic use (frequency and duration) were made and posted on the acousticpioneer.com website. At that time, a pilot study was conducted to determine the effectiveness of ZCS for improving DL skills in a subset of children identified by their teachers as being at educational risk and who demonstrated DL difficulties.

Participants

After completing the ethical and confidentiality processes through local school boards, the teachers of 4 New Zealand classes of school children aged 8 to 12 were asked to identify up to 20% of the children in each class who were struggling with their educational progress compared to their same-aged peers, particularly regarding the ability to follow orally presented instructions and/or exhibiting lower reading scores. There were 29 children referred from the 4 classes (14 females, 15 males). Each potential participant had no other known diagnosis or disorder (e.g., autism spectrum disorder, Down's syndrome, cognitive impairment, etc.)

All 29 children passed an initial hearing screening at 20 dB HL for the four octave-frequencies from 500 to 4000 Hz in both ears through calibrated TDH39 headphones. The participants were also screened using tympanometry and all 29 participants revealed Jerger type A tympanograms, indicative of normal middle-ear function. They then underwent dichotic testing using the Dichotic Digits (DD) test [1]. This test consists of 25 sets of two pairs of numbers, one to each ear, presented dichotically. The listener is to report all numbers heard, regardless of order (free-report condition). Stimuli were delivered at a comfortable listening level through TDH39 headphones *via* a CD player and two-channel Interacoustics audiometer per standard recommendations for administration of this test. Results were recorded as a function of percent correct per ear. Each participant was re-tested within 7-14 days of the initial testing to provide two baseline, pre-treatment measures and to confirm results of initial dichotic testing. This dual baseline measure will be the within-group control for comparison to the post-therapy measures. Results of DD testing were compared to published norms for New Zealand (Kelly, 2007). Those children identified as exhibiting a consistent dichotic deficit in at least one ear of at least two standard deviations below the mean on both testing sessions were selected for inclusion in the study (n=15; 8 males, 7 females; mean age 10.3).

Procedure

ZCS is available for use through a web browser on a computer or as an iPad app. For this study, all 15 children used the iPad app version following the recommended protocols discussed in the introduction and recommended on the website at www.acousticpioneer.com, which suggests the training to be used twice per week through stereo headphones set at an easily audible yet comfortable volume. For participants progressing noticeably more slowly (participants 5 and 15), the frequency of play was increased from twice to three or four times per week, depending on the availability of the support person. The training was supervised by either a teacher or teacher's aide. As previously discussed, each training session automatically ends between 15 to 20 min (based on progress) by the ZCS application and there is a mandatory 12 h stand-down period following each session of gameplay. The actual number of sessions completed varied amongst the children as the algorithm is individualized for each child's speed and level of progress.

The data presented in Table 1 represent each participant's initial and repeat pre-treatment DD scores for right and left ears, number of sessions engaged in prior to post-treatment testing, and post-treatment DD results for right and left ears. It should be noted that not all children completed all levels prior to post-treatment testing.

For participants 5, 7 and 15, factors were present that did not allow them to finish the final level of the ZCS training (e.g., end of school year); however, all three spent a minimum of 10 sessions on the sixth and final level. Participants 2 and 10 completed ZCS in less than 4 weeks and/or in less than 9 sessions, so they were asked to repeat the training for a second time. Interestingly, both of these participants required more sessions to complete the training the second time through.

Participants	Gender	Age	Pre-Tx1 L	Pre-Tx1 R	Pre-Tx2 L	Pre-Tx2 R	Number of sessions	Post-Tx L	Post-Tx R
1	Female	9	70	92.5	67.5	87.5	13	80	85
2	Female	10	62.5	82.5	75	82.5	20	90	100
3	Female	12	80	90	85	97.5	12	90	92.5
4	Female	9	70	100	67.5	97.5	18	97.5	95
5	Male	12	80	77.5	87.5	77.5	36	100	100
6	Male	8	55	80	60	90	9	70	80
7	Male	8	75	67.5	67.5	70	21	75	80
8	Male	12	62.5	82.5	82.5	85	10	88	95
9	Female	12	72.5	72.5	75	93	12	92.5	92.5
10	Male	12	72.5	75	70	82.5	12	90	95
11	Male	11	65	80	60	87.5	18	87.5	90
12	Male	11	63	95	75	75	14	95	97.5
13	Male	10	68	70	75	80	16	90	95
14	Female	9	53	73	55	70	16	87.5	95
15	Female	10	60	80	65	77.5	42	87.5	92.5

Table 1: Pre-Treatment 1 and 2 and Post-Treatment Right- and Left-Ear Scores on Dichotic Digits, Test and Number of Sessions for each Participant.

Results

Data were subjected to a 3 x 2 x 2 Analysis of Covariance (ANCOVA), with Therapy (pre-treatment 1, pre-treatment 2, post-treatment), Ear (right, left), and Gender (male, female) as the independent, or within-group, variables and percent correct score on the DD test as the dependent, or between-group, variable. Age was entered as the covariate given the known maturational effect of age on the DD test. Post-hoc Bonferroni comparisons were used for significant pairwise effects of Measure, and Cohen's d was calculated as a measure of effect size.

Results revealed a significant main effect of Therapy [$F(2, 77)=36.46$; $p=00.000$] on DD scores. Post-hoc Bonferroni comparisons indicated that, when collapsed across ears, both pre-treatment measures were significantly poorer than the post-treatment score ($p=00.000$, $d=1.68$ for pre-treatment 1; $p=0.000$, $d=1.38$ for pre-treatment 2). There was no significant difference between the two pre-treatment scores ($p=0.369$; $d=0.28$).

Results further revealed a significant main effect of Ear on DD scores [$F(1, 77)=41.056$; $p=00.000$; $d=0.92$], with the left ear being worse than the right ear overall. This was an expected finding given the well-recognized right-ear advantage for dichotic tasks in children. No significant effect of Gender on DD scores was found [$F(1, 77)=3.331$, $p=0.032$, $d=0.17$]. Finally, a significant Therapy X Ear interaction was found [$F(2, 77)=3.61$; $p<0.05$); however, no other significant interactions were noted. These results are shown graphically in Figure 3.

To explore further the Therapy X Ear interaction, two separate ANCOVAs were conducted (one for each ear) with Therapy (pre-treatment 1, pre-treatment 2, post-treatment) as the independent variable and DD score as the dependent variable. Once again, age was entered as the covariate and Cohen's d was calculated as a measure of effect size. For the left ear, results revealed a significant main effect of Therapy on left-ear DD scores [$F(2, 41)=37.85$, $p=0.000$). Post-hoc Bonferroni comparisons once again revealed that scores for both pre-treatment 1 ($p=0.000$; $d=2.58$) and pre-treatment 2 ($p=00.000$; $d=1.94$) measures were significantly poorer than post-treatment scores; however, there was no difference between the two pre-treatment measures ($p=0.396$; $d=0.44$).

Similar, but somewhat less dramatic, results were found for right-ear DD scores. Analyses revealed a significant main effect of Therapy on right-ear DD scores [$F(2, 41)=7.785$, $p<0.01$). Post-hoc Bonferroni comparisons once again revealed that scores for both pre-treatment measures were significantly poorer than post-treatment scores ($p<0.01$; $d=1.58$ and ($p<0.05$; $d=1.15$, respectively); however, there the two pre-treatment measures did not differ from one another (NS; $d=0.25$).

A final analysis was carried out to determine if the number of sessions in which each child engaged correlated significantly with degree of improvement (pre-treatment 1 versus post-treatment). Results revealed no significant correlations between number of sessions and degree of improvement overall ($r=0.399$; $p=0.07$) or for right ($r=1$; NS) and left ($r=0.338$; $p=0.10$) ears separately.

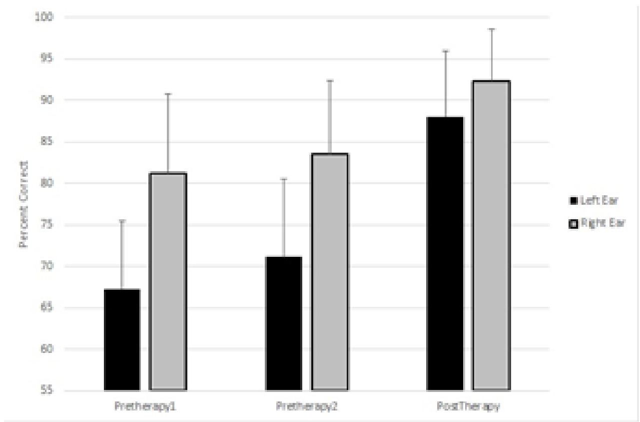

Figure 3: Percent correct Dichotic Digits score by ear for the three Therapy conditions (pre-treatment 1, pre-treatment 2, & post-treatment). Error bars represent one standard deviation.

In summary, analyses revealed that, although the DD scores for the two pre-treatment measures did not differ from one another, DD scores did significantly improve following ZCS therapy, with the most dramatic improvement seen in left-ear scores. Furthermore, the number of sessions engaged in did not correlate with degree of improvement, which underscores the importance of individualization of treatment recommendations.

Conclusions

Dichotic listening has been investigated in regards to its impact on listening and auditory processing since Broadbent and Kimura's pioneering work [2,3]. Although there is evidence that DL deficits may correlate with learning, language, and communication deficits, these complex relationships are still under investigation. It is of note, however, that in the current study, of the 29 children who were identified as being in the lowest 20% of their class, just over half (15) were identified as having a consistent and significant DL deficit, which indicates that those children who are struggling with education may have a very high likelihood (>50% in this study) of having DL deficits that may be a contributing factor to their educational difficulties.

The present study investigated the effectiveness of a novel computer/tablet-based DLT program (ZCS, Acoustic Pioneer, Ltd.) for improving DL skills in children with documented dichotic deficits. Results of this study demonstrated that, although the two pre-treatment measures of dichotic listening did not differ from one another (the within-group control), significant improvements occurred in DL skills following direct auditory training twice per week using the ZCS program. These improvements occurred for both ears, but were most pronounced for left-ear stimuli. That these improvements cannot be explained by "training to the test" is evidenced by the differences in the stimuli used for the testing measure [1] as compared to the training paradigm (animal sounds utilizing interaural timing delays). Further, although some participants took longer to complete the program than others, the magnitude of the improvements seen cannot be attributed primarily to maturational effects when one examines the normative data for this test. Finally, the finding that number of sessions needed did not correlate with degree of improvement underscores the need for individualization of therapy programs when making treatment recommendations for children with DL deficits.

Although this study did not examine the effect of improved DL skills on listening, learning, and related skills, several unsolicited comments (e.g., "I can definitely see that [child's name] has improved in his ability to follow multi-step commands at home," and "I can see that [child's name] feels more confident and calm in the classroom") were received during the course of the study that suggest that real-world abilities improved, as well. Of course, anecdotal remarks such as these do not meet a high level of scientific scrutiny. As such, a systematic, blind investigation of the effects of improved DL abilities on listening, learning, and related skills is needed.

Further, although the participants in this study had no known diagnosis of learning, cognitive, or related disorders, the possibility of the presence of such disorders cannot be ruled out. It should also be emphasized that, even though these children exhibited DL deficits, they did not undergo full central auditory processing evaluation. Therefore, it is not known whether these children met diagnostic criteria for central auditory processing disorder (CAPD; AAA, 2010; ASHA, 2005). Given these limitations, it may be premature to conclude that ZCS is a useful tool for ameliorating CAPD in children. However, the fact that most children with CAPD exhibit DL deficits, the results of this study, along with other studies cited previously, certainly provide convincing support for the use of this type of paradigm in the treatment of children with CAPD presenting with DL deficits. Therefore, additional research needs to be done to establish the effectiveness of ZCS for children with CAPD, as well as for adults and those with other listening and learning concerns. Also, as this initial study used a within group control paradigm, further research using 2 matched groups and with a sham/placebo therapy introduced to the control group is recommended.

In summary, despite these limitations, results of the present study add to the current body of literature supporting the use of DLT for treatment of dichotic listening deficits. In particular, this study provides evidence that Zoo Caper Skyscraper (Acoustic Pioneer, Ltd.), which is easily accessible *via* PC computer, android tablet or Apple iPad, and which does not rely on linguistic stimuli thus rendering it suitable for home or classroom use, is effective in improving dichotic listening skills, which may hold significant implications for treatment of a variety of listening and related disorders [25,26].

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