The Design and Evaluation of an Activity Monitoring User Interface for People with Stroke

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***Abstract*— Usability is an important topic in the field of telerehabilitation research. Older users with disabilities in particular, present age-related and disability-related challenges that should be accommodated for in the design of a user interface for a telerehabilitation system. This paper describes the design, implementation, and assessment of a telerehabilitation system user interface that tries to maximize usability for an elderly user who has experienced a stroke. An Internet-connected Nintendo® Wii™ gaming system is selected as a hardware platform, and a server and website are implemented to process and display the feedback information. The usability of the interface is assessed with a trial consisting of 18 subjects: 10 healthy Doctor of Physical Therapy students and 8 people with a stroke. Results show similar levels of usability and high satisfaction with the gaming system interface from both groups of subjects.**

I. Introduction

A person affected with stroke tends to be middle aged or older: in 2010, the average age at first stroke was 72.3 years for females, and 68.8 years for males [1]. A challenge exists in engineering a cost-effective and highly usable user interface for a telerehabilitation system operated by older people with stroke.

While methods for developing appropriate technologies based on user capabilities already exist, more empirical research on designing for older adults, who are often novice computer users, is crucial [2],[3]. In general, a user-centered design that derives its requirements through close analysis of capabilities, limitations, and concerns of older and/or disabled populations has been shown to be successful in the design of user interface software [4]-[7]. Current rehabilitation research has incorporated gaming systems as a feasible, cost effective rehabilitation tool [8]-[12], but has not yet evaluated the usability of a gaming system specifically as an interface tool for older people with stroke. For this purpose a gaming system might prove both highly usable and cost effective. The user interface reported in this manuscript is a part of a telerehabilitation system for individuals recovering after stroke. The telerehabilitation system utilizes shoe-based sensors (SmartShoe) for monitoring activity and gait in people with stroke [13]-[15]. The data collected by the shoe sensors could provide feedback for people recovering from a stroke in a home environment and aid in rehabilitation. This paper investigates the usability of a Nintendo® Wii™ gaming system and web-based software as the user interface component of this in-home monitoring system. The system determines the activity level of the person by characterizing how many minutes the patient has been walking, standing and sitting over the course of a day. The interface displays feedback information in the form of daily sums and the patient's progress toward activity objectives. The interface is displayed on a television within his or her own home as well as to a physical therapist over a remote computer interface. The interface also allows the user to set daily activity objectives, provides feedback on whether the objective has been met for that day and allows for communication with the physical therapist. In the following sections, the design, implementation and evaluation of the gaming system interface will be described.

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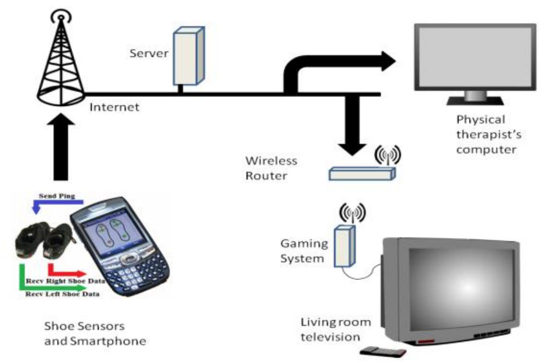

Figure 1: SmartShoe telerehabilitation system from [15] connected to a user interface.

II. Methods

In this work, monitored physical activity information is collected by the SmartShoe system previously described in [15], which consists of shoes modified with pressure sensors and accelerometers, as well as a small module that sends raw sensor data wirelessly via Bluetooth to a smart phone in the wearer's pocket (Figure 1). The smart phone then sends raw sensor data to a server machine, after which a MATLAB script implements pattern recognition using a Support Vector Machine (SVM), extracting activity information and dividing activities into three categories: 'walking', 'standing', or 'sitting'. The MATLAB script then computes the time durations of each activity and sends the result to a server machine that processes the information using PHP (a server-side scripting language). The processed activity duration information is then stored in a Structured Query Language (SQL) database on the server. The user interface is

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implemented as a website displaying the activity data. The interface is accessed in the patient's home, or by a physical

Figure 2. The opening screen of the user interface visual display on the Nintendo® Wii™.

therapist (Figure 1). In light of the required functions and objectives, a Wii™ gaming system was selected as the hardware platform for the interface as user's existing analog or digital television could be used for visualization of activity data. An Internet connection, modem, and router are required in addition to the Wii™. The visual display on the user's TV screen consists of a web site with JavaScript [16] functions that extract information from the SQL database and send it over the Internet to the display on the user's television. The display is a website optimized for viewing by the Opera v9.27 [17] web browser, almost identical to v9.30 used by the Internet Channel application in the Wii™.

The functions of the interface are as follows: to allow the primary user, an older person who experienced a stroke, to receive feedback on their daily and monthly activity level, and also to allow a physical therapist to remotely gauge his or her patient's improvement and make recommendations to the patient. To design the software, elements of the Goal Directed Design (GDD) technique [18] were used, which is a user-centered technique of a similar nature to those implemented in [19], [20] that emphasizes researching the user's capabilities and understanding the user's goals in using the product. Key age-related characteristics of the user are changes in visual and cognitive ability, as well as in motor control [3]. In interviews conducted with people who experienced a stroke, stroke-related impairments also contribute to user capabilities and limitations. In the words of one interviewed person, "learning any new technology poses challenges". In another statement, a user said she would "learn to take shortcuts" when dealing with unfamiliar technologies, due to her disability. Also, due to the stroke, technologies that were once easy unexpectedly become much harder to use. The aptitudes of the primary user include an added resolve and determination, but also significant exasperation, with technological interfaces.

Compensating for age-related and condition-related changes in visual acuity and motor control, any text and graphics were made large to be easily read. Buttons were made large so that they were easy to hover the cursor over. Additionally, the buttons on the built-in on-screen keyboard of the Wii™ enlarge when the mouse hovers over them, decreasing the chance of accidently pressing an adjacent button. To reduce the frustration caused by excessive cognitive processing, the minimalistic interface included

TABLE I. SUMMARY OF SUBJECT GROUP BACKGROUND CHARACTERISTICS AND FAMILIARITY WITH INTERFACE TECHNOLOGY

	Students	**People with Stroke**
Number of subjects	10 (8F, 2M)	8 (5F, 3M)
Age	23.9±1.7 yr	63.0±9.7 yr
Time since subject experienced a stroke:	N/A	Average: 5.8 yr Range: 1.5 -11.5 yr
On a scale from 1 to 10, with 1 being least comfortable and 10 most, How comfortable do you feel with modern technology?	8.6±1.0	5.8±4.1
How often do you use a computer?	Daily: 10 2-3 Times/wk: 0 Once a month: 0 Very Seldom: 0 Never: 0	Daily: 2 2-3 Times/wk: 1 Once a month: 0 Very Seldom: 3 Never: 2
How often do you use a gaming system such as a Wii™ or Xbox™?	Daily: 0 2-3 Times/wk: 0 Once a month: 2 Very Seldom: 7 Never: 1	Daily: 0 2-3 Times/wk: 0 Once a month: 1 Very Seldom: 2 Never: 5

only the most necessary functions (Figure 2). In addition, Eighteen subjects were recruited to participate in the usability testing, including 10 Doctor of Physical Therapy (DPT) students and 8 people who had suffered from a stroke. A University Institutional Review board approved the study and all subjects provided informed consent. Table I compares the background characteristics of both groups.

A Proscan® 32" 1080p TV was placed approximately 7 feet from the subject, mounted on the wall with its base 5 feet from the ground. Prior to being tested on the interface, subjects completed a survey that asked about their demographics and familiarity with technology. Each subject was either read or asked to read a short user manual describing the interface, its overall purpose and its functions. This trained the subjects with the basics of the interface and familiarized them with its operation. The subjects were allowed no more than 15 minutes to practice with the interface using the Wii™ remote, during which they were able to ask any questions they had regarding the purpose and operation of the interface. Each subject was then asked to complete five tasks with the interface. Both subject groups completed the same tasks, although the tasks were worded slightly differently for the DPT students, who were asked to imagine that they were remotely checking the information of a hypothetical patient. It was made clear to the subjects that the interface was being tested, not them. Subjects with stroke were allowed to use their unaffected hand. The movements of the cursor on the TV screen were videotaped while the subjects completed the tasks, which were read aloud to the subject one at a time, as he or she completed them. Partial completion was defined separately for each task. The first two tasks required only comprehension of the information displayed on the starting screen for this task, and no navigation using the remote. Partial task completion was arbitrarily assigned. No partial completion was awarded for the first two tasks. The third task required the user to navigate to the 'sitting' activity data in the 'Progress' tab, and to count how many days that he/she has reached the 'sitting goal'. Twenty-five percent completion was awarded for each of the two correct button presses required, another 25% for counting data from a chart, and another 25% for correct counting. The fourth task required the user to set new goals for all three activities. Twenty percent completion was awarded if the subject navigated to the goal screen, 50% for entering a goal for each activity and pressing the 'Set Goal!' button, and ten percent for each goal that was the correct value. In the fifth task, the DPT students and subjects with stroke were asked to send a message to their hypothetical patient and caregiver, respectively. For both groups, twenty-five percent completion was awarded for navigation to the 'Goal' tab, 25% for entering a name, 25% for entering a sentence and 25% for sending the message. After finishing the five tasks, the subject completed a survey inquiring about his or her experience with the interface.

Usability of the interface for each subject group was reported using standard measurements used for determining efficiency and effectiveness [21], including task completion, time-on-task, number of errors made, and user satisfaction. Task completion, defined in the previous section, varied for each task. For all five tasks, clicking with the Wii™ remote on a wrong feature of the screen, wrong button or wrong tab, counted as an error. For the fourth task, inputting a wrong activity goal number was also counted as an error. For the fifth task, entering the wrong information in the wrong box (i.e., message in the name box), or entering no information in one or both boxes, were also counted as errors. Time-on-task and errors were determined by observing the video recordings of the screen. The metric for efficiency was calculated for each task by dividing the subject group's mean completion rate by the subject group's mean time-on-task. All survey questions were asked on a 10-point (Table 1) or 7-point (Table 2) semantic differential scale, and the mean and standard deviation for each rating was calculated. For all measurements, the statistical significance of the difference between each group was determined using a Mann-Whitney U test, $p<0.05$.

III. Results

TABLE II: SUBJECT RESPONSES TO SURVEY QUESTIONS ABOUT THEIR EXPERIENCE WITH THE INTERFACE

On a scale from 1 to 7, where 1 is the extremely easy, 7 is extremely hard, and 4 is neither easy nor hard:	Students	People with stroke	P value
How easy were five the tasks to do, as a whole?	3.9±1.5	3.9±2.0	p>0.05
How easy was it to read the numbers and words on the screen?	2.3±1.8	2.0±1.2	p>0.05
How easy was it to click buttons on the interface with the Wii™ remote?	3.7±2.1	3.8±2.0	p>0.05
How easy was it to learn the layout of the interface – to learn where certain information or tools could be found?	2.7±1.6	2.5±1.4	p>0.05
With 1 being extremely unsatisfied, 7 being extremely satisfied, and 4 being neither satisfied nor unsatisfied: Please rank your overall experience with the interface.	5.3±0.8	5.5±1.7	p>0.05

Tables 2 and 3 summarize the post-test results. Table 3 shows the results of the usability measurements for each task, and compares the DPT student and stroke subject groups. Although the students appeared more efficient while using the interface, there was no significant difference in efficiency between the two groups, except in task 3. There were no significant differences for completion rate, time-on-task, and errors per subject, except for time-on-task for task 3, where the students were significantly faster. The two groups had similar numbers for errors per subject. In Group 1, only one out of ten people decided to use the keyboard instead of the sliders to enter a goal, while in Group 2, six out of eight people used the keyboard.

IV. Discussion & Conclusion

Table 2 demonstrates very similar ease-of-use and satisfaction ratings between the students and people with stroke. The table also shows that both groups found most of their experience with the interface, such as reading the information, clicking buttons, and understanding the layout, as generally easy. The tasks as a whole were rated 'neither

TABLE III. COMPARISON OF USABILITY FOR STUDENTS (GROUP 1) AND PEOPLE WITH STROKE (GROUP 2)

	Completion Rate, % of tasks completed (std)		Time-on-task, seconds (std)		Efficiency (Completion rate/time-on-task) (std)		Mean Number of Errors per Subject (std)	
	Students	People with stroke	Students	People with stroke	Students	People with stroke	Students	People with stroke
Task 1	90(±32)%	88(±35)%	5.3(±3.1)	11.4 (±16.8)	27.7(±18.0)	55.6(±44.8)	0.20 (±0.42)	0(±0)
Task 2	100(±0)%	100(±0)%	6.6(±7.0)	5.7(±4.3)	28.6(±17.6)	17.8(±16.6)	0.40 (±0.70)	0(±0)
Task 3	80(±19)%	69(±29)%	14.4 (±10.7)*	88.1 (±71.0)	8.3(±5.8)*	2.2(±2.5)	0.50 (±0.71)	1.1 (±1.6)
Task 4	94(±15)%	88(±35)%	45.0 (±27.9)	137.8 (±99.7)	2.6(±1.0)	1.6(±1.6)	0.60 (±1.6)	0.14 (±0.38)
Task 5	93(±12)%	84(±35)%	184.4 (±70.6)	295.7 (±237.9)	0.56(±0.19)	0.63(±0.57)	0.90 (±0.74)	0.43 (±0.79)
	No significant difference between groups, p>0.05		*DPT students were significantly faster on Task 3, p<0.05		*DPT students were significantly more efficient on Task 3, p<0.05		No significant difference between groups, p>0.05	

easy nor hard by both groups. Additionally, a very similar rating of satisfaction with the overall interface experience was observed between the two groups: both groups of subjects ranked their satisfaction at a level between satisfied and extremely satisfied. The first and second tasks were considered the easiest by both subject groups, although the people with stroke also thought that the fifth task (sending a message to one's therapist) was also very easy. In general, group 2 was proficient in using the on-screen keyboard in sending a message. The third task was considered relatively difficult by both groups. When asked in the survey to justify marking a task as 'easiest', a patient responded, "It was right on the screen" (Task 1). Students responded similarly, saying "Right on the front page," and "The 1st page, 'Today' has a lot of the information needed for a couple of the tasks". When asked what they like about the interface, three of the people with stroke responded with variations of "It was fun!", and another wrote that it was "good to have a way to communicate [with the PT]". It was also observed, as in another study [7], that the people with stroke appeared more careful and deliberate in their use of the interface controller, as if determined not to make any mistakes.

When asked what they did not like about the interface, one of the people with stroke responded with "Confusing at first, then it got better." Another commented with displeasure that he "Didn't like not knowing whether [he] was using the Wii™ the way it was supposed to be used." The limited button size likely contributed to stated issues with the Wii™ remote ("It was difficult to hold the remote steady"). The number of buttons on the remote also caused confusion, since only one of the buttons was required for the interface, and the rest would simply hamper operation. Although screen space exists to increase the size of the buttons on the interface, a definite limiting factor with this hardware is the amount of pixels available for use. Although TVs offer a wide range of resolutions, the Wii™ Internet Channel only offers a fixed number of pixels in the vertical direction, and information quantity had to be balanced with size of font and buttons to fit the entire layout on the screen.

Save for time-on-task for task 3, no significant differences were found between efficiency measurements between the people with stroke and a much younger group of students who were more familiar with the interface technology. In addition, the number of the errors per subject were about the same, while the students were somewhat more familiar with gaming systems and had used computers on a daily basis. Only a limited number of subjects were available to participate in the study. Even so, Table 2 indicates ratings made by the people with stroke of relatively high ease of use and satisfaction, and these ratings were surprisingly similar to those made by the DPT students.

The incorporation of human factors, user-centered design, and usability evaluation is critical to interfacing with telerehabilitation systems. A satisfactory user-centered design appears largely unrestricted by the selection of a low-cost, commonly available gaming system as a platform. For the critical usability needs of older adults with stroke, a gaming system may serve as a simple and cost-effective solution.

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