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Developing a new software program "Karawan" for the habilitation of pre-lingual Arabic-speaking cochlear implanted children

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Abstract

Objectives: The aim of this work is to introduce the newly developed "Karawan" software program for the habilitation of pre-lingual, Arabic-speaking cochlear implanted (CI) children. It is the first comprehensive, interactive multimedia software program that targets both auditory and linguistic habilitation of pre-lingual Arabic-speaking CI children. "Karawan" covers the seven stages of auditory habilitation, namely: sound detection, sound discrimination, sound identification, sound comprehension, auditory closure, auditory sequencing and listening in background noise.

The main purpose of the "Karawan" program is to maximise the performance of CI children in real-world listening conditions. **Material and methods:** The materials were selected to be culturally and linguistically suitable for Arabic-speaking, Egyptian children. It includes 880 training screens, 640 testing screens with 1,360 audio files and 150 video files which were recorded in a special sound treated studio. The final form of the "Karawan" program was first pilot tested with ten non-CI normal children to examine the clarity and suitability of the tested items. Then the validity of the "Karawan" program was examined by three judges who were independent professional phoniatricians. **Results:** The program was amended according to the suggestions of the non-CI children to make the items clearer. All judges unanimously agreed that the "Karawan" program is culturally and linguistically suitable for the habilitation of pre-lingual cochlear implanted Arabic-speaking children. **Conclusion:** The "Karawan" program is a well-designed software program that can be used for the auditory and linguistic habilitation of pre-lingual Arabic-speaking CI children.

Keywords: cochlear implant; software program; Arabic language; child disability; phoniatric habilitation.

Introduction

Pre-lingual permanent hearing loss is identified in about one in every 1,000 births [1, 2]. The main consequence of hearing loss in children is the negative impact on their communication abilities and their ability to participate in education, learning, social interactions, and leisure activities [3, 4]. Cochlear implants (CI) are currently the only food and drug administration (FDA) approved medical treatment available for partial restoration of hearing in patients with a severe-to-profound sensorineural hearing loss (SNHL) [5]. Since its approval by the FDA-USA in 1984, thousands of pre-lingual deaf children have received CIs, and many have shown an overwhelmingly positive effect on auditory and communication skills [5]. CI is now a routine practice in Egypt for children with severe-to-profound SNHL under the age of five years and financially covered by Egyptian health insurance.

The Aural habilitation/rehabilitation (AR) therapy is a well-known interactive process that facilitates a hearing impaired patient's ability to maximise and/or prevent the limitations and restrictions that auditory dysfunctions can impose on well-being and communication [6-7]. Auditory training, which is one aspect of auditory habilitation, is the process of training a person's residual hearing ability. Any intervention program should consist of four stages, namely: detection, discrimination, identification, and comprehension of sounds and speech [8]. Additionally, three stages should also be included, namely: auditory closure (AC) [9], auditory sequencing [10] and listening in background noise [11]. Olson and Canada [12] and Yin, Rose, Saz and Lleida [13] stated that "auditory stimuli should range in difficulty from simple tones to connected speech. Similarly, auditory tasks for understanding speech should range in difficulty from detection to comprehension."

Both adults and children with hearing loss could benefit from computer aided auditory rehabilitation as a part of the intervention training program [14]. Kaplan et al. [15] stated that "game-like interface, graphical reinforcement, minimum amounts of text and auditory features; all are the main features required to fulfil a successful computer-based auditory training intervention." Computerised auditory training programs provided the option of training in a home environment which may increase the training opportunities and increase the benefits achieved by the implant user.

In the literature, there are three software programs designated for auditory rehabilitation (AR) therapy that mainly target adults. They include:

1. Computer-Assisted Speech Perception Testing and Training at the Sentence Level (CASPER sent) (Rehabilitation Engineering Research Center (RERC) of Gallaudet University. Washington, USA) [16]: This program was designed for the evaluation of auditory, visual and auditory-visual speech perception performance at the sentence level. This tool was addressed to adults only and depends exclusively on sentence level with limited numbers of activities. It did not include animated options or flash cards. It also neglected other stages of AR like sound detection, auditory discrimination, auditory identification, audi-

tory comprehension for other activities rather than the sentence level, auditory closure, auditory sequencing, and listening in a background noise.

2. Computer-Assisted Speech Training (CAST) (TigerSpeech Technology, Los Angeles, USA) [17]: CAST is a dynamic program which was originally designed for adults with CI. CAST uses more than 1,000 novel words spoken by four different speakers. The CAST program is adaptive in that the level of difficulty is adjusted automatically according to the patient's performance. CAST provides a wide range of closed-set discrimination, identification tasks, and auditory resolution training. However, this program was also exclusively geared towards adults and only highlighted auditory discrimination activities, neglecting other AR tasks such as auditory comprehension activities, auditory closure, auditory sequencing, and listening in a background noise.

3. Listening and Communication Enhancement (LACE) (Neurotone Inc., Redwood City, CA, USA) [18]: LACE is a home-based program which provides a variety of interactive and adaptive tasks that were divided into three main categories: degraded speech, cognitive skills, and communication strategies. Training was organised into distinct topics such as health issues, money matters, exercise, etc. The patient listens to and identifies the signal, then views the correct/incorrect responses on the screen. Again this program is also directed towards adults only and its activities depend only on an advanced level of AR, which is not suitable for the habilitation of pre-lingual CI children. Moreover, other stages of AR like sound detection, auditory discrimination, auditory identification for semantics, auditory comprehension for other activities rather than the sentence level, auditory closure, auditory sequencing, and listening in a background noise were not included.

On the other hand, there are many programs that were designed for the habilitation of children with CI including:

1. Sound and WAY Beyond™ program (TigerSpeech Technology, Los Angeles, USA): It is a software program that was designed and based on the CAST to facilitate speech perception at word discrimination levels. The program focused on listening skills and is interactive, providing sound samples, discrimination and identification exercises, tests, and feedback. The program includes tones, environmental sounds, vowel and consonant sounds, words, sentences, musical instruments, and familiar tunes [17].

The Sound and WAY Beyond™ program introduced the auditory activities through non-animated options which are less attractive to young CI children. It depended mainly on auditory discrimination, auditory identification and auditory comprehension for sentences, while it neglected other auditory comprehension activities such as auditory comprehension for functional words, verbs, phrases, questions, sequencing, telling stories, some environmental daily activities and conversations in everyday life situations at home and in the classroom. Also, it paid no attention to other important AR tasks such as auditory closure, auditory sequencing, and listening in background noise.

2. Angel Sound™ (TigerSpeech Technology, Los Angeles, USA) [17]: It is an upgraded and free version of "Sound and WAY Beyond", which is also based on CAST technology. It is a PC-based interactive listening habilitation program for children with CI. It mainly targeted discrimination and identification of sounds and speech components through a series of self-paced modules. The program provided audio-visual feedback with the ability to adjust the level of difficulty in order to match the child's developing listening skills. Angel Sound™ program introduced the auditory activities through fixed non-animated options and depended on reading rather than images in many auditory training tasks. Both are also less attractive and not suitable for the habilitation of pre-lingual CI. Moreover, this program highlighted only auditory discrimination activities, neglecting other tasks of AR auditory comprehension for different activities. Additionally, it neglected auditory closure and auditory sequencing activities.

All of the previously mentioned programs are not applicable in our local Arabic-speaking context because the main goal of the AR is to train the patient to listen and speak his/her native language [14, 19]. With an increasing number of children receiving CI in our local Arabic-speaking context, and the limited availability of skilled practitioners, it was vital to create a bridge between clinic-based services and home-based rehabilitation program [20]. King Saud University (Riyadh, Kingdom of Saudi Arabia) has developed "Rannan", a home-based program for AR to support the growing CI-user population to acquire auditory skills, geared mainly toward the activities regarding listening skills, such as sound detection, sound discrimination, sound identification, and responding to orders [21]. However, the "Rannan" home-based program had some limitations. It gave little attention to the importance of discrimination of the six ling sounds. It also did not include sound identification of words that vary in length, either monosyllabic, disyllabic or polysyllabic words. The use of symbolic language was also not included, as well as auditory closure, auditory sequencing, and listening in background noise. Additionally, for many Arabic speakers, there is difficulty in understanding the colloquial form of Arabic spoken in Saudi Arabia.

All of the above reasons encouraged the growth of this work and demonstrated the need for developing a computer-based habilitation program for Arabic-speaking pre-lingual cochlear implanted Egyptian children in order to overcome the previous shortages. Table (1) demonstrates the differences between the previously mentioned software programs used for AR therapy of CI patients and the "Karawan" program that will be described in detail in the following sections.

Software Program	Age	Sound detection	Auditory discrimination	Auditory identification	Auditory comprehension		Auditory closure	Auditory sequencing	Listening in background noise
					Respond to orders	Repeat sentences			
CASPER sent.	adults					√			
CAST	adults	√	√	√		√			
LACE	adults					√			
Sound& Beyond™	children	√	√	√		√			
Angel SoundTM	children	√	√	√					√
Rannan	children	√	√	√	√				
Karawan	children	√	√	√	√	√	√	√	√

AR= Aural rehabilitation, CI = Cochlear Implant

Table (1): The differences between software programs used for AR therapy of CI patients versus the "Karawan" program

The aim of this work was to develop a comprehensive interactive multimedia software program that targets both auditory and linguistic habilitation of pre-lingual Arabic-speaking CI Egyptian children in order to maximise their performance in real-world listening conditions.

Material and methods

Development of "Karawan" program passed through the following stages to be finally set up:

A) Design stage
B) Pilot testing stage
C) Validation stage

Ethical committee approval: The study was reviewed and approved by Institutional Review Board (IRB). All parents/legal guardians provided informed written consent prior to study enrollment.

A) Design stage:

The idea of the newly introduced "Karawan" software program was first proposed by the first author, and then the program was constructed by three professional phoniatricians and one expert audiologist, taking in consideration social, cultural and linguistic appreciation of Egyptian culture and society for each proposed item in each section. The Arabic word "Karawan" means the curlew bird, which has one of the most beautiful and distinguished songs and call in the world. The "Karawan" program includes ten cartoon charac-

ters which were designed to motivate the CI children for training tasks. The program consists of seven sections for AR therapy and includes 880 training screens using animated options (visual cues) and 640 testing screens without visual cues. The designed program includes 1,360 audio files and 150 video files, which were recorded in a special sound treated studio by professional phoniatricians. The program was designed to cover the early auditory experiences of a CI child in a closed set-up to more advanced auditory training in open sets and real life situations through animated cartoons. The testing screens and tasks were randomised automatically with every trial of the testing task so that the child could not anticipate the testing auditory task with unlimited options of testing screens.

The seven sections of the designed "Karawan" program involve the following:

I. Sound detection:

This is the initial and most important stage [8].The child should demonstrate awareness of the presence and/or absence of sound. In this early stage, children should recognise and detect the essential non-speech and speech acoustic attributes, aimed at stimulating the awareness of frequencies band and common pronunciation [13, 14, 19]. This stage should be parallel to the stage of the audiological programming of the channels of the cochlear implant device, depending mainly on the frequency spectrum of the familiar sounds, either speech or non-speech within the area of the speech banana. This stage involved graded levels for sound detection, including pure tones, narrow band noises, broadband noise, non-speech sounds (figure 1), whispering, and speech sounds.

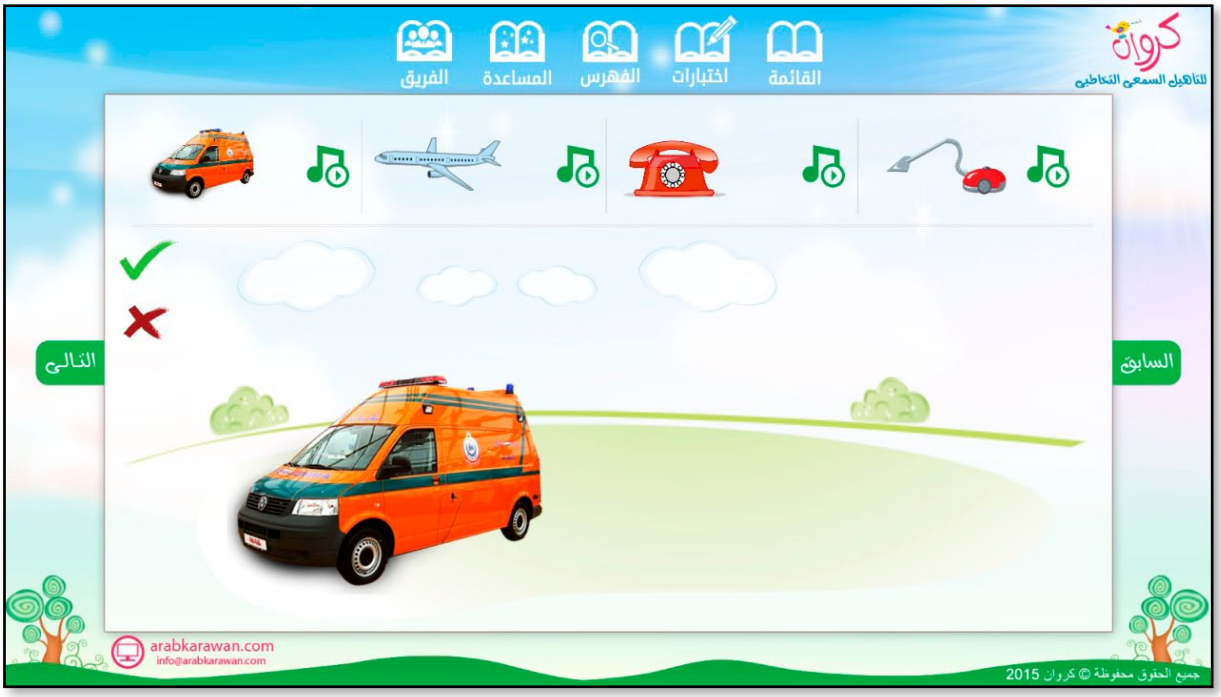

Figure 1: Sound detection stage: the CI child was asked to detect a non-speech sound (ambulance) at the frequency range 4000 Hz using animated visual cues

II. Auditory discrimination:

In this section of training, the child should be able to discriminate the familiar pronunciation with respect to some parameters, such as duration and tone, direction, and the intensity of sound [13, 14, 19].The designed program involved the following sub-sections:

a) Discrimination of tone, direction, and the intensity of the sound [8] in the form of discriminations between loud versus soft sounds, shouting versus whispering sounds, modeling versus singing sounds, long versus short sounds (figure 2,3), single versus repeated sounds, continuous versus interrupted sounds, and high versus low pitched sounds.

Figure 2: Auditory discrimination stage (training), e.g. auditory discrimination between long versus short sound. The CI child was asked to listen and discriminate the long sound using animated visual cues.

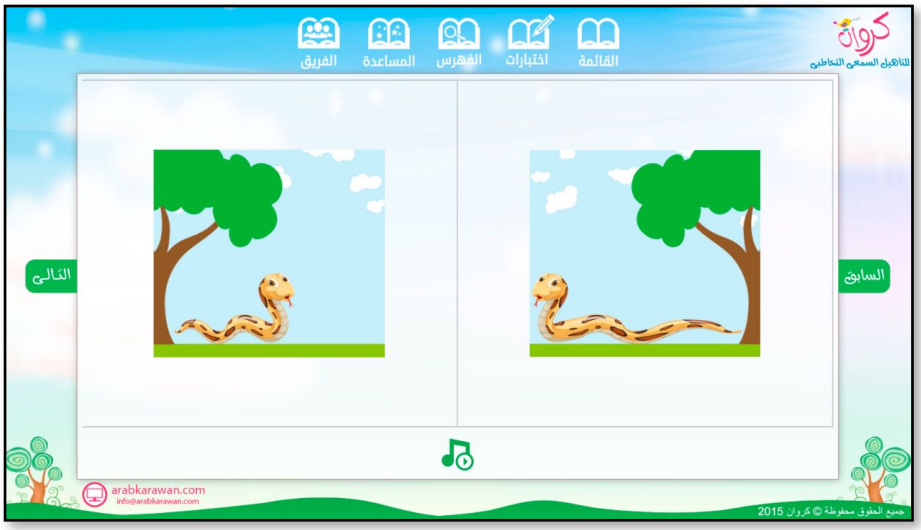

Figure 3: Auditory discrimination stage (testing), e.g. testing the auditory discrimination between long versus short sounds. The CI child was asked to discriminate between the long versus short sounds through listening only (without animated images).

b) Discrimination of the six ling sounds (aa, oo, ee, ss, ʃʃ, mm) using the Ling-6 Sounds Daily Check table [22].

c) Discrimination of the familiar environmental sounds, both indoor and outdoor sounds, especially for threatening circumstances (e.g. oncoming traffic, sirens, animals, etc.) [14, 19].

d) Discrimination of familiar musical instruments [13, 14, 19].

e) Discrimination of speech sounds, including the child's ability to control his/her vocal play or babbling with the development of the normal consonants and vowels systems [8].

III. Auditory identification:

This is the stage in which the child is asked to associate words to speech [13, 14, 19]. This stage includes words varying in length, either monosyllabic, bisyllabic or polysyllabic words (figure 4), as well as sequences involving colours, numbers, and days of the week. Also, this stage involved the identification of the semantics in isolation, then in groups (i.e. every word in each semantic group is presented as a flash card in a separate screen, then all words in the same semantic group are presented within the same screen using flash cards), thus the clinician may ensure that the CI child mastered his/her auditory identification ability when he/she chooses the correct response from multiple choices within the same semantic group.

Figure 4: Auditory identification stage: the CI child was asked to identify words varying in length including monosyllabic (/bæ:b/ = door), bisyllabic (/fos.tæ:n/ = dress) and polysyllabic (/fa.raw.lah/ = strawberry) words (with visual cues first, then without)

IV. Auditory comprehension:

This stage involved multiple tasks and activities that include: functional words, verbs, phrases, sentences, questions, sequencing, storytelling (figure 5), some environmental daily activities, music and nursery rhymes (figure 6), and conversations in everyday life situations at home and in the classroom (figure 7, 8) [13, 16, 19].

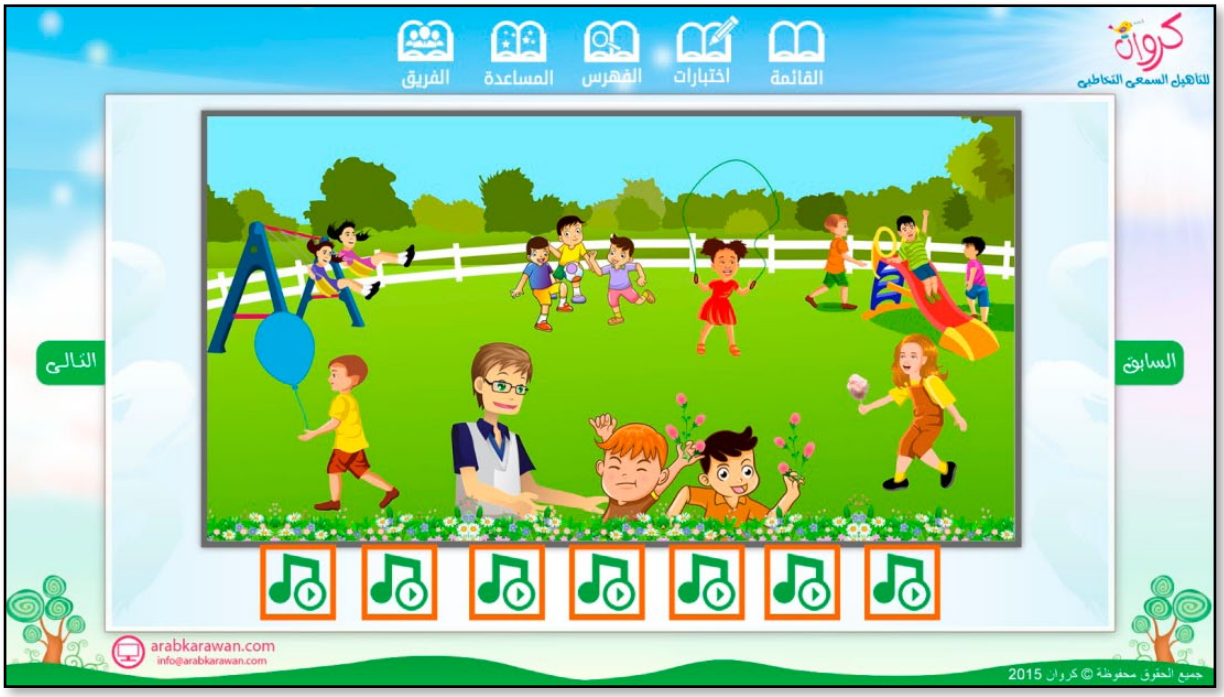

Figure 5: Auditory comprehension stage: the CI child listens to a story and then was asked to respond to different questions on that story

Figure 6: Auditory comprehension stage: enhancing the CI child for auditory comprehension of music and singing by using a nursery rhyme in an animated form

Figure 7: Auditory comprehension stage: training on auditory comprehension for a conversation in the classroom (as an example for daily life situation)

Figure 8: Auditory comprehension stage: testing auditory comprehension for a conversation in the classroom by listening to different questions without any animated options

V. Auditory closure (AC):

AC is the perceptual process by which partial auditory information is integrated into a whole [9, 23]. This process involved taking small pieces of auditory information and using them to construct a whole message [24]. This stage involved AC training of the CI child for incomplete words and incomplete sentences.

VI. Auditory sequencing:

Auditory sequencing refers to the working auditory memory, which is the ability to mentally store and manipulate the information over short periods of time [25]. This stage involved auditory sequencing training for words, digits, obeying multi-step orders (figure 9), and re-telling multi-step sequencing.

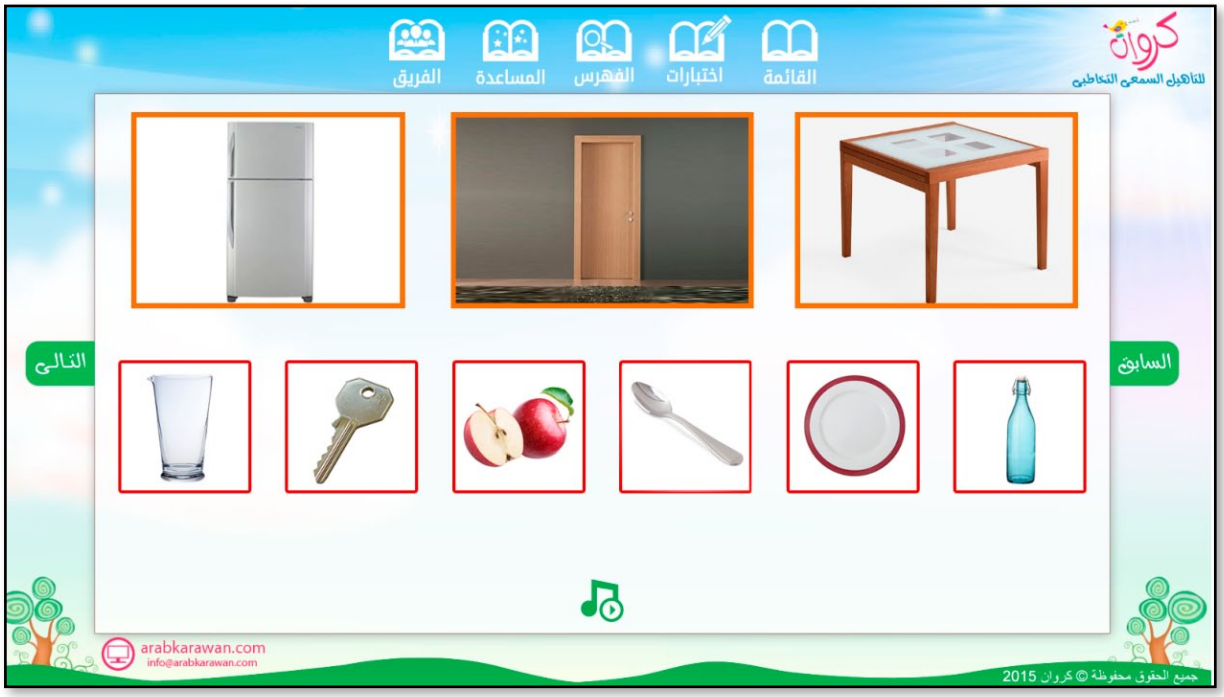

Figure 9: Auditory sequencing stage: the CI child was asked to respond to an auditory order consisting of two steps (e.g. put the dish over the table and then put the bottle in the refrigerator)

VII. Listening in background noise:

Understanding speech in a noisy background is more challenging for all individuals than understanding speech in a quieter setting. A number of typical and atypical groups show even greater difficulty with speech perception in noise, including listeners with SNHL [11]. Many AR tasks were introduced in the "Karawan" program with three signal-to-noise ratios (SNR), namely: low (1/3), medium (1/2), and high (3/3) SNR (figure 10), all of which are aimed at increasing the auditory abilities of those children.

Figure 10: Listening in background noise stage: the CI child was asked to choose the correct answer from four options in the presence of different levels of background noise (mild, moderate, or severe)

We designed the program on the basis of using animated options (visual cues) to enhance the auditory cues for all training tasks. Also, the program was designed with an option to test auditory abilities without visual cues, i.e. all the testing screens depend only on the fixed images without any animated options.

The authors collaborated with a specialised technical team, which included one product manager, one creative director, one instructional designer, four graphic artists/animators, and two software developers. The authors and the technical staff discussed each proposed item in each section of the seven sections of the "Karawan" program both prior to and following suggestions made during the pilot testing stage.

B) Pilot testing stage:

The final form of the "Karawan" program was pilot tested with ten non-CI children who were chosen using criteria of average mental capacity, average physical health, and average language development. They were six male children and four female children. Their ages ranged between 24 and 84 months (mean was 58.8 months). This sample was taken to check the materials used in the program (clear or not, and suitable or not), as well as to check the pattern of presentation of the program items themselves, and their order of presentation.

C) Validation stage:

Three judges, who are independent and expert phoniatricians in CI habilitation from three different Egyptian medical faculties, were asked to review the constructed habilitation program and to respond to a questionnaire (table 2).

Items	Judge 1	Judge 2	Judge 3
Is the program suitable for the habilitation of prelingual cochlear implanted children?	Y	Y	Y
Is the program culturally and linguistically suitable for Arabic-speaking children?	Y	Y	Y
Is the program fulfiling all stages for auditory rehabilitation/ habilitation therapy?	Y	Y	Y
Are the chosen images and animated materials obvious, familiar and culturally suitable for the Egyptian Colloquial Arabic-speaking children?	Y	Y	Y
Are the sound recordings obvious, familiar and culturally suitable to the Egyptian Colloquial Arabic-speaking children?	Y	Y	Y
Are the rewarding animations and the game-like interface suitable for the trained children?	Y	Y	Y
Are the materials used for testing the children after training sufficient to detect the progress of them?	Y	Y	Y
Can the program be used as a home-based therapy beside the clinical based therapy sessions?	Y	Y	Y
Any suggestions for the program in general?	N	N	N

Y = Yes, N = No

Table (2): Summary of the responses of the judges to the questionnaire

Statistical analysis

We assumed that the item identification portion should have at least a 75% correct response among the pilot tested non-CI children in order for it to be included in the program; otherwise the item is exchanged or removed. Face (judge) validity was used to validate the program. It refers to the extent in which the "Karawan" program can be used in the habilitation of pre-lingual Arabic-speaking cochlear implanted Egyptian children.

Results

Results of pilot testing study and the associated modifications

The program was amended according to the suggestions of the non-CI children to make the items clearer. Table (3) demonstrates the results of the pilot testing and the associated modifications for each section of the "Karawan" program.

Stages of the "Karawan" program	Associated modifications
1) Sound detection	■ There is no modification.
2) Auditory discrimination	■ In discrimination of the six ling sounds: the ling sound /mm/ in male voice became louder and clearer. ■ In discrimination of the familiar indoor environmental sounds: the radio sound was removed as the normal children did not recognise this old media sound.
3) Auditory identification	■ In identification of the birds' semantic group: the image of hen was amended to be easily recognised by the children.
4) Auditory comprehension	■ There is no modification.
5) Auditory closure	■ There is no modification.
6) Auditory sequencing	■ There is no modification.
7) Listening in background noise	■ There is no modification.

Table (3): Summary of the results of the pilot testing for the "Karawan" program

Results of judge validity and the associated modifications

All judges unanimously agreed that the "Karawan" program is suitable for the habilitation of pre-lingual cochlear implanted children, and is indeed culturally and linguistically suitable for Arabic-speaking children. Also, they emphasised that the program fulfiled all stages of auditory rehabilitation/ habilitation therapy and gave no additional suggestions for the program in general. The responses of the three judges to the questionnaire are summarised in table (2).

Discussion

Bradham and Jones [4] stated that "Young children who experience severe-to-profound SNHL face challenges in developing spoken language because of an inability to detect acoustic-phonetic cues that are essential for speech recognition, even when fitted with traditional amplification devices." Yin, Rose, Saz, and Lleida [13] reported that, "the main material in aural rehabilitation therapy is sound. It is a three-dimensional concept with parameters of intensity, frequency and time. Sound can be speech, which is generated by human sound systems or a non-speech sound as environmental sounds and noise." Sweetow and Palmer [14] concluded that, "an interesting feature of using computers in auditory training is having a mobile therapy as patients can resume the therapy without a time and place limitation."

In this work, we introduced the newly-developed "Karawan" software program for the habilitation of pre-lingual Arabic-speaking CI Egyptian children. "Karawan" covers the seven stages of auditory habilitation, namely: sound detection, sound discrimination, sound identification, sound comprehension [8], auditory closure [9], auditory sequencing [10],

and listening in background noise [11]. The main material in the "Karawan" program is sound; either speech, which involves vowels, consonants, and rhythm, or non-speech, such as environmental sounds, music, and noise. The materials were selected to be culturally and linguistically suitable for Arabic-speaking Egyptian children.

The "Karawan" program is the first comprehensive interactive multimedia software program that targets both auditory and linguistic habilitation of pre-lingual Arabic-speaking CI children by covering the seven stages of auditory habilitation. There are many salient features of the "Karawan" program as it is cost effective, practical, and easily accessible, enabling a CI child to resume training at home using a personal computer, including the game-like attractive materials with graded levels of difficulty for training and testing, while providing reinforcement to the child. It also integrates listening training with repair strategies, providing feedback regarding progress or lack of progress of the CI child and it makes the patient assume some degree of responsibility for the ultimate outcome objective. The program is not replacing the face-to-face language therapy sessions, but rather it augments the conventional AR training for CI children at both clinic and home-based settings. It will also be of value for those CI children who could not attend the therapy session regularly because of the remote distance of the habilitation centres.

The results of the pilot testing that was performed on the final form of the "Karawan" program ensured that all of the tested items were clear and culturally and linguistically suitable for the habilitation of pre-lingual Arabic-speaking CI children. The program could be applied to children as young as two years of age, and up to seven years of age or older. The validity of the "Karawan" program was then examined by three independent expert phoniatricians who ensured the validity of the software as an effective software program for the habilitation of pre-lingual Arabic-speaking CI children. We are currently testing the efficacy of the "Karawan" program on both auditory and linguistic skills of CI Arabic-speaking children.

Limitations of the study

Other Arabic dialects need to be developed to culturally suit the non-Egyptian Arabic-speaking children. The letter limitation is under consideration by the authors of the program.

Conclusion

The "Karawan" program is a well-designed software program that can be used for the auditory and linguistic habilitation of pre-lingual Arabic-speaking CI children.

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