Usability Evaluation of Digital Games for Stroke Rehabilitation in Taiwan

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Abstract—**This study aimed to compare the effectiveness and usability of using conventional devices, Wii and XaviX, in rehabilitation, and to propose advices to improve the digital game design. A clinical trial was implemented to evaluate the effectiveness and the usability of using Wii and XaviX in rehabilitation; they were assessed by stroke patients. Twenty-eight stroke patients were divided in three groups: Conventional, Wii, and XaviX groups. The results can be summarized into the following points: (1) The effectiveness index in each group indicated improvements for upper extremity function in stroke patients. However, the effectiveness indexes of each assessment between three groups do not have significant differences. (2) All patients in this clinical trial had fun when using the digital gaming devices for rehabilitation. (3) The suggestions for improving the design in digital games are as follows: to increase difficulty, and the response time, levels of the games need adjustment; to record movement data and game scores each time, the hand controller must be interchangeable for the users; the controller should be adjustable to fit different hand dimensions of the patients; the game and controller movements need to be designed to correspond to real-life activities; and the controller's operation needs to be simplified. In order to make these devices more suitable to use in rehabilitation, a comprehensive follow-up design development based on these proposed guidelines would be necessary in order to embody design improvements of the devices.**

Keywords- commercial video game; stroke; upper extremity rehabilitation.

I. INTRODUCTION

Stroke is one type of the cerebrovascular disease threatening people in modern societies. Upper-extremity motor deficit is one of the main symptoms for the stroke patients [1]. Many daily living tasks are performed by the upper extremity; therefore, rehabilitation treatment of upper extremity is very important for stroke patients. In order to restore the movement function of patient's upper extremity, patients must accept the rehabilitation activities. A rehabilitation device is an essential tool in the process of rehabilitation therapy. A study [2] has found that the current clinical upper extremity rehabilitation devices are mostly static and provide no feedback to the patients. Patients easily feel bored while repeating the same activity, hence generating a negative attitude toward the therapy process [3][4][5]. In order to increase mental satisfaction and physical vitality in rehabilitation therapy, some therapists have tried to use the off-the-shelf digital game devices in rehabilitation and have found effective treatment outcomes in in addition to enhancing the patient's treatment motivation [4][6][7].

There are already many studies focused on digital game devices in rehabilitation such as Wii [4][5][7][8][10], Playstation EyeToy [6][9] and Kinect [5]. For example, a study examined the feasibility and safety of the Wii gaming system and compared it with recreational therapy in facilitating motor function of the upper extremity [8]. The results showed that Wii gaming technology represents a safe, feasible, and potentially effective way to facilitate rehabilitation therapy and promote motor recovery after stroke. However, some of Wii's disadvantages were that stroke patients found the control of the handset buttons difficult and frustrating to use; however, this obligatory hand use improved gross motor dexterity. Stroke patients did not simply play Wii sports, rather the device was used as a rehabilitation tool with targeted and movement goals aimed at reinforcing appropriate and coordinated motor patterns [7].

The above-mentioned studies reveal that there are some usage problems to directly apply the off-the-shelf digital game devices in clinical rehabilitation. User-centered design emphasizes that designers observe the behaviors and usage situation of the actual user's experience, that is, how users use a product and what problems and needs exist. About the medical and rehabilitation equipment, variables for evaluation may include effectiveness, ease of use, comfort, and acceptability [10]. Through design, these off-the-shelf digital game devices can be tailored for different stroke patients for their respective requirements in the rehabilitation therapy. It will make the devices more suitable for rehabilitation therapy, and enhance the use safety and effectiveness for stroke patients.

These existing devices are originally designed for entertainment with normal people with healthy physical and action conditions, not intended for rehabilitation therapy

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purposes or for people with physical disabilities [6]. Further confirmation and evaluation is necessary to see if a digital game device can really meet the user's usability needs in addition to its rehabilitation effectiveness.

Nintendo Wii and XaviX have been tested in clinical rehabilitation in several hospitals in Taiwan. However, whether the superiority of Virtual Reality systems can facilitate conventional therapy currently in use remains to be determined [3][11][12]. Further development is required to ensure that these devices are easy for patients and therapists to set up in a clinic [6]. A pilot trial was implemented to evaluate the effectiveness, usability and satisfaction between conventional devices, Wii, and XaviX in rehabilitation [13]. However, the result of effectiveness showed no statistically significant improvements between groups, due to the number of patients is limited. Therefore, this report aimed to increase larger number of patients to compare the effectiveness and usability of using conventional devices, Wii and XaviX in rehabilitation, and to propose advices on improve the digital game design.

In the following sections, the methods applied and results obtained will be described respectively, and then the implication of the results will be discussed, followed by a brief conclusion.

II. METHODS

A clinical trial was implemented to evaluate the effectiveness between conventional devices, Wii, and XaviX in rehabilitation. In addition, the usability of using Wii and XaviX in rehabilitation were also assessed by stroke patients. The following two sections describe the research contents for these two kinds of subjects, respectively.

A. Effectiveness evaluation

Stroke patients were recruited from the occupational therapy department of Chung Shan Medical University Hospital. Inclusion criteria were the following: (a) Hemiparetic with upper extremity dysfunction following a single unilateral stroke, (b) a history of first-time stroke (3-48 months post stroke), (c) the required upper extremity rehabilitation convalescent levels were Brunnstrom stage III to IV, i.e., having basic upper extremity synergies to perform joint movement voluntarily, (d) ability to communicate, (e) able to understand and follow instructions. Exclusion criteria were the following: (a) engaged in any other rehabilitation program during the study and (b) serious aphasia or cognitive impairment. Each patient gave informed consent. This study was approved by the Human Research Ethics Board of Chung Shan Medical University Hospital.

A total of 28 post-stroke patients were admitted to the Occupational Therapy Department of Chung Shan Medical University Hospital. The mean age of the patients was 53.1 years (SD 15.1), with a mean post-stroke time of 9.2 months (SD 7.5). The characteristics of the patients in the three study groups are shown in Table 2. As the data were not normally distributed, non-parametric tests were conducted. There were no statistically significant differences among the three groups with regard to age, time since stroke onset. Of the 4 who did not finish, 1 was transferred out of the hospital, 1 was discharged, and the other 2 failed to continue treatment. Twenty-four consecutively screened stroke patients finally completed the trial.

Conventional equipment, Wii, and XaviX, were used in this trial (Table 1). Each group was assigned to use two games or equipment in the additional treatment. The games and equipment for the groups were selected by three occupational therapists, and were considered as similar in training effect on upper extremity movements. For Nintendo Wii, two games (boxing and bowling) of Wii Sport were selected to use in this trial. As for XaviX, two games (bowling and ladder climbing) were selected to use in this trial. Ladder climbing contains three levels (easy, normal and difficult). While playing bowling, the user needed to hold a soft bowling ball, fixed to the hand with a safety belt. In ladder climbing, the user needed to wear glove sensors in the palms of both hands [14]. Corresponding to the Wii games (Bowling and Boxing) and the XaviX games (Bowling and Ladder climbing), two conventional equipment (Curamotion exerciser and the Climbing board and bar) were selected in this trial. Both are commonly used in rehabilitation.

Four functional assessments were used as follows:

a) Fugl-Meyer Assessment of Physical Performance (FMA) [15]. It was used to evaluate the motor functions. The upper extremity motor test part with a possible highest score of 66 was adopted in the evaluation. The reliability of Fugl-Meyer Assessment is generally considered reliable [16].

b) Box and Block Test of Manual Dexterity (BBT). It was used to test gross manual dexterity of a patient's affected side [17]. In the test, the patient was asked to move as many cubes (of side length of 2.5 cm) as possible using only the thumb and index fingers during a timed 60s trial.

c) The Functional Independence Measure (FIM). This scale assesses physical and cognitive disability. The scale includes 18 items, of which 13 items are physical domains based on the Barthel Index and 5 items are cognition items. Each item is scored from 1 to 7 based on level of independence, where 1 represents total dependence and 7 indicates complete independence. This measurement was assessed and shown to have high reliability and validity [18][19][20].

d) Upper extremity range-of-motion (ROM). This is used to assess the passive and active range-of-motion on the affected side [21].

The training comprised 20 sessions during 2 months, with each session lasting 30 minutes (excluding set-up time). The effectiveness was evaluated before and after completing the 20 training sessions. In addition to these trainings (Wii, XaviX, and Conventional) in this study, all patients also received at least 1 hour of occupational therapy and 1 hour of physical therapy. After training, all patients asked to fill in a questionnaire. The content of the questionnaire is shown in the following section.

B. Usability evaluation by the patients

Three 5-point Likert type questions about satisfaction, motivation, and fun were then presented on a sheet of paper for the patients to answer. By this trial, we expected to understand the patients' satisfaction with using the digital gaming devices in clinics.

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C. Usability evaluation by the occupational therapists

The method of expert interview was conducted to survey the current situation of the use of digital game devices and evaluate the usability of such devices in upper extremity rehabilitation therapy. The locations, participants, contents of the interview and process are as follows.

The selection criteria for the interview subjects were mainly based on hospital size, type (public vs. private), geographic location, and types of digital games used. Two hospitals were selected in a preliminary investigation: Taipei Veterans General Hospital (TVGH) and Kaohsiung Veterans General Hospital (KVGH). Wii was used in Kaohsiung Veterans General Hospital and XaviX was used in Taipei Veterans General Hospital.

The occupational therapist plays a major role in the rehabilitation process to determine how the digital game device is used. As a professional, the occupational therapist possesses expertise about therapy theory and experiences, which are useful for the evaluation of rehabilitation devices or the commercial products applied in rehabilitation.

Selection criteria for the interviewed therapists were: at least 5 years of work experience in occupation therapy, and at least one year experience in adopting the digital game device intervention in rehabilitation treatment. In total, eight therapists were selected and interviewed, three (one male [A] and two females [B, C]) from KVGH and five (two males [D, E] and three females [F, G, H]) from TVGH. They have an average age of 35.1 yrs (SD=6.3) and work experience of 10.8 years (SD=6.3).

TABLE I. GAMES AND CONTROLLERS OF NINTENDO WII AND XAVIX

Groups	game		controller	usage situation
Nintendo Wii	bowling			
	boxing			
XaviX	bowling			
	ladder climbing			

Semi-structured interviews were used, which mainly consisted of two parts: (1) Therapist personal profile - therapist gender, age, hospital name, and work experience in years, and (2) Questions about the usability evaluation of existing digital gaming device: The questions were:

1. Effectiveness: How do you feel about the therapy effectiveness of the device in restoring the patient's upper extremity functions?
2. Ease of use: Do you have any usage problems in setting up the device to be used for therapy? What needs to be improved in the design of the devices?
3. Acceptability: How do the patients respond to the use of digital game device in rehabilitation? Do they accept it and like it?

D. Data analysis

All data were analyzed with SPSS for Windows version 13.0 (IBM SPSS, Inc., Chicago, IL, USA). Intention-to-treat analysis (ITT) was used to analyze all data in each group [22]. The missing subjects who actually did the pre-test were included as subjects who had received treatment, and their pre-test scores were addressed so that they equaled their post-test scores; however, these scores indicated very little about the efficacy of the treatment. The characteristics of the study groups were described as mean and SD. The Wilcoxon signed rank test was the non-parametric alternative to the two-related samples tested for pre- and post-tests in each group, and the Kruskal-Wallis one way analysis of variance by ranks test was used for differences in the effectiveness index between groups. Differences were considered significant when $p<0.05$. For each group, the effectiveness index of each functional assessment was calculated, i.e., the post-test score minus the pre-test score, and then divided by the maximum possible progress (possible highest score of the assessment minus pre-test score) [23]. To analyze the interview data from occupational therapists, the recording was firstly transcribed verbatim. Similar opinions were combined and all unique responses were independently itemized for further discussion. To analyze the questionnaire, data from stroke patients who completed treatment according to the devices used (conventional devices, the Wii device and the XaviX device). For each question on the questionnaire, the mean and standard deviation were calculated.

III. RESULTS AND DISCUSSION

A. Within-group differences in score changes for each group

Comparison of the pre- and post-test subjects in each group showed significant improvements for upper extremity function in stroke patients (Table 3). The XaviX group had significant differences on four assessments: the FMA ($p=0.009$), BBT ($p=0.022$), FIM ($p=0.009$), ROM-proximal ($p<0.001$), and ROM-distal ($p<0.001$). However, the conventional group and the Wii group had significant differences on three assessments: the FMA, FIM, and ROM. In addition, the results showed that the effectiveness index of each group indicated improvements for upper extremity function in stroke patients on the FMA, BBT, FIM, and ROM (Table 3).

B. Between-group differences in score changes of effectiveness index

The Krusal-Wallis one-way analysis of variance ranks showed no significant differences among the three groups for the FMA ($p=0.349$), BBT ($p=0.950$), FIM ($p=0.644$), ROM-proximal ($p=0.186$), and ROM-distal ($p=0.114$). On the other hand, comparing the effectiveness index of each assessment in three groups, we found that the effectiveness index of the Wii group on the FMA (mean=0.37, SD=0.21) indicated greater improvement than that of the XaviX group (mean=0.27, SD=0.33) and conventional group (mean=0.26,

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SD=0.05). The mean score of the effectiveness index of the XaviX group was close to that of the conventional group.

TABLE II. CHARACTERISTICS OF STROKE PATIENTS

Characteristics		Conventional	Wii	Xavix	P-value*
Number of subjects		8	9	11	
Gender (male/female)		5/3	6/3	7/4	
Age (years)	mean (SD)	48.5 (16.4)	49.6 (15.1)	59.5 (13.1)	0.184
Time from stroke onset to involvement in gaming (months)	mean (SD)	6.3 (3.7)	9.8 (3.5)	10.7 (11.0)	0.143
Paretic side (left/right)		4/4	4/5	5/6	
Brunnstrom stage	proximal (median, range)	4.0 (4-4)	4.0 (4-6)	4.0 (3-5)	
	distal (median, range)	4.0 (2-4)	4.0 (3-6)	4.0 (1-5)	

* P for conventional group versus Wii group versus XaviX group
FMA (UE): The upper extremity portions of the motor subscale of the Fugl-Meyer Assessment; FIM: Functional Independence Measure; BBT: Box and Block Test of Manual Dexterity; ROM: Upper extremity range-of-motion.

TABLE III. WITHIN-GROUP DIFFERENCES IN CHANGE SCORES FOR PRE- AND POST-TEST IN EACH GROUP

assessments	Conventional		Wii		Xavix	
	mean (SD)	P-value [a]	mean (SD)	P-value [a]	mean (SD)	P-value [a]
FMA (UE) (pre-test)	27.0 (7.0)	0.006**	42.2 (13.9)	0.006**	39.6 (18.6)	0.009**
FMA (UE) (post-test)	37.9 (4.5)		50.3 (10.5)		44.7 (18.4)	
BBT (pre-test)	8.5 (10.5)	0.103	23.9 (16.6)	0.070	24.5 (20.4)	0.022*
BBT (post-test)	10.0 (12.0)		28.2 (18.5)		26.7 (21.8)	
FIM (pre-test)	72.3 (12.8)	0.009*	80.3 (9.1)	0.021*	75.5 (9.1)	0.009**
FIM (post-test)	96.6 (11.1)		82.6 (7.8)		79.1 (7.5)	
ROM-proximal (pre-test)	63.9 (41.7)	0.000**	81.8 (48.5)	0.000**	76.5 (46.7)	0.000**
ROM-proximal (post-test)	80.1 (47.6)		91.1 (50.7)		88.8 (45.8)	
ROM-distal (pre-test)	18.1 (27.4)	0.000**	41.6 (33.9)	0.000**	30.6 (36.0)	0.000**
ROM-distal (post-test)	27.3 (29.8)		50.0 (32.9)		39.0 (37.6)	

a P for Within-group differences in change scores for pre- and post-test
* Significant at ≦0.05 level
** Significant at ≦0.01 level

C. *Results of usability assessment by stroke patients*

Motivation. Did it promote your treatment motivation when you used the Wii, XaviX or conventional equipment for treatment? Patients of the Wii and XaviX groups agreed that digital games used in the treatment promoted their treatment motivation (Wii: mean=3.8, SD=1.0; XaviX: mean=3.8, SD=0.9; Conventional: mean=3.5, SD=0.5).

Fun. Do you feel that using the Wii, XaviX or conventional equipment for treatment was more interesting than traditional rehabilitation devices? Patients of the Wii and XaviX groups agreed that these devices were more interesting than traditional rehabilitation devices (Wii: mean=4.3, SD=0.9; XaviX: mean=4.4, SD=0.5; Conventional: mean=2.3, SD=0.9). Seven of them specially mentioned that these devices provided useful information, such as the scores, audio and video feedbacks, as well as interesting interactions, making them feel positively toward doing the treatment activities.

D. *Results of usability assessment by occupational therapists*

Effectiveness: How do you feel about the therapy effectiveness of the devices in restoring the patient's upper extremity functions? For effectiveness of Wii, all three therapists with experience in Wii (A, B, and C) agreed that the Wii Sport was effective in upper extremity rehabilitation, in addition to enhancing the patient's treatment motivation. In addition, Therapist A suggested that Wii Fit was especially suitable for balance therapy for stroke patients. For effectiveness of XaviX, all five therapists with experience in XaviX (D, E, F, G, H) agreed that the device is effective in upper extremity rehabilitation, and could enhance the patient's treatment motivation and pleasure. D also commented that some of the game projects with their controllers can effectively strengthen the training of reaching and grasping movements and achieve better therapy effectiveness as compared to the traditional devices. For instance, when the patient wears the gloves as controllers in the XaviX games, his/her hands are required to actually do the reach and grasp movements to complete the game task. In so doing, the training of the hands in those movements are apparent and practical. In addition, therapists E and F mentioned that the existing traditional devices are still important in rehabilitation and not possible to be fully replaced by digital gaming devices. The traditional devices do not require the patient to react in time and restrict his/her movement speed, hence the patient can repeat the movement as many times as he/she wishes and at a speed at his/her own control. Therefore, the digital game device can play a supporting role in rehabilitation treatment by providing diversification and interesting game projects for improvement of patient motivation toward the treatment.

Ease of Use: Do you have any usage problems in setting up the devices to be used for therapy? What needs to be improved in the design of the devices? For the Wii, all three therapists (A, B, C) considered that the device is easy to set up, except some errors may occur when setting the game software items. The usage problems of this device are:

- The current software interface is in Japanese and not easy to understand, hence is prone to cause errors in the set-up process;
- The required response time of the game is too fast and not easy to keep up with by the patients;
- Some patients may have difficulty to hold the hand controller, hence need additional bandage to tie it on the hand;

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- For some patients, the games are too difficult.

For XaviX, all five therapists agreed that the hardware is easy to set up, except the software interface operation may cause occasional mistakes. The usage problems of this device are:

- The current software interface is in Japanese and not easy to understand, hence is prone to cause errors in the set-up process, especially for the games of visual perception and memory training, which are impossible to operate without literacy of the Japanese language;
- The sensor is not sensitive enough, e.g., the action may obstruct the reflective film and interrupt the detection by the sensor;
- The controller gloves have only one single size, do not necessarily fit to all patients;
- Although the games are available in three levels of difficulty, the differences between the difficulties are too abrupt and hard to meet the patient's required degree of difficulty.

Acceptability: How do the patients response to the use of digital game devices in rehabilitation? Do they accept it and like it? The result shows that all eight therapists agreed that most patients can accept the use of Wii or XaviX for treatment. Therapist B explained that people interested in the game have a very high degree of acceptance of such devices. However, some elderly patients tend to prefer using the traditional rehabilitation devices, because they feel that the traditional devices are some physical objects that can be held and manipulated, hence giving a feeling of the effect of treatment. On the contrary, digital game devices give an impression of laxness and frivolity, and hence are inefficient and ineffective.

IV. CONCLUSION

This study conducted a clinical trial to examine the therapeutic effectiveness and usability of using conventional devices, Wii and XaviX on upper extremity functional recovery after stroke. We also used the intention-to-treat concept to analyze all data (except for motivation and enjoyment) in order to avoid overoptimistic estimates of the efficacy of an intervention resulting from the removal of non-compliers by accepting noncompliance and protocol deviations. The effectiveness index in each group indicated improvements for upper extremity function in stroke patients. However, the effectiveness indexes of each assessment between three groups are not significant differences.

The results obtained from the interviews, it was found that the digital game devices currently used in clinical rehabilitation have been evaluated by professional therapists as useful and effective in supporting the treatment, though some design improvements may be necessary. In order to involve stroke patients in rehabilitation treatment as users of game devices for general players, factors concerning usability and safety in terms of interface with the stroke patients need to be further enhanced. Design guidelines concerning the improvement of existing digital game devices can be synthesized as follows, where items a to d are about software design, and items f to i about hardware: (a) To increase the response time of the games. (b) To increase difficulty levels of the games in order to better suit the various patients with different abilities of upper extremity functions. (c) To expand the sensor's sensing scope. (d) To be able to record movement data, such as: reaction time, operating time. (e) To improve the ways to fix the controller on the user's hand. (f) To fit the controllers size for different hand dimensions of the patients. (g) To provide better correspondence between the game and real-life movements. (h) To provide controllers for body control training, such as chest strap and belt. (i) To simplify the controller's operation.

Two suggestions are proposed for future studies: (1) the therapists in the study had all chosen to use digital devices for intervention for at least a year, it may biased the results. It will be better if the views of those therapists who choose not to use digital games were also further surveyed. (2) In order to make these devices more suitable to use in rehabilitation, a comprehensive follow-up design development based on these proposed guidelines would be necessary in order to embody design improvements of the devices.

ACKNOWLEDGMENT

This study is supported by the National Science Council of the Republic of China with grant No: NSC 100-2221-E-040-009-MY2.

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