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6-24-2014

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Article

Stroke Patient Rehabilitation: A Pilot Study of an Android-Based Game

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Abstract

Background. Cerebral vascular accidents (strokes) are the primary cause of disability worldwide and the second leading cause of death both in the Philippines and internationally. In recent years, a number of computer-based applications have been developed to assist in the stroke recovery process.

Aim. This article discusses an Android-based tablet game, FINDEX, that aids in the rehabilitation process of stroke survivors with impaired fine motor skills.

Method. FINDEX was designed and developed in the Philippines. The game contains assessment and monitoring support for tracking the patient's progress in terms of fine finger dexterity, for example, finger control, isolation and coordination, and range of motions. The baselines for data comparison and analysis were gathered through an initial test with subjects with normal hand function. Three stroke survivors then participated in a pilot study, using the game for a total of nine testing sessions.

Results. Objective measures showed that patients' dexterity did in fact improve, although it is not possible to draw strong conclusions because of the small sample size. In subsequent interviews, patients indicated that they believed that the games helped in their recovery and said that they preferred playing with the game over performing the standard therapeutic activities.

Conclusion. The development of this game and the preliminary findings from the pilot study suggest that games may indeed be effective instruments for therapy.

Keywords
cerebral vascular accident, dexterity, game, recovery, rehabilitation, stroke, therapy

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A cerebral vascular accident (CVA), commonly known as a stroke, is a brain injury that results when blood flow is interrupted (Rudd, Irwin, & Penhale, 2005). It is the second leading cause of death both in the Philippines and worldwide (Makati Medical Center, 2011). Although strokes can leave survivors permanently disabled, many still have an opportunity to recover. Rehabilitation, if properly timed (Biernaskie, Chernenko, & Corbett, 2004), capitalizes on the brain's ability to reroute neural pathways to work around the damage (Nudo, 2007). It enables survivors to relearn the skills that have been hampered or lost because of the damage or to develop other ways for completing a task to compensate for the impairment.

Health professionals and simulation/game designers have a history of collaborating to create games to support health (see Lane, Slavin, & Ziv, 2001; Streufert, Satish, & Barach, 2001; Thompson et al., 2010). The relatively recent emergence of tablet PCs and game platforms, such as the Wii and the Xbox 360, presents opportunities for rehabilitation applications. Indeed, computer games developed on these platforms are found to be effective rehabilitation tools. The entertainment that computer games provide, particularly the sense of success and achievement that patients feel while playing, motivates them to perform the rehabilitation exercises (Whitcomb, 1990). However, the use of games for therapy is subject to certain constraints. As a stroke's damage varies, each game can only address a specific set of problems or dysfunctions. The lack of instruments in measuring dexterity in fine motor functions becomes a hindrance in quantifying the patient's problem (Stein & Yerxa, 1989) and in determining the effectiveness of the designed exercises. Commercial games themselves are not always appropriate for therapy because they lack functionalities specific to therapy, such as adaptation to patients' limitations, tracking and monitoring of patients' motions, and so on (Borghese, Pirovano, Lanzi, Wuest, & de Bruin, 2013).

In response to this need for therapeutic games, we have developed an Android tablet-based game with assessment and monitoring support that can be used to track a stroke patient's progress during rehabilitation. The game described in this article, FINDEX, is used as an intervention in enhancing the fine motor skills of stroke survivors, particularly their fine finger dexterity.

Related Literature

Fine motor skills are some of the voluntary and goal-oriented movements controlled by the primary motor cortex of the brain (Institute of Neurosciences, Mental Health, and Addiction, 2002). These are the coordination of small muscle movements that enable our fingers to perform delicate, complex, and skilled movements. Loss of control in a person's fine motor skills makes simple tasks tedious and unmanageable (Healthtalkonline.org, 2011). When patients suffer from strokes, their fine motor skills are sometimes adversely affected, necessitating rehabilitation.

Stroke rehabilitation plays a crucial role in achieving optimal stroke recovery. Rehabilitation helps stroke survivors regain their independence by improving their physical, mental, and emotional states. Stroke survivors who suffer from fine motor impairment are subjected to therapies that improve gait and range of motion, restore muscle strength (The Patient Education Institute, 2010), and help regain fine motor

function through hand and finger exercises (Chase, 2011). Apart from gripping and squeezing exercises for restoring hand grip and strength (Chase, 2010), therapy schemes commonly used involve resistance and stretching exercises, rubber band exercises, and bilateral therapy, which push patients to do similar tasks with their functional and affected hands simultaneously (Chase, 2010).

The Use of Games to Promote Recovery

Health professionals have recognized that computer-based games can contribute to patient recovery. In 2001, the group of Jack et al. developed a PC-based desktop virtual reality system to rehabilitate stroke victims' hand functions. Patients used a force-feedback glove to interact with a virtual environment. According to Berkley (2003), force feedback simulates directional forces of physical attributes such as the weight of a solid object, and even the "mechanical compliance of an object," and also the concept of inertia. By using a force-feedback device like the glove, a patient is then able to control the amount of force he or she can direct toward a virtual object. After 2 weeks, patients' hand movements showed improvement. In a more recent meta-analysis, Saposnik and Levin (2011) reviewed 12 studies that made use of virtual reality as a therapeutic tool. The authors reported that virtual reality technologies "can be combined with conventional rehabilitation for upper arm improvement after stroke" (Saposnik & Levin, 2011).

Therapeutic specialists point to the potential usefulness of home systems such as the Wii, the Kinect, and the Playstation as platforms for therapy. Aside from being low cost and familiar, patients enjoy playing games on these systems, participating actively for a longer span of time. The extended engagement has the potential to increase the intensity of treatment and promote motor recovery (Saposnik & Levin, 2011). In a study by Lauterbach, Foreman, and Engsberg (2013), for example, recovering stroke patients were asked to play two Kinect-based games that required upper extremity movements. Patients remained engaged in the game and reported high levels of satisfaction with the experience. In addition, the game play averaged 34 repetitions of the stroke-affected extremity, proving that the Kinect has the potential to become an economical, engaging therapy tool.

The latest trend in therapy incorporates the iPad in rehabilitation programs. The sensitivity of the iPad's multitouch interface allows for a more accurate monitoring of the patient's current health state. One of the many iPad-based therapeutic tools developed is DEXTERIA, which is designed to improve fine motor skills. Primarily, it seeks to develop the patient's "strength, control, and dexterity" through a set of hand exercises involving tapping, pinching, and writing. The game fosters finger flexion, extension, dexterity, and isolation (Wood, 2011).

The iPad's existing commercial games have also been used to make the rehabilitation of stroke patients more engaging. One of the games with which neuroscientists have had significant success is the iPad version of FRUIT NINJA, where a player swipes across the screen to slice airborne fruits in half (Gambotto-Burke, 2011). According to Smith, the "frequent rapid precision wrist movements used to slice the virtual fruit mimic the exercises used in fine motor-skills therapy" (Gambotto-Burke, 2011).

In addition to being engaging, games for therapy need to provide other functionalities for therapists and their patients. Borghese et al. (2013) developed the Intelligent Game

Table 1. Available Computer-Based Games for Stroke Rehabilitation.

Game/game engine	Researcher	Year of publication	Platform/ device used	Target	Contribution
PC-based desktop virtual reality system	Jack et al.	2001	PC, force-feedback glove	Hand functions	Faster improvement (2-week time)
Kinect-based games	Lauterbach, Foreman, and Engsberg	2013	Kinect	Upper extremities	Engaged in the game, satisfaction with the experience
DEXTERIA	Wood	2011	iPad/tablets	Fine motor skills	Accurate monitoring in patient's health state
FRUIT NINJA	Stuart Smith and Penelope McNulty (Gambotto-Burke, 2011, August 13)	2011	iPad/tablets	Fine motor skills	Engaged in the game
IGER	Borghese, Pirovano, Lanzi, Wuest, and de Bruin	2013	Different platforms like Ninentendo Wii, Microsoft Kinect, Balance Board	Varies on the minigame used, but ranges from upper extremities to a person's ability to balance	Sensitivity to patient needs and abilities, monitoring to enforce correct motions, real-time feedback

Note. IGER = Intelligent Game Engine for Rehabilitation.

Engine for Rehabilitation (IGER). Games developed in IGER allow difficulty levels to be configured based on the abilities and needs of the patient. IGER games also monitor patients' actions and postures to enforce correct motions. Finally, IGER games incorporate real-time feedback to inform patients of correct or wrong movements. Table 1 summarizes some of the computer-based games that can be used for stroke recovery.

Our objective is to discuss the design, development, and testing of a game for stroke patient recovery. The game was intended to be engaging and fun, as well as to measure patients' progress objectively.

Game Design and Development

The implementation of the monitoring functionality of our game application was drawn principally from two reliable and valid finger dexterity assessment tools: Purdue
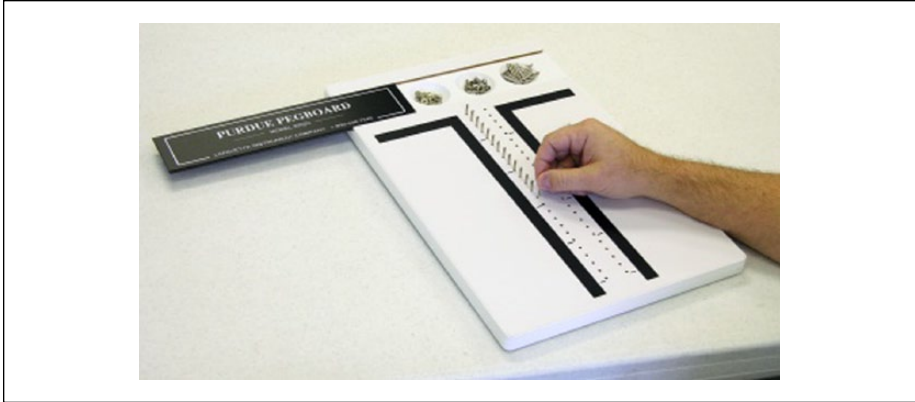
Figure 1. Purdue Pegboard.
Source. http://www.oandp.org/olc/

Pegboard (PP; Yancosek & Howell, 2009) and Rosenbusch Test of Finger Dexterity (Stein & Yerxa, 1989). PP measures how quickly and accurately a person can place small pegs in the holes lined consecutively on the board (Figure 1). PP was one of the three dexterity assessments that experts consider to have "solid psychometric properties," making it valid and reliable at measuring fine finger dexterity (Yancosek & Howell, 2009).

Rosenbusch Test of Finger Dexterity measures "interdigital manipulative skill." Patents must hold six objects and then roll them into six depressions on a testing board. In a study to assess its reliability and validity, results show relatively high reliability and validity coefficients as the test compares favorably with commercial dexterity assessment tools. Furthermore, content validity is strong as there is agreement among experts that Rosenbusch Test does indeed measure fine finger dexterity (Stein & Yerxa, 1989).

The assessments that our game, FINDEX, uses to monitor patient's progress are strongly based on the Rosenbusch Test's scoring rubrics. Finger dexterity's assessment relies heavily on precision and fine coordination (Stein & Yerxa, 1989). The Rosenbusch Test for Finger Dexterity uses two objective measures in its assessment: time and accuracy. Therapists measure the number of seconds it takes for a patient to place six objects in specific indentations correctly and with the targeted finger movements. The score is adjusted if the patient fails to use the correct movements. Therapists measure the patients' accuracy of finger movements as well as substitution patterns for correct movements. Furthermore, the test notes two types of subject errors: inaccuracy of movement and inaccuracy of placement. Inaccuracy of movement occurs when an object is rolled in a manner that differs from what is prescribed. Inaccuracy of placement refers to the positioning of the object in the wrong indentation (Stein & Yerxa, 1989).

FINDEX's design is based on everyday functional activities, which include household and work-related activities. Upon logging in, the player is brought to a view of

Figure 2. House foyer.

Figure 3. Dragging task.

the house foyer where three doors leading to certain parts of the house are available. Each door corresponds to a specific task (Figure 2).

This dragging task (Figure 3) is for finger control. The player's objective is to place all the pizza toppings in their corresponding spaces within 2 minutes.

The tapping task (Figure 4) focuses on addressing finger isolation and coordination. In all stages of the task, the player must tap specific piano keys using particular fingers. A number that corresponds to a particular finger appears above the key that the player needs to tap. As the game progresses, notes appear in more rapid succession. Accuracy level is based on the number of correct notes tapped within the duration of the song.
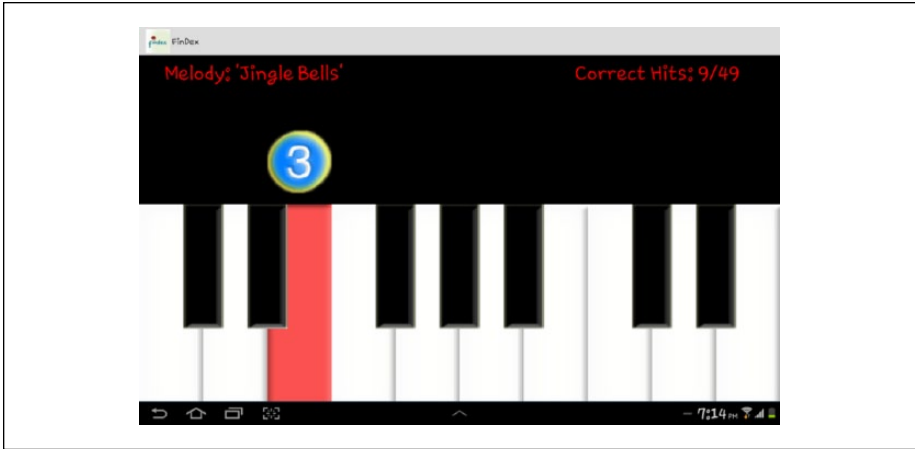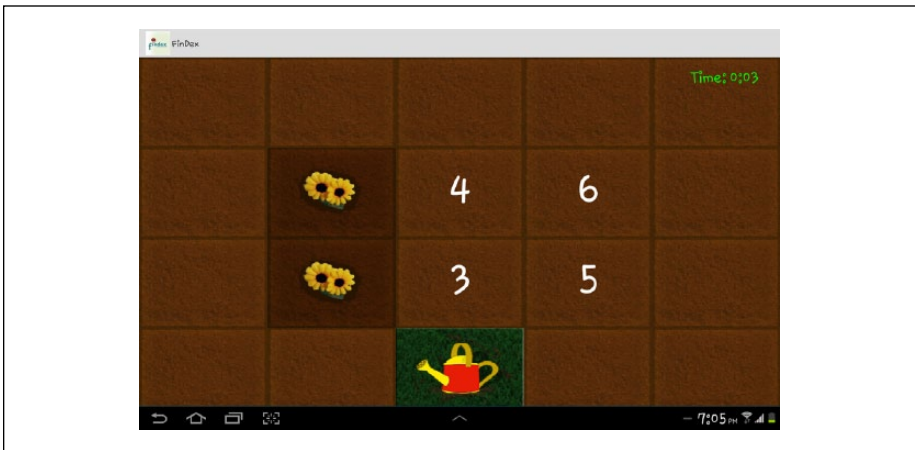
Figure 4. Tapping task.

Figure 5. Stretching task.

The stretching task (Figure 5) is for increasing finger range of motion. The player's goal is to water as many flower plots as possible by keeping the thumb on the watering can and tapping the plot area that needs water.

Gauging the Player's Performance

The measures used to assess player performance differ per task (Table 2). To establish baselines for performance, the game was first played by players with normal hand functions. The performance measures of these players were recorded and used to arrive at an achievement star rating. A three-star rating implies that the user's

Table 2. Bases of Assessment.

Game type	Fixed variable/s	Monitored data
Dragging	Total number of toppings, time	Accuracy, time taken
Tapping	Total number of notes, time	Accuracy
Stretching	Total number of plant plots, accuracy	Time taken

performance is more or less similar to players having a normal hand function. If the player meets the qualifying outcome level or is able to complete the specified task, the next level is automatically unlocked. He can then choose to continue with the current task or proceed to another task.

Pilot Testing and Debriefing

After obtaining approval from the Ateneo de Manila University's University Research Ethics Committee, we pilot tested FINDEX with three patients recovering from strokes. The following inclusion/exclusion criteria were used to select patients:
Inclusion criteria:

1. Able to extend wrist and fingers at least 10 degrees
2. Functional hearing and vision
3. Undergoes a standard rehabilitation program

Exclusion criteria:

1. Severe pain in the impaired arm

We initially recruited five stroke patients from Sta. Ana Hospital in Manila. However, only three out of five patients were able to complete all the testing sessions. Table 3 summarizes patient information with the pseudonyms as patient identifiers. Note that none of the patients had previously played touch-screen (TS)-based games and only one of the patients used and owned his or her own touch-screen device. All patients played all tasks in the game for a maximum of 30 minutes. The actual number of trials and maximum level that a patient achieved depended on that patient's performance and health condition.

In-Game Measures

The game was used in conjunction with standard therapy over a 1.5-month period. As the players used the game, the game gathered objective performance data. The data gathered in the game were used in the analysis of the game's ability to improve patients' fine finger dexterity. To determine if the fine finger dexterity of the patients had indeed improved, we calculated the percentage differences of the results of the first testing session and the results of the last session after the 2-week break. Table 4 shows that all patients had achieved progress: Their performances in the last testing session were generally better than their performance during their first game attempts.

Table 3. Test Subject Details.

Patient	Gender	Age	Months post-stroke	Affected hand	Rehabilitation schedule	Capabilities of affected hand	Use TS devices	Own TS devices	Play TS-based games
A	M	47	67	Left, dominant	3×/week	Household chores including sewing and sketching	Y	Y	N
B	F	64	28	Left, nondominant	2×/week	Mostly household chores	N	N	N
C	F	57	23	Right, dominant	1×/week	Mostly household chores	N	N	N

Note. TS = touch-screen.

Table 4. Percentage Difference Between the Performances of the Patients During the First and Last Game Trials.

		Patient A	Patient B	Patient C
Task	Objective measure	% difference	% difference	% difference
Dragging	Accuracy	0.6	−1.4	0.9
	Time taken	26.8	45.2	44.6
Tapping	Accuracy	37.8	20.1	14.0
Stretching	Time taken	63.8	27.6	3.8

The patients had improved in varying degrees for a specific fine finger skill. Patient A achieved the largest improvement on a single task—63.8% for stretching. His score was followed by Patient B—45.2% for dragging. However, it can be observed that these percentage differences were not from the same task, and thus, they involved a different fine finger skill. On the one hand, Patient A had improved more in his finger extension and flexion than in his finger isolation and coordination, which were addressed by the stretching and tapping tasks, respectively. On the other hand, for Patient B, it was the skill involved in the tapping task which had improved more. Therefore, we could say that despite performing the same game tasks with the same frequency, the fine finger skill that improves can still vary depending on the players. This generalization supports the idea that stroke patients develop fine finger dexterity skills in different paces depending on their health conditions, the differences of the standard rehabilitation program they have, and the frequencies of their standard therapy treatment.

Debriefing Interviews

The debriefing process serves several purposes. It enables players to reflect upon the gaming experience and learn from it (Crookall, 2010). It also allows game creators to

Table 5. Summary of Debriefings.

Debriefing	Duration	Patient responses	Researcher observations	Patient suggestions
1	20 min	Patients had difficulty with the game when they experienced numbness in the upper arm or limited fine motor skills		One patient suggesting making the game more challenging
2	15 min	Patients had difficulty with the game because of hand numbness and jitter. One patient also experienced eye fatigue	Patients are more satisfied with the game. Patients expressed preference for using the game in conjunction with or instead of standard therapies	One patient suggested making the game more challenging
3	20 min	Patients had difficulty with the game because of hand numbness	Patients fine motor skills were improving	

find out what players liked or did not like about the game and how the game can be improved (Lennon, 2010). To these ends, the researchers surveyed the players for their opinions using structured interviews.

Before the start of the testing period, the selected participants were required to sign a patient information and informed consent form. This form stated that the patient was willing to participate in the study and had read and agreed with the terms and conditions in the form. Among the terms and conditions were the possible health benefits as well as risks of playing the game. The form further stated that debriefing interviews were built into three of the testing sessions. These interviews were administered personally by one of the researchers, on a one-on-one basis with each patient, immediately after a testing session. The researcher followed a written interview guide that contained standard questions. Each debriefing lasted no more than 20 minutes. The main goals of the debriefing interviews were to gather feedback from the patients and to assess their perceptions of their fine motor performance. Table 5 summarizes the findings from the three debriefings.

Debriefing 1. We conducted the first debriefing session during the first testing session. It aimed to capture the background of the patients with regard to using a touch-screen device, and then their initial response on their first attempts in playing each tasks of the game. We found that only one of the patients used and owned a touch-screen device and that none of the patients had ever played a touch-screen game.

For the dragging task, Patient A did not find it difficult to place the toppings accurately on their designated spots, while both Patients B and C thought that their hands were still adjusting with the game play itself as it was their first time to play

touch-screen games. Patients also explained that the numbness of their arms and the muscle strain that they felt when lifting their shoulders prevented them from advancing to the next levels.

For the tapping task, Patients A and C said that they had an easy time tapping the piano keys. However, Patient B complained that it was difficult for her to reach the key dedicated to her left thumb. Both Patients B and C agreed that it was difficult to follow the prescribed order of the tapping task because the pace of the task was too fast and their hand coordination was not yet good.

For the stretching task, it was only Patient C who had a hard time pressing the watering can as she complained that her thumb often slid away from the designated spot. Patient C also complained that she had a hard time tapping the soil slots while pressing the watering can with her ring and little fingers. All patients agreed, though, that following the order in tapping the soil was relatively easy.

When asked for suggestions about the games in general, Patient A suggested making the games in more challenging while Patient C gave an insight that if patients practice the tasks more, they will eventually get better scores.

For the tapping task, Patients A and C said that they had an easy time tapping the piano keys. However, Patient B complained that it was difficult for her to reach the key dedicated for her left thumb. Both Patients B and C reported difficulty with the task because the pace was too fast and their hand coordination was not yet good.

For the stretching task, it was only Patient C who had a hard time pressing the watering can as she complained that her thumb often slid away from the designated spot. Patient C also complained that she had a hard time tapping the soil slots while pressing the watering can with her ring and little fingers. All patients agreed, though, that following the order in tapping the soil was relatively easy.

When asked for suggestions about the games in general, Patient A suggested making the games in more challenging while Patient C gave an insight that if patients practice the tasks more, they will eventually get better scores.

Debriefing 2. We conducted the second debriefing session on the eighth testing session. It aimed to measure the progress that the patients had made from the series of testing sessions that they had undergone. Most of the questions from the first interview were repeated in order to capture the possible changes that may have transpired while they were undergoing the sessions. The remaining questions dealt with the development of the condition of the patients. The researchers noted an improvement in patients' performance. By the eighth session, all patients were able to unlock all levels of each task. Likewise, their satisfaction with the game had increased. Patient A noted that the dragging task became more difficult than the tapping task while he still viewed the stretching task to be relatively easy. Patient B's views of all the tasks had not changed—she still found them easy. Patient C thought all the tasks were easier to play than before, especially the dragging and stretching tasks.

The patients were asked how the game had helped them medically. Both Patients A and B thought that the game has greatly helped them in improving their fine motor performance, while Patient C thought that the game had in some ways helped her in

improving her condition. When asked whether they preferred using the game over undergoing the standard finger exercises, Patient B said she favored using the game entirely. On the other hand, Patients A and C thought that the game could be used for rehabilitation in conjunction with the standard finger dexterity exercises.

The next part of the interview examined the difficulties that the patients had encountered throughout the time they were using of the game. For the dragging task, all of them still found it difficult to place the toppings on their designated spots because of the hand numbness and jitter. Some of the other problems that hindered the patients from advancing to the next level in the dragging task were the difficulty in differentiating topping spots—matching a topping to its spot took several tries. Also, Patient C reported that staring at the tablet screen for a long time made the patients' eyes hurt. She suggested that patients take a break of at least 3 minutes after each game attempt.

For the tapping task, all of the patients did not have a problem in tapping the piano keys. However, Patient C still found it hard to follow the prescribed order of the finger to be used in tapping especially on the levels where the transition from one key to the other is fast. Patient A supported this when he commented that sometimes he felt frenzied and frantic while playing the game.

Last, for the stretching task, all patients found pressing the watering can and tapping the soil slots in order relatively easy, except when using the ring and little fingers. Other complaints for the stretching task included the feeling of being frenetic while playing the game, as well as how the game could be strenuous when played continuously.

A new section that was not included in the first interview, but was the focus of the second interview, was the set of questions that aimed to measure how the patients see their progress since the second day of their testing session. Patients generally agreed that they were improving.

Finally, when asked for comments and suggestions, Patient A still thought that the patients using the game should be given more challenge. Patient C agreed with the idea of Patient A by saying that there should be more levels for the stretching task. Patient B commented that the game would be very helpful for stroke patients like her.

Debriefing 3. We conducted the third and final debriefing session at the end of the last testing session. We intended to measure whether the patients maintained the progress they made throughout the duration of the testing period, even after the 2-week break given. The patients were again asked about the difficulties that they had encountered during their last trials in performing the tasks in the game. For the dragging task, Patient B still had the difficulty dragging the toppings on their designated spots. She attributed this problem with hand numbness which she in turn attributed to her failure to take the medicine that her doctor prescribed. Patient C said that she felt that the pressure she exerted in dragging the toppings was still weak. Patient A did not have any difficulties with the game other than the occasional tension that he felt in trying to achieve the 3-star rating.

For the tapping task, Patient B did not have any difficulties in either tapping the piano keys or following the prescribed order; her only complaint was that she still had the feeling of disconcertment when playing the last level of the game. Patient C said that she felt the improvement she gained in playing the game. She said that she could move her fingers more easily and could tap the correct piano keys. She also said that she did not find it too hard to follow the sequence of keys to be tapped; her only complaint was that the game could be tiresome when played continuously for a long period of time. For Patient A, the tapping task had been an easier game to play; he did not have any problems when playing it.

Finally, for the stretching task, all patients said that it was easy to press the watering can and follow the order of the soil plots to be tapped.

Conclusion

Therapeutic specialists have been taking advantage of computer-based games to facilitate the recovery process of stroke patients. Most recently, therapists have been incorporating touch-based devices such as tablets PCs as tools for therapy. In this article, we discuss the motivation, design, development, and pilot testing of FINDEX, an Android tablet-based game, for fine finger dexterity therapy for stroke survivors. The three tasks within the game addressed three types of finger movement: dragging (for finger control), tapping (for finger isolation and coordination), and stretching (to increase range of motion). The game was designed to monitor and report patient progress.

Once developed, we piloted the game with three stroke survivors. The patients reported that both the dragging and stretching tasks were relatively easy. The tapping task, on the other hand, was perceived as moderately difficult. In the debriefing, patients said that they found the game useful in that it helped them improve fine motor performance. From their own subjective perspectives, the game generally helped patients improve in all the task types. Patients also reported that this format of therapy was more engaging than standard physical therapy activities.

Although the results of the study were promising, the work is subject to two main limitations. First, we recorded the game performance of several test subjects to whom we considered to have normal hand function to establish our baseline measures. However, the hand functions of these test subjects were not first measured using objective tests such as the Purdue Pegboard or the Rosenbusch Test of Finger Dexterity. We therefore recommend that succeeding versions of the game validate the baseline measures.

Second, the sample size of the testing population was small and patients were engaged in other therapies. This game therefore cannot claim sole credit for improvements in patients' fine motor skills. We recommend that succeeding versions of the game be tested with a larger population and that these tests control for the impact of other therapies.

Despite these limitations, what we may draw from this study is that games can indeed become instrumental in achieving better health. Therapy can become play, monitoring can become incidental and unobtrusive, and games can become more than just fun.

Author Contributions

CC, CD, and EP were responsible for the design, development, and testing of the program as well as much of the writing of this article. MR helped conceptualize the application, provided guidance and monitoring throughout the design, development, and testing process, and contributed substantially to writing the article.

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