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18th International Conference, ICCHP-AAATE 2022
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Contents – Part II

ICT to Support Inclusive Education - Universal Learning Design (ULD)

Design for Assistive Technologies and Rehabilitation

Multimodal Wearable System for Motor Rehabilitation: Usability and Acceptability

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Abstract. Wearables are one of the most promising technology for easing the transition towards a personalized medicine, bringing healthcare and rehabilitation from hospitals to homes. Wearables inherently carries with them all the problems of small, portable devices and technologists. These problems could be related to the design phase as the real needs of the user are often not taken into consideration. This paper aims to describe the design and application of a new method for usability and acceptability evaluation of wearable devices, which can be applied after the first low fidelity prototype or and the end of development phase in order to evaluate how easy the system is to use, when comfortable and invasive, but above all if it reflects.

Keywords: Wearable design · Rehabilitation · Usability protocol · Co-design · User-centered design

1 Introduction

Population aging and especially Covid-19 pandemic situation are leading most of society to reshape healthcare systems, transforming a system based on hospital care into a system in which care is more personal, personalized and delocalized within homes. These circumstances changed people habits, and also healthcare system has been forced to evolve, changing protocols and medical environments, bringing prevention, diagnosis and treatment no longer in clinics, but in everyone's houses.

In this transition, advanced technologies play a fundamental role transforming the cure in care and improving patients and caregivers life quality.

In this day and age, wearable devices could be the best solutions in term of costs/services ratio for monitoring people outside hospitals. Wearables are one of the most promising technology which can help in the transaction from

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today medicine (based on cure and treat people) towards a more personalized, predictive, preventive and participatory medicine [1].

Wearables are by definition instruments that are in close contact with the human body; for this reason human factor and usability are fundamental and need to be considered and tested during all the development phases. Current wearable solution for telemedia and tele-rehabilitation often came from consumer products, and for this reason are cumbersome and developed for use in other areas and with different users; these because the design phase does not take into consideration all the actors and the stakeholders who can operate and wear the system. Moreover, the use of small and wearable technologies requires dealing with different barriers related to the users' health status, which cab further undermine the effectiveness of the diagnosis/treatment due to the difficulty of use.

Starting from a wearable system developed involving directly the various stakeholders from the earliest stage of design [2], this paper aims to define a usability and performance validation approach applied for the testing of wearable sensing platform.

2 Materials and Methods

The MW (Multimodal Wearable) system is a wearable system designed for monitoring and evaluating motor rehabilitation activities in post-stroke patients. MW born form a project funded by "Centro Protesi" Inail, one of the research centers of the National Institute for Insurance against Accidents at Work in Italy. MW is a suit embedding sensors to monitor rehabilitation sessions or supporting the restart of working activities without affecting functions and/or mobility. The hardware components are small devices to be worn and placed into the dedicated receptacles mounted on the suit, and the smartphone app to start/stop/record sessions's data complete the system. The suit is composed in two parts, upper and lower body, which consists in a long sleeves shirt and trousers each of which has 7 hooks for connecting sensors. Based on the rehabilitation exercise, a full-body or an half-body configuration can be worn. The suit would result in an increase of comfort and efficacy of the therapy.

As described above in the introduction paragraph, the main core of the MW project is the migration form the classic clinics rehabilitation, to a more personal and comfortable home rehabilitation. This objective underline the importance of co-designing the entire system directly with users and stakeholders in order to be able to correctly respond to their needs and desires.

The MW system was developed based on User-Centred Design (UCD) full-stack ten tails (FSTT) approach defined by Perego et al. [3]. The FSTT approach is based son ISO9421 UCD that consists in for main stages: brief and user definition, co-design, features definition, developing and testing.

As described by the FSTT the testing stage is not related only to the last part of the design, but is consistent with all the development approach. As show in Fig. 1, the FSTT is not a linear sequential method, but consists of a continuous circular process of product/service improvement until the performances required by all the stakeholders are achieved.

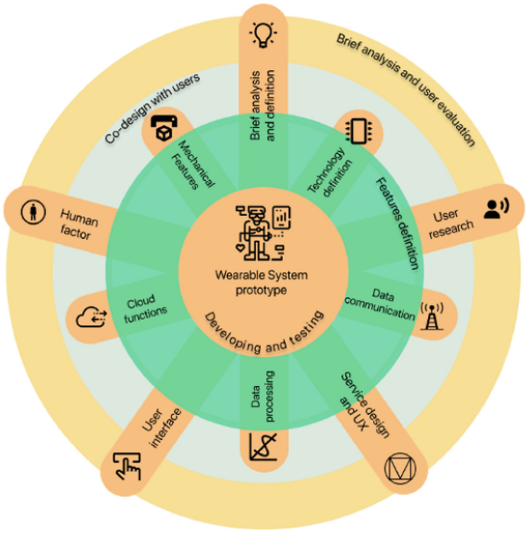

Fig. 1. Overview of the Full-stack ten tails (FSTT) approach.

The design iterations end only when the required performance off all the users and stakeholder are satisfied: both patients and doctors, nurses, physioterapists, relatives...

Having to meet the requirements of a plethora of different users and stakeholders, testing and iteration processes could become very time-consuming and expensive. For this reason, the drafting of an analysis and testing protocol is a mandatory part of the FSTT approach.

As for the FSTT approach, four main steps for the protocol definition are defined:

1. *Goals definition*
   The goals of the testing protocol is the outcome that designers desire from the test. It can consists in perceived comfort test regarding sensitized clothing, usability of the system, battery duration or system performances. Tasks definition needs to be strictly related to goals in order to optimize times and costs of carrying out the tests.
   In the use case of MW system, the expected goals/outcomes for the performance and usability protocols are:
   - Usability
   - Perceived comfort
   - Performance

   The goals of testing include establishing a baseline of user performance, establishing and validating user performance measures, and identifying potential design concerns to be addressed in order to improve the efficiency, comfort, and end-user satisfaction.

In order to have an index of performance, a baseline needs to be provided; for this reason, the performance test compares data of the MW system with respect to a gold standard technology. For this purpose, BTS mocap system and/or Xsens wearable mocap system, in standard protocol and movements of the upper limb according to Garofalo et al. 2009 [5], is used as comparison. The usability and perceived comfort tests focus on determining the design inconsistencies and usability problems during the use of the system (e.g. dress/undress problem, placement of the devices, functional performance, comfort problem).

2. *Tasks definition*
The main tasks of the system are defined during the initial definition stage in which a task analysis is executed. Task analysis is the process of learning about users by observing them in action to achieve a goal. Tasks analysis helps identify the tasks that applications must support. The tasks definition of the protocol drafting retraces the initial task analysis, to test all the main tasks that the user will perform within the system.
The task for usability test and performance test are different. Performance test is going to acquire the upper limb movements using both MW system and a gold standard. Comparison of the range of motion and angle patters in a timer normalized series is considered for validating and reliability assessment. The usability tasks were derived from test scenarios developed from use cases and/or with the assistance of a participant-matter expert. Preliminary sessions carried out during the development phase of the project have provided necessary input to the definition of this test plan and related protocol. Due to the range and extent of functionality provided in the application, and the short time for which each participant is available for the test, the tasks are the most common and relatively complex of available functions. The tasks are identical for all participants of a given user role in the study.
The usability testing protocol consists of 3 steps or phases:
Phase 1: observing the MW system and touching it; The facilitator and the project team members introduce MW system with its general description. The users can touch the system and devices but not wear and use it. Then, the user fills in the short questionnaire for this phase and describing product expectations.
Phase 2: wearing the system and preparing, before the rehabilitation session. The user is asked to wear the MW system. Ability to self-wearing the MW system and related time will be recorded. Non-critical errors will be eventually noted. The user has also to place the devices into the corresponding receptacles. In case of need of assistance, the facilitator will support the user in wearing the MW system and this operation is noted. Also in this second case wearing time will be recorded and non-critical errors will be eventually noted.

Phase 3: after having undressed the MW system and after the rehabilitation session.
The user activates the recording app on the smartphone. The user starts the simulated rehabilitation session for 10 min. At the end of this session, the user is asked to undress the MW system. Ability to self-undressing the MW system and related time will be recorded. Non-critical errors will be eventually noted. In case of need, the facilitator will assist the user in undressing the MW system and this operation is noted. Also in this second case wearing time will be recorded and non-critical errors will be eventually noted. After all these tasks, the user fills in the short final questionnaire for this phase and to verify the matching of the initial product expectations.

3. *Definition of the users:*
As for the ideation and product/service design phase, the definition of the users is a fundamental part for the protocol definition. The protocol needs to take into consideration different users, based both on expertise and other characteristics such as age, sex, schooling, disabilities...
All these characteristics, together with the cognitive age, digital literacy contribute to the acceptance of digital technologies [4]. Choosing the types of users for carrying out the tests is essential in order not to have final bias on the acquired data. For example, choosing users and experts in the field of mobile technologies can cause a wrong evaluation of the acceptability and usability of the system, as they are accustomed to the technology and are already aware of all those mental paths necessary for the use.
The usability testing includes 2 categories of users: direct users and caregivers, both considered primary users. Secondary users such as those participating in MW cleaning/maintenance and other secondary functions or in relation to the product lifecycle are not considered in this test plan due to the Covid-19 pandemic emergency which strongly affects the original protocol plans.
Having to test usability, perceived comfort and performances and having a fairly high number of stakeholders and type of users, the definition of the users for the tests can be different depending on the defined goals and tasks. In MW tests, the performance test is carried put on a sample of 5 healthy participants preferably ranging from the 5th female percentile in stature (about 155 cm) up to the 95th male percentile (about 185 cm). The user panel for the acceptability and usability test is designed as follows:
   - 5 health participants (also the same of the performance test);
   - 5 rehabilitation therapists/caregivers leading the therapeutic rehabilitative session and supporting some tasks (e.g. wearability, undressing the suit, first configuration...);
   - 5 patients or fragile people - the direct users - with acquired or congenital functional limitation running rehabilitation sessions.

Due Covid-19 emergency, the last 5 users only visual insect the MW system and fill in the assessment questionnaire without wearing and testing it for safety reason.
According to Faulkner [6], the above described sample is coherent to reach a confident value of 90%.
All users needs to be aged 18 or more and sign the informed consent. The panel need to possibly be gender balanced. The participants try to complete a set of representative task scenarios presented to them in as efficient and timely a manner as possible, and to provide feedback regarding the usability and acceptability of the user interface. The participants are directed to provide honest opinions regarding the usability of the application, and to participate in post-session subjective questionnaires and debriefing.
Moreover, the participants are going to receive an overview of the usability test procedure, equipment and methods before acceptance and participation to the test.

4. *Metrics definition*
Metrics are fundamental to quantify the tasks outcomes. Depending on the number and type of tasks and goals, different evaluation metrics can be defined. These can be metrics derives dorm standardized methods (for example standardized usability test such as the SUS and the QUIS questionnaire), or associated with numerical values defined by the designer. In this second case the Likert scale is the most used and consists of a scale used to represent people's attitude to a topic.
Usability metrics refers to user performance measured against specific performance goals necessary to satisfy usability requirements. Scenario completion success rates, adherence to dialog scripts, error rates, and subjective evaluations will be used. Time-to-completion of scenarios will also be collected.
Three questionnaires will be administered to participants in three steps of user experience and usability of the product:
   – Showing the MW suit and system before wearing it;
   – After having worn the MW system;
   – At the end of the session, after having undressed the MW suit.

The questionnaires are based on the Visual Analog Scale (VAS) or the Likert scale, each question with the proper resolution 5/7/9 points according to the validated semantic scale. A body part discomfort score complements the questionnaire. Some performance measures (e.g. time to complete the task) are recorded as well.
Other two metrics are include in the protocol: successful self wearability/undressing (0/1 - N/Y, binary value); self wearability/undressing time (time in seconds with 2 decimals).
Completion rate is recorded for any session; completion rate is the percentage of test participants who successfully complete the task without critical errors (Fig. 2).

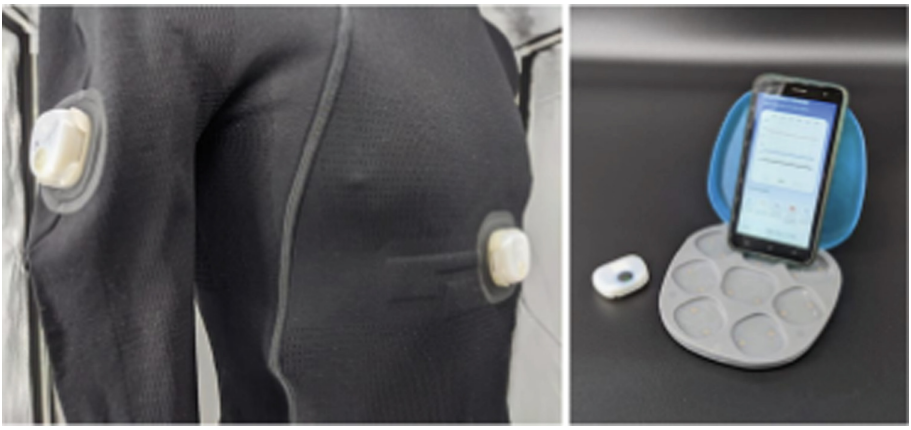

Fig. 2. The MW sensorized suit with the sensors, battery charger and mobile app.

3 Results and Discussion

15 participants (6 males and 9 females, aged between 25 and 60 years) participated to the usability tests. Out of total of 15 participants, 5 are healthy participants, 5 are therapists from the Centro di Riabilitazione Villa Beretta (CRVB) Valduce Hospital, 5 are participants with pathologies under treatment at CRVB. The factors that influence or not the digital acceptance by people are strongly linked with the same factors that determine the usability of a digital interface. Usually users with low digital acceptance, who tend not to be attracted to the products/services provided by digital and make very little or almost no use of them, are the same who, when interfacing with them, have greater difficulties in using them. This is because their low exposure to these interfaces does not put them in the position of being able to correctly recognize and use the design patterns that are usually implemented in digital interfaces. For this reason an heterogeneous sample of participants was selected; however all participants were in possession and regularly used a smartphone.

Wearability tests and surveys has been executed by healthy participants and therapists, and after that a standardized questionnaire (SUS - System Usability Scale) [7] has been administered to them; the SUS has been accompanied by other questions based on the Likert scale in order to measure the degree of acceptability of the system. For the pathological participants it has not be possible to carry out the wearability tests for precautionary reasons due to the Covid-19 pandemic emergency. The results (Fig. 3) emerged from the final overall evaluation show that there is an excellent adherence between the high initial expectations of the participants involved and the post-test evaluation of the system. This reasons that the system responds to the expected users' needs, in particular thanks to the first co-design phase that characterized the MW project. In general, the perceived quality of the system is high, a score that is substantially confirmed by the parameters analyzed in the usability assessment.

It should be emphasized that the quality of the information received by the system, the overall acceptance and appropriateness of the operations carried out by MW reach an optimal score (>6/7) while the other evaluation parameters are at very good values, close to the optimal. The slightly lower scores relate to wearability (4.1/5) and aesthetic acceptability (5.40/7) underlines the opportunity to improve the system, by working on the suit design and aesthetics and the methods of wearing and unwiring. The usability test also measured the wearing times of the system, which is around four minutes for dressing, and around a minute and half for undressing.

Finally, the mobile application developed to detect data has been tested by users; this App has an overall acceptability high score SUS 75.5/100 and in particular, by the category of users for which it was developed, the therapists, the score achieved has been 87.5/100.

Preliminary Evaluation	A01	A02	A03	A04	A05	B06	B07	B08	B09	B10	C11	C12	C13	C14	C15	AVD	STD	MEDIAN
Evaluation of expected functionality (1-7)	7	6	6	6	7	6	6	6	6	6	6	6	5	6	5	6,00	0,53	6,00
Wearability(1-5)	4	3	4	5	4	4	4	4	5	4	3	4	3	2	2	3,67	0,90	4,00
Level of expected comfort (1-5)	4	4	4	4	4	4	3	5	5	4	4	4	4	4	4	4,07	0,46	4,00
Aesthetics(1-7)	7	4	4	7	4	6	6	7	6	6	6	6	6	6	6	5,80	1,01	6,00
Overall acceptance (1-7)	7	5	6	6	7	6	6	7	6	6	6	6	6	6	6	6,13	0,52	6,00
Quality of information(1-7)	7	6	6	7	6	6	7	7	6	5	6	6	6	6	5	6,13	0,64	6,00
Global importance of the MW system(1-7)	6	6	7	6	6	6	6	6	6	5	6	6	6	6	5	5,93	0,46	6,00

Final Assessment	A01	A02	A03	A04	A05	B06	B07	B08	B09	B10	C11	C12	C13	C14	C15	AVD	STD	MEDIAN
Evaluation of perceived functionality (1-7)	6	6	5	5	6	6	6	7	7	6						6,00	0,67	6,00
Wearability (1-5)	3	4	2	5	3	4	5	5	5	5						4,10	1,10	4,50
Comfort perceived (1-5)	5	4	4	4	4	5	4	5	5	5						4,50	0,53	4,50
Aesthetics (1-7)	7	4	6	6	4	6	6	7	6	6						5,80	1,03	6,00
Overall perceived acceptance (1-7)	7	4	6	5	6	6	6	6	7	7						6,00	0,94	6,00
Quality of the information received by the system (1-7)	7	4	7	6	7	6	7	7	7	6						6,40	0,97	7,00
Evaluation of the operations appropriateness with MW system (1-7)	7	4	6	4	6	6	7	7	7	6						6,00	1,15	6,00
Evaluation of the overall importance of the system (1-7)	7	6	7	5	7	6	6	7	7	4						6,20	1,03	6,50
Level of satisfaction (1-7)	6	4	6	4	6	6	7	6	7	6						5,80	1,03	6,00
level of global quality of the MW system (1-5)	5	5	4	4	5	4	4	5	5	5						4,60	0,52	5,00

Legend
A1/A2/A3/A4/A5 Healty subjects
B6/B7/B8/B9/B10 Therapist
C11/C12/C13/C14/C15 Patients

Fig. 3. The chart shows the results of the usability test.

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