A USER-CENTRED DESIGN CASE STUDY: DESIGN OF A WEARABLE sEMG SYSTEM

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INTRODUCTION

Surface electromyography (sEMG) is a non-invasive technique employing electrodes fixed to the surface of the skin to record the electrical activity produced by muscle contractions. Analysis of the acquired data can be used to quantify the relative strength and timing of muscle contractions [1]. SEMG can be used to better understand neuromuscular injury or disease (i.e. cerebral palsy, muscular dystrophy, and Parkinson's [2]) during walking (gait analysis) or other movements.

Due to various technical issues, conventional sEMG based motion analyses are often limited to laboratory settings and involve specially trained technicians or engineers operating the computer system. Conventional sEMG acquisition has a relatively long set-up time that includes skin preparation (e.g., cleaning with alcohol and often shaving or abrading the area to improve the signal quality [3]) and placement of electrodes based on anatomical landmarks [4]. Including setup, system calibration, and client assessment, a visit to a motion lab equipped with a conventional sEMG acquisition system can take from two to four hours [5]. Another limiting factor is the financial cost, which quickly mounts as initial system purchase, ongoing maintenance, and staff salaries are considered. Consequently, sEMG is not extensively used in clinical motion analysis despite validated advantages [6]. A clinically feasible sEMG system is required that addresses the time, cost, and complexity issues [6].

To reduce the time required and inconvenience involved with conventional sEMG based movement analyses, we are designing the Wearable EMG Analysis for Rehabilitation (WEAR) system. WEAR is a proof-of-concept prototype intended for use in clinical gait analysis and consists of three main sub-systems: 1) physical interface, 2) electronics and 3) post-processing. The physical interface includes the electrode array, which reduces setup time by eliminating the need for anatomical measurements in electrode placement, the electrode mount (i.e., the wearable sleeve), foot switches, and an accelerometer; the latter two to align sEMG data with specific gait events. The electronics sample and process the sEMG input prior to storing and transmitting the data for post-processing, which occurs offline on a computer. During post-processing, the best quality set of data from the array is selected. Readers can refer to [7] for a more complete system description.

Ongoing research and development of this portable, wearable, and clinically feasible system incorporates the end-users into the design process by analyzing their environment, assessing their needs and obtaining their feedback on design concepts. We are following an iterative method known as User-Centered Design (UCD), which has been proven to improve productivity, reduce operator errors, reduce the amount of training and support required, and improve acceptance of a product or system by the users [8],[9]. UCD is an iterative design process incorporating end-user feedback and validation at each stage (Fig. 1).

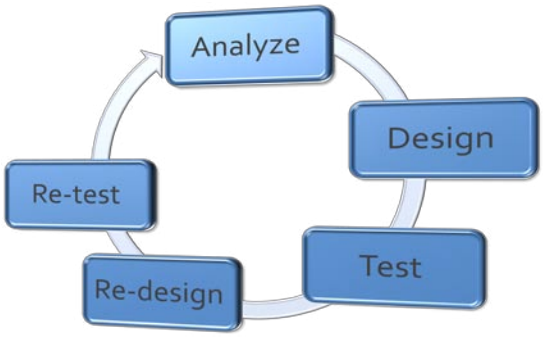

Figure 1: UCD Lifecycle [11]

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User involvement comes in various forms, including but not limited to, being shadowed by researchers throughout their regular activities, one-on-one interviews, group discussion forums, or participation in usability tests with system prototypes. UCD methodology has made deep inroads in sectors such as defense and aviation, where human factors or usability engineers are an integral part of design teams [10]. Multidisciplinary fields, such as biomedical engineering, lend themselves particularly well to UCD since the systems being designed must be used by people with varying levels of technology expertise. This paper describes the design of the WEAR system as a case study of applying UCD methodology to biomedical technology development.

Methodology

Following the UCD methodology outlined in Fig. 2, this paper covers a single iteration of the first three stages - analyze, design, test - of the UCD lifecycle.

Analysis

Production conception discussions with high-level stakeholders (principal and co-investigators) led to the justification for the design and development of the WEAR system, as described in the introduction. The next step involved identifying primary and secondary users and the development of “personas”.

Due to their frequent use of motion analysis in the treatment of neuromuscular injury and disease, physiotherapists (PTs) stood out as the primary users and the object of focus during the first design iteration. This means that the main design and testing efforts will address these users. Physical rehabilitation clients who received physiotherapy treatment were identified as the secondary end-users. Personas, a detailed depiction of fictional users, were developed for the primary users. These enabled the design team to visualize the system in use, in its intended context and environment, to make better design decisions [12].

Once the system users had been identified, the usability goals (requirements) for the WEAR system were defined. The goals are effectiveness, efficiency, learnability, and wearability. The effectiveness goal can be achieved through error free system operation, and efficiency is defined in terms of speed of use when compared with the average time required to setup and operate a conventional sEMG system [13]. In terms of learnability, WEAR will require little time (potentially 20-30 minutes) for new users to confidently use the system, including error avoidance/recovery [14]. Finally, wearability is defined as the interaction between the system and human body while stationary or in motion [15]. Secondary end-users must be able to maintain natural movement patterns throughout data acquisition.

Following the production conception discussions, user research was employed to validate the expected personas and usability goals as well as to establish end-user requirements. User research for the WEAR system began with a preliminary context assessment, to be followed by one-on-one interviews and open discussion forums with a group of PTs, the primary end-users [16].

The context assessment will consist of an observational field study of conventional sEMG based gait analysis. The field study will provide insight into the task flow involved in conventional sEMG analyses, including data collection and analysis. The goals of the field study are to develop a scheme for WEAR system validation and to comprehend how such tasks could be incorporated into the PTs’ assessment and rehabilitation programs. Task-based workflows will be conceived to help ensure that system functionality will be user-oriented [17].

A sample group of ten PTs will be recruited from various clinics throughout Ottawa, Canada. Ten subjects are sufficient for this qualitative and exploratory purpose, to generate ideas to support the design process [18]. The selection criteria requires PTs who routinely work with clients exhibiting neuromuscular abnormalities in the lower leg and are familiar with industry accepted assessment and rehabilitation techniques for such deficiencies.

By studying their environments and workflows, we intend to identify their needs. The open forum discussions will help to

determine how our system would best be used within a PT environment and allow the development team to adjust the design specifications appropriately.

The one-on-one interviews will be exploratory in nature, conducted at the PT clinics to gain familiarity with their environments. The interviews may be conducted while shadowing the PTs while they conduct their normal work activities. Through open ended questions, they will describe their roles and provide scenarios that detail their assessment procedures for gait related issues. We will discuss which tools and methods they use to assess clients, how they use this information for clinical decision-making, and which tools they use to track client progress. Aspects of these tasks that cause frustration will be explored; such as, time delays, level of complexity, and functional limitations.

As the interview progresses, the line of questioning will lead towards technology with the goal of discovering the therapist's muscle evaluation needs. We will also endeavor to determine their current level of sEMG knowledge. Information gathered from the exploratory interviews will be compiled and a list of high priority limitations and frustrations will be produced for use as the main discussion points in the discussion forum.

The discussion forum will bring the focus group together to openly explore the WEAR concept and identify any disregarded needs [16]. The forum will begin with a brief review of sEMG and conventional sEMG based gait analysis to provide background information. This will be followed by the presentation of storyboards depicting context based usage scenarios of the WEAR system along with some low-fidelity concept images of the WEAR system [19].

Based on limitations and frustrations tabulated from the exploratory interviews, needs will be assessed through an open discussion. System features based on fulfilling these needs will be proposed and examined within the group. A spreadsheet, visible to all participants, will be used to associate the discovered needs and required system features. This spreadsheet will be used for qualitative analysis purposes in the development of the sEMG system.

Physiotherapist feedback will be analyzed through association of the discovered needs with the system features using non-parametric frequency oriented statistics to generate a set of end-user requirements, with a focus on usability design goals. These requirements will be used to develop functional prototype design concepts. At this stage, system component selection will be completed as the process moves to the design phase.

Design

The WEAR functional prototype will be developed to satisfy the requirements discovered in the analysis phase. Engineering specifications will be followed to ensure that sEMG data can be reliably captured. Since this will be a proof-of-concept prototype, form factor and mass will not be priorities. Technical goals for achieving comparable sEMG signal quality relative to conventional sEMG systems will be prioritized, but basic functionality will be implemented based on the established end-user requirements.

Once the WEAR prototype is functionally reliable and can produce repeatable outcomes in pilot testing, system testing will commence.

Test

A new group of ten able-bodied participants will be recruited to perform a series of tasks, alternating between the WEAR and conventional sEMG data acquisition systems. System validation sessions will inform the design team about the efficiency gained over conventional systems, while allowing us to receive wearability feedback from the device before formal evaluations with people with disabilities (secondary end-users).

Data analysis will show whether technical and efficiency goals have been met. Verbal feedback from participants collected during the validation stage will be analyzed and tabulated. The wearability data will be used to generate a new set wearability requirements during the next design iteration.

Due to time and project scope restrictions, the design team will conduct the testing, thus

effectiveness and learnability statistics from PTs will not be collected in this iteration. Ideally, the original group of PTs would be provided a brief training session with WEAR and would then conduct the tests themselves. Think aloud techniques, where the user is encouraged to explain what she/he is thinking/doing throughout the test could be employed [20]. This type of usability will be conducted in a second UCD lifecycle iteration.

Conclusions

The WEAR system design is currently in the analysis phase of the UCD lifecycle. It is anticipated that the user interviews will validate the personas and goals determined in the production conception discussions that occurred during the analysis phase. We expect that incorporating user input into WEAR system development will have an advantage over conventional approaches in terms of ease of use, setup time, and learnability. In addition, the WEAR system will have the advantage of being low-cost and portable. While we expect a tradeoff in the form of decreased sEMG signal quality due to electrode technological issues, this decrease should be within a clinically acceptable range. However, WEAR's usability and accessibility advantages obtained through use of UCD should offset the loss in signal quality. Through this case study, we hope to show the advantages of UCD in biomedical technology development.

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