Qawqaa: Aural Rehabilitation System for Children with Cochlear Implant Using Virtual Reality (VR)

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***Abstract*—Qawqaa is a virtual reality based game for accessible and engaging aural rehabilitation in Arabic for children from eight to twelve years old with bilateral cochlear implants. The system contains two parts providing the game side that aims to enhance auditory skills, language development, and overall rehabilitation experience, and a monitoring and tracking side for rehabilitation center therapists, facilitating efficient tracking of a child's progress within the game. Using Qawqaa, we minimize clinic visits, enable effective progress monitoring, and ensure an enjoyable rehabilitation experience for the children.**

Keywords-virtual reality; healthcare; cochlear implant; gamification; digitalization.

I. INTRODUCTION

The use of modern technologies across various domains is widely acknowledged for its ability to enhance service quality. Saudi Arabia's 2030 vision is currently spearheading digitalization efforts across industries, notably in healthcare, through comprehensive transformation programs. This initiative prioritizes enhancing care quality, improving patient experiences, and promoting sustainable health development at an international level [1].

In recent years, Virtual Reality (VR) has emerged as a valuable tool in numerous medical fields. VR is the use of computer technology to create simulated environments, immersing users in three-dimensional experiences instead of simply viewing a screen. The use of VR in medicine has shown success in various clinical applications, such as rehabilitation programs that help individuals recover and regain motor skills after injuries or neurological conditions. Rehabilitation services have been rolled back or stopped in most hospitals during COVID-19 [2]. It has had a significant impact on patients with disabilities emphasizing the need for digital home-training kits tailored to their requirements [3].

For people with Cochlear Implants (CI), rehabilitation after cochlear implant surgery is crucial to maximize its benefits. A cochlear implant is a device surgically implanted in the inner ear to stimulate the hearing nerve directly. It is suitable for individuals with severe to profound hearing loss in one or both ears, for whom hearing aids no longer provide sufficient benefit [4].

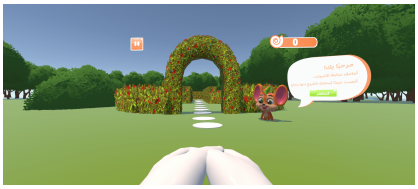
Children born with severe to profound sensorineural hearing loss, which occurs in approximately 1.5 per 1,000 cases globally [5], experience significant challenges in speech and language development. Aural rehabilitation helps children identify sounds and their meanings, while speech therapy aids in developing and understanding spoken language [6].

Gamification is the process of using game design elements and principles in non-game settings to captivate and motivate individuals, enhance desired behaviors, and improve user experiences. By integrating these game-like elements, rehabilitation programs become more interactive and enjoyable for patients, increasing their adherence and overall involvement in the treatment process [7].

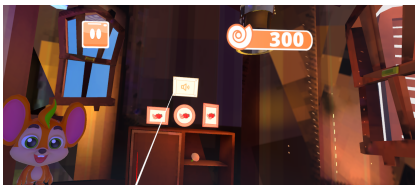
Some existing research has used VR, mobile applications, or websites for CI rehabilitation. However, these systems lack monitoring and assessment features for specialists. For instance, Bears is a new VR game designed to enhance spatial hearing and speech perception in noisy environments, but it is not a fully integrated system with a monitoring component [8]. Ranan is an Arabic web-based tool used for clinical training, but it lacks the immersive experience of a 3D environment and is only usable in a clinic under specialist supervision [9]. Lastly, Karawan, a mobile app, offers multiple skills training but does not provide progress monitoring for the child [10].

So, we propose our solution, Qawqaa, a VR-based hearing training system in Arabic for children with bilateral cochlear implants. Qawqaa is designed as a home-based training solution that helps children overcome challenges related to (C1) limited access to rehabilitation services and (C2) provides the necessary training in an engaging, interactive environment filled with sounds, words, and phrases. Children advance through different stages of the game, leveling up as they progress. Unlike existing solutions, Qawqaa includes a dedicated therapist module, filling a critical gap by enabling therapists to monitor each child's progress through detailed scores and performance reports, making oversight easy and effective. The game is designed to improve the child's hearing and language reception skills, including sound localization, speech discrimination, and recognition. Overall, Qawqaa aims to enhance the child's abilities, reduce the need for clinic visits, and make the training process an enjoyable experience.

The rest of the paper is structured as follows. In Section II, we present the system overview. Section III shows the demonstration. We conclude the work in Section IV.



(a) Sound localization game



(b) Word discrimination game

(c) Speech recognition game

Figure 1. Three auditory training games

II. System Overview

In this section, we discuss the technical details of the Qawqaa system. Qawqaa has two main pieces of software, a VR game that serves as a training game for children, and a website used by specialists for monitoring children's progress in the games. These two parts are connected by a database. In this paper, we will go through the VR game only.

The Qawqaa VR game provides an interactive environment for children to stimulate rehabilitation training in an immersive and enjoyable way. The game has three skill modules to train as listed below.

Sound Localization: The ability to correctly localize sounds is an important feature of the auditory system directly linked to the ability to extract binaural information from the sound. In such situations, sound localization can help a listener quickly identify and orient themselves toward the talker in a group conversation. This is particularly important for CI users, because other cues for speaker identity, such as voice pitch, are diminished [11]. Here, we train the child's ability to hear a sound and localize the source of that sound with noise in the background in a 3D maze park, as shown in Figure 1(a), from where the child should get out by following the sound as an engaging element. The game gets harder with a louder noise in the background and more choices for sound sources.

Word Discrimination: Word Identification is the ability to accurately and automatically identify sight words and apply decoding strategies to read unfamiliar words. Auditory or speech perception focuses on auditory perception and sensory integration. It is composed of musical exercises that help one to identify and discriminate between different components of sound, such as time, tempo, duration, pitch, rhythmic patterns, and speech [12]. Here, we train the child with several similar words in sound, then he should choose the meaning as a picture of this sound. Figure 1(b) shows the sound icon with three images to choose from. This training combines the ability to differentiate between similar sounds and understanding the meaning of the sound. The difficulty in this skill is based on increasing the number of choices and the similarity between words' pronunciation. For example, both level one and two have two choices for each question, but the questions in level one consists of one word where level two consists of two words like the red flower and yellow flower. For level three, there are three choices with three words in the question such as the circled red painting, yellow squared painting, and green rectangular painting.

Speech Recognition: This represents the ability of an individual with hearing loss to accurately perceive and understand spoken language using technological aids or therapeutic interventions. It involves the process of converting spoken words or sounds into text or visual representations, allowing individuals with hearing impairment to access auditory information more effectively [13]. In this training game, we simulate the farming experience, as depicted in Figure 1(c), through three levels which are danging, seeding, and collecting crops. The child faces different words related to farming through voice commands given to him to assess his ability to recognize words and then follow commands. The difficulty for the three levels are increased by adding more words to sentences. For example, in level one a command given is (put the seed). For level two, the command is longer (the bean is good for the environment, put it in the seed). Lastly, in level three, a command is (the yellow corn on the top of the plant, put it in its box).

III. Demonstration

In this section, we show how a child interacts with the system using a sound localization scenario.

In a 3D environment, we simulate spatial hearing to enable the child to detect the source of sound in a maze theme park, as shown in Figure 1(a), which consists of three levels, beginner, intermediate, and advanced. The difficulty level is based on the background noise level, where the beginner level has have little noise, the intermediate level has moderate noise, and the advanced level is very noisy. For engagement purpose, when the child detects the source of sound using the controller, he scores points. The assessment is based on the ability to correctly define the sources. After completing five questions in the level, he will get out of the maze and a reward board will be shown.

IV. Conclusion and Future Work

In this paper, we present Qawqaa as a step toward advancing aural rehabilitation for Arabic-speaking children. By offering a home-based training solution, Qawqaa reduces the need for frequent clinic visits while allowing therapists to efficiently monitor each child's progress. Looking ahead, we plan to expand Qawqaa by integrating artificial intelligence for advanced data analysis, providing children with more detailed insights into their progress. Additionally, we aim to introduce an interactive environment where children can engage with each other through a virtual world and leaderboard system, making the rehabilitation process more engaging and rewarding.

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