Research Article

Development of a Smart Game Application for Auditory Training of Children with Spatial Processing Disorder in Iran: A Pilot Study

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Highlights

- The designed game can be used for auditory rehabilitation of children with SPD
- The designed game is fascinating and user friendly
- The game has the potential for spatial speech in noise training

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ABSTRACT

Background and Aim: Identifying sound localization defects in children and using appropriate rehabilitation methods lead to improve their problem to use binaural processing skills to successfully suppress background noise and selectively attend to a particular auditory source. This pilot study aims to design a game for auditory training of children with Spatial Processing Disorder (SPD) in Iran and compare their performance in engagement time and speech recognition in noise with those of normal peers.

Methods: The game application was designed based on the spatial separation of target and competing stimuli by applying head-related transfer functions. The child's task was to identify the picture of the target word from among the displayed options. Participants were 24 children with SPD and 27 normal peers aged 7–9 years, who performed the speech recognition tasks using the designed game.

Results: The game was fascinating and easy to use for most participants. There was no significant difference in mean engagement time between the two groups. The mean engagement time of participants was significantly different between the two groups in terms of age. The children with SPD obtained lower scores in speech recognition in noise tasks. There was no significant difference in speech recognition scores between girls and boys.

Conclusion: The designed game application has the potential for speech recognition in-noise training of children with SPD in Iran. It is a fascinating and user-friendly tool for simulating the real-life auditory situations for these children.

Keywords: Smart game; speech recognition; application; auditory training; design; spatial auditory processing disorder

Introduction

Target sound detection in noisy environments challenges the auditory system, where many speakers are active at the same time and the listener tries to focus on only one of them. An important determinant of speech perception in such conditions is the spatial correlation between the target signal and maskers [1]. Children with Spatial Processing Disorder (SPD) are deficient in the ability to use binaural cues [2] to achieve spatial release from masking [3, 4] and utilize spatial processing for speech perception in noise; therefore, they experience more problems in difficult listening situations (e.g., when they are in the classroom) [2]. Contrary to children with normal spatial processing, these children cannot process the teacher's speech and filter the background noise simultaneously using binaural cues; hence, they experience difficulties listening in the classroom [5], which can affect their academic achievement [4]. The spatial separation of target signal and maskers improves speech perception compared to when target and masker are co-located [1]. Children do not have the sufficient motivation during clinical interventions, which hinders progress. Thus, computer games can be used to boost their motivation, since children are more interested in playing games. Some efforts have recently been made to design educational games using computer applications. These games are not just for fun or leisure activity. They are applied to bridge the real and virtual worlds and have extensively been used for intervention and training [5, 6]. For example, the LiSN and Learn auditory training software, developed by Cameron and Dillon in 2010, is used to improve the ability to use binaural cues through repeated exposure to these cues. This software has been beneficial for the intervention of people with SPD [7, 8]. The current study focuses on designing and development of a smart application as a supportive tool for training the speech in-noise perception using games for the rehabilitation of Persian-speaking children. It is assumed that localization training may improve the children's performance in using spatial cues for separating target signals from the competitive sounds, and can enhance their speech perception in everyday listening situations and academic performance. After desiging this educational game, we provide a preliminary report regarding the effectivness of this game in auditory training of children with SPD and nomral peers.

Methods

Participants

This is a pilot study. The participants were recruited from the primary schools in Tehran, Iran. Twenty-four children were suspected to have SPD based on having abnormal listening behaviors (according to teachers and parents' reports), low scores in the parent and teacher versions of the speech, spatial and qualities of hearing scale and the Spatial Word In Noise (SWIN) test. Twenty-seven normal age-matched children with no auditory problems were also recruited.

The age range of all participants was 7–9 years. There were 10 girls in each patient and control groups. None of the children had speech disorders, attention deficit/hyperactivity disorders, or autism spectrum disorders. All children were Persian with a pure tone threshold<20 dB HL at 250–8000 Hz and an A_n tympanogram type.

Application design and development

The application was designed for improving the children's speech recognition in noise by selecting the correct images. Based on the children's performance, the difficulty level can be adjusted by reducing the Signal-to-Noise Ratio (SNR) and the azimuth of target sentences and distracting stimuli separation. In this application, the user is asked to find the image corresponding to the word s/he heard through headphones which became three-dimensional using head-related transfer function). Therefore, although the user was wearing headphones, it was like the stimuli were arriving from different directions in a virtual auditory environment.

Selection of educational materials

The educational materials and the difficulty of training were determined by the research team. The words with age of acquisition<7 years were selected so that they could be spoken by children aged 7–9 years easily. The words with certain emotional connotations were removed. Finally, the words were categorized into four groups, including nouns, adjectives, adverbs (time and place), and verbs for use in the sentences. Considering the mean length of utterance in children<7 years of age [9], several four-word sentences (regardless of prepositions and conjunctions) were generated randomly. Each word was assigned a code saved in a Notepad file format to be used in the designed application for generating sentences. For random generation of these sentences, one word was selected from each group by the computer. Random sampling was done 1200 times to generate the sentences. Finally, 600 sentences were selected and assessed. The sentences were designed in such a way that they provided limited contextual cues for perception. They were structurally correct, but it was difficult to guess the target word in their structure. The content validity of sentences was assessed by 13 audiologists, speech therapists, one linguist expert in phonetics, and experts in children's literature. The criteria were accuracy of grammar, unpredictability, and difficulty. Some modifications were made in the sentences according to the experts' comments. Finally, the sentences with the highest scores and similar difficulty levels were selected. Two stories were used as distracting stimuli including "The Fox and the Stork" and "The Mouse Who Knew" in Persian published for children aged 7–9 years by Roshd Press in Iran.

Recording and editing of educational materials

The educational materials of this designed application was read by a female Persian speaker (a speech-language pathologist) considering the phonotactic rules in an acoustic booth in the Virtual School of Tehran University of Medical Sciences and recorded using the Adobe Audition v.3.5.1.12 along and a sound monitoring package and sound card in the WAVE format (1.44 kHz,16-bit mono). All speech stimuli were recorded with the standard accent and a clear voice while maintaining the speech rhythm and avoiding emphasis on the key words. Afterwards, the recorded materials were edited in terms of sound level, noise, and hesitations between words. Pauses were removed from distracting stories to ensure that the stories were presented smoothly at a constant intensity. Each target sentence was normalized to a Root-Mean-Square (RMS) level of -22 dB using the Adobe Audition software. The distracting stories were normalized to an RMS level of –25 dB. The sentences were sent to a linguist expert in phonetics and a speech-language pathologist for phonetic evaluation, which led to elimination of inappropriate sentences. Finally, 388 sentences were remained.

Spatialization of educational materials

To add the effect of head-related transfer function when recording speech materials, a real-world listening condition was simulated in an acoustic room in the Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences. Two microphones were placed at the tympanic membrane level of a girl with average head size. The recorded sentences were presented from a loudspeaker located at 0° azimuth. Distracting stories were presented from loudspeakers located first at ±90°, then at ±45°, and finally at 0° azimuth: one from the right side to the right ear (+90°) and the other from the left side to the left ear (–90°); one to the right ear (+45°) and the other to the left ear (–45°); and two from the front (0°). The two distracting stimuli were presented at the same time. Loudspeakers were placed at the level of the ears and one meter away from the head. Materials were collected at the right and left tympanic levels and recorded on separate left and right channels. Materials were presented using the Adobe Audition software installed on a laptop (Lenovo model G510) and recorded using the Snooper application. The set-up was designed by Pejvak Ava Sahar Company (Iran). Recorded sentences were edited in the Adobe Audition software. Silent periods were removed, and the stories were normalized to similar RMS levels.

Selection and illustration of stimuli

Picturable target stimuli (common words including nouns, verbs, adjectives, and adverbs) were selected from the sentences. It was necessary to select three words as deviant items for each target sentence. Therefore, the research team, by reviewing the studies in literature, attempted to find the words with the rhymes, onset, and codas similar to those of target word, and could be easily illustrated by pictures [10]. 550 words that met the criteria were further evaluated by experts and selected as deviant items for 193 target words. A set of cartoon pictures was illustrated by a children's graphic designer based on the words. A panel of experts including the research team, an expert in children's literature, and a number of elementary teachers evaluated the pictures in terms of color, resolution, familiarity, and appropriateness for the Iranian culture. Based on the opinions of the panel of experts, some changes were made on the pictures. They were then presented to a small number of children with normal auditory processing aged 7–9 years. They were asked to identify the words from the pictures. The pictures that could not led to identification of words were re-illustrated. If the majority of children could not identify the words based on a picture, it would be replaced by another appropriate picture.

Structure of designed application

The main menu provided access to educational programs, reports, and games. When a child selected the start button on the screen, the distracting stories began. The target sentence was presented two seconds after distracting stories and the stories ended one second after the end of target sentence. The game was selected automatically by the application at each session. In all games, the child's task was to differentiate the target words in the presence of background noise (two distracting stories). The target sentences were presented at higher intensity levels compared to the distracting stimuli. A 1000-Hz tone-burst stimulus was presented for 200 ms before each sentence to increase the child's awareness, and a 500 ms gap separated the tone-burst stimulus from the beginning of the sentence. Immediately after presenting the sentence, four pictures and a question mark appeared at the top of the screen. The child should select one of the pictures corresponding to the target word (Figure 1).

If the child was not certain about the answer, he would select the question mark. Each session lasted for about 20 minutes, and the number of games in each session was determined based on the child's cooperation level. In total, the children were trained three times a week until the games were played completely.

Application development based on artificial intelligence

The application based on artificial intelligence was designed in four phases: Screening, design, development, and assessment. The screening phase included a study on the requirements of spatial audiometry test considering the scenarios, identification of the stages, contents, and attractiveness of the application. For development of the application, some factors should be considered, such as adding features for entertainment (animations, sounds, 2D effects, different games, etc.) and reward (sounds and animations), children-friendly content, randomness of questions, ability to set the difficulty level based on the user performance, recording/saving the responses, and purposefulness of the game. In the design phase, different sources were used to develop the application, including 2D Sprite images (for selection), 3D objects, sounds (competitive noise, target stimulus, winning and losing sounds), animations (winning, losing, and uncertainty), 2D effects, and 2D tables and charts. The development phase included the used tools and software. A desktop platform (Microsoft Windows) was employed with Unity 3D engine (version 2020.3.30f1) for creating games using C# programming language. Due to the use of this engine, the games were compatible for Microsoft Windows, Android, IOS, Linux, and WebGL. The set-up file size of the application was approximately 1.24 GB. A game application uses different sensory methods (color, sound, motion) and provides immediate and repeated feedback on the quality/precision of the function (through graphics, sounds, and scoring). Such applications can improve the children's cognitive performance more than boring and repetitive experimental tests [11]. Therefore, game graphics are of significant importance. Three 3D games, including football, ballet, and basketball, were designed for the application. Boy and girl cartoon characters were used as game avatars, which competed against each other in three stages. The Scene Manager Class was used to switch between scenes. At the end of each stage, the user's data and performance were saved in a text format.

In the assessment phase, the data received from the user during the game (number of correct, wrong, and uncertain answers, SNR of the user (in dB) at each stage of playing, and number of games played when distracting stories presented at different azimuths) were

Figure 1. Example of game options (one of which is true, three are false and one is a question mark)

assessed. The saved data were loaded in the form of 5 scripts using C# programming language to a JSON file in Unity v.2.0.1 package. The application was made of 17 scripts written in C# language, in which System, System.Collections.Generic, System.IO, System.Linq, System.Text.RegularExpressions, TMPro, UnityEngine, UnityEngine.Audio, UnityEngine., SceneManagement, UnityEngine.UI were used. The application had 12 scenes: Menu, Intro1, Intro2, Intro3, Tutorial, +90–90, +45–45, +0–0, ChooseGame90, ChooseGame45, ChooseGame0, and Chart. The functioning of these scenes is summarized in Figure 2.

In the Menu, there were two options: Sign up and Log in. To register in the game, the user's national code and date of birth were needed (Figure 3A). After registration, each user was given an ID. A folder named "Player ID" was thus created, which included a .txt file containing the results obtained from each user in answering to 20 questions in each game. Some instructions were given to the first-time users to get familiar with the game (Intro1 and Intro2 scenes). There was also a training phase with five questions (Tutorial scene). To enhance the attractiveness of the game and maintain the child's attention while playing with the application, three games

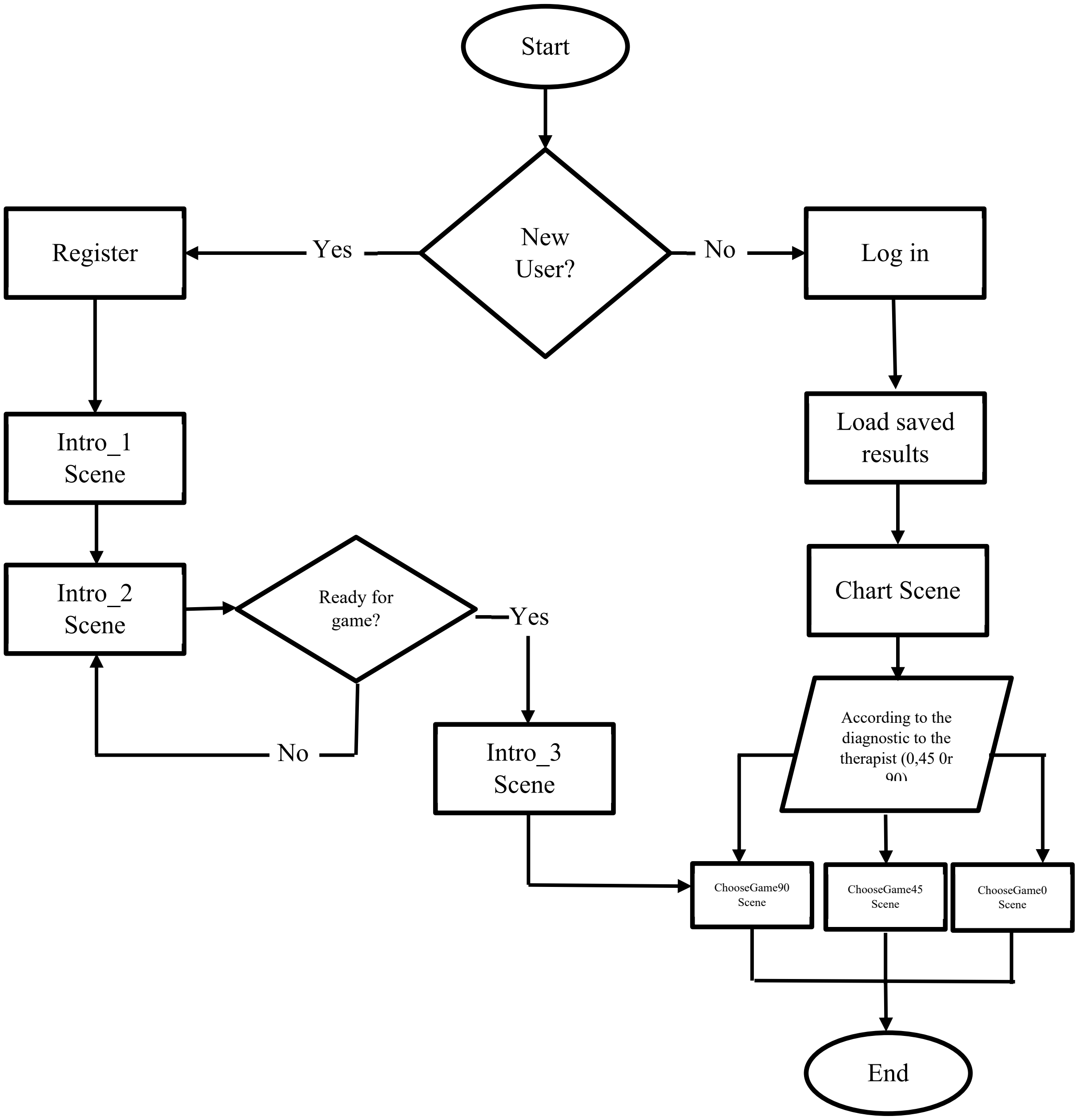

Figure 2. Summarized flowchart of the application scenes

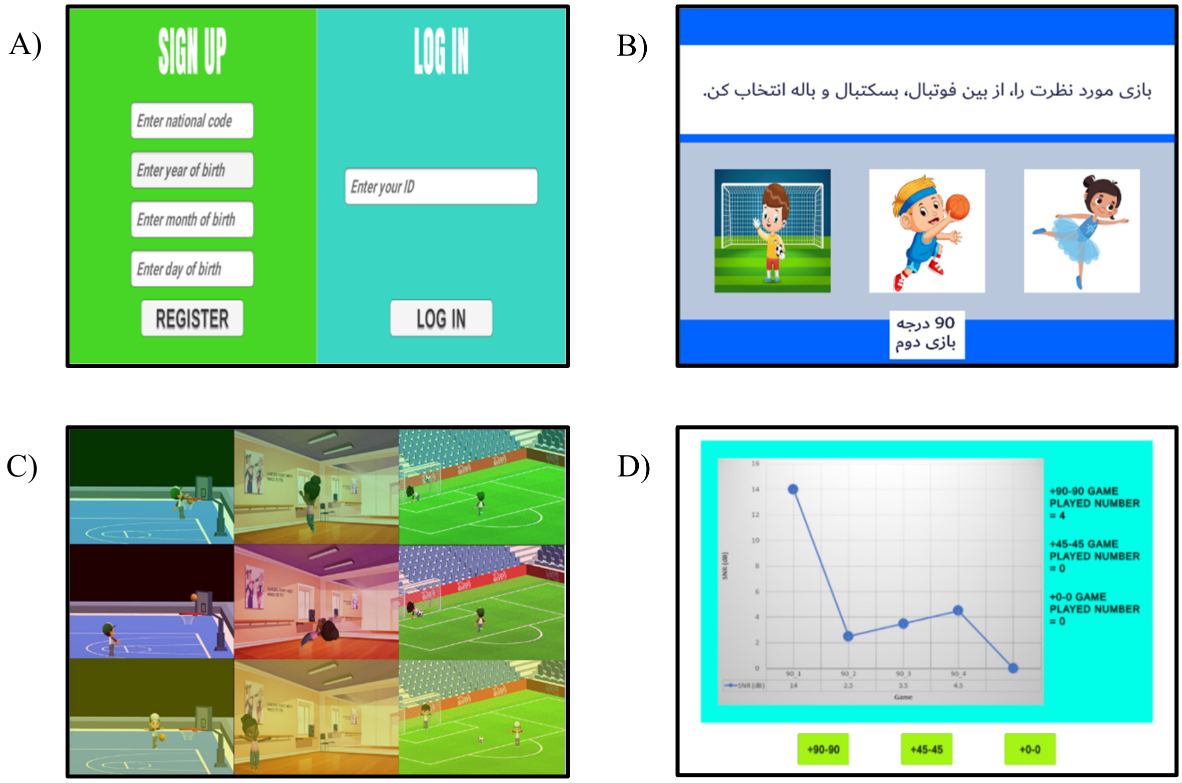

Figure 3. A) menu page, B) game scenes, C) reaction of the characters in each game, and D) an example of chart.

including football, basketball, and ballet were available for the users to choose based on their preferences in the ChooseGame90, ChooseGame45, and ChooseGame0 scenes (Figure 3B). Each game reacted differently to correct, wrong, and uncertain answers. For a correct answer, the game character scored a goal in the football or basketball games and performed a Pirouette in ballet game. For a wrong answer, the character could not do any of the mentioned acts (Figure 3C). To interact with children and keep them motivated, a clapping sound for applause and a sound for losing were played after giving correct and wrong answer, respectively.

An artificial intelligence algorithm was used in this application for adaptive training. The up-down adaptive method was used to set the intensity level of the target sentence. The SNR was reduced by 1.5 dB upon choosing the correct picture and increased by 2.5 dB upon choosing the wrong picture. If the question mark was selected, the SNR increased by 1.5 dB. When a child chose the question mark for the same sentence twice, a different sentence with a higher SNR was presented. Non-repetitive sentences were presented in each game, and the SNR changed relative to the previous question based on the child's response. The SNR decreased in a range of +7 and –3 dB upon improvement in adaptive training performance. In addition, to change the difficulty level of the tasks and place more emphasis on the spatial cues, the distracting stimuli changed from ±90˚ to ±45˚and finally to 0.

Before starting the game, instructions were given to the children and one round of the game was played by each child as a trial. At least five sentences were presented for trial starting at a 62-dB sound pressure level. Each game included 20 sentences. The results were automatically saved by the software. After each stage of the game, the chart scene was shown to the therapist (Figure 3D). Based on this data, the therapist could decide how to continue the training process. After finishing the game development and addressing its primary drawbacks, its content validity and face validity were confirmed by a panel of experts.

To evaluate the initial efficiency of the application, the application was administrated to both groups of children. An audiologist was present in the room to observe the children's performance. The acceptance rate, duration of playing each game, and word identification tasks scores at different noise azimuths (±90, ±45, and 0˚) were measured for both groups. At the end of the training session, a three-question survey was used to investigate the children's experience and game attractiveness: "Was the game easy for you?", "Did you enjoy your game?", and "Do you like to play the game again?". The questions 1 and 2 were rated on a 5-point Likert scale and the third question was answered by Yes or No.

Statistical analysis

Statistical analysis was done in SPSS v. 17. Descriptive statistics were used to report the users' experiences on using the application. Kruskal-Wallis test was applied to compare the mean engagement time in terms of age. Mann-Whitney U test was used to compare the speech perception and mean engagement time in terms of sex and study groups.

Results

Fifty out of 51 children reported that the application was easy to use, and 39 "very" enjoyed playing the game. Nine children answered that they enjoyed it, and three children "little" enjoyed the application. In addition, all children were interested in using the application again. All students participated in three games. The mean engagement time of control (10.97±2.71 min) and SPD (12.48±3.29 min) groups was not significantly different (p=0.128). The control group performed each game for 7–18 minutes while the engagement time for children with SPD was 8–20 minutes.

Table 1 presents the mean scores of participants in word recognition tasks at ±90˚, ±45˚, and 0˚ azimuths. A significant difference was observed between the two groups. The highest score in both groups was obtained at ±90˚azimuth and the lowest score was obtained when the target signal and competing noise came from the same location, i.e. 0˚. In addition, the SPD group had lower scores in all three stages of recognition task compared to the control group. Table 2 shows the word recognition scores in two groups based on sex. There was no significant difference in word recognition ability in noise between boys and girls (p>0.05).

Table 3 provides the mean engagement times of participants in terms of age. The mean engagement time of participants was significantly different between the two groups in terms of age. The post-hoc test for

Table 1. Mean percent of correct responses of speech recognition in different noise locations in normal auditory processing and spatial processing disorder groups

	Mean(SD)		
	Normal auditory processing (n=27)	SPD (n=24)	p
Recognition in ±90 (%)	94.29(3.14)	65.21(5.00)	
Recognition in ±45 (%)	92.03(3.42)	64.58(5.30)	0.001
Recognition in 0 (%)	89.34(3.74)	46.27(6.67)	

SPD; spatial processing disorder

Table 2. Mean percent of correct responses of speech recognition in different noise locations of boys and girls in normal auditory processing and spatial processing disorder groups

	Normal auditory processing			SPD		
	Girl (n=10)	Boy (n=17)		Girl (n=10)	Boy (n=14)	
Location of noise	Mean(SD)	Mean(SD)	p	Mean(SD)	Mean(SD)	p
Recognition in ±90 (%)	93.16(3.58)	94.84(4.22)	0.9	66.25(5.17)	63.75(3.41)	0.19
Recognition in ±45 (%)	92.83(3.58)	90.66(4.57)	0.2	64.37(4.95)	62.81(4.06)	0.8
Recognition in 0 (%)	89.50(4.52)	88(3.38)	0.3	48.12(9.97)	46.56(6.25)	0.19

SPD; spatial processing disorder

Table 3. Mean and median of engagement time of three age group in normal auditory processing and spatial processing disorder groups

Age (year)	Mean(Median)	
	Normal auditory processing	SPD
7	12.88(13)	14.60(15)
8	10.05(10)	12(12)
9	9.32(9)	10.64(10)
p	0.01	0.007

SPD; spatial processing disorder

pairwise comparison showed a significant difference in children aged 7 (p=0.04) and 8 years (p=0.02) compared to children aged 9 years in the SPD group. In the control group, the significant difference was found only between children aged 7 and 9 years (p=0.009).

Discussion

In the current study, a game application was designed to train children with SPD using binaural cues to suppress the background noise and promote attention to the target speech. The 3D listening environment created using the headphone was found to be a reliable technique for improving speech recognition in noise. Both groups of children engaged in the game actively. This accomplishment was so significant that made game easy and interesting to them; however, it challenged their ability for spatial segregation. In both groups, most of participants stated that they enjoyed the games and were interested in playing them again. This indicates that children with SPD had a good motivation for speech recognition training in virtual spatialized noise using the games. The designed educational application allows the users to choose the desired game to increase their motivation and maintain the application's attractiveness throughout the training sessions. Brasil et al. showed that training using a rehabilitation application had a satisfactory acceptance among children [12]. Cameron and Dillon also reported that the use of game application was useful for spatial auditory disorders [7].

To ensure the effectiveness of educational games and keep the users motivated, they should play the game for 12–60 minutes in each round [6, 7, 13, 14]. In the present study, the mean engagement time in each game was 12.48 minutes Children could play at least two games or more in a day with adequate attention and motivation. As expected, children with SPD could not recognize as many correct words as those with normal auditory processing. The most satisfactory word recognition performance was reported for spatial segregation of the target sentence from the distracting stories, while the weakest performance was observed when the competitive noise and target stimulus were presented from the same direction. In a study, using the listening in spatialized noise-sentences test, the required SNR for recognizing the target sound in the presence of distracting sounds was significantly higher for subjects with SPD compared to normal peers [15]. In other words, at similar SNR levels, children with SPD were less capable of tracking the target stimulus in background noise. The designed application may help children with SPD to focus through directing their attention to the screen. It keeps them concentrated and prevents distractions [5].

In the present study, we applied the virtual reality technology in combination with a computer game for training and rehabilitation of word recognition in noise. Funny cartoon characters were used in the designed application, and the task difficulty could be automatically adapted to the children's performance during the training period. The use of this application can save the therapist's time and energy for training children process and keeping them motivated and concentrated. After playing its three games, almost all children in both groups reported a pleasant experience with the game. The children with SPD had lower performance in speech recognition compared to normal peers. Therefore, it seems that this game can be used for these children, but its usefulness should be further investigated in future studies with a larger sample size and follow-up periods. According to the results of this pilot study, training by using game and virtual reality may be an appropriate approach for rehabilitation of children with impaired speech perception in noise. It should be noted that the difficulty level of each speech recognition in-noise task was determined in a hierarchical format; thus, more research is required to evaluate the challenges of low SNR levels in spatial segregation of target signals and maskers.

Conclusion

The designed game application has the potential for speech recognition training of children with Spatial Processing Disorder in Iran. This application is user friendly for educational or intervention purposes to simulate the real-life auditory situations.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Tehran University of Medical Sciences, Tehran, Iran, Code No. IR.TUMS.FNM.REC.1398.184.

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Authors' contributions

ST: Study design, acquisition of data, interpretation of the results, statistical analysis, and drafting the manuscript; MAG: Study design, interpretation of the results, project supervisor, critical revision of the manuscript; SF: Study design; NR: Study design, interpretation of the results, critical revision of the manuscript; AT: Study design, software design; PB: Software design; SJ: Statistical analysis.

Conflict of interest

There are no competing interests declared by the authors.

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