SPEECH REHABILITATION PLATFORM FOR PARKINSON'S DISEASE

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ABSTRACT
Around 90% of patients with Parkinson's disease (PD) experience speech disorders. These can be improved effectively by speech rehabilitation, which can be divided into two parts: hospital treatment and home practice. Home practice is a key factor, but because the quality of home practice is difficult to determine, its treatment effect is poor in most PD patients. This study deployed a platform for assisting the home speech practice of PD patients aimed at ensuring the quality of home practice. The proposed model of home rehabilitation is also suitable for other types of rehabilitation, such as for patients with stroke, orthopedic diseases, or neuromuscular diseases.

KEY WORDS
Parkinson's disease, speech rehabilitation, telehealthcare.

1. Introduction

Parkinson's disease (PD) is named after the English physician James Parkinson. The main symptoms are tremor, limb rigidity, and slowness, and the main underlying mechanism is the absence of neurotransmitters in central motor neurons. Other factors such as genetics, pesticides, industrial waste toxins, and aging accelerate the disease progression. The most obvious symptom of PD is impaired motor function, but this disease is also associated with non-motor-function symptoms such as mood swings, sleep disturbances, thinking difficulties, and speech delay. The neurological disorders of this condition mean that the motor function symptoms progressively worsen. The prevalence of PD increases with age: in the overall population it is reportedly 0.1–0.2%, but increases to 1–2% in those older than 60 years, and to about 15% in those older than 65 years; the mean age at onset is about 60 years. There are currently about 500,000 cases of PD in Europe, and about one million cases in the United States and Canada [1].

Most PD patients (89%) experience speech disorders [2–4] that will result in their speech becoming increasingly unclear. Common speech disorders are low volume (hypophonia), monotonic intonation (monotone), and dysarthria. Muscle stiffness can also result in sluggish facial expressions (commonly known as the masked face) [5, 6], which can further impair verbal expression. A low speaking volume hinders understanding and the ability to use tone to express emotions. There can also be difficulty in using diction and grammar, which will tend to lead to the use of simple sentences with open-class words (e.g., nouns, verbs, and adjectives) and the avoidance of using closed-class words (e.g., auxiliary verb qualifiers and prepositions). The frequency and duration of dialogue hesitation and pauses will gradually increase. These communication problems will cause great frustration in patients with PD, and adversely affect their social lives due to them avoiding talking to people and reducing their interactions with other people. Further long-term frustrations seriously affect the prognosis of PD [7–9].

Currently the most common treatments for PD are drugs and surgical procedures. However, both of these types of therapy mainly improve muscle movement function, and do not address speech disorders. Although the behavioral speech therapies applied to speech disorders have improved significantly, a prerequisite is the need to improve muscle movement function, and such therapies are currently combined with drugs such as levodopa. Speech therapy is usually conducted by a speech and language therapist (SLT) via a series of face-to-face treatments that include pronunciation exercises, learning to control the speed of speech, articulation exercises, emotional expression, intonation, volume control, and breathing regulation. These treatments need to be assisted by acoustical feedback, an amplifier, rhythm boards, and other auxiliary equipment [10–15].

However, behavioral speech therapy is a highly personalized and time-consuming treatment, and so SLTs need to determine the appropriate treatment course based on the individual conditions. Moreover, because PD is a progressive disease, this therapy must be accompanied by long-term follow-up and rehabilitation. Speech disorder symptoms are likely to gradually worsen after the

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treatment is stopped. Therefore, the first requirement for effective treatment of the speech impediment is the availability of a large number of SLTs so as to ensure effective monitoring and evaluation. However, a lack of SLTs is a worldwide problem [16]. Enderby and Davies estimated that there were only 26.2 SLTs for every 100,000 people [17]. Moreover, these therapists are distributed extremely unevenly, with most of them concentrated in medical centers and language rehabilitation institutions. The ability to provide speech therapy is therefore subject to severe temporal and spatial limitations, which restricts the treatments themselves, as well as the follow-up monitoring and evaluations, and hence their overall effectiveness. In addition, although SLTs can teach patients to practice properly, their ability to alleviate symptoms mainly depends on whether the patient actually performs home exercises. The current method of speech therapy delivery means that patients are unable to ask questions about home practice between their relatively infrequent visits to SLTs. This can result in patients continuing to deteriorate, and makes the effects of such home exercise difficult to monitor.

This study addressed the above-described limitations of speech therapy. We used information technology, in conjunction with the participation of SLTs, to improve current treatment programs. This study adopted a digital learning technology to develop a platform that can be used as an auxiliary tool for remote rehabilitation. This platform initially focuses on helping patients learn to control their speaking volume and to improve their speech intelligibility. This will improve the performance of home practice, and allows SLTs to monitor both the quality and quantity of home exercises performed by patients. When the treatment provided to patients ends, the rehabilitation platform will help them to persist with their practice, which will in turn slow their deterioration. Finally, during the development of the learning technology, this study also considered that PD can cause muscle control difficulties that prevent a user from operating a computer.

2. Methods

Speech problems normally first appear as the condition of a PD patient worsens. Neurologists usually transfer such a patient to a speech rehabilitation department, where an SLT teaches the patient to perform exercises and provides him/her with home practice materials. When the patient next visits the department, the SLT would check the effectiveness of exercise and adjust the subsequent home practice courses accordingly. The patient's home exercise is a key factor in effective rehabilitation.

The speech rehabilitation platform developed in this study is designed to help patients perform home practice, and make it possible to immediately evaluate the effectiveness of that practice. Fig. 1 illustrates the entire process of home practice.

To help patients to perform effective home exercise, the basic requirements of the speech rehabilitation platform are as follows:

- Ease of use: Most PD patients are elderly, and many of them are living alone, which makes ease of use the most important consideration.
- Provision of learning feedback: Motivation will be lower if the patient does not understand the effectiveness of the practice. The learning feedback function can allow patients to quantify the effectiveness, or the absence thereof. This feedback can increase motivation.
- Data recording, storage, and sending (store-and-forward function): The home exercise records can reveal various relevant data items, such as the number of exercise sessions, practice times, and practice effect. The patient's entire process will initially be stored on the patient side, and periodically transmitted to the hospital, which facilitates monitoring. If the home practice situation is identified as being abnormal, a timely intervention can be issued without having to wait until the next hospital visit.
- Online update practice material: The results of each patient's home exercise are not the same; some will indicate a good condition and some will indicate a poor condition. Therefore, the home exercise course can be modified if necessary.

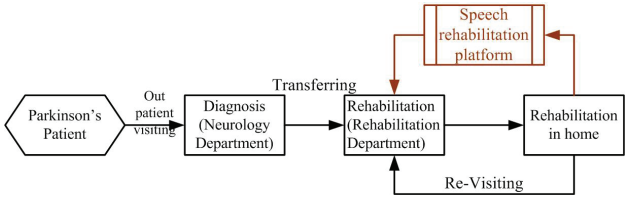


Figure 1. Speech rehabilitation process.

2.1 Layout of User Interface

In the home speech rehabilitation exercise, it is necessary to first measure the background noise of the home environment; currently most SLTs suggest that 50 dB SPL as the maximum value for testing at a patient's home. If the background noise is too high, the system will advise the patient to move to another room to practice. If the background noise is within the acceptable range, the system main menu displays the Tone Exercises, Word Exercises, Idiom Exercises, and Sentence Exercises functions. The default option is the Tone Exercises, which includes volume exercises, lasting exercises, treble exercises, and bass exercises. The other exercises relate to volume control and intelligibility improvement. In addition, a questionnaire is used to determine the patient's satisfaction with the speech rehabilitation process (see Table 1).

2.2 System Hardware

The main user interface of a personal computer (PC) comprises a mouse and keyboard, which are difficult for the elderly who have never used a PC before. Moreover, the muscle control disorders present in PD can prevent the use of a PC. Therefore, this study adopted a lightweight tablet PC on which to develop the platform. A tablet PC does not use a keyboard or mouse, and can be used wirelessly. Users only need to use their fingers to operate it, which is highly suitable for PD patients. This study used the Android operating system to develop the barrier-free user interface. The tablet PC's gesture-based interface is employed by touching the screen, tapping, dragging, or swiping. Note that since a user might have only one ear with normal hearing, the same audio signal is supplied to the left and right headphones.

2.3 Volume and Intelligibility

Volume and speech intelligibility are the main feedback parameters provided to the patient during home exercise. The main evaluation indicators are the sound pressure level and the pronunciation duration. In rehabilitation clinics, the SLT normally uses a sound level meter, chromatic tuner, timer, and other equipment to assess the patient's performance. This study used software with a combination earphone and microphone to measure the patient's performance, which was calibrated using pure tones and the patient's voice. The configuration for pure-tone calibration is shown in Fig. 2. Pure tones were generated by the generator at several frequencies, and then amplified to drive the speakers. A speech analyzer was used to calibrate the earphone/microphone and the tablet program. The configuration for the vocal validation is shown in Fig. 3. The subject's vocal signal was simultaneously fed to the tablet PC and the sound level meter, and then verified. The results of the pure-tone calibration and vocal validation were analyzed using the *t*-test.

Table 1. Questionnaire used to measure the patient's satisfaction with the process.

	Question	Answer
1.	Is the system easy to use?	☐Yes ☐No
2.	Is the screen content legible?	☐Yes ☐No
3.	Are the instructions easy to understand?	☐Yes ☐No
4.	Are the practice courses too difficult?	☐Yes ☐No
5.	Do the practice courses allow timely adjustments?	☐Yes ☐No
6.	Do you prefer using the home platform with rehabilitation exercises over visiting an SLT?	☐Yes ☐No
7.	Is the home environment suitable for self-practice?	☐Yes ☐No
8.	Can you practice alone, without family help?	☐Yes ☐No

This study used the PESQ (Perceptual Evaluation of Speech Quality) instrument to assess the speech intelligibility [18]. The PESQ was originally used to evaluate voice quality of communication equipment, as was in the No. P.862 standard of the ITU-T (International Telecommunication Union—Telecommunication Standardization Sector). The PESQ architecture is shown in Fig. 4. Both the reference signal and the degraded signal are first subjected to level alignment, and then pass through the input filter beforetime alignment and equalization to ensure convergence. If a large time difference is detected between the two signals in the "Identify bad intervals" procedure, they are realigned. The quality difference between the reference and degraded signals is determined by disturbance processing. Finally, cognitive modeling is used to scale the intelligibility quality on a 5-point scale, where "5" is the best and "1" is the worst.

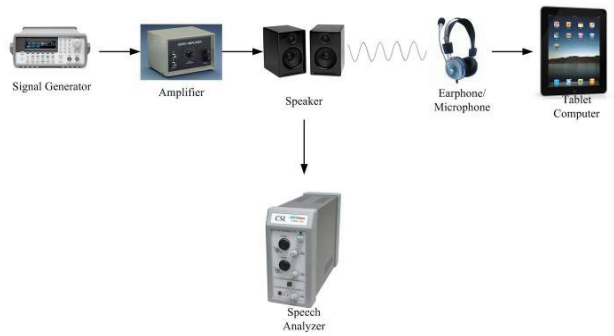


Figure 2. Setup for pure-tone calibration.

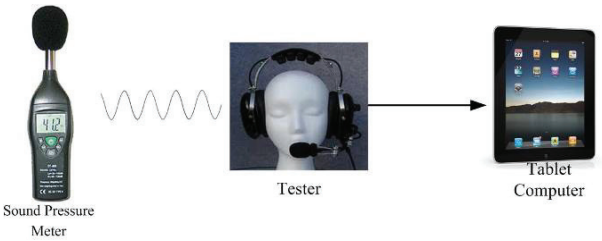


Figure 3. Human speech calibration.

The PESQ reference signal is chosen by the SLT from the best pronunciations produced by the patient practicing at the hospital, while the PESQ degradation signal comes from the patient's pronunciations at home. The analysis of these two signals provides the patient with information about the effectiveness of the PESQ method. The validation of the PESQ method was performed by two senior SLTs. The average scores of the two SLTs were mapped onto the PESQ 5-point scale.

2.4 Clinical Trials

The Institutional Review Board at National Taiwan University Hospital approved this study. The number of subjects was calculated based on the samples used in studies involving the Lee Silverman Voice Treatment (LVST) [19, 20]. The LVST evaluates the patient by comparing differences in sound pressure between before and after treatment. The threshold for a significant

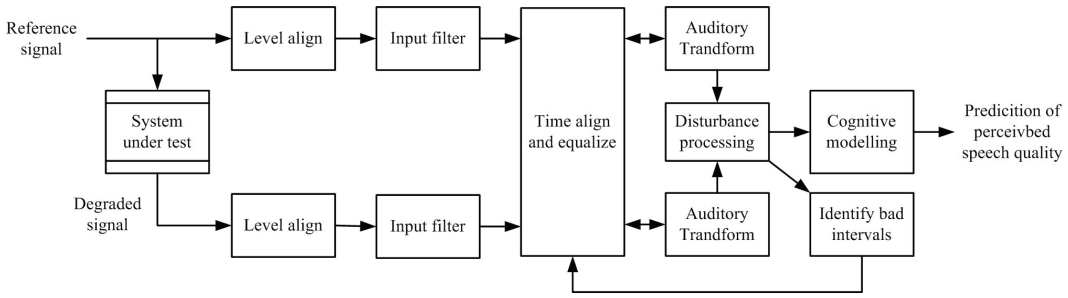


Figure 4. Block diagram of the PESQ.

difference was set at 4.5 dB, with a standard deviation of 2.48 dB. In the present study, α was set at 0.05 (type-I error), the statistical power was set at 80%, and the subject dropout rate was assumed to be 20%. The calculated minimum sample size was 16, and so was aimed to recruit 20 cases. The following inclusion criteria for the subjects were applied:

- Aged 20 to 90 years.
- Consciousness characteristics diagnosed by a physician, with speech disorders appearing with PD.

The following exclusion criteria were applied:

- A physician assessment that muscle control is serious impaired.
- Vulnerable groups, including prison inmates, aboriginals, pregnant women, and the mentally ill.

3. Results and Discussion

The study subjects were enrolled in a medical center, and they were randomized into the control and experimental groups. Both groups received the convention rehabilitation process, while the experimental group additionally used the tablet PC platform. Subjects were followed for 16 weeks, during which the interviews, home visits, and questionnaires were used. After the experiment, the subjects' performances were compared between before and after the experiment, including the sound pressure and intelligibility.

The user interface of the system main menu is shown in Fig. 5. The Oral Cavity Motion Exercises function presents videos prerecorded by the SLT that show how the mouth and tongue move during pronunciation. The patient can use these videos to facilitate self-review at home. The Tone Exercises are used for practicing pronunciations, providing pronunciation tips and the associated voice files; the system evaluates the patient's pronunciation and provides feedback to the patient. The Word Exercises are used in the monotone exercise, which also provides patients with the correct pronunciation and feedback. The Idiom Exercises and Sentence Exercises represent advanced courses; their user interfaces are shown in Fig. 6. The Exercise Review elucidates the status of past practice sessions. In the next hospital visit, the records of the patient's home exercises can be inspected by the SLT, who can adjust the treatment course accordingly.

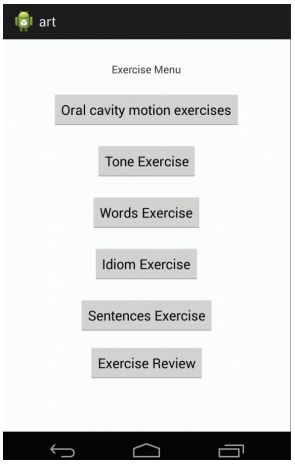
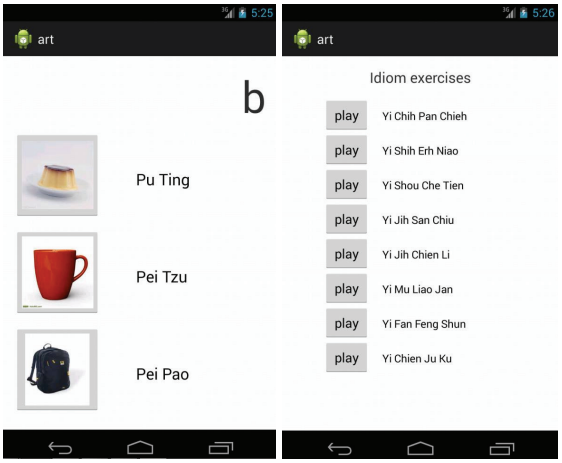


Figure 5. System main menu.

4. Conclusion

All of the platforms developed previously for pronunciation exercises lack feedback, progress records, or convenience of usage. This study focused on the factors that would encourage patients to continuously practice and record their home practice progress. The developed platform provides more resources for both the patients and their carers, and acts as an auxiliary tool for home speech rehabilitation that improves and strengthens home practice. Moreover, the platform also allows the SLT to monitor both the quality and quantity of a patient's home practice. After a hospital treatment course has finished, the developed platform facilitates the continuation of practice at home, which will slow the rate

of deterioration associated with PD. Therefore, the platform can improve the quality of life for the patient.



(a) (b)

Figure 6. (a) Word exercises and (b) Idiom exercises.

Home practice is a key factor in effective rehabilitation, with failures usually being attributable to the poor quality of home practice. This research has developed an information technology platform for assisting the home speech rehabilitation of PD patients. This platform facilitates practicing by patients and their recording of the practice content and time, which help to ensure its quality. The proposed model of home rehabilitation is not only suitable for PD patients, but would also benefit other types of rehabilitation, such as for patients with stroke, orthopedic diseases, or neuromuscular diseases.

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