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The BioVisualSpeech Serious Game with Voice Exercises for People with Parkinson's Disease with Hypokinetic Dysarthria

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Abstract

People with Parkinson's disease (PD) can have dysarthria, a voice disorder that affects speech intelligibility. To fight this disorder people may resort to speech and language therapy. Unfortunately, weekly speech therapy sessions may not be enough, because to achieve and maintain good voice quality, intensive training is required. Additionally, the COVID-19 pandemic brought attention to the need for alternative speech therapy treatments that complement face-to-face appointments.

Here, we propose a serious therapy game to improve voice loudness that can be used for intensive therapy or when face-to-face appointments are not possible. The game integrates three voice exercises used in speech therapy sessions for people with PD and aims to provide motivation for patients to perform the exercises on a daily basis.

This application evaluates the vocal intensity, vocal frequency and maximum phonation time, offering real-time visual feedback. It also allows pathologists to customize the exercises difficulty to the needs of each patient.

Keywords:

Parkinson's disease; voice disorders; speech and language therapy.

Introduction

Parkinson's disease (PD) is a degenerative disease of the central nervous system which mainly affects motor performance [1]. After Alzheimer's disease, it is the most common neurodegenerative disease in the world, and in 2016, the number of PD patients was around 6.1 million worldwide [2]. With the disease's progress, changes in speech may occur due to the combination of stiffness and bradykinesia, responsible for damage in sensory and cognitive processing [3]. The main and most common speech modification is hypokinetic dysarthria, which is mainly characterized by a reduced voice intensity, difficulty in articulating words, a hoarse voice, and a monotonous pitch (which is a measure of human's perception of vocal frequency) [4].

These speech changes affect the social, professional and mental life of people with PD. Thus, it is important that these disorders be treated, using specific and appropriate speech therapy treatments and methods so that the care takers and family of people with PD can hear and understand them correctly. Nonetheless, although about 89% of people with PD undergo speech changes, only 3-4% attend speech therapy [4].

Speech and language pathologists (SLPs) use specific voice exercises to help people with PD improve their speech quality. Usually, people with PD tend to speak with a low vocal intensity because they have the perception that they are speaking at a normal level. On the other hand, when they speak at a normal level, they perceive it as if they were shouting. Thus, most voice exercises focus on improving the patient's voice intensity.

There are some intensive methods of speech therapy for PD patients, which have shown effective results, such as *Lee Silverman Voice Treatment* (LSVT), *Pitch Limiting Voice Treatment* (PLVT) and *SPEAK OUT!* with LSVT being the most well-known and studied method [3, 5, 6, 7]. These methods focus primarily on improving the loudness of the patient's voice (or vocal intensity) but also work on other aspects of the voice such as pitch and articulation.

Speech therapy sessions are very dependent on the patient's effort. Therefore, it is important that SLPs motivate patients on performing the exercises regularly but also with high vocal intensity. Intensive training is important to achieve and maintain a good voice quality. Thus, in addition to practicing the voice exercises at the therapy sessions, patients have daily exercises to practice at home. Yet, this can become exhaustive and discourage patients from performing them.

Feedback and motivational features are also very important and necessary aspects in all exercises. Motivational features aim to keep patients motivated on practicing, while appropriate feedback is key to give them the correct perception of their voice performance, which allows patients to auto correct themselves. However, when a patient performs the exercise alone at home, without the presence of an SLP, it is difficult to get this desired feedback and motivation. One solution would be for patients to attend more therapy sessions per week or have the SLP assistance in their own home. Our proposal is to combine therapy, technology, feedback, and fun to motivate patients to practice the voice exercises regularly and at home, and to give them the appropriate feedback that allows them to understand their performance.

To the best of our knowledge, only a few computational applications are available for speech therapy for people with PD. The LSVT Companion can be used for applying the LSVT method [8]. However, this is a paid application, and it requires that SLPs attend a certification course in order to use it. Also, its motivational features are very few and limited, being as simple as an encouraging voice and words on the screen. Krause et al. proposed a game that focus on improving voice loudness but it does not work other voice attributes and is not customizable [9].

Here, we propose a game controlled by the user's voice that focuses on improving the voice and communication quality of people with PD or other neurodegenerative diseases that causes hypokinetic dysarthria. The game integrates three voice exercises commonly used in speech therapy sessions and gives real-time visual feedback on the user's voice performance. The choice of the exercises was discussed with SLPs specialized in speech therapy for PD patients. The gamification of these exercises aims to help SLPs motivate patients to perform the voice exercises and repeat them several times daily, both in

therapy sessions but also in their homes. The exercises can be customized according to the patient's needs.

Methods

This paper discusses the development and validation of a serious therapy game for hypokinetic dysarthria for people with PD. This application, which runs both on computers and mobile platforms, aims to improve the quality of the voice and communication of people with PD by focusing mainly on exercising their vocal intensity.

The game is controlled by the user's voice, who has to perform speech therapy exercises in order to play it. Additionally, the game gives real-time visual feedback on the voice production quality, through the movement of the game's characters. The aim is to provide feedback on the voice production characteristics in a fun way that motivates patients to improve their performance. The following sections discuss the speech therapy exercises used in the game (section **The game's speech therapy exercises**) and the game's main features (section **Game**).

The game's speech therapy exercises

During the design phase of the proposed application, we have interviewed one SLP specialized on working with people with PD. The speech therapy exercises that are integrated in the game were defined as an outcome of this interview: (1) the sustained vowel exercise, (2) the sustained vowel with frequency variations exercise, and (3) the functional phrases exercise. These exercises focus mainly on strengthening the voice, that is, increasing its intensity, but also on varying the voice's frequency to avoid a monotonous pitch.

Sustained Vowel Exercise

The sustained vowel exercise is commonly used by SLPs to correct voice problems of people with PD, but also of children with voice disorders [5, 7, 10]. In addition, this exercise is also used by voice professionals such as singers and actors to control breathing and improve vocal skills. In the case of people with PD, this exercise helps them to control and increase voice intensity.

The purpose of the exercise is to sustain a vowel for as long as possible with a stable intensity. People with PD practice this exercise with a high intensity. The aimed intensity level is a factor defined by the SLP, as it should be appropriate to the patient's voice status.

Sustained Vowel with Frequency Variations Exercise

The sustained vowel with frequency variations exercise is identical to the previous exercise, but with an addition, which consists of adding variations on another voice attribute: frequency. The exercise is performed for a few seconds with high intensity, and at the same time, increasing or decreasing the voice frequency.

Functional Phrases Exercise

The interviewed SLP mentioned the importance of including the exercise of functional phrases in the proposed game due to the lack of computational applications with this functionality. This exercise consists of saying several sentences that the patient usually uses in his/her daily routine (functional phrases), with a high intensity. Once again, the aimed intensity level should be determined by the SLP. Interrogative and exclamatory sentences are the most used because they change the tone of voice (*i.e.,* the frequency) throughout the sentence.

Game

The proposed game has three different modes, one for each speech exercise mentioned above. In each game mode, the user has to perform the speech exercise of that mode in order to play the game. The game goal, in all three modes, is to make the main character move in a straight line, from an initial position towards a target position, where a surprise box can be found (figure 1). The game is completed with success when the player reaches this box.

(a) (b) (c) (d)

Figure 1. The game in the (a) sustained vowel mode, the (b) sustained vowel with frequency variations mode, and the (c) functional phrases mode. The yellow and blue boxes show information about the vocal intensity and vocal frequency, respectively. (d) Several scenarios and characters are available and can be unlocked through a points and rewards system.

The character is controlled through the player's voice in the same manner in all three modes: it moves towards the box when the player's vocal intensity is within the established limits (previously chosen by the SLP). If the intensity is not within the limits, the character stops. The player has a few seconds to return his/voice to the desired intensity values before failing the exercise. In this way, the character's movement provides intuitive visual feedback on the player's vocal intensity.

The **sustained vowel mode** and the **functional phrases mode** are very similar: the player has to maintain the intensity between the defined limits, while sustaining a vowel (figure 1.a) or while saying the sentences that appear on the screen (figure 1.c), respectively. In order to change the sentence, the user presses the yellow tick in the sentence box. These sentences are filled in by the SLP prior to the start of the game.

The **sustained vowel with frequency variations mode** has an extra voice attribute to be evaluated, the voice's frequency. Thus, it includes an extra visual cue to give feedback on the vocal frequency: a bird that flies over the main character (figure 1.b). The feedback on vocal frequency is given by the vertical movement of the bird.

Customization

The degree of the voice disorder varies from patient to patient. Thus, it is important that SLPs can adapt the exercises to the needs of each patient. To this end, the game includes several parameters that can be manually set by the SLP. All parameters have three preset default intervals or values that the SLP can use if he/she does not want to manually set the parameters.

In this way, it is intended that SLPs can make several combinations with the different parameters so that the exercises are different for each patient, taking into account their specific difficulties and needs. Also, once the patient starts improving

his/her voice qualities, the parameters can be used to increase the game's difficulty. These parameters are described below.

Intensity, which is measured in decibels (dB), is the voice characteristic that the game focuses the most on improving. The game includes an **intensity range** parameter that allows the SLP to set the aimed **minimum intensity**. To progress in the game, the patient has to maintain the voice intensity above that value. It is important to choose an aimed intensity appropriate to the patient's voice status. Patients at an early stage of the disease, and patients at a more advanced stage of the disease, should train with different levels of intensity.

Since speaking very loudly may be prejudicial to the voice, the intensity range has an upper limit, the **maximum intensity** (according to an interviewed SLP this value should be lower than 90 dB). Since it is difficult to maintain a constant voice intensity, patients are allowed to have intensity fluctuations provided they are within the aimed intensity range. However, if the SLP aims that the patient practices the exercises with a stable intensity, he/she can reduce the intensity range by decreasing the difference between the minimum and maximum intensities.

In order to analyze the patient's vocal intensity performance evolution, the SLP can check the average intensities graph provided in the game. This graph shows the daily average of intensities obtained in the last 30 days in which the patient played. The purpose of this graph is to help the SLP understand whether training is producing good results or has to be adjusted.

Minimum phonation time is another significant parameter as it corresponds to the minimum time required to complete the exercise. In other words, it is the minimum time duration of the speech production (either a sustained vowel or the functional sentences). Since the game successfully ends when the character picks up the box with the reward, the minimum phonation time is directly related to the distance between the character's starting position and the box position.

After the character reaches and picks up the box, the exercise is considered successful. Yet since it is beneficial that the patient keeps exercising, the game allows continuing holding the vowel or reading the sentences until the player stops.

The **timer**, unlike other parameters, does not evaluate any voice characteristics. Instead, it establishes a time limit to recover from failures and finish the exercise, whether it is successful or not. This corresponds to the total time, in seconds, that the patient's voice intensity may be lower than the aimed intensity value. When the voice intensity is lower than that value, the character stops and a countdown timer is activated. If the person can control his/her voice so that it is higher than the aimed intensity again, the character starts moving again and the timer stops. Every time the user's voice intensity decreases to a value lower than the aimed intensity, the character stops again, and the timer resumes from where it left, until it reaches zero, ending the exercise.

The **frequency range**, which is measured in Hertz (Hz), is a parameter that is only used in the sustained vowel with frequency variations mode. Unlike the previous parameters, the frequency does not determine if the exercise should end or if it is successful. It is evaluated to give feedback on this voice characteristic. This feedback is provided by the height of the bird throughout the exercise.

The bird flies up when the vocal frequency increases above the aimed frequency range, and it descends when the vocal frequency decreases below that range.

Motivational features

The game's aim is for patients to use it daily so they can maintain consistent training and have a satisfactory evolution. In order to remind patients to practice the exercises, the game includes a push notification system for *Android* and *iOS* devices, which sends a notification to the users if they have not opened the app for more than a day.

The interviewed SLPs reported that training of 10 to 15 minutes daily is desirable. Such an obligation can become exhausting. For this reason, the game includes several interesting, fun, and motivational gamification features that seek to make exercises more appealing, more fun, and challenging, in order to encourage patients to practice the exercises daily at home.

These features include a **points system** and a **rewards system**. The player earns points while his/her vocal intensity is within the established limits. The rewards system grants coins to the player, taking into account the number of points the player has scored. These coins can be used to unlock new characters and new scenarios (figure 1.d). Figure 1.a-c show three different characters and scenarios. Figure 2 shows the game menu with three unlocked scenarios from a total of eight possibilities. In addition, when the player reaches the surprise box, the rewards system offers new styles for the various characters.

Figure 2. Game menu. Buttons for (1) microphone calibration; (2) choose/edit character; (3) graph with average vocal intensity; (4) settings; (5) exit; (6) available and (7) locked scenarios; (8) earned coins.

Results

This work was developed during the COVID-19 pandemic. Unfortunately, due to the restrictions imposed during this pandemic, it was not possible to do a longitudinal study on the game use by people with PD, to know the effects that the game may have on therapy. Instead, the game was validated through meetings and interviews with SLPs specialized in this area.

Six SLPs, one male and five females, who work or have worked with patients with PD, participated in the validation phase of the proposed serious therapy game. The participating SLPs were from different age groups: two SLPS were 25-30 years old and had 3-5 years of experience, two SLPs were 35-40 years old and had 15-17 years of experience, and the other two SLPs were 55-60 years old with 30-37 years of experience. Four out of the six SLPs used applications or board games and computer games during their sessions.

The validation protocol consisted of answering a questionnaire, after attending (or reading) a tutorial and exploring the game freely. The SLPs installed the game in their devices in order to explore it. In order to avoid direct contact because of the COVID-19 pandemic, online individual tutorial meetings were held (through the Zoom platform) with four SLPs. Two SLPs, which were not available to meet on-line, received a video tutorial and written description that shows all the game features.

Figures 3 to 7 present the answers to the questionnaire's more relevant questions. The answers were given with a 5-point Likert scale and a free answer box in which the SLPs could

write their opinion and feedback. The Likert scale answer 5 can be associated with *very motivating* or *very helpful* depending on the question, while answer 1 is *not very motivating* or *not very helpful*.

Discussion

An important factor in performing speech therapy exercises is motivation. Therefore, the first two questions (figures 3 and 4) are related to the usefulness of the game as a tool to motivate the exercise practice both in sessions and at home. It was possible to realize that, in general, SLPs consider that the game can motivate patients to practice these exercises, but more likely in sessions than at home. The game can be a good option for patients to train without the presence of a SLP, every day or consistently, however it has some features that may depend on the SLP, such as microphone calibration and customization. Thus, it would be required that the game is parameterized at a therapy session prior to being used at home.

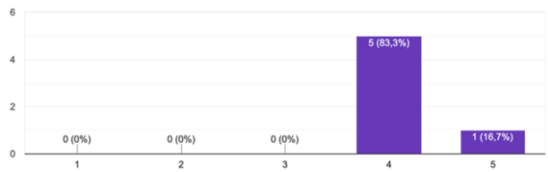

Figure 3. Results from question: Do you find the game useful for keeping patients motivated during sessions?

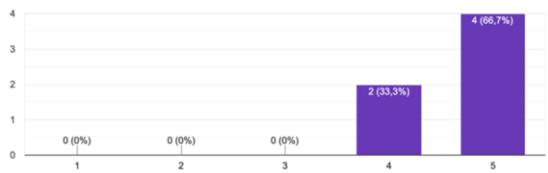

Figure 4. Results from question: Do you think the game would motivate patients to train at home?

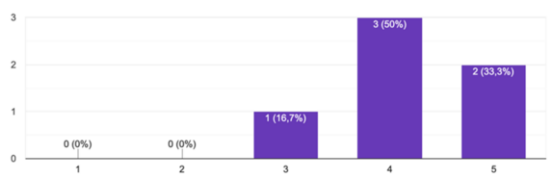

Figure 5. Results from question: Do you consider the game appropriate for people with Parkinson's disease?

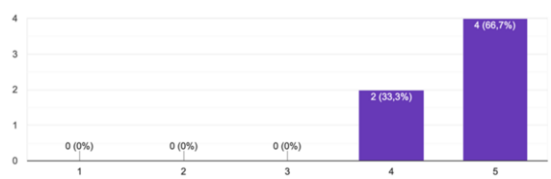

Figure 6. Results from question: Do you consider that the real-time feedback given by the character's movement throughout the exercise helps the patient control the voice?

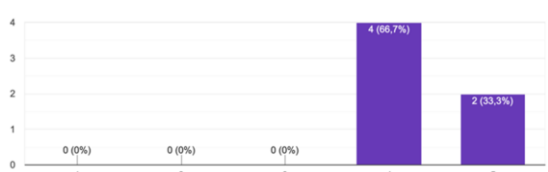

Figure 7. Results from question: Do you think the game can bring improvements in patient performance?

The opinions about the design and layout were divergent. Some SLPs commented that the game was a little chill. In their opinion, it is important that people with PD feel that the game is serious and therapeutic and that it serves to improve their quality of life. Nonetheless, in the initial phase of development, we consulted two people aged 59 and 63 to assess if the design and layout were appropriate. They both gave positive feedback on the choices of scenarios, characters, and layout.

In general, it was considered that the game and its exercises are appropriate for people with PD (figure 5). Yet, the need to press a button to generate a new sentence in the functional phrases' mode did not have good feedback because people with PD may have difficulty performing various tasks simultaneously.

Manual parameterization and the possibility of entering phrases were considered very important, as it is essential that SLPs can adapt the game taking into account the difficulties and needs of each individual patient. Other features that had positive feedback were the graph and notification system. The graph may be a good option for allowing SLPs to monitor the performance and progress of patients throughout the days. SLPs found that the notification system could be an interesting feature if patients establish a routine with training included, thus avoiding forgetting practicing the voice exercises.

Based on the SLPs' opinions, the game successfully fulfills its objective of offering real-time visual feedback to the person who is performing the exercises, so that they can control their voice (figure 6). If the patient has no way of knowing if he or she is doing the exercise correctly, he/she may not feel motivated to continue them with the same commitment. In addition, regarding the patient's performance, SLPs considered that the game can bring improvements to it (figure 7).

Conclusions

We propose a serious game for computer and mobile devices, to treat hypokinetic dysarthria of people with PD. The purpose of the game, which focuses primarily on improving vocal intensity, is to motivate people with PD on practicing voice exercises in order to improve their voice and communication quality.

The game is controlled by the patient's voice and, unlike previous applications that use the sustained vowel exercise, it gives visual feedback on the patient's vocal performance in a fun and intuitive way, through the movements of the game's characters. In addition, the game offers the possibility of customizing several parameters to adjust the exercises to the specific needs of each patient.

As ideally patients should use the game daily at home, and not only in the presence of an SLP during therapy sessions, a notification system was implemented to remind patients to practice. Additionally, the game contains several gamification elements that aim to motivate patients to use the application consistently, such as a points system, and a reward system.

Based on the SLPs' validation and feedback, the game fulfills its main objectives: (1) it motivates training, (2) it is suitable for home training provided there is an initially in-person session for customization, (3) it gives intuitive visual feedback on the player's voice performance and (4) it has potential to help improve voice performance.

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