Facilitating Trunk Endurance Assessment by means of Mobile Health Technologies

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UbiComp/ISWC '15 Adjunct, September 7-11, 2015, Osaka, Japan.

http://dx.doi.org/10.1145/2800835.2800899

Abstract
Trunk endurance tests are widely used in physical medicine to assess the muscle status of people affected by low back pain. Nevertheless, traditional evaluation procedures suffer from practical limitations, which can lead to potential misdiagnoses. This work presents mDurance, a novel mobile health system aimed at supporting specialists in the functional assessment of trunk endurance by using wearable and mobile devices. The system makes use of a wearable inertial sensor to track the patient trunk posture, while portable electromyography sensors are employed to seamlessly measure the electrical activity produced by the trunk muscles. The information registered by the sensors is processed and managed by a mobile application that facilitates the expert normal routine, while reducing the impact of human errors and expediting the analysis of the test results. The reliability and usability of mDurance is proved through a case study, thus demonstrating its potential interest for regular physical therapy routines.

Author Keywords
Mobile Health; Physical Therapy; Trunk Endurance; Inertial Sensors; EMG Sensors

ACM Classification Keywords
J.3 [Computer Applications]: Medical information systems.

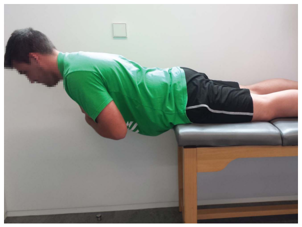

Figure 1: Subject during the execution of the Sorensen test. The person holds a horizontal unsupported posture with the inguinal region at the edge of the bench.

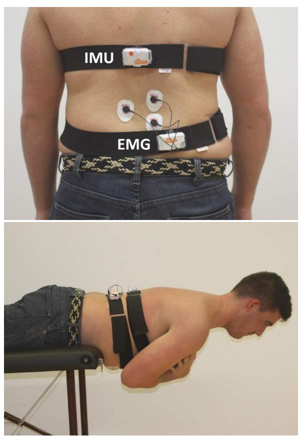

Figure 2: mDurance sensors deployment. Both IMU and EMG sensors are attached to the lumbar zone to ensure stability and comfortability.

Introduction

Low back pain (LBP) constitutes a major cause of disability worldwide [4]. This condition normally appears due to a lack of muscle endurance, which leads to a poor trunk stability. Consequently, a high emphasis has recently been placed on the functional assessment of the trunk endurance [5]. Trunk endurance assessment (TEA) tests normally consist in the measurement of the time a person can hold a specific posture involving the trunk muscles. For example, in the Sorensen test [2], the most extensively used medical procedure for TEA, the subject has to maintain, as long as possible, a horizontal unsupported posture while extending the upper body beyond the edge of a bench (see Figure 1). The timing begins when the posture is horizontal and unsupported, and the test ends under the following circumstances: the position is held up to a maximum of 240s; the individual drops below the horizontal position more than 10° (a second chance is given to regain it after the first attempt); or the subject reports LBP or cramping in their legs. During the execution of the test, the health professional has to control the patient position and decide when the test ends, according to the above termination criteria. The results obtained for a given patient help experts determine their status and muscular capacity, as well as their ability to hold a posture normally related to daily living activities.

Limitations of Traditional TEA Tests

Diverse practical limitations can be seen in the course of the realization and evaluation of endurance tests [7]. The determination of the start and end of the test is completely subject to the expert visual interpretation. In fact, specialists often report on the difficulties faced during the observation of the trunk angle variation and termination criteria. Besides, the expert has to supervise various aspects simultaneously, such as time, position, and possible abnormalities during the test, which in traditional procedures could be despised [3]. Lastly, specialists can principally elaborate their diagnosis on the time recorded during the performance of the test, and that is the only information to compare with in future tests. These potential issues complicate the comparison of values measured by different testers and among sessions.

mDurance: a Mobile Health System for TEA

In the light of the limitations of traditional TEA approaches, this work presents *mDurance*, an innovative system to support practitioners during regular trunk endurance procedures. The system consists of a wearable IMU sensor (Shimmer3) to estimate the trunk position and an attachable electromyography sensor (Shimmer2) to measure the activity of the trunk muscles (see Figure 2). All the sensory data generated in the execution of the endurance tests is seamlessly and securely streamed to a mobile application, which processes it for the visualization of health outcomes. The app builds on some of the functionalities of a previous mobile health framework [1].

Automatic Trunk Posture Estimation

Determining the human trunk posture is of key importance to help experts set the start (i.e., horizontal posture) and identify the end (i.e., angle limit is exceeded) of the test. mDurance uses the IMU signals to measure the absolute attitude of the body part the sensor is located. The sensor orientation is estimated through the Madgwick's algorithm [6]. This technique employs acceleration, angular rate and magnetic field measurements to analytically derive a quaternion representation of motion. Quaternions are then simply translated into Euler angles to make the readings human-understandable. From the three Euler components, the roll angle is particularly considered to represent the trunk inclination given the sensor placement.

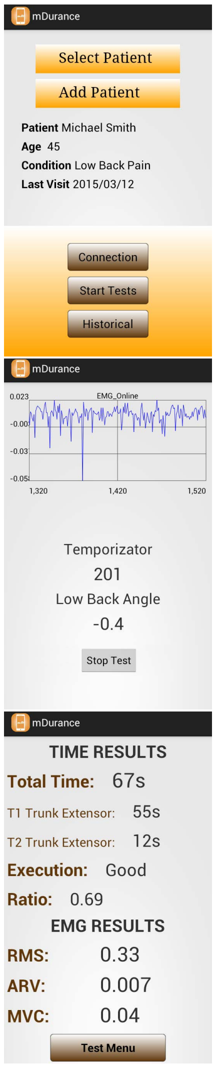

Figure 3: mDurance application snapshots: (**top**) Patient selection; (**center**) Test execution; and (**bottom**) Test results summary.

Muscle Fatigue Monitoring

During the endurance test, the muscles are normally subject to a high level of activity and stress. Having a continuous description of the evolution of this activity is of much clinical relevance to determine the muscle fatigue and potential physiological abnormalities. Through the EMG sensor, mDurance allows the expert to continuously monitor the electrical activity produced by the skeletal muscles. The system also computes some well-known metrics that help categorize the muscle fatigue level, i.e., root mean square (RMS), average rectified value (ARV), and maximum voluntary muscle contraction (MVC). These metrics are of much interest to compare the evolution of the muscle strength among sessions and measure the effectiveness of potential treatments.

mDurance App

All the mDurance functionalities are made available to the expert through an intuitive Android app (see Figure 3). The practitioner can access the application contents by logging in with their username and password. Once the expert is authenticated, they can select a patient from an existing registry or create a new one. After selecting a patient, their most prominent personal information is shown to the expert (Figure 3-top). From here, the specialist can initiate the connection of the smartphone with the wearable sensors, which is performed through the Bluetooth Low Energy protocol. Then, the expert can proceed to the test phase, for which a new screen (Figure 3-center) is displayed including a graph to continuously visualize the EMG signal and the time left according to the maximum duration of the test. It also shows the measured trunk angle, which is of particular use for the expert to initiate the test once the patient adopts the starting position. The test is automatically finished when any of the termination criteria are met, i.e., the trunk angle exceeds 10°, the test lasts more than 240s, or the expert decides it. After the test finalizes, the expert can observe a summary of the results (Figure 3-bottom). This includes the total duration of the test (sum of the two attempts), the endurance ratio, and the RMS, ARV and MVC values. Also, the session is categorized into "bad", "good" and "perfect" based on the statistical overall duration of the patient [5]. The ranges are bad=$[0, 61s]$, good=$[62, 131s]$ and perfect=$[132, 240s]$.

Results

A preliminary analysis of the reliability and usability of mDurance has been performed. To that end, ten volunteers, eight males and two females ranging from 21 to 37 years old, were recruited to be evaluated, after informed consent and explanation of the tests, by three external physical therapists using both mDurance and traditional procedures. The test execution was similar from the subject perspective; however, in the traditional approach experts had to visually determine the start and end of each test and time it using a stopwatch, while in the use of mDurance these processes were automated.

Reliability

The inter-rater reliability between the traditional TEA and mDurance is determined through a statistical analysis. To that end, the endurance times measured for each individual and procedure are contrasted by using a Bland-Altman plot (see Figure 4). This method, widely used in medical statistics, depicts the differences between the measurements of two procedures against their averages, which helps better understand the agreement between both methods. If the differences fall within the limits of agreement the two methods can be used interchangeably. Indeed, this is seen to be the case for the evaluated procedures, thus not suggesting the presence of

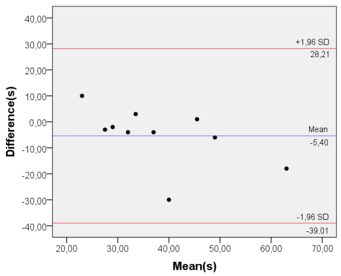

Figure 4: Agreement analysis between traditional TEA and mDurance through Bland-Altman plots. The mean of differences ($\bar{x}$) is represented by a blue line, while the limits of agreement ($\bar{x} \pm 1.96\sigma_X$) are depicted in red.

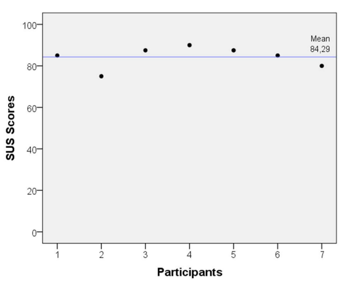

Figure 5: Experts SUS scores after using mDurance. The average score is depicted in blue.

relevant disagreement. Though these results show very promising, a study with more subjects, and patients with LBP, would be required to further confirm these findings.

Usability

The three experts were asked to provide their impressions after the use of mDurance. First, they noted the practicality of the automatic angle measurement to determine the user start position and to estimate the end-of-test. Furthermore, they greatly appreciated the EMG runtime representation to observe the muscle contraction during the realization of the test. The experts also highlighted the utility of having an automated log of time and muscle fatigue values to evaluate the patient progresses. On the contrary, they mentioned that simpler guidelines should be provided along with the mDurance application to accelerate its understanding and operability, especially for the use of the sensors. Besides, they considered desirable to share the data among diverse platforms, instead of limiting its use to a single device.

A more formal evaluation of the experts experience is made by using the System Usability Scale (SUS). This is a *de facto* industry standard utilized to quantify technology user experience. SUS consists of ten statements that are scored by the user through a five-point scale anchored with "strongly disagree" and "strongly agree". SUS provides a percentage estimate of usability: scores above 70 are acceptable, while highly usable products score above 90. For this evaluation, seven independent specialists were asked to use mDurance during a small trial. The mean SUS score was 84.29±5.15 (see Figure 5). The scores indicated high levels of acceptability, ease of use and confidence when utilizing mDurance. A study with a higher number of experts is needed, but preliminary findings seem to be favorable.

Conclusions and Future Work

This work has introduced mDurance, a novel system to support practitioners during the assessment of trunk endurance. To the best of our knowledge this is the first mHealth system dealing with this problem. An initial evaluation of the mDurance system has been performed, showing a remarkable reliability and usability, which supports its potential regular use. Given the interest shown by experts, next steps include the use of mDurance on a large scale clinical test bed, now under development.

Acknowledgements

Work supported by the ICTD Program under grant agreement #10049079, MOTIE, Korea.

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