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Development of Device and Serious Game Contents for the Multi-finger Rehabilitation

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Abstract

In modern society, with the increasing use of such compact devices as smart phones and computers, finger and hand mobility is very important for daily living. Generally, in the case where there is impaired motor function of the hands or fingers, rehabilitation involves boring repetitive exercises. In this study, serious games were implemented using a dynamometer which made it possible to measure grip width and finger grip strength according to the size of the hand. The game was developed based on rhythm games, and, by selectively training the fingers that need rehabilitation, it is possible to improve a variety of functions such as finger agility, power and endurance. In addition, by analyzing data changes during the training process, the intensity of the rehabilitation can be quantitatively assessed. Furthermore, it provided users with an active and fun rehabilitation environment because they could choose and use their own desired music files during their rehabilitation.

Keywords: Dynamometer, Multi-finger Rehabilitation, Rhythm Game, Serious Game

1. Introduction

Hands and fingers are the parts of the body that perform the most functions in carrying out daily living and this closely affects life. These days the ability to freely use hands and fingers is very important due to the increasing use of such compact devices as computers and smart phones, and for driving or in the working environment. In particular, as the average life span of people is extended due to advancements in medical technology, age-related illnesses such as stroke, Parkinson's disease, dementia and Alzheimer's disease are increasing. Thus more elderly people are experiencing reduced motor function of the hands or fingers which makes it more difficult for them to live independently[1].

According to prior research results, stroke causes serious physical and cognitive disabilities, and Parkinson's disease causes motor function impairment such as slowed movement, rigidity, tremors, and impaired posture[2,3]. Furthermore, because of the damage to physical and cognitive function in dementia patients, which decreases their capacity in everyday life, it is difficult for them to live independently[4].

This has a significant impact on the quality of life of older people who are increasingly participating in social activities in an aging society. Therefore, it is very important to research ways to evaluate, maintain and improve the motor function of hands[5,6].

In general grip strength has most often been used as a way to evaluate hand mobility. Through this, it is possible to determine the degree of recovery of upper limb function impairment in stroke patients, and it has also been used to assess the motor skill impairment of Parkinson's patients[7–9]. In addition, for patients with motor intentional disorders, a quantitative assessment is carried out using such characteristics as hand agility, power and endurance. However most prior studies have evaluated hand mobility rather than evaluating each finger of the hand. The conventional evaluation method for finger mobility is to measure the power of two fingers using a pinch grip or to use such tools as Pegboards and Mobile Vocational Evaluation (MVE) to evaluate finger motor function, and the ruler drop test is often used for evaluation of reaction time. However, such methods which assess the function of the hand, cannot be expected to give evaluation results on the function of each individual

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finger[10]. In addition, even when using a standardized tool, a quantitative assessment cannot be expected since it is made in accordance with the subjective evaluation of the rehabilitation therapist. There is also the inconvenience of having to visit the clinic since the rehabilitation depends on the instructions of the therapist.

Rehabilitation requires accuracy and repeatability of actions with the active involvement of the patient. This is possible by following the instructions of the therapist, but actively engaging the interest of the patient is difficult[11]. As a way to improve this situation, research is being carried out on serious games, which improve both cognitive skills and rehabilitation at the same time[12]. By utilizing more body senses than general games and by maximizing the satisfaction of users, serious games, which make use of various senses, have the advantage of being able to increase the patient's participation more than general treatment methods[13]. In recent years, the development of functional contents based on standardized testing tools is helping patients to feel less bored during rehabilitation and to be more proactive in rehabilitation treatment.

In this study, since grip strength can be influenced according to grip size, rehabilitation contents regarding such characteristics as agility, power and endurance for hand mobility were developed using a dynamometer, which made it possible to adjust the size and to measure the grip strength of each finger. This research implemented rehabilitation contents based on rhythm games to guide users to willingly participate and become interested in their rehabilitation. In order to encourage users to become absorbed in their rehabilitation, they were allowed to choose their favorite music according to their preferences. Based on the quantitative evaluation results of previous research about agility and power, the contents were constructed in stages according to content levels[14].

2. Method and Material

2.1 Dynamometer Design

The dynamometer used in this study is one which allows adjustment for grip size as shown in the design drawing in Figure 1(a). Figure 1(b) shows the actual finger dynamometer that was made. This was to minimize the error caused by variations in grip position due to the user's hand size and finger length. It was designed to be able to measure individual finger strength using Flexi Force (Tekscan Inc.), which is a film-type pressure sensor. Each sensor has a measuring range of 0-40 kg and is able to measure all patients, from children to adults. In order to integrate the training contents with the dynamometer, by using a MCU(ATmega16), data from the four pressure sensors was collected in the ADC (Analog to Digital Converting), and then 100Hz sampling results were transmitted by the UART to the PC, and the data was processed[14].

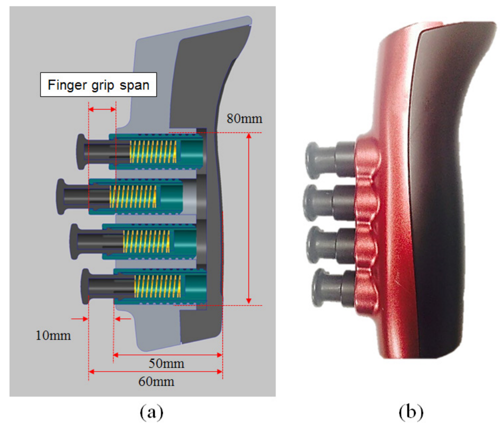


Figure 1. Dynamometer for measuring individual finger strength.

2.2 Finger Rehabilitation Contents

In general, the way to perform hand exercise training was to exercise repeatedly using a dynamometer made with springs and, in hospital, finger rehabilitation involved simple repetitive exercises such as gripping rubber balls and cylinders. It was easy to feel fatigue and lose concentration with these activities thus weakening their effectiveness[15]. In order to solve these problems, training contents are needed which can focus on rehabilitation through appropriate and interesting goal setting, and which is more systematic than current simple repetitive rehabilitation.

In this study, rehabilitation contents based on rhythm games were implemented in order to encourage users to feel a sense of fun during rehabilitation and to motivate users' voluntary participation. The rhythm games were made up of a combination of visual and auditory aspects, and by using a dynamometer, this provided a sensory experience that included tactile elements. This was intended to offer effective psychological and physical therapy and to improve self-esteem. In addition, this training method can provide strong motivation and be effective in improving the motor function in the fingers and in reducing depression through music therapy[16,17].

In this study, users select an MP3 or Wave file for the rhythm game music, so they can run the training contents. By users organizing the contents in line with their favourite music, the contents are matched to their own musical preferences. This allows users to more pro-actively participate and become immersed in their rehabilitation than if the generally fast beat of a rhythm game were used. Figure 2 shows a flowchart of the overall contents. Firstly, by using the difference in the input value of the agility, power and endurance of the contents, which was based on the maximum value of the grip strength obtained from each finger of the user, it made it possible for the contents to be used by not only patients needing finger rehabilitation but also for the general public. In addition, depending on the selection of the contents' mode, it was possible to focus the exercises on only the fingers that needed rehabilitation.

The contents' development environment is based on Windows 7, the input device is a finger dynamometer, and the display device is a PC monitor. The development tools are Unity5 and Visual Studio 2014. Maintaining the Integrity of the Specifications.

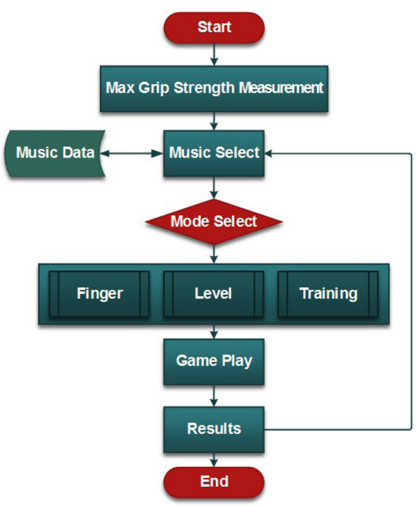
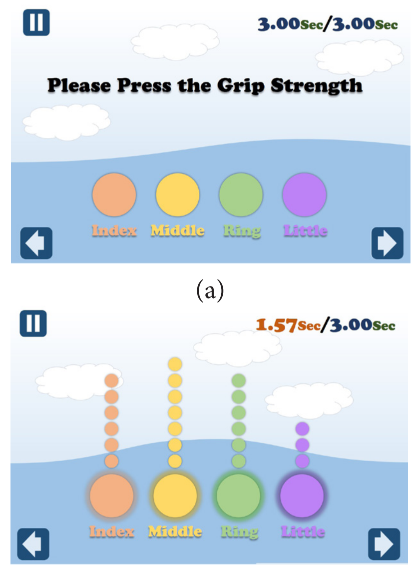


Figure 2. Flow chart of contents.

3. Results

3.1 Grip Strength Measurement Screen

Figure 3(a) shows each separate finger by color on the screen, to enable the measurement of the maximum grip strength of each finger over a period of three seconds after the training contents are executed. The index, middle, ring and little fingers were assigned the colors orange, yellow, green and purple respectively, and this color coding was applied to all contents. Figure 3(b) shows the maximum grip strength of each finger of the user in real time and, after measuring the grip strength of each finger of the user for three seconds, the maximum grip strength of the fingers is stored in the program and then moves on to the music selection screen.



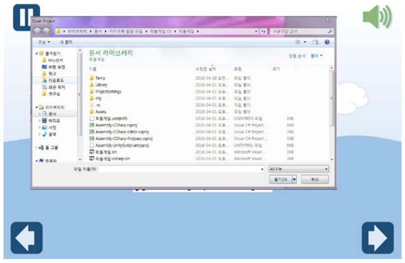
(b)

Figure 3. Grip strength measurement screen.

3.2 Music Selection Screen

Figure 4(a) shows the music selection screen which, after the grip strength measurement is completed or after the completion of a game, is configured to allow the user to select the desired music when they play the game again. After the user clicks on the music selection button in the center of the screen, they select the music file that they want to use in the rhythm game. After the audio signal of the selected music file is analyzed, the program is set to operate using this as the task pattern of the rhythm game. When the music selection is completed, it moves on to the mode selection screen where the user can choose such options as which fingers, training type and level that they want to use.

(a)



(b)

Figure 4. Music selection screen.

3.3 Mode Selection Screen

Figure 5(a) shows the mode selection screen where the game level and which fingers will be used can be selected. It is also where to set up the tasks for agility, power and endurance. The four fingers, being the index, middle, ring and little fingers, can be selected, and users can select only the fingers that they want to focus on in the training, before proceeding with training.

(a)

(b)

Figure 5. Mode selection screen.

For example, it is possible to measure the Simple Reaction Time (SRT) of training by selecting only one finger as in Figure 5. Here, SRT is the reaction rate for a simple stimulus and is a way to evaluate cognitive function. In the case where two or more fingers are selected, it is possible to use SRT together with Choice Reaction Time (CRT) measurement, which is widely used in cognitive function evaluation. CRT measures the reaction rate for the correct selection from two or more choices. More than SRT, there is a huge difference in the reaction rate between an ordinary person and a patient with cognitive impairment. Because of this it can be used to determine the patient's cognitive function[18].

Users can select the desired training from agility, power and endurance as in Figure 5. Agility measures the time from when the task appears to when the user responds by gripping. Power is classified into five levels according to the percentage of the maximum grip strength from the measured maximum grip strength for each user. It is then measured as the time taken to reach a given percentage of the maximum grip strength. Furthermore, endurance is measured by whether the user can maintain the maximum grip strength for three seconds according to the given level. In this regard, Table 1 shows the time taken to generate a grip response, the percentage of the maximum grip strength, and the time taken to reach the percentage of the maximum grip strength. Setting values for each of the levels was based on quantitative evaluation of fingers from previous research experiment results[14].

Figure 6 shows the tasks being used by the training contents. (1) Agility, (2) Power, and (3) Endurance are displayed in different colours and shapes. The fingers which are not being used and the success of the given training conditions are shown in the status separately.

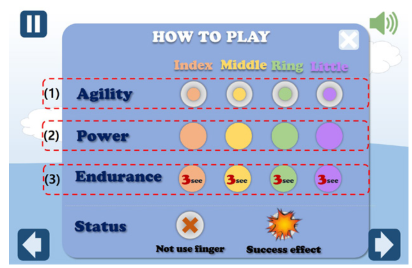


Figure 6. Game tasks design.

3.4 Game in Progress Screen

Figure 7 shows the game in progress screen. For example, Figure 7(a) is the screen where index finger training was selected, and it shows that only the index finger task is activated.

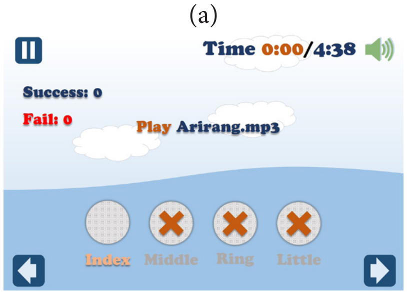
When the countdown in the middle of the screen reaches '0', the music plays and the game starts. Figure 7(b) is a game in progress screen and it shows the progress of the index finger agility task with music. In this way, each task appears in the designated position depending on the selected type of training and selected fingers by the user. In full-screen configuration the playback time of the music used in the game is shown in the top right hand corner, and the number of successes and failures are

Table 1. Rhythm game training categories and levels

Level	Agility		\`Power	Endurance
	Time Taken to generate a grip response(sec)	Precentage of the Maximum grip strength(%)	Time taken to reach the percentge of the meximum grip strength(sec)	Percentage of the maximum grip strength(%)
Very Easy	5	60	5	60
Easy	3	70	3	70
Normal	1	80	1	80
Hard	0.5	90	0.5	90
Very Hard	0.3	95	0.3	95

shown on the upper left of the screen. When the music ends, the game finishes and the game results are shown on the results screen.

(a)



(b)

Figure 7. Game in progress screen.

3.5 Results Screen

After finishing the game, the results screen displays information about the success rate, and displays the related results for ability, power and endurance respectively as shown in Figure 8. For example, in Figure 8 if the task success rate is over 90% the word 'clear' is displayed, and if it is less than that, the word 'fail' is displayed. In addition, when the agility tab is selected, it shows the average response time and a graph showing the changes in the reaction time for the agility training task. When the power tab is selected, it shows the average time it took to reach the maximum grip strength percentage and a graph showing the changes in the time it took to reach that. For endurance, after reaching the percentage of maximum grip strength required, it shows the average time this was maintained and the changes in times were shown in a graph. There is an end of game button and a replay button at the bottom of the screen. If replay is chosen, the program returns to the music selection screen as shown in the contents flow chart in Figure 2. The exit button (x) finishes the game.

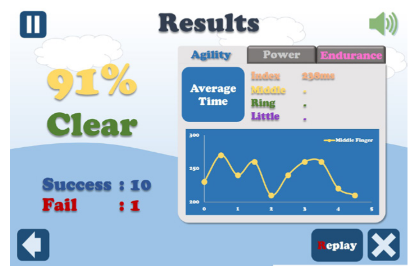


Figure 8. Game results screen.t

4. Conclusions

In this study a rhythm game was implemented, which made possible finger rehabilitation by utilizing a dynamometer capable of quantitative measurements of each finger's grip strength. By designing a rhythm game which combined game elements in rehabilitation, this game is intended to encourage voluntary participation and interest in rehabilitation for patients with finger injuries or with impaired finger function due to age-related diseases.

In this rhythm game users can selectively train the fingers which need rehabilitation, and it is able to show various aspects of finger training and the related results. It is possible to select the desired training for agility, power and endurance separately or to do these at the same time. While the rhythm game is running, as the results related to each aspect of training are saved, the average data and changes in data can be checked. Based on these results, by analyzing the average data changes during rehabilitation, the intensity of the rehabilitation can be determined, and the effectiveness of the rehabilitation can be quantitatively verified. In addition, unlike traditional rhythm games, since users can do rehabilitation while listening to music they selected themselves, this helps users to voluntarily participate in their rehabilitation.

Prior studies have shown the effect of repeated finger movements on brain activity[19]. This is due to a significant portion of the brain being involved in sensory and motor nerves. If the brain is stimulated by repeated finger movement, this can not only improve brain function, but also upper limb rehabilitation and concentration in brain stroke patients. It could also help in the brain development of very young children[20].

In the future, by using the dynamometer proposed in this study, a variety of additional training contents required for individual finger rehabilitation could be implemented. Whether they improve the upper limb function and brain activity of stroke and Parkinson's disease patients and whether these results are affected by age, gender and occupation will also need to be quantitatively assessed.

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