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RESEARCH ARTICLE

Development and evaluation of a computer-based auditory training program for rehabilitation of children with decoding deficit

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Abstract

Background and Aim: Decoding deficit is the most common central auditory processing disorder (CAPD). Given the benefits of computer-based auditory training programs for treatment of central disorders and the lack of such programs in Persian language, this study aimed to develop a computer-based auditory training program for decoding skill. We also evaluated this program in 8 to12 year old children with CAPD.
Methods: The first stage of research was to develop a computer-based auditory training program. This program consists of three levels of phonological discrimination, syllable discrimination, and word discrimination. The second stage was to determine the content and face validity of the program. The third stage was to assess the program effect on five children with decoding deficit. The research method was interventional and had a pretest and post-test design with another five children as control group. The staggered spondaic word, phonemic synthesis (PS) and speech in noise tests was used to assess the children performance before and after training.
Results: Mean scores of staggered spondaic word (SSW) and PS tests of the experimental group were significantly difference before and after the auditory training ($p<0.05$) as compared to control group. However, there was no significant difference with regard to the speech-in-noise test results ($p>0.05$).
Conclusion: This computer-based auditory training program can be considered as a preliminary tool for the rehabilitation and treatment of decoding deficits in children with CAPD.
Keywords: Computer-based auditory training; decoding; central auditory processing disorders

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Introduction

Central auditory processing disorder (CAPD) is a deficit in perceptual processing of auditory stimuli in the central auditory nervous system and its underlying neurobiological processes. CAPD is not due to higher order language or cognitive disorders [1]. One of the disorders in children with CAPD is decoding problem. The problem lies in the phonemic area located in the left posterior temporal lobe, i.e. the primary auditory cortex. Decoding is the precise and fast reception of speech stimuli, especially at the phonemic level. Based on Buffalo model (1990), decoding deficit can result in difficulties in phonemic identification, control, and recalling. Reading or lexical accuracy and spelling problems are usually part of decoding deficit. In this condition, difficulty in discrimination and vocabulary is due to misperception of auditory stimuli. Based on Bellis/Ferre (1999) model, decoding deficit includes weak phonemic representation, discrimination problems, difficulty in blending phonemes, and remembering learnt phonemes [2]. By far, decoding deficit is the most common auditory processing deficit [3]. The results of the central tests in decoding deficit includes low staggered spondaic word (SSW) scores in right competing and left non-competing conditions; low scores of phonemic synthesis (PS) test, weaker right ear versus left ear performance on the monaural low-redundancy speech and speech-in-noise test [2].

Auditory training is widely used for CAPD intervention [4]. Brain plasticity is the key factor in auditory training outcome [5]. Direct management and auditory training used for decoding deficit has been introduced by Katz and Smith (1991) and includes phonemic training program (PTP) and PS. Both methods use words, nonsense syllables, or repair strategies for teaching speech sounds. The aim of the PTP is the precise perception of speech sounds. It is assumed that subjects with decoding deficit perceive vague, inaccurate, or overlapping concepts of speech sounds. In PS, each word is presented phoneme by phoneme and subjects are asked to repeat the blended word or point to the target image [6].

Another program was suggested by Sloan called the minimum difference between discriminative pairs. Sloan approach was mainly focused on consonant discrimination and the most similar consonants are paired and presented to children such as /t/ and /d/. The child is expected to perform a fast and accurate discrimination [4].

After verifying the neurophysiologic representation of sound stimuli and improvement of listening and related functions in children and adults by auditory training, different software programs for auditory training for various auditory language and learning disorders were developed The best-known programs are Fast ForWord (Scientific Learning Corporation, 2001), Earobics (Cognitive Concept, 1999), Learning Fundamentals, Otto's World of Sounds, Conversation Made Easy, LiSN and Learn (for spatial hearing disorder) and dichotic interaural intensity difference (for dichotic processing deficit conducted by audiometer and computer game) [4,7]. Computer-based programs enable us to accurately control stimuli. They provide easy access to different training levels and games. Furthermore, their equipment is available and trainings are standard [8].

Decoding deficit is one of the most common type of auditory processing disorder (APD) and needs auditory training. In addition computer-based auditory training programs are shown to be effective for APD. However, there is no Persian computer-based program available, so the present study aimed to design a computer-based auditory training program for improving decoding skills in Persian-speaking children with CAPD and evaluate its effects.

Methods

The present study was conducted in three stages. Stage one comprised designing a computer-based auditory training program. In this stage, after reviewing different computer-based programs and considering treatment and management approaches for decoding deficits, the intended program framework was designed. In the next stage, an original version the program with non-phonemic stimuli was written and assessed by specialists. Phonemes, syllables, and words were used as the materials. Therefore, this program consists of three levels of phonemes, syllables and words discrimination (Fig. 1). The used syllables and words were different in their initial or final consonants. Each level has different difficulty levels from easy to difficult.

The Phonemic level has 6 stages, including 22 consonants and 6 vowels. They were divided into five 6-phoneme-group and one 8-phoneme-group. Consonants were arranged from easy to

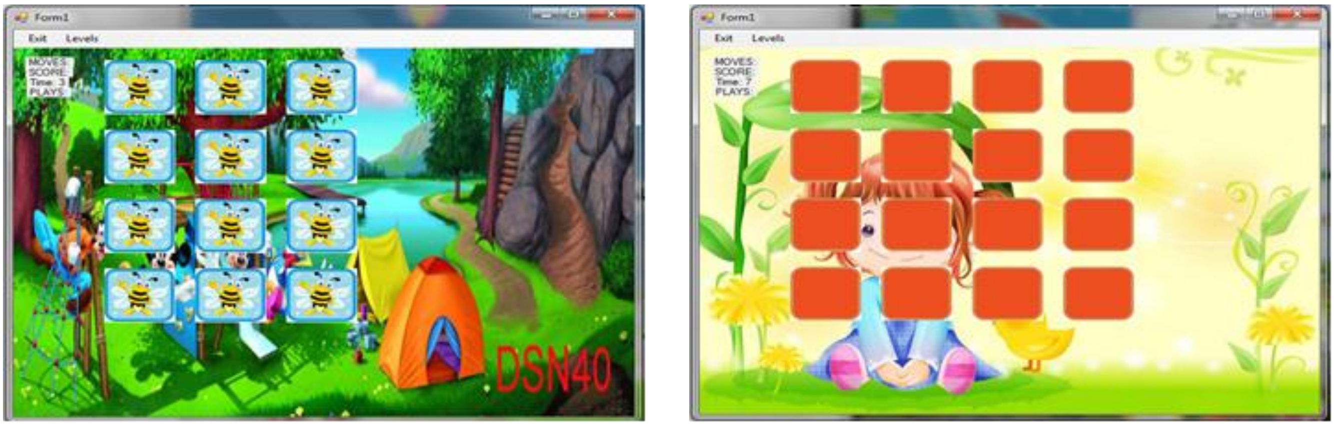

Fig. 1. Samples of 12- and 16-box stages of the computer-based auditory training program.

difficult based on voicing, manner of articulation, and place of articulation. First level included /â/, /a/, /u/, /o/, /i/, and /e/. Second level included consonants with similar voicing, manner and place of articulation consisting of /d/, /j/, /v/, /m/, /r/, and /y/. The third level includes consonants with similar voicing and manner of articulation but different place of articulation consisting of /s/, /š/, /f/, /x/, /h/ and /y/. The fourth level includes consonants with similar manner of articulation consisting of /b/, /p/, /t/, /d/, /k/, and /g/. The fifth level included two consonant groups with similar place of articulation; 1) /t/, /d/, /s/, /z/, /n/, and /l/, and 2) /š/, /ž/, /j/, /č/, /k/, /g/, /x/, and /q/.

The syllabic level had three stages. Phonemes of the last three stages of the first level were used in combination with vowels. In stage one, /â/ was used in combination with the consonants of the fourth stage of phonemic level, including /dâ/, /tâ/, /kâ/, /gâ/, /bâ/, and /pâ/. In stage two, /e/ was used in combination with the consonants of the fifth stage of phonemic level, including /šu/, ž/u/, /ju/, /ču/, /ku/, /gu/, /xu/, and /qu/.

At the word level, the program includes 21 stages in which words with different initial or final consonants were sorted in eight or six-word groups. The stages of this level were arranged based on available vowels. Vowels in the words had easy to difficult order: /â/, /a/, /o/, /e/, /u/, and /i/. There were 14 stages, including words with different first consonants such as /bâl/, /sâl/, /šâl/, /xâl/, /fâl/, /lâl/, /mâl/, /yâl/, /tang/, /sang/, /jang/, /čang/, /zang/, /rang/, /mang/, /nang/. The last seven stages included words with different final consonants such as /bâd/, /bâj/, /bâr/, /bâz/, /bâk/ , /bâl/, /bâm/, /baq/, /did/, /dir/, /dis/, /dig/, /din/, and /div/.

The stages of the program included 12-box sets (matched six pairs) and 16-box sets (matched eight pairs) and different icons with different images (Fig. 1). With hovering the mouse cursor on each icon, the related sound will be played and with a click, its color, or image will be changed (depending on the stage). The child is asked to find similar sounds among other sounds. If a child does not recognize the correct sound, the icon will be returned to the default status. If the child correctly recognizes it, the correct response will be shown in the form of an animation or motion picture. Motion pictures for each correct response motivates children to continue auditory training. This process continues until all icons are being activated.

The program is designed in a way that if one stage is repeated, the place of each icon is randomly changed. This will neutralize the effects of visual memory for each phoneme place and child's response will only depend on auditory information. in the left upper corner of the page, there are "move," "score," "time," and "play." "move" shows the number of icon matching. "score" indicates child's results and each correct answer has 10 positive scores while each wrong answer has one negative score. For example, if the child moves 8 icons correctly, his score will be 80 and his moves will be 8. “time” is indicative of the time lasted until a level is completed. “play” shows the total number of mouse movements on icons.

The second stage was to determine the content validity of the program. Content validity form was prepared and handed out among 10 audiologists who were experts in central auditory processing and speech and language pathology. They were asked to use a 4-point scale (from 1 to 4) to score phonemes, syllables, and words based on predetermined criteria, including necessity, relevance, clarity, and simplicity. Based on their comments and scores, the content validity index was calculated and experts’ comments were applied to the lists. Schipper designed a Table in which the minimum acceptable content validity ratio (CVR) in relation to a number of experts is shown. Based on this Table and for 10 experts, the minimum acceptable CVR is 62%. If the index for a group of phonemes was lower than 62%, that group must be modified. All groups showed an index of higher than 62%. Then phonemes, syllables, and words were recorded in the educational technology center supported by IRIB studio by a male voice actor with standard condition (clear, undistorted, and familiar).

In the next step, the details of the stages and principles were described for a software engineer and the computer-based program was designed and developed by AutoPlay software and Photoshop. Afterwards, the CD of the program was distributed among five audiologists to check and consider its face validity, including its relevance to the aim of the study, the acceptability of components and overall program, encompassing important aspects of the study aims, and being appropriate for the target age group. Experts’ comments were reviewed and any recommended revisions were made.

The third stage of the study was conducting research on the study population. This study is an interventional study with pretest and post-test design and a control group. The study population comprised all children with CAPD in Ahvaz City aged 8 to 12 years. The sample size was selected based on similar studies and included 10 children (5 cases and 5 controls). Non-probability sampling with considering inclusion and exclusion criteria was used to enroll the study samples.

Inclusion criteria included obtaining written consent from parents; having normal peripheral hearing; being 8 to 12 years old, having decoding deficit based on PS [9], SSW [10], and SIN test [11]; lacking visual impairment for playing with the computer, speaking Persian language as their native language; and not involving in any previous auditory training program. Tests included otoscopy, immittance acoustic test for the evaluation of the middle ear status, puretone audiometry, speech recognition in quiet, and central auditory tests consisted of PS [9], SSW [10], and SIN test [11] for confirming decoding deficit. PS quantitative score, right non-competing (RNC), right competing (RC), left non-competing (LNC) and left competing (LC) scores in SSW and also SIN test scores were recorded. For subjects who fulfilled the inclusion criteria, auditory training sessions with the computer-based program were started in the case group. Based on a preliminary study, the number of stages and the time needed for the training was ten 30-minute sessions, three times per week in the Consulting Center of Ahvaz Education Department. The training was performed with Laptop under headphone at the most comfortable level (MCL). MCL was set via presenting 4-5 words from one of the stages and asking the child to judge MCL. The instruction was given to the child after starting the program. Before giving the main training, there were few familiarization steps. The number of rehabilitation stages in each session was dependent on the child’s score in each stage. The stage was completed only if he could gain score of 60 for 12-box stages and 80 for 16-box stages. The total score in each stage was extracted. Finally, after completion of the auditory training, the central tests (SSW, PS, and SIN) were administered again to all children and their improvement in the case group was evaluated.

For analyzing data, at first Levene’ test was

Table 1. Mean (standard deviation) of the staggered spondaic word, phonemic synthesis, and speech in noise test scores in experimental and control groups before and after training

Test		Mean (SD) scores		
		Experimental group (n=5)	Control group (n=5)	p
SSW				
RNC	**Before**	11.80 (5.31)	9.40 (6.26)	
	After	2.80 (2.38)	8.60 (4.82)	<0.05
RC	**Before**	23.00 (9.77)	23.80 (6.64)	
	After	12.40 (6.80)	22.60 (5.77)	<0.05
LNC	**Before**	10.20 (5.54)	9.40 (5.89)	
	After	3.00 (3.08)	8.00 (5.33)	<0.05
LC	**Before**	18.80 (5.93)	23.20 (5.63)	
	After	9.60 (5.32)	22.20 (5.11)	<0.05
PS	**Before**	7.60 (7.09)	11.80 (4.55)	
	After	14.40 (6.54)	12.80 (4.81)	<0.05
SIN				
RE	**Before**	70.40 (15.64)	64.00 (20.97)	
	After	74.40 (13.44)	62.20 (21.24)	>0.05
LE	**Before**	73.60 (15.38)	64.40 (20.80)	
	After	76.00 (11.66)	64.80 (21.05)	>0.05

SSW; staggered spondaic word, RNC; right non competing, RC; right competing, LNC; left non competing, LC; left competing, PS; phonemic synthesis, SIN; speech in noise, RE; right ear, LE; left ear

administered for evaluation of variance equality and then Kolmogorov-Smirnov test for checking the normal distribution of scores. Next, for comparing the mean scores from pre to post intervention, paired t test was used. All tests were performed by SPSS 24. The significant level was set at 0.05.

Results

Table 1 presents the mean and standard deviation of SSW, PS, and SIN results before and after computer-based auditory training in both groups. As it is seen, there was a significant difference between children with CAPD in case and control groups in regards to SSW RNC (p=0.02), RC (p=0.02), LNC (p=0.01) and LC (p=0.001). In addition, there was a significant difference between two groups with regard to PS score (p=0.01). There was not any significant difference between two groups in SIN at SNR-10 in two ears: right ear (p=0.07) and left ear (p=0.4).

Discussion

The present study aimed at developing a computer-based auditory training for decoding deficit in Persian and its evaluation in 8 to12 years old children with CAPD. In this study, the computer-based auditory training made a significant difference in SSW and PS scores of children in the case group. Computer-based auditory training improved the mean scores of RNC, RC, LNC, and LC in SSW and PS tests in the case group in comparison to control group. The amount of this effect for RC was 0.85 which means 85% of RC score improvements after auditory training is attributed to computer-based training. This effect for RNC and LC was 0.83 and for LNC 0.67. The amount of mean PS score improvement in children with CAPD in the case group was 0.62.

Battin et al. studied the effects of computer-based Fast ForWord (FFW) program on the performance of children with CAPD on the SCAN [12]. FFW has different levels for different age groups. It is actually a game for improving basic cognitive skills such as memory, attention, and order with special focus on phonemic awareness and language structure. For older children, the program focus is on the processing skills, and reading enhancement via perception of speech sounds, phonemic awareness, and word recognition. The stimuli were non-speech tones or modulated speech with lengthening their characteristics (for example formant transition) in comparison with natural speech [13]. The results showed that after 6 to 8 weeks of auditory training, children's score in the screening test for auditory processing disorder in children-revised-c (SCAN-C) improved significantly. SCAN-C includes Auditory Figure Ground, Filtered Words, Competing Words, and Competing Words and Competing Sentence subtest [12]. In addition, Wertz and Hall studied four 8 to 12-year-old children with CAPD who received rehabilitation via FFW and Earobics [14]. Earobics was a comprehensive program for phonemic awareness and language-auditory processing training. This program consists of sets of games designed for language development, phonemic awareness, alphabetical knowledge, decoding, spelling, reading, and writing improvement [15]. They reported significant improvement in SCAN-C and a dichotic task following training [14].

Miller et al. studied 7 to 9-year-old children with CAPD. Three children received FFW, two children Earobics and two children traditional auditory processing trainings. Auditory processing, language, speech, and writing tests were performed before and after the training. The results supported auditory processing improvement in all children [16].

Krishnamurti et al. studied the effects of auditory training on auditory brainstem response (ABR) in two school children with CAPD. FFW was selected as an intervention. Click ABR and speech ABR were studied before and after auditory training. Auditory training lasted for eight weeks. Click ABR did not show any significant change but speech-ABR components showed significant alterations from pre- to post intervention [17]. In agreement with these studies the results presented in our research demonstrate that auditory training programs improve auditory performance in subjects with CAPD which reflect neural plasticity in the central auditory system. Speech encoding-decoding is altered by cognitive functions such as auditory-language experiences and these effects can change neural activity within the brain structures. In the present study there were no significant improvements on the SIN performance in the right and left ears.

The probable reasons can be related to limited sample size or other CAPD deficits such as integration or tolerance-fading memory.

Conclusion

Based on the results, this computer-based auditory training program can be effective in improving decoding deficits in children with CAPD and seems to provide a preliminary tool for rehabilitation and treatment of decoding deficit in subjects with CAPD. Nevertheless, due to pathological heterogeneity of CAPD more research with larger sample size is needed before it can receive widespread acceptance for utilization in clinical populations.

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Conflict of interest

The authors declare that they have no conflict of interest.

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