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Usability Study of a Web-Based Platform for Home Motor Rehabilitation

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ABSTRACT In the recent years, software applications for medical assistance, including the tele-rehabilitation, have known a high and continuous presence in the medical field. Guaranteeing the correct use of these applications induces to incorporate a study of usability in the life cycle of any interactive system. This paper synthesizes the results obtained from a study of effectiveness, efficiency, and subjective user satisfaction conducted with ePHoRt. ePHoRt is a web-based platform for home motor rehabilitation; 39 participants tested the platform. We report the empirical results based on the subjective usability perception and self-reported feedback based on the IBM Computer System Usability Questionnaire. The results suggest that ePHoRt is useful, effective, efficient, easy to use, and its interfaces are acceptable. Overall, the participants are satisfied to use the platform. The main findings of this paper show that the user guidance is a critical aspect to ensure a good usability of the tele-rehabilitation platform.

INDEX TERMS User centered design, user interfaces, telemedicine, tele-rehabilitation, agile development, user experience, user study.

I. INTRODUCTION

Innovation and technological advances represent one of the fundamental pillars that lead us to offer products and services of value to societies that are interested in improving their quality of life. In the last decade, research on the use of telemedicine has reported benefits in the control, monitoring and evaluation of several clinical conditions [1]. The same phenomenon has been observed in the field of rehabilitation, where numerous studies describe the advantages of the use of distance rehabilitation (tele-rehabilitation). Tele-rehabilitation programs have been directed in large numbers to the treatment of neurological and cardiopulmonary conditions [2], [3]. Recent studies have expanded the use of tele-rehabilitation platforms to musculoskeletal disorders [4] and orthopedic conditions such as knee arthroplasties [5] and hip [6]. The results of these studies show the effectiveness of technological platforms providing remote health care in real time. Hondori and Khademi [7] review technical and clinical impact of the Microsoft Kinect in physical therapy and rehabilitation.

The context of ePHoRt rehabilitation is an initiative that aims to develop a web-based system for the training and remote control of rehabilitation in patients after hip replacement surgery [6]. Its intention is to facilitate and improve motor recovery, because patients can perform therapeutic movements at any time. The philosophy of the project is to use low-cost technologies to develop the platform, with the aim of democratizing its access. ePHoRt incorporates the Microsoft Kinect as a mechanism for acquisition of movements and emotions of patients.

Currently the project is still in its development and experimentation phase. Guaranteeing the correct use of these applications induces to incorporate a study of usability in the life cycle of any interactive system. Usability studies are an essential and iterative component of technology development [8]. We need to meet usability and user experience objectives while adhering to agile principles of software development. User involvement has generally positive effects, especially on user satisfaction [9]. Thus, we adopt a User-Centered agile Development (UCD) approach [10] to specify and design the web system required by ePHoRt in a flexible and efficient manner.

The agile development life cycle centered on the user experience (UX-ADLC) guarantees an evaluation of the system interfaces throughout the process [11] results of each iteration, including the errors and usability problems found, will be the entries for the next phase. An agile life cycle considering usability and user experience objectives has been applied in mobile health (mHealth), specifically, in the development of a mobile monitoring application for patients with diabetes [12].

Formative and summative usability tests are methods of evaluating software products widely adopted in User-Centered Design (UCD) [11]. Summative usability allows in later phases of the design to assure the quality of the user experience (UX) for a software product in development. Agile development is a widely accepted and adopted approach to software development. The focus is on short work periods (or iterations) where usability tests (formative and summative) must be contemplated. This paper synthesizes the results obtained from a systematic study of effectiveness, efficiency, and subjective user satisfaction conducted with ePHoRt.

The remainder of this paper is organized as follows. Next section reviews some related works in the context of usability studies for tele-rehabilitation systems. Third section introduces the functionalities of the ePHoRt platform. In the fourth section, the usability study is presented. Next, the results are presented and discussed. The sixth section concludes the paper and discusses some future work.

II. RELATED WORK

In this section, we start with a review on usability, next we focus on the IBM Computer System Usability Questionnaire (CSUQ) [13], and finally, we present an overview of previous works on usability studies focusing on tele-rehabilitation systems.

A. USABILITY

The ISO standard 9241-11 [14] provides a framework for understanding the concept of usability and applying it to situations where people use interactive systems, and other types of systems (including built environments), and products (including industrial and consumer products) and services (including technical and personal services). The official ISO 9241-11 definition of usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [14].

Usability evaluation can be formative or summative [15]. Kieffer *et al.* [11] state that formative and summative usability tests are methods of evaluating software products widely adopted in User-Centered Design (UCD). Formative usability is an iterative method of vital testing and refinement in the early stages of the design process. This method helps to detect and solve usability problems. As a complement, the summative usability allows to assure the quality of the user experience (UX) for a software product in development. Formative usability supports decision making during the design and development of the product, while summative usability is a tool to describe the user experience (UX).

Tullis and Stetson [16] conducted a study to determine the effectiveness of some of the standard questionnaires to measure the formative usability. The study concludes that the greatest effectiveness is found in the questionnaires SUS [17] and the IBM Computer System Usability Questionnaire (CSUQ) [13].

The CSUQ provides a qualitative measure. Its structure focuses on studying: (1) the utility, (2) the quality of the information and (3) the quality of the interface. The utility refers to the opinion of users regarding the ease of use, learning, speed of operation, efficiency in completing tasks and subjective feeling. The quality of the information studies the subjectivity of the user regarding the management of system errors, the clarity of the information, the intelligibility. Likewise, the quality of the interface measures the affective component of the user's attitude in the use of the system.

B. SYSTEM USABILITY QUESTIONNAIRE

The IBM Computer System Usability Questionnaire (CSUQ) [13] is an instrument benefiting from a coefficient alpha exceeding. 89, reliability coefficient related to usability. This instrument allows to measure users' satisfaction with the usability of computer systems. In other words, the answers provided by participants to this questionnaire demonstrate a high correlation with the usability of the system being evaluated. Specifically, it consists of nineteen empirically-validated 7-point Likert scale questions (1 = strongly disagree, 2 = largely disagree, 3 = disagree, 4 = neutral, 5 = agree, 6 = largely agree, 7 = strongly agree) distributed into 4 sections. The 7-point rating scales allow three levels of either positive or negative ratings. The most common way to estimate the reliability of these types of scales is with coefficient alpha [18]. Coefficient alpha can range from 0 (no reliability) to 1 (perfect reliability).

Table 1 shows the questions of the IBM CSUQ grouped by the system usefulness section (SYSUSE: Questions 1 through 8), the information quality section (INFOQUAL: Questions 9 through 15), the interface quality section (INTERQUAL: Questions from 16 through 18) and the satisfaction section (OVERALL: Questions 19).

C. USABILITY STUDIES FOR TELE-REHABILITATION SYSTEMS

Usability studies have a potential impact on the development of e-healt systems. The potential for e-health to improve healthcare is partially dependent on its ease of use [19]. Academics and industrial studies have been conducted to evaluate the usability in e-healt systems. Reference [19] present a systematic review to identify psychometrically tested questionnaires that measure usability of e-health tools, and to appraise their generalizability, attributes coverage, and quality.

TABLE 1. Structure of the IBM CSUQ.

Category	Number	Question
SYSUSE	01	Overall, I am satisfied with how easy it is to use this system
	02	It was simple to use this system
	03	I could effectively complete my work using this system
	04	I was able to complete my work quickly using this system
	05	I was able to efficiently complete my work using this system
	06	I felt comfortable using this system
	07	It was easy to learn to use this system
	08	I believe I could become productive quickly using this system
INFOQUAL	09	The system gave error messages that clearly tell me how to fix problems
	10	Whenever I made a mistake using the system, I could recover easily and quickly
	11	The information (such as online help, on-screen messages, and other documentation) provided with this system was clear
	12	It was easy to find the information I needed
	13	The information provided for the system was easy to understand
	14	The information was effective in helping me complete the tasks and scenarios
	15	The organization of information on the system screens was clear
INTERQUAL	16	The interface of this system was pleasant
	17	I liked using the interface of this system
	18	This system has all the functions and capabilities I expect it to have
OVERALL	19	Overall, I am satisfied with this system

The main usability attributes found during the revisions were: learnability, efficiency, and satisfaction. Likewise, Quality appraisal showed that face/content and construct validity were the most frequent types of validity assessed.

In this section, we will focus on presenting some of the relevant works in the field of usability perception in tele-rehabilitation systems.

Eguiluz-Perez and Garcia-Zapirain [20] highlights that high levels of usability resides in the substantial quality-of-life, which could result from acceptance of tele-rehabilitation systems. The implication is that very high levels of system usability are essential to clear the path to acceptance of new behaviors and attitudes. Reference [21] present a usability study to evaluate patients' rehabilitation-evolution and shows that the system is usable for both patients and professionals. The authors conclude that ease of use is one of the advantages of the tele-rehabilitation system.

A usability study of a Virtual Rehabilitation System Designed to Demonstrate, Instruct and Monitor a Therapeutic Exercise Program was presented in [22]. The usability evaluation was performed into two distinct evaluation stages and certain system modifications were undertaken prior to the second stage. Firstly, the authors conducted an expert walkthrough to identify initial usability problems, to find defects or omissions in the system, to collect suggestion on how to improve the system, and to consider alterations to the system. Secondly, User evaluation was conducted by using VRUSE, a computerized usability questionnaire designed specifically for the evaluation of virtual reality applications [23].

Weiss *et al.* [24] present the development, validation and usability testing of a low-cost, markerless full body tracking virtual reality system designed to provide remote rehabilitation of the upper extremity in patients who have had a stroke. Eight patients with stroke participated in the study. Outcomes included participant responses to the 5-point Short Feedback Questionnaire (SFQ) [25], a usability questionnaire documenting their enjoyment, and perception of success and control while using the system. The Borg scale [26] was used to rate their perceived effort while playing the games. In addition to these subjective ratings, game performance scores were tabulated.

In [27], an assessment methodology for home-based telerehabilitation system for post-stroke arm rehabilitation was evaluated. The usability study of the ArmAssist system was performed using written questionnaires. Questionnaire feedbak was collected via a series of structured interviews and 7 point Likert-based evaluation questions measuring the level of agreement.

Reference [28] present the rehabilitation visualization system and the results of a randomized controlled study in which we investigated the usability and feasibility of the system in the home. It work have employed the principles of user-centered design throughout the phases of the development of the system. The study was performed through the System Usability Scale or SUS questionnaire [17] as a self reported measure of perceived usability of the rehabilitation visualization system. The study also explore some additional metrics such as quality of life and improved knee function that are meaningful to the patients and health professionals.

Reference [29] presents the feasibility and user acceptance of using a telerehabilitation system called KiReS [30] in a real scenario, with patients attending repeated rehabilitation sessions after they had a Total Hip Replacement (THR). The study used a Likert scale questionnaire to assess the patient's subjective perceptions at the end of each exercise session. The questionnaire consisted of 13 questions about the session with five possible answers from 1 (strongly disagree) to 5 (strongly agree). The questions were divided in 3 categories: the system; the experience of the user; and the interface. The questionnaire also asked about the participant's prior knowledge about telerehabilitation and asked for any suggestions regarding the system. The evaluation yielded positive feedback from patients regarding the system although some constructive criticism, especially about the interface, was received [29].

In [8] five user interfaces with three simultaneous users and a remote monitoring setup was evaluated. The usability study uses both traditional and a empirical methods to assess the viability of the interfaces design. The paper describes how usability testing and software design iteration were performed collaboratively by a group of engineers and clinician scientists. The formative evaluation was carried out by an expert domain user on the Rutgers Ankle Rehabilitation System (RARS).

ePHoRt platform has also been the subject of previous usability studies. Pilco *et al.* [31] assert that lack of usability that may prevent effectiveness, efficiency, and the satisfaction of patients, may lead to problems of confusion, error and delay, or even abandonment of the physical therapy. However, they perform a preliminary empirical heuristic evaluation with ePHoRt. The user interfaces evaluated were: (1) Login; (2) a questionnaire and (3) the Exercise Assessment screen. The study does not provide results in relation to the efficiency, effectiveness and satisfaction of patients. Thus, the authors concluded that is necessary to perform a new iteration of usability evaluation. A second usability study was conducted with the ePHoRt platform [32]. The user experience was evaluated through the completion time of the tasks and the SUS questionnaire [17] and the results were related to an empirical sociodemographic questionnaire. The overall value of the usability score was 76.1 out of 100, which can be considered as a good evaluation of the usability of the platform.

III. THE ePHoRt PLATFORM DESCRIPTION

In order to give the reader a good understanding of ePHoRt, this section describes the main features of the platform and focuses on the patient's interface. The main functionalities are concentrated around a therapeutic education and a real time evaluation of the exercises. These functionalities are the following:

A. THERAPEUTIC EDUCATION

The *therapeutic education* approach allows to empower the patient, who can perform autonomously a set of rehabilitation activities from a program elaborated by the health professionals (e.g. physiotherapists) [33]. Several functionalities are implemented in the platform, in order to support the patients in their self-recovery process. These functionalities are described below:

1) GENERAL RECOMMENDATIONS

For each rehabilitation process, patients are provided with a set of multimodal learning resources on the appropriate use of the platform and the right procedure to complete the therapeutic program. Figure 1 shows the user interface for selecting general recommendations. Once the patient makes a selection, a second user interface offers three different types

FIGURE 1. The user interface for learning general recommendations.

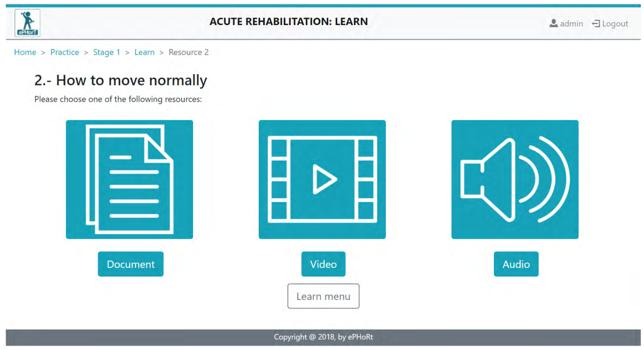

FIGURE 2. Rehabilitation learning resources.

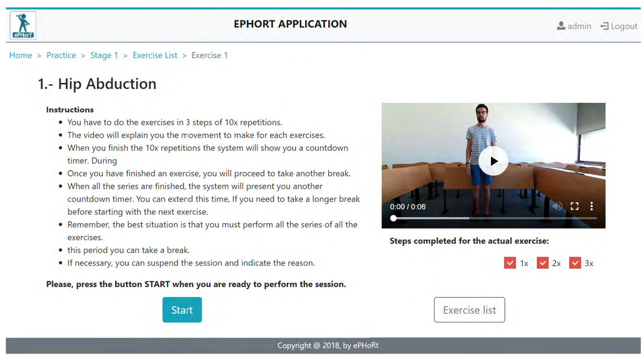

FIGURE 3. The exercise instructions user interface.

of learning support: rich document, audio and video (see Figure 2). Patients can choose the modality of any learning resource according to their preferences.

2) DESIGN OF THE EXERCISE

After replying an exploratory questionnaire regarding their health status, patients are authorized to perform the motor rehabilitation exercises. The exercises start with a set of instructions to perform the movements (see Figure 3). Then, the patient's avatar is displayed in a virtual environment (see Figure 4).

The exercises are implemented following a game-based approach to promote the engagement and motivation of the patient. The realism of the human's action is enhanced by

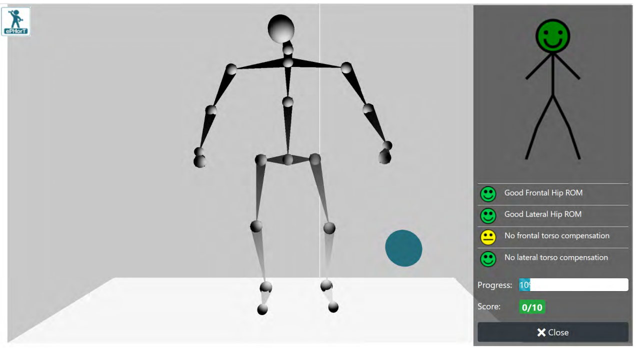

FIGURE 4. The patient's avatar user interface.

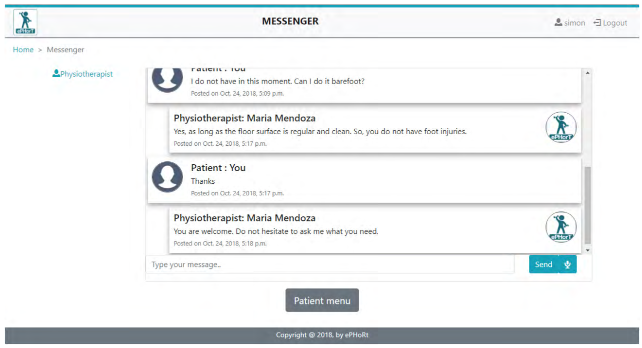

FIGURE 5. Messaging user interface.

constraining the virtual objects to physical law (e.g. gravity). The definition of an exercise is based on the composite design pattern [34]. This means that a rehabilitation exercise can be composed with multiple simple or compound exercises.

Once the patient begins a rehabilitation session, the system activates the execution interface of the exercises (see Figure 4). This interface invokes the acquisition module and the game associated with the activity that the patient must perform. Also, the execution interface maps together the patient's movement and the avatar's motion in real time. A progress bar provides the patient with a feedback on the number of trials performed, while the score indicates the number of trials correctly performed (e.g. each time the patient's leg gets the right range of motion and shoots a virtual ball).

3) DESIGN OF THE REPETITIONS

For each exercise the patient must perform a series of repetitions according to the reeducation plan defined by the physiotherapist. There is a short break between each repetition to provide the patient with a feedback on the quality of the movement. The trials are assessed in terms of range of motion (ROM) and compensatory movements. Once a trial is completed, the patient receives a graphic-based feedback regarding the movement amplitude of the trial.

Once all the repetitions for an exercise have been completed, the patient receives a global graphic-based feedback regarding the quality of the exercise carried out. Finally, the patient can suspend a rehabilitation session at any time. In this case, they have to provide the physiotherapist with the reason why they were not able to fully complete the planned daily program.

4) COMMUNICATING BETWEEN THE STAKEHOLDERS

Patients and physiotherapist can communicate to each other through a message exchange module. These message can be text-based and/or audio-based (see Figure 5).

B. REAL-TIME EVALUATION OF THE EXERCISES

An assessment module is implemented in the platform, in order to provide the patient with a real-time feedback regarding the correctness of the executed movement. Each time the patient executes an exercise, the 3D coordinates of the main body joints are captured. Then, the data is processed by a comparison with the correct execution of the movement, which is used as reference. The evaluation of the quality of movement is carried out by an AI algorithm based on the *Dynamic Time Warping (DTW)* method [35]. This algorithm processes the skeleton data and provides the user with a discriminative evaluation of the accuracy of different body angles as a feedback result.

Figure 4 (right side) shows an example of the graphical feedback presented to the patient. It includes simple messages with an associated emoticon and a basic doll in two dimensions with the parts of the body. The messages consider the angles and the position of the body parts involved in the exercise while the emoticons consider three emotions (happy neutral and sad) to make the messages understandable and familiar to the patient's emotions. Also, a progress bar and a score was added in order to observe the progress of the exercise with regard to the set of series and to know how well the exercise was performed.

IV. EXPERIMENT

We conducted a user experiment to understand the perceived usability for the ePHoRt platform.

A. PARTICIPANTS

The participants were drawn by convenience sampling. A total of 41 people participated in the study. Surprisingly all of them were right-handed. Participants identified by the IDs 6 and 32 were excluded since they did not finalize the demographic questionnaire. Thus, of the 41 participants only 39 were retained (distributed in 32 male and 7 female) volunteered for the experiment. No specific skill was necessary for participants. A number of 36 participants (or 92.3%) were between 18 and 30 years old. All participants reported that they had never used a tele-rehabilitation system. 'Appendix A' contains the summary statistics of socio-demographic and user experience data. Table 2 on page 7943 contains the data summary of the socio-demograpich survey and the Table 3 on page 7944 presents a summary of the ranking variables which will be analyzed in this section.

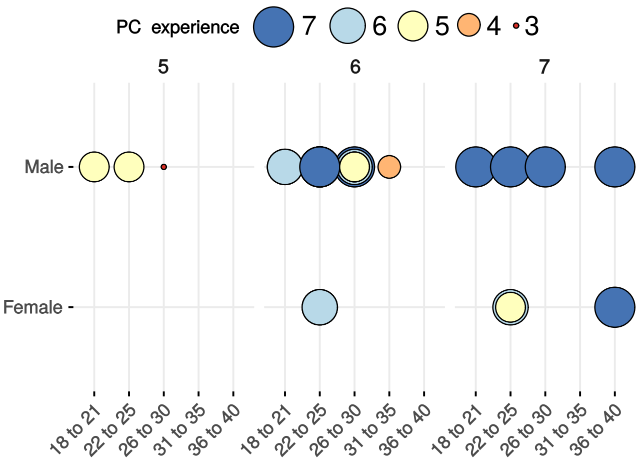

FIGURE 6. **PC experience versus browser ability (columns 5, 6 and 7) faceted by age (x-axis) and gender (y-axis).**

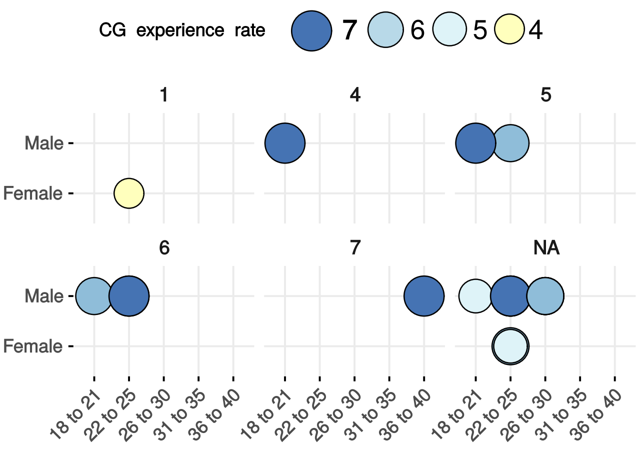

FIGURE 7. **Computer game (CG) experience versus Gesture User Interface (GUI) technologies experience faceted by age (x-axis) and gender (y-axis).**

Figure 6 shows a balloon plot diagram[1] in which the variables mentioned below are crossed: PC experience, browser ability, age and gender. Columns identified with the numbers 5, 6 and 7 represent the subjective appreciations of participants in the ability to use a browser. These values were measured using a Likert scale from 1 (or lowest) to 7 (highest). The diagram reports that the most experimented participants in the use of computers also have high experience with browsers. In addition, the same demographic profile is evidenced for both genders. Likewise, the age does affect the aforementioned pattern.

A number of 34 participants (or 87.2 %) reported that they used a computer game whereas 5 participants (or 12.8 %) reported that they never used a computer game. A number of 27 participants (or 69.2 %) reported that they never used Gesture User Interface (GUI) technologies. From these participants, Figure 7 shows a balloon plot diagram in which

[1]The balloon plot diagrams presented in this section provide a qualitative view based on variables cross-referencing. Readers who wish to consult the quantitative summary data of each variable can refer to Appendix 1.

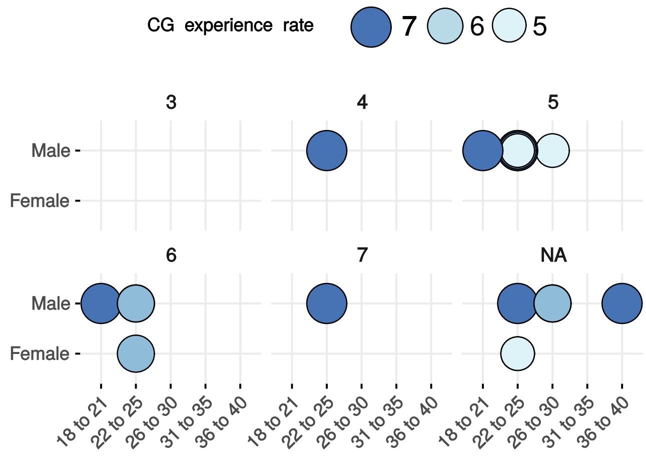

FIGURE 8. **Computer Game (CG) experience versus Kinect experience faceted by age (x-axis) and gender(y-axis).**

the variables mentioned below are crossed: Computer game experience, Gesture User Interface (GUI) technologies, Age and Gender. Panels per Columns represent the subjective appreciations of participants according to the use of GUI technologies. Participants who have never used a GUI have indicated lower votes regarding appreciations in the computer game experience rate. Participants who have used GUI have a high computer games experience rate. In general, the younger the participants, the better their experience in GUI and computer games.

A number of 34 participants (or 87.2 %) reported that they used a computer game (CG) whereas 18 participants (or 46.15 %) reported that they used a Kinect device. For the aforementioned participants, the reported CG and Kinect experience rate were high, between 5 and 7, being slightly higher for CG than Kinect. This can be appreciated qualitatively in Figure 8. Also, can be appreciated in Figure 8, that the best rates of experience in the use of the Kinect device are among the participants between 18 and 25 years old.

A number of 12 participants (or 30.8 %) reported that they used Gesture User Interface (GUI) technologies. The low number of participants asserting that they have used GUI, may be due to participants not realizing that GUI technologies are ubiquitous nowadays, i.e. Smart-phones, as well as the Kinect device. Thus the number of participants responding that they have used a Kinect device is higher than the participants responding that they have used GUI technologies. These participants consider that they have acceptable experience in the use of these technologies, being lower for GUI than Kinect. Likewise, we can observe in Figure 9 that the most experimented participants in use of the Kinect device are those between the ages from 22 to 25.

B. TASKS

We defined five tasks to be performed by participants in the therapeutic program in several stages, as show in Figure 10.

The number and the order of the stages are defined by the physiotherapists. Three states with a turquoise or gray color

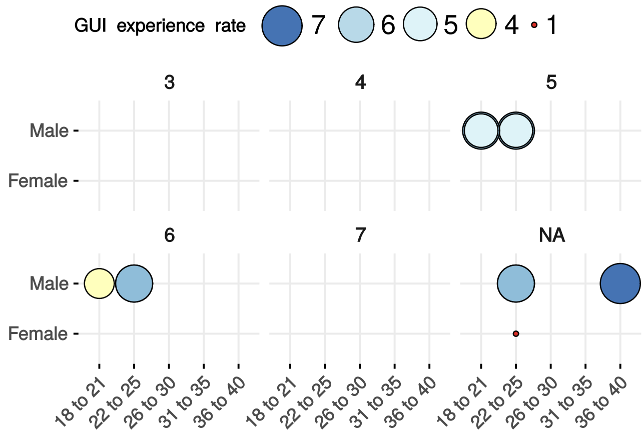

FIGURE 9. Gesture User Interface (GUI) technologies experience versus Kinect experience faceted by age (x-axis) and gender (y-axis).

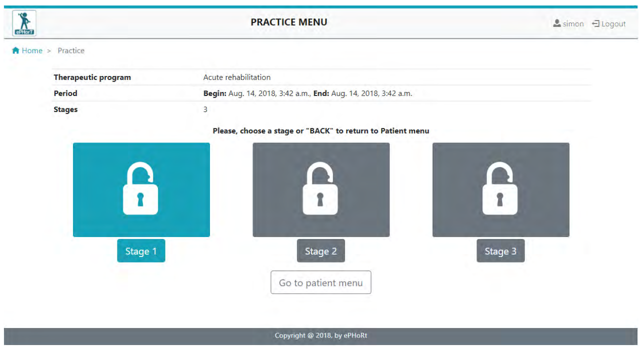

FIGURE 10. Therapeutic program.

FIGURE 11. Stage 1.

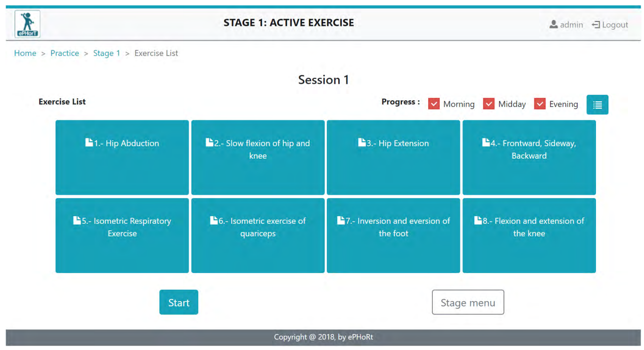

FIGURE 12. Active Exercise.

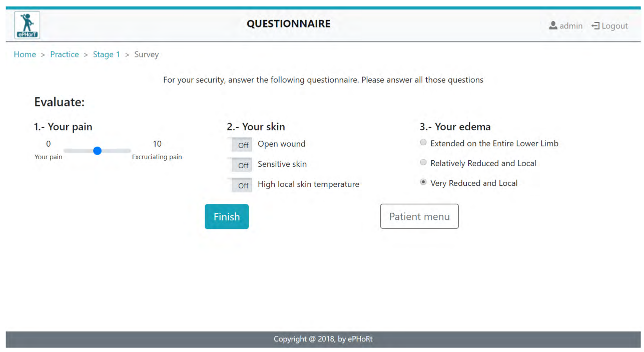

FIGURE 13. Preliminary Questionnaire.

were defined in the figure. The turquoise color represents an active state that must be executed by the patient. The gray color represents inactive states. Inactive states will be activated once the patients have been completed the previous state. Each stage has the *open learning object* and the *active exercise* tasks as shown in Figure 11.

1) OPEN THE LEARNING OBJECT: "2. HOW TO MOVE NORMALLY" OF THE STAGE 1

In this task the participant was asked to study the Learning Object "2. How to move normally" which is inside the "LEARN" option of the "STAGE 1" menu. The participant could select the learning mode he/she wanted (document, video, audio) (see Figure 2).

2) PERFORM AN ACTIVE EXERCISE OF THE STAGE 1

In this task the participant was asked to perform an ACTIVE SESSION from the STAGE 1. An ACTIVE SESSION is a set of exercises of rehabilitation (see Figure 12). The exercises are organized in three day periods (morning, midday, evening) and the patient can select the exercise to perform. Additionally, before starting the exercises the patient is asked to answer a preliminary questionnaire with three simple questions to determine if he/she can perform the exercises based on a criteria. The questions are provided by the physiotherapist as well as the criteria (see Figure 13).

If the patient answer the questionnaire according to the criteria, he can execute any exercise and see a set of instructions with a video before start the movement (see Figure 3). When he starts it a new screen is presented with an avatar to follow his movements in real time. Data of the patient movement is captured and processed as explained before and a feedback is presented at the end of the movement as shown in Figure 4.

3) OPEN THE GENERAL CONDITIONS OF THE STAGE 2

In this task the participant was asked to read the general recommendations document which is inside the "LEARN" option of the "STAGE 2" menu. The patient must accept the

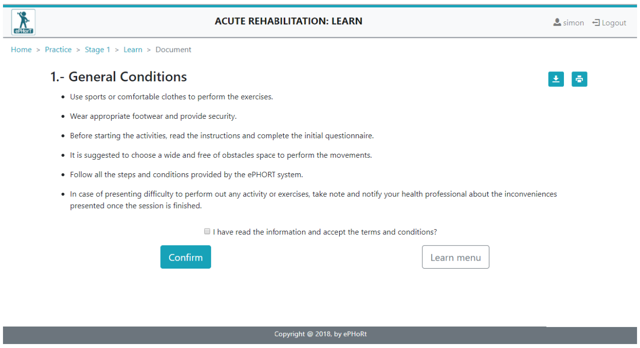

FIGURE 14. General Conditions.

condition by clicking the check-box before continuing with the therapeutic program (see Figure 14).

4) PERFORM AN ACTIVE EXERCISE OF THE STAGE 2

In this task the participant was asked to perform an ACTIVE SESSION from the STAGE 2. As an additional condition, the participant was asked to start the exercise and then proceed to suspend it.

5) SEE THE NEW MESSAGES FROM YOUR THERAPIST

In this task the participant was asked to enter into the interface to consult the new messages and to send messages to the physiotherapist. The messages can be text or audio (see Figure 5).

C. PROCEDURE

The experimental protocol started with the signing of a consent form by each participant before participating in the experiment. Next, the participants were requested to fill out a questionnaire with demographic information. Then, the participants were requested to follow an accommodation phase where they followed a tutorial on how to use the platform and practiced with the platform. Once the scenario of telerehabilitation was clarified and after the participants were confident with the platform, they were asked to complete the 5 tasks described in the preceding section. The total time for the completion of the 5 tasks was 15 minutes. At the end of the experiment, when all tasks were completed, the participants were asked to fill in the IBM Computer System Usability Questionnaire (CSUQ) [13] plus one optional open question for constructive feedback (i.e., Are there any comments you'd like to make about ePHoRt or your experience in using it during the experiment?).

V. RESULTS AND DISCUSSIONS

In this section, we report the results of applying the IBM CSUQ according to the participant's subjective perception and self-reported feedback.

Individual results presented in Figure 15 indicate that participants 21 and 35 were the least critical (Mean(μ) = 7.00, Median(M) = 7.00, Standard Dev(σ) = 0.00). On the contrary, participant 31 was the least critical (Mean(μ) = 4.21, Median(M) = 4.00, Standard Dev(σ) = 0.42). Question 3 of the IBM CSUQ (see Table 1) received the highest score, suggesting that the participants could effectively complete the asked tasks using ePHoRt (Mean(μ) = 6.03, Median(M) = 6.00, Standard Dev(σ) = 1.01). Question 9 of the IBM CSUQ, was the least appreciated by the participants Mean(μ) = 4.77, Median(M) = 5.00, Standard Dev(σ) = 1.51). This last result revealed an important usability problem since the system did not give clear error messages to fix problems.

Figure 16 depicts the results of the IBM CSUQ questionnaire. In general, positive trends are observed, because the participants mostly agreed with the statements. In most cases, the averages of the questions were greater than 5 with a standard deviation less than 1.19. The results of questions 9 (Mean(μ) = 4.77, Median(M) = 5.00, Standard Dev(σ) = 1.51), 10 (Mean(μ) = 5.31, Median(M) = 5.00, Standard Dev(σ) = 1.51), 11 (Mean(μ) = 5.38, Median(M) = 5.00, Standard Dev(σ) = 1.04) belonging to the information quality or INFOQUAL (Mean(μ) = 5.49, Median(M) = 6.00, Standard Dev(σ) = 1.15) confirm that the users were not in full agreement, but also not in disagreement, with the error messages, online help and any other documentation provided with the platform. However, the result to question 15 (Mean(μ) = 5.92, Median(M) = 6.00, Standard Dev(σ) = 0.84) indicates that the participants agree on the fact that the organization of the information on the user interface is clear.

Figure 17 depicts the average values for the IBM CSUQ measures. Concerning the system usefulness or SYSUSE (Mean(μ) = 5.84, Median(M) = 6.00, Standard Dev(σ) = 0.94) show that the participants in general have been appreciated the platform, although the participants in question 8 (Mean(μ) = 5.72, Median(M) = 6.00, Standard Dev(σ) = 0.92) assert that do not believe that they can become productive quickly using this system. In this sense, we consider that we could make future evaluations to measure the performance of the participants when using the platform.

Information quality or INFOQUAL (Mean(μ) = 5.49, Median(M) = 6.00, Standard Dev(σ) = 1.15) also suggests that participants have appreciated the quality of information manage by ePHoRt. The participants have indicated that the information provided by the system was easily understood, this helped them to complete the tasks and scenarios. Future efforts will concentrate on improving the feedback provided by the system, especially at the time that errors occur.

Interface quality or INTERQUAL (Mean(μ) = 5.50, Median(M) = 6.00, Standard Dev(σ) = 1.11) shows that the user interfaces of the platform are acceptable for the participants. However, we consider that the tool requires additional improvements, for example: The incorporation of speech recognition to facilitate remote interaction. Likewise, we hope that the new changes, such as the simplification of user interface for the exercise's execution, may increase the appropriation of the system by the participants.

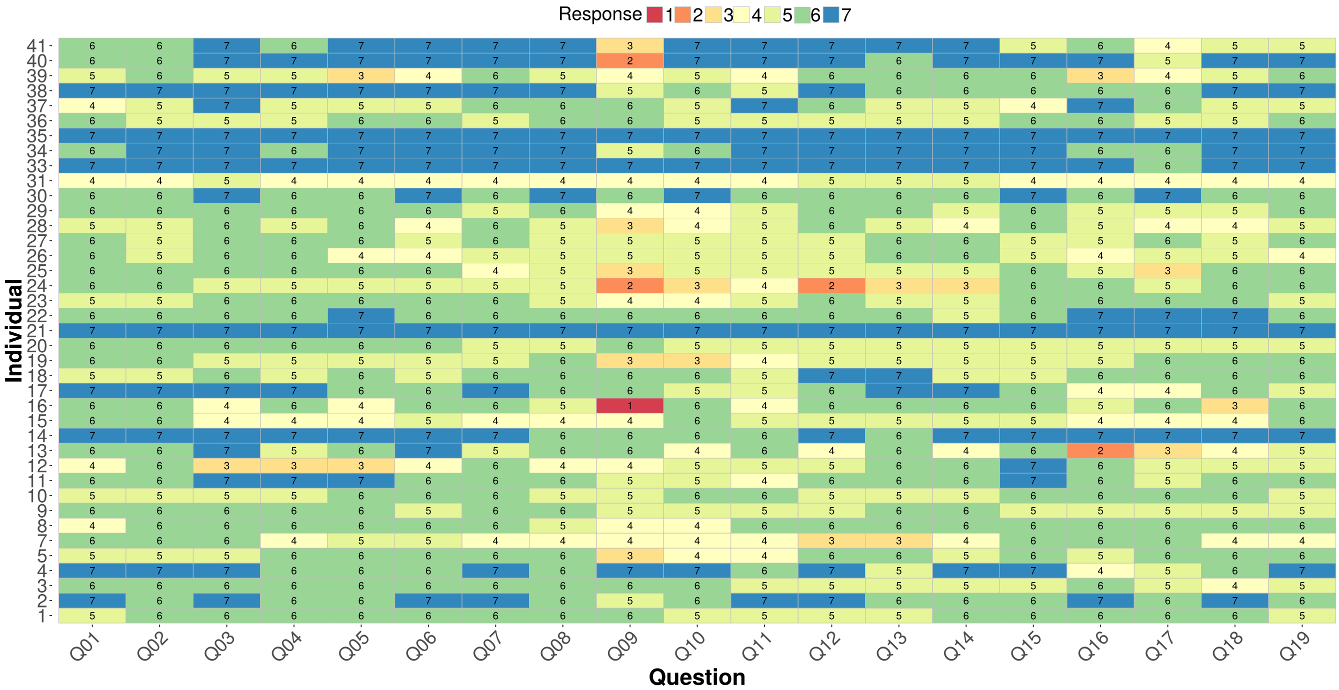

FIGURE 15. Individual results of the IBM CSUQ measures for the 39 participants.

Overall satisfaction or simply OVERALL (Mean(μ) = 5.74, Median(M) = 6.00, Standard Dev(σ) = 0.88) suggests that ePHoRt is positively perceived for the participants. They reported a positive attitude against the difficulty to solve errors. Finally, the system usability (USABILITY) suggests that the participants agree with the statements proposed by the survey. Overall, they seem to like the system and their functionalities.

We incorporate in the questionnaire an optional question for constructive feedback (see the previous section). The additional comments regarding the tool and the experience of using it during the experiment suggest that users require better error messages. Likewise, the participants propose visualizing the learning resources and the list of exercises through lists instead of blocks of images or having both functionalities. We will analyze this proposal, in order to include it in the interfaces that require it. Finally, participants suggest adding supports for several languages. Future work is aimed at addressing these ergonomic aspects, especially when we have to incorporate new features into the tool.

A. ONE-WAY ANALYSIS OF VARIANCE AND CORRELATION

A one-way analysis of variance has been performed for the mean responses of the different categories of the questionnaire. Fig 17 shows a strip plot describing the IBM CSUQ mean response measures: SYSUSE, INFOQUAL, INTERQUAL and OVERALL. Jittering is used for a better visualization of the answers for each category.

Figure 17, also provides the minimum value score given by the participants in each category, as well as the

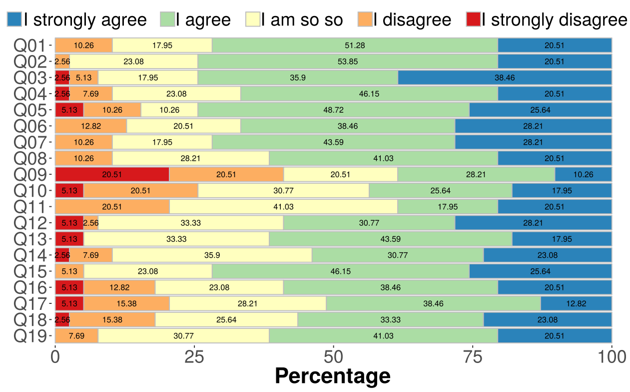

FIGURE 16. Results from the IBM CSUQ.

category mean. A confidence interval for the mean is depicted for each category. No significant difference was observed between categories (p-value = 0.184), indicating a similar positive perception for all CSUQ questionnaire categories.

Fig 18 depicts the correlation between the mean responses of the IBM CSUQ categories. The higher correlation for OVERALL is with the SYSUSE category (corr = 0.63). That is the positive overall perception is associated with a positive response of the participants for the SYSUSE questions (Q1 to Q8). This can also be observed in Fig 16 where the appreciation for the aforementioned questions is highly positive (agree and strongly agree). The correlation between INFOEQUAL and SYSUSE is the higher between the categories (corr = 0.75), indicating that the more comprehensible is the system information the more friendly and productive is the system for the user.

TABLE 2. Data summary.

No	Variable	Stats / Values	Freqs (% of Valid)	Valid	Missing
1	P2_Gender [factor]	1. Male 2. Female	7 (17.9%) 32 (82.0%)	39 (100%)	0 (0%)
2	P3_Age [factor]	1. 18 to 21 2. 22 to 25 3. 26 to 30 4. 31 to 35 5. 36 to 40	5 (12.8%) 24 (61.5%) 7 (17.9%) 1 (2.6%) 2 (5.1%)	39 (100%)	0 (0%)
3	P4_Degree [factor]	1. Bachelor's degree 2. High school	14 (35.9%) 25 (64.1%)	39 (100%)	0 (0%)
4	P5_Handedness [factor]	1. Right handed	39 (100.0%)	39 (100%)	0 (0%)
5	P6_Sensory_motor_limitation [factor]	1. No	39 (100.0%)	39 (100%)	0 (0%)
6	P7_Which_limitation [logical]		All NA's	0 (0%)	39 (100%)
7	P8_PC_use [factor]	1. Yes	39 (100.0%)	39 (100%)	0 (0%)
8	P9_PC_use_how_long [factor]	1. 1 to 2 years 2. 3 to 5 years 3. 6 to 8 years 4. 9 to 10 years 5. Less than 1 year 6. Over 10 years	1 (2.6%) 6 (15.4%) 6 (15.4%) 8 (20.5%) 4 (10.3%) 14 (35.9%)	39 (100%)	0 (0%)
9	P10_PC_use_hours_per_day [factor]	1. 2. 1 to 2 hours 3. 3 to 5 hours 4. 6 to 8 hours 5. Less than 1 hour 6. Over 8 hours	1 (2.6%) 2 (5.1%) 14 (35.9%) 11 (28.2%) 6 (15.4%) 5 (12.8%)	39 (100%)	0 (0%)
10	P11_PC_experience [integer]	mean (sd) : 5.85 (0.99) min < med < max : 3 < 6 < 7 IQR (CV) : 1.5 (0.17)	3.00 : 1 (2.6%) 4.00 : 3 (7.7%) 5.00 : 7 (17.9%) 6.00 : 18 (46.2%) 7.00 : 10 (25.6%)	39 (100%)	0 (0%)
11	P12_PC_work_ability [integer]	mean (sd) : 5.97 (0.87) min < med < max : 4 < 6 < 7 IQR (CV) : 2 (0.15)	4.00 : 2 (5.1%) 5.00 : 9 (23.1%) 6.00 : 16 (41.0%) 7.00 : 12 (30.8%)	39 (100%)	0 (0%)
12	P13_Learn_software_ability [integer]	mean (sd) : 5.18 (1.25) min < med < max : 1 < 5 < 7 IQR (CV) : 1 (0.24)	1.00 : 1 (2.6%) 2.00 : 1 (2.6%) 4.00 : 7 (17.9%) 5.00 : 13 (33.3%) 6.00 : 13 (33.3%) 7.00 : 4 (10.3%)	39 (100%)	0 (0%)
13	P14_Browser_ability [integer]	mean (sd) : 6.21 (0.57) min < med < max : 5 < 6 < 7 IQR (CV) : 1 (0.09)	5.00 : 3 (7.7%) 6.00 : 25 (64.1%) 7.00 : 11 (28.2%)	39 (100%)	0 (0%)
14	P15_Discuss_software_strengths_weaknesses [integer]	mean (sd) : 5.1 (1.02) min < med < max : 3 < 5 < 7 IQR (CV) : 1.5 (0.2)	3.00 : 3 (7.7%) 4.00 : 7 (17.9%) 5.00 : 14 (35.9%) 6.00 : 13 (33.3%) 7.00 : 2 (5.1%)	39 (100%)	0 (0%)
15	P16_PC_self_learning [integer]	mean (sd) : 5.33 (1.15) min < med < max : 2 < 6 < 7 IQR (CV) : 1 (0.22)	2.00 : 1 (2.6%) 3.00 : 2 (5.1%) 4.00 : 5 (12.8%) 5.00 : 10 (25.6%) 6.00 : 17 (43.6%) 7.00 : 4 (10.3%)	39 (100%)	0 (0%)
16	P17_Solve_PC_problem_different_manners [integer]	mean (sd) : 5.54 (1.07) min < med < max : 2 < 6 < 7 IQR (CV) : 1 (0.19)	2.00 : 1 (2.6%) 4.00 : 6 (15.4%) 5.00 : 7 (17.9%) 6.00 : 20 (51.3%) 7.00 : 5 (12.8%)	39 (100%)	0 (0%)
17	P18_Not_needing_PC_best_way_use [integer]	mean (sd) : 4.62 (1.44) min < med < max : 2 < 4 < 7 IQR (CV) : 2 (0.31)	2.00 : 4 (10.3%) 3.00 : 3 (7.7%) 4.00 : 13 (33.3%) 5.00 : 7 (17.9%) 6.00 : 8 (20.5%) 7.00 : 4 (10.3%)	39 (100%)	0 (0%)

TABLE 2. ***(Continued.)*** **Data summary.**

18	P19_Prefer_learning_PC_software _by_myself [integer]	mean (sd) : 4.92 (1.4) min < med < max : 1 < 5 < 7 IQR (CV) : 2 (0.28)	1.00 : 1 (2.6%) 2.00 : 2 (5.1%) 3.00 : 2 (5.1%) 4.00 : 8 (20.5%) 5.00 : 10 (25.6%) 6.00 : 13 (33.3%) 7.00 : 3 (7.7%)	39 (100%)	0 (0%)
19	P20_Tele-rehabilitation_system_use [factor]	1. No	39 (100.0%)	39 (100%)	0 (0%)
20	P21_TR_system_use_how_long [logical]		All NA's	0 (0%)	39 (100%)
21	P22_TR_system_use_hours_per_day [logical]		All NA's	0 (0%)	39 (100%)
22	P23_TR_experience_rate [logical]		All NA's	0 (0%)	39 (100%)
23	P24_TR_work_ability [logical]		All NA's	0 (0%)	39 (100%)
24	P25_Computer_game_use [factor]	1. No 2. Yes	5 (12.8%) 34 (87.2%)	39 (100%)	0 (0%)
25	P26_CG_use_how_long [factor]	1. 2. 1 to 2 years 3. 3 to 4 years 4. 5 to 6 years 5. 7 to 8 years 6. 9 to 10 years 7. Less than 1 year 8. Over 10 years	5 (12.8%) 4 (10.3%) 5 (12.8%) 2 (5.1%) 2 (5.1%) 5 (12.8%) 3 (7.7%) 13 (33.3%)	39 (100%)	0 (0%)
26	P27_CG_use_hours_per_day [factor]	1. 2. 1 to 2 hours 3. 3 to 4 hours 4. 5 to 6 hours 5. 7 to 8 hours 6. Less than 1 hour	5 (12.8%) 11 (28.2%) 11 (28.2%) 3 (7.7%) 2 (5.1%) 7 (17.9%)	39 (100%)	0 (0%)
27	P28_CG_experience_rate [integer]	mean (sd) : 5.74 (1.19) min < med < max : 1 < 6 < 7 IQR (CV) : 1 (0.21)	1.00 : 1 (2.9%) 4.00 : 2 (5.9%) 5.00 : 8 (23.5%) 6.00 : 15 (44.1%) 7.00 : 8 (23.5%)	34 (87.18%)	5 (12.82%)
28	P29_CG_use_ability [integer]	mean (sd) : 5.47 (1.28) min < med < max : 1 < 6 < 7 IQR (CV) : 1 (0.23)	1.00 : 1 (2.9%) 4.00 : 6 (17.6%) 5.00 : 8 (23.5%) 6.00 : 12 (35.3%) 7.00 : 7 (20.6%)	34 (87.18%)	5 (12.82%)
29	P30_Kinect_Device_use [factor]	1. No 2. Yes	21 (53.8%) 18 (46.2%)	39 (100%)	0 (0%)
30	P31_KD_use_how_long [factor]	1. 2. 1 to 2 years 3. 3 to 4 years 4. 5 to 6 years 5. Less than 1 year 6. Over 10 years	21 (53.8%) 3 (7.7%) 5 (12.8%) 1 (2.6%) 8 (20.5%) 1 (2.6%)	39 (100%)	0 (0%)
31	P32_KD_use_hours_per_day [factor]	1. 2. 1 to 2 hours 3. 3 to 4 hours 4. 5 to 6 hours 5. Less than 1 hour	21 (53.8%) 6 (15.4%) 1 (2.6%) 1 (2.6%) 10 (25.6%)	39 (100%)	0 (0%)
32	P33_KD_use_experience_rate [integer]	mean (sd) : 5.22 (0.88) min < med < max : 3 < 5 < 7 IQR (CV) : 1 (0.17)	3.00 : 1 (5.6%) 4.00 : 1 (5.6%) 5.00 : 10 (55.6%) 6.00 : 5 (27.8%) 7.00 : 1 (5.6%)	18 (46.15%)	21 (53.85%)
33	P34_KD_work_ability [integer]	mean (sd) : 5.11 (0.9) min < med < max : 3 < 5 < 7 IQR (CV) : 0.75 (0.18)	3.00 : 1 (5.6%) 4.00 : 2 (11.1%) 5.00 : 10 (55.6%) 6.00 : 4 (22.2%) 7.00 : 1 (5.6%)	18 (46.15%)	21 (53.85%)
34	P35_GUI_use [factor]	1. No 2. Yes	27 (69.2%) 12 (30.8%)	39 (100%)	0 (0%)

TABLE 2. ***(Continued.)*** **Data summary.**

35	P36_GUI_which [factor]	1. 2. Enable Viacam 3. jugar 4. wii 5. Wii 6. Wii, PlayStation Move 7. Wii, PS Camera 8. wii, ps4, nintendo	27 (69.2%) 1 (2.6%) 1 (2.6%) 2 (5.1%) 5 (12.8%) 1 (2.6%) 1 (2.6%) 1 (2.6%)	39 (100%)	0 (0%)
36	P37_GUI_use_how_long [factor]	1. 2. 1 to 2 years 3. 3 to 4 years 4. Less than 1 year	27 (69.2%) 1 (2.6%) 3 (7.7%) 8 (20.5%)	39 (100%)	0 (0%)
37	P38_GUI_use_hours_per_day [factor]	1. 2. 1 to 2 hours 3. 3 to 4 hours 4. Less than 1 hour	27 (69.2%) 2 (5.1%) 1 (2.6%) 9 (23.1%)	39 (100%)	0 (0%)
38	P39_GUI_experience_rate [integer]	mean (sd) : 5.25 (1.54) min < med < max : 1 < 6 < 7 IQR (CV) : 1 (0.29)	1.00 : 1 (8.3%) 4.00 : 1 (8.3%) 5.00 : 3 (25.0%) 6.00 : 6 (50.0%) 7.00 : 1 (8.3%)	12 (30.77%)	27 (69.23%)
39	P40_GUI_use_ability [integer]	mean (sd) : 5.33 (1.5) min < med < max : 1 < 6 < 6 IQR (CV) : 0.25 (0.28)	1.00 : 1 (8.3%) 4.00 : 1 (8.3%) 5.00 : 1 (8.3%) 6.00 : 9 (75.0%)	12 (30.77%)	27 (69.23%)

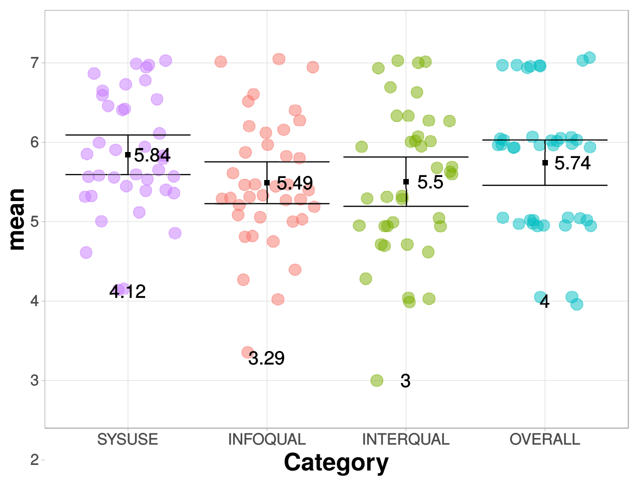

FIGURE 17. Average values for the IBM CSUQ categories.

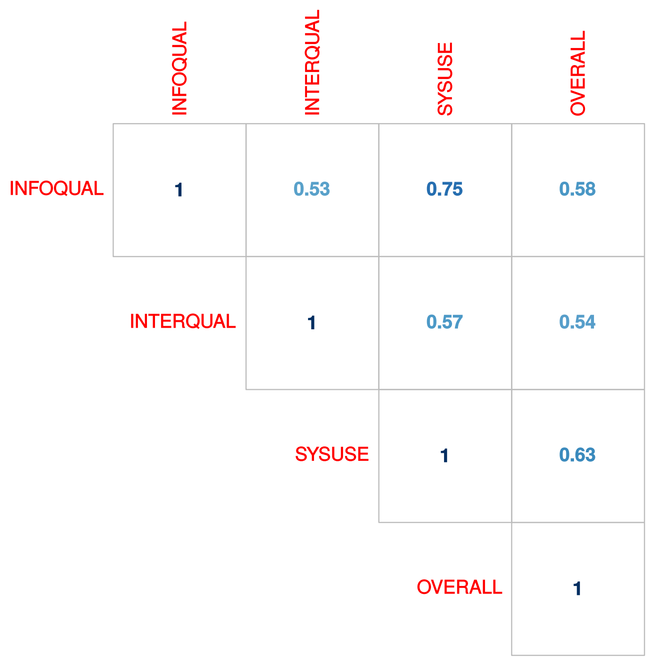

FIGURE 18. Correlation between mean responses for the IBM CSUQ categories.

B. REDESIGN OF THE USER INTERFACES

This section presents the new interface for the exercise's execution (see Fig. 19). The changes of this interface were done based on the results and the suggestion of the participants. In order to improve the user interface to make more friendly, we included a rectangle area for helping patients positioning in the field of vision of the Kinect and for allowing them a well recovery of the limb mobility.

The graphical-based feedback includes green and red color to describe how well the patient performed the movement. The red color represents a bad amplitude of the limb movement, while the green color indicates a correct one.

We have included textual descriptions to give the patient a better understanding of the performed movement. Likewise, we have included the current information regarding the serial number and the repetitions performed. Finally, we have separated the progress indicator and the score obtained after each movement.

VI. CONCLUSION

We presented the results obtained from a study of effectiveness, efficiency, and subjective user satisfaction conducted

TABLE 3. Summary of ranking variables.

	Mean	Std.Dev	Min	Q1	Median	Q3	Max	MAD	IQR	CV	Skewness	SE.Skewness	Kurtosis	N.Valid	Pct.Valid
P11_PC_experience	5.85	0.99	3.00	5.00	6.00	7.00	7.00	1.48	1.50	5.92	-0.82	0.38	0.28	39.00	100.00
P12_PC_work_ability	5.97	0.87	4.00	5.00	6.00	7.00	7.00	1.48	2.00	6.84	-0.41	0.38	-0.72	39.00	100.00
P13_Learn_software_ability	5.18	1.25	1.00	5.00	5.00	6.00	7.00	1.48	1.00	4.13	-1.11	0.38	1.88	39.00	100.00
P14_Browser_ability	6.21	0.57	5.00	6.00	6.00	7.00	7.00	0.00	1.00	10.88	0.01	0.38	-0.39	39.00	100.00
P15_Discuss_software_strengths_weaknesses	5.10	1.02	3.00	4.00	5.00	6.00	7.00	1.48	1.50	5.00	-0.34	0.38	-0.56	39.00	100.00
P16_PC_self_learning	5.33	1.15	2.00	5.00	6.00	6.00	7.00	1.48	1.00	4.62	-0.85	0.38	0.36	39.00	100.00
P17_Solve_PC_problem_different_manners	5.54	1.07	2.00	5.00	6.00	6.00	7.00	0.00	1.00	5.17	-1.03	0.38	1.16	39.00	100.00
P18_Not_needing_PC_best_way_use	4.62	1.44	2.00	4.00	4.00	6.00	7.00	1.48	2.00	3.20	-0.10	0.38	-0.83	39.00	100.00
P19_Prefer_learning_PC_software_by_myself	4.92	1.40	1.00	4.00	5.00	6.00	7.00	1.48	2.00	3.51	-0.82	0.38	0.24	39.00	100.00
P28_CG_experience_rate	5.74	1.19	1.00	5.00	6.00	6.00	7.00	1.48	1.00	4.83	-1.81	0.40	5.01	34.00	87.18
P29_CG_use_ability	5.47	1.28	1.00	5.00	6.00	6.00	7.00	1.48	1.00	4.26	-1.14	0.40	2.04	34.00	87.18
P33_KD_use_experience_rate	5.22	0.88	3.00	5.00	5.00	6.00	7.00	0.00	1.00	5.95	-0.41	0.54	0.59	18.00	46.15
P34_KD_work_ability	5.11	0.90	3.00	5.00	5.00	6.00	7.00	0.00	0.75	5.68	-0.20	0.54	0.23	18.00	46.15
P39_GUI_experience_rate	5.25	1.54	1.00	5.00	6.00	6.00	7.00	0.74	1.00	3.40	-1.60	0.64	1.98	12.00	30.77
P40_GUI_use_ability	5.33	1.50	1.00	5.50	6.00	6.00	6.00	0.00	0.25	3.56	-2.01	0.64	2.93	12.00	30.77

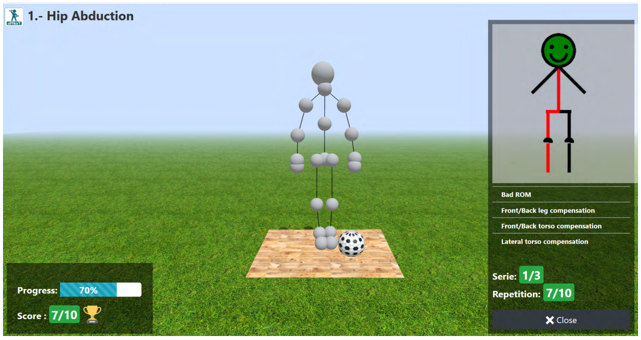

FIGURE 19. **The new patient's avatar user interface.**

with the Web-Based platform for Home Motor Rehabilitation (ePHoRt).

The work done is a contribution for the development of telemedicine platforms, context in which the usability factor is vital for the success of medical or therapeutic treatments of patients. Web-based platforms for home rehabilitation are of interest not only for patients and their families, but also for public health, since the use of technology saves infrastructure costs. In this context, studies like this one are necessary to guarantee the quality of the service provided to the patient.

The magnitude of the System Usability measure obtained for this study show a good usability of the platform. Participants reported a positive attitude of the tool against the difficulty to solve errors when they occur. This work enables us to identify specific usability aspects that should be implemented to ensure an efficient user experience of patients interacting with a tele-rehabilitation platform. The main finding of our study is that the error feedback should be as detailed as possible. The usability test shows that a lack of or an ambiguous user feedback can be a great barrier in the acceptance of the platform. To confirm this outcome, future work will consist of (i) conducting tests to measure the performance (e.g. time, efficiency...) of patients when using the platform, and (ii) carrying out accessibility and cognitive tests (e.g. mental workload). As a final thought, we are convinced that research efforts in the combined area of tele-medicine and usability are fundamental to incorporate new mechanisms of patient-computer interaction, such as natural user interfaces and machine-learning based chatbots.

APPENDIX A
SUMMARY STATISTICS OF SOCIO-DEMOGRAPHIC AND UX DATA

See Tables 2 and 3.

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