# Measurement of Heel-Rise Test Results using a Mobile Device

Ivan Miguel Pires[1,2], Márcia Andrade[1], Nuno M. Garcia[1,3],
Rute Crisóstomo[4,5,6] and Francisco Florez-Revuelta[7]

[1]*Instituto de Telecomunicações, University of Beira Interior, Covilhã, Portugal*
[2]*Altranportugal, Lisbon, Portugal*
[3]*ECATI, Universidade Lusófona de Humanidades e Tecnologias, Lisbon, Portugal*
[4]*Laboratório de Biomecânica e Morfologia Funcional (LBMF), Faculdade de Motricidade Humana, Universidade de Lisboa, Lisbon, Portugal*
[5]*Centro Interdisciplinar Para o Estudo da Performance Humana (CIPER), Faculdade de Motricidade Humana, Universidade de Lisboa, Lisbon, Portugal*
[6]*Instituto Politécnico de Castelo Branco, Escola Superior de Saúde Dr. Lopes Dias, Castelo Branco, Portugal*
[7]*Faculty of Science, Engineering and Computing, Kingston University, Kingston upon Thames, U.K.*



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Abstract: The heel-rise test measures the ability to perform eccentric and concentric muscle actions of the plantar flexor muscles with unilaterally consecutive elevations of the heel. This test is easy to administer and is a non-invasive test for strength and endurance of the calf muscle. Despite the part that this test has proven reliability, it has been difficult to measure its results, as it depends on the subjectivity of the examiner and conditions of the place of testing. This research consists in the design and development of a mobile application for the heel-rise test. The algorithm makes use of sensors to measure the exercise, implementing the rules to detect a pattern of the accelerometry sensors during the test. The heel-rise test consists in detecting periodically the number of correct exercise repetitions. Then, physiotherapists can use this heel-rise automatic test in their examinations.

## 1 INTRODUCTION

Technology is nowadays widely used in people's daily life to support their work and improve their quality of life. During the last years, the use of smartphones or portable devices has increased (eMarketer, 2014), connecting people to the digital world anywhere at anytime. Most of these devices incorporate embedded sensors that capture signals at real-time and that can be used to improve health, detect falls and monitor activities of daily living. These technologies and services establish what is usually named as Ambient Assisted Living.

Mobile applications are software components with less functionality than desktop software and that are specially designed for a specific task, due to the fact that mobile devices have some limitations (Biel et al., 2010). Mobile applications have an important impact on society, but their use depends on several factors, such as screen resolution, hardware limitations, expensive data usage, connectivity issues, and limited interaction possibilities. (Islam et al., 2010).

Sensors can help to identify physical activities and their consequent effects such as fatigue, cardiac arrhythmia, among others (Moran and Marshall, 2006). On the other hand, the regular physical activity is important to reduce the risk of some diseases, such as obesity, cardiovascular accidents, diabetes, Parkinson, chronic diseases… (Thompson et al., 2003). Mobile devices acquire data related to the activities performed and analyse that data to identify the type of activity performed by the user. The activity detection consists of different phases, such as pre-processing, minimization of noise, and classification of the collected data, related to some task, using statistical methods or other methods, such as machine learning or pattern recognition. Usually, the equipment must be positioned in a specific location of the user's body for better recognition. Adequate automatic methods allow, in some cases, monitoring and treating health problems easier and more accurate than manual methods. However, for an acceptance by the medical communities, these technologies must be medically validated (Barton, 2012, Brusco, 2012).

In physiotherapy, the use of some tests to assess health dysfunction and physiological parameters is common. For instance, the Heel-Rise Test is used to detect muscular fatigue. The Heel-Rise Test consists in the ability to perform eccentric and consecutive concentric actions of the ankle plantar flexor muscles with maximum heel elevation possible (Sman et al., 2014, Yocum et al., 2010). Currently, due to the inexistence of automatic methods using technological devices, the exercise related to the Heel-Rise Test needs the presence of an examiner that observes and validates the exercise performed by the patient. The measurement of the heel-rise test needs external devices to control the time between the repetitions, for example a metronome or other counting device, and needs a previous evaluation and preparation of some physical conditions.

This work presents the design of an automatic algorithm for the Heel-Rise Test and its implementation in a mobile application. The developed mobile application makes use of pattern recognition techniques to measure the number of correct repetitions performed during the test with the mobile device attached to the user's waist. This test is easy, inexpensive and non-invasive. The development of this mobile application has a validated algorithm. The validation of the algorithm consists in the readings from the mobile device's accelerometer comparing the results the readings from an external tri-axial accelerometer and a force platform.

This study uses data collected with the collaboration of the Assisted Living computing and Telecommunications Laboratory (ALLab), which is part of the Institute of Telecommunications, located in the University of Beira Interior, in Covilhã, and the Escola Superior de Saúde Dr. Lopes Dias, which belongs to the Polytechnic Institute of Castelo Branco.

This paper is organized as follows: in section 2, some research studies, carried out by other authors, about the Heel-Rise Test are presented. Section 3 presents the details about the automatic method for Heel-Rise Test. In section 4, the current results about the mobile application and algorithm created are discussed. The conclusions about this study are presented in the section 5.

## 2 RELATED WORK

Physiotherapists, use the Heel-Rise Test (Veilleux et al., 2012a) to identify muscle fatigue by studying the number of repetitions of heel-rise movements until the user achieves muscular fatigue This test allows them to relate the results with specific health problems.

The Heel-Rise Test can be used to assess muscle strength, endurance, fatigue, and balance and equilibrium of the whole body (Sole et al., 2010).

The protocol to be applied in this test is an elevation as high as possible with knee test member in extension (Segura-Orti and Martinez-Olmos, 2011) with people's barefoot, every two seconds (Silbernagel et al., 2010), controlled with a metronome. The contralateral foot is kept just above the ground (Segura-Orti and Martinez-Olmos, 2011). Before the test, the examiner will do 5 repetitions for exemplification and then the participants will try to maintain balance on one foot, touching the wall with his fingertips, flexed arms to shoulder height to avoid leaning hard against the wall, and, finally, they will perform transfers weight (Österberg et al., 1998, Segura-Orti and Martinez-Olmos, 2011, Yocum et al., 2010). Then, the participants make 2 repetitions to identify the maximum elevation obtained during these repetitions, followed by a 5-minute-break to start the test (Yocum et al., 2010). In the training repetitions, the maximum height achieved by the participant will be marked on the wall above the participant's head, giving the objective of reaching the mark in each repetition (Yocum et al., 2010).

Thus, the measurement of the Heel-Rise Test consists of the number of repetitions that the exercise is correctly performed (Yocum et al., 2010). So, according to (Segura-Orti and Martinez-Olmos, 2011, Yocum et al., 2010), the test will be suspended when:

- The participant says to stop;
- The force of the knee flexion, according to the observation of the examiner;
- The member is pushing against a wall, according to the observation of the examiner;
- The participant fails to reach 50% of height marked on the wall;
- The contralateral limb touches the ground or misses the rhythm of the metronome on 2 consecutive repetitions.

This test has some variations, such as the single heel-rise test and the double heel-rise test. The Single-Leg Heel-Rise Test may also be a useful performance measure regarding footwear or other therapeutic interventions, as it incorporates elements of both the late stance phase when sensory input is gathered and the more challenging heel-off phase of the gait.

It is also important to assess the calf-muscle performance (Crossley et al., 2007). During this test, participants maximally raised their heel off the floor, returning to the floor at a rate of 1 heel rise every 2 seconds. Five practice heel rises were performed followed by a 1-minute rest prior to the actual test. The participant was asked to perform as many heel rises as possible. Repetitions were counted each time the foot went back to the ground. The test was terminated if the participant leaned forward with a force greater than 2% of the body weight, the participant's knee flexed, or the participant failed the time with contact to the ground during three consecutive heel rises.

Chen et al. (Chen et al., 2012) created a three-dimensional musculoskeletal finite element model of the foot to quantify the precise role of the gastrocnemius–soleus complex in terms of biomechanical response of the foot, which corresponds to a muscle-demanding posture during heel rise, with simulated activation of major extrinsic plantar flexors. This model can measure the force necessary to do the exercise and the posture during the exercise. In (Dutta et al., 2012), electromyography is employed in the heel-rise test, measuring the muscular fatigue with good accuracy.

The heel-rise test rates ankle plantar flexor strength from 0 to 5 according to the number of heel rises that the subject is able to complete (Caudill et al., 2010). Performance of 20 repetitions corresponds to a maximum score of 5, whereas a score of 2 corresponds to full range of antigravity ankle plantar flexion motion. Therefore, the recommended number of heel-rise repetitions for adult people is 25 (Lunsford and Perry, 1995, Gefen et al., 2002), as the standard for a score of 5, until the person becomes fatigued. In (Lunsford and Perry, 1995) the average number of standing heel-rise repetitions completed was 28.

The results of Heel-Rise Test consist in the number of repetitions of the exercise. Only 25 consecutive repetitions are recommended (Bennett et al., 2012). The test has different stop criteria, such as the occurrence of the knee flexion, the elbow or wrist flexion during three times, the failure to contact the string for three consecutive repetitions, or the inability to continue due to fatigue (Bennett et al., 2012).

The authors of (van Uden et al., 2005) verified that patients with severe chronic venous insufficiency had a significantly lower number of heel rises, indicating decreased calf muscle endurance.

Besides, results of the test can be influenced by using a medial hind foot wedge in the barefoot condition, which causes a decrease of the performance during the task (Sole et al., 2010). The rheumatoid arthritis on foot function also affects the delay of heel-rise, causing the decreasing of the performance too (Turner et al., 2006).

Other studies were performed to test the reliability of the Heel-Rise Test and obtain the muscle endurance in patients with chronic diseases (Pieper et al., 2008), cerebral palsy (Russell et al., 2007), lateralized neuromuscular perturbation (Vuillerme and Boisgontier, 2010), Achilles Tendon Rupture (Silbernagel et al., 2010), hemodialysis (Segura-Orti and Martinez-Olmos, 2011), peripheral arterial occlusive disease (Monteiro et al., 2013), and other diseases (Veilleux et al., 2012b).

Sensors can help in the measurement of the Heel-Rise Test results, *e.g.* measuring the angle and knee motions with kinetic measuring devices (Hastings et al., 2013, Haber, 2004, Sman et al., 2014) and electromyograms (Kasahara et al., 2007), showing that the repeated motion method estimates muscle endurance rather than the muscle power. The accelerometry signal is useful to detect the pattern of Heel-Rise Test and validate the exercise, as showed in (Schmid et al., 2011, Österberg et al., 1998), with good accuracy, without interaction of the examiner.

# 3 AUTOMATIC HEEL-RISE TEST

The proposed solution consists in a mobile application to perform the Heel-Rise Test with good accuracy. The application uses an accelerometer embedded in a mobile device and shows the processed results of the Heel-Rise Test.

## 3.1 Detection of Activities using Accelerometers

The accelerometer is an instrument capable of capturing the instant acceleration of a subject's body or an object. This data can later be processed to identify activities of daily living using different techniques, such as pattern recognition or machine learning techniques. The captured data needs to be pre-processed, smoothed (reducing the noise) and classified.

Different authors have made studies about the relation of the accelerometry data and the detection of daily activities. In (Chernbumroong et al., 2011) neural networks and decision trees are used to detect the daily activities using only a wrist-worn accelerometer with an accuracy of 94.13%.

In (Andreas et al., 2014) both accelerometers and gyroscopes are used in different body locations for activity recognition. Best results were obtained using a single sensor in the hand and the worst ones when located in the arm.

Fulk et al. (Fulk et al., 2012) proposed a novel shoe-based sensor system to identify different functional postures in people with stroke disease, that consists of five force sensitive resistors built into a flexible insole and an accelerometer on the back of the shoe. The system measures the pressure and accelerometer data and sends the data via Bluetooth to a smartphone, identifying sitting, standing and walking activities with an accuracy, precision and recall greater than 95% (Fulk et al., 2012).

### 3.2 Method Implemented

The mobile application receives the values of the outputs (X, Y and Z) of the tri-axial embedded accelerometer and calculates the magnitude of the vector at every moment.

The implemented algorithm incorporates the conditions of the regular test (supervised by an examiner) and some rules specifically obtained by the accelerometry signal. In the mobile device's accelerometer, the values of the outputs and the values of the magnitude of vectors are in $m/s^2$.

A correct exercise should present variations of the acceleration similar to the example in figure 1.

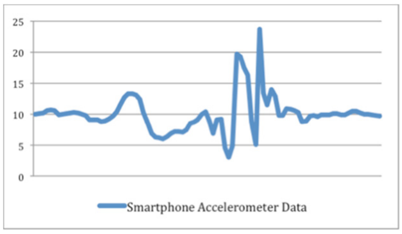


Figure 1: Representation of the acceleration values of a repetition of the exercise during the Heel-Rise Test. The vertical axis represents the values of the magnitudes of the vectors of all the outputs acquired by the accelerometer (values in $m/s^2$). The horizontal axis represents time in milliseconds.

The creation of the algorithm requires a learning phase in order to identify the relevant features. The collection of data starts with a beep signal that indicates the time to start. After the beep signal, the user has 2 seconds to perform the exercise that is part of the Heel-Rise Test. This test consists in a repetition of consecutive maximum heel elevations (Sman et al., 2014, Yocum et al., 2010), performing eccentric and concentric muscle actions of the plantar flexor muscles. This algorithm consists in the validation of each repetition, stopping the algorithm and playing an acoustic signal after the user fails the exercise in 2 consecutive repetitions.

The accelerometer data is collected at time intervals of 2 seconds. After this time, the algorithm implemented in the mobile application evaluates the collected data to verify the validity of the exercise. The validation is done with a recursive algorithm for peak detection, to detect the maximum peak acceleration values and the minimum depressive acceleration values.

The exercise is validated with a sequence of rules, which are:

1. Collect the data of the smartphone accelerometer, after beep signal (figure 2-A);
2. Verify if the value of the point at the start of data collection is comprised between Earth's gravity with a margin of the correction value ($9.81 \pm 1$ $m/s^2$). If the value is out of this range the algorithm assign a fail. This comparison was performed to verify if people is in movement, when they should start an repetition of the exercise of Heel-Rise Test;
3. Verify if the value of the point at the end of data collection is comprised between Earth's gravity with a margin of the correction value ($9.81 \pm 1$ $m/s^2$). If the value is out of this range the algorithm assign a fail. This comparison was performed to verify if people is in movement, when they should has in a static position, because they ended an repetition of the exercise of Heel-Rise Test;
4. Detect the maximum peak acceleration values, recursively, until obtain only one point of maximum peak is obtained (figure 2-D);
5. Detect the minimum depressive acceleration values, recursively, until obtain only one point of minimum depression (figure 2-C);
6. Verify if during the time interval exists points higher or smaller than the values comprised between Earth's gravity with a margin of the correction value ($9.81 \pm 1$ $m/s^2$). If all peaks are in the range, the

algorithm assign a fail;

7. Verify if the instant of time related to the point of maximum peak (figure 2 - D) is higher than the instant of time related to the point of minimum depression (figure 2 - C). If the algorithm doesn't pass in this condition, a fail is assigned;
8. Verify if the time interval between the instant of beep signal (figure 2 - A) and the instant of landing (figure 2 - D) is smaller than 2 seconds. If the algorithm doesn't pass in this condition, a fail is assigned.

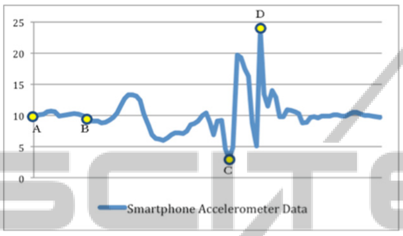


Figure 2: Representation of the acceleration values (in m/s$^2$) of a repetition of the exercise of Heel-Rise Test with points marked in the graph. The point A represents the time instant (in milliseconds) of the beep signal. The point B represents the time instant (in milliseconds) of take-off. The point C represents the time instant (in milliseconds) of peak. The point D represents the time instant of landing.

The validation is done on each repetition of the exercise. During this sequence of analysis, the algorithm stops when 2 consecutive failed repetitions of the exercise of Heel-Rise Test are verified.

For further analysis, various time intervals are identified, such as the time of preparation, time of take-off and the time of landing (figure 3). Each repetition of the exercise consists of the sequence of these time intervals. The time of preparation is the time interval between the instant of the beep signal and the instant when the user starts the movement. The time of take-off is the time interval between the instant when the user starts the movement and the instant when the user ends the heel elevation, corresponding to the rise time. The time of landing is the time interval between the instant when the user ends the heel elevation and the instant when the heel of the user returns to the ground.

During the repetitions of the exercise, the time of preparation and the time of take-off increase, and this increases the probability of fails during the Heel-Rise Test. On the other hand, the time of landing decreases throughout time, because the user, due to fatigue, falls faster to the ground than at the beginning of the test.

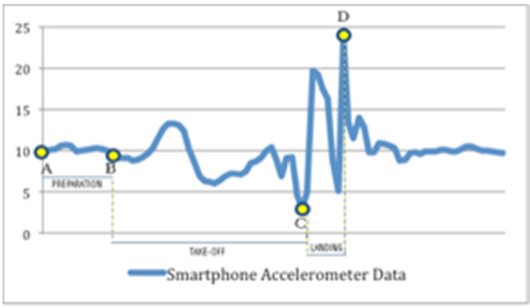


Figure 3. Representation of the acceleration values (in m/s$^2$) of a repetition of the exercise of Heel-Rise Test with time intervals marked in the graph. The time interval (in milliseconds) between points A and B is considered the time of preparation. The time interval (in milliseconds) between points B and C is considered the time of take-off. The time interval (in milliseconds) between points C and D is considered the time of landing.

When the test is finished, the results are showed to the user and saved for future analysis. The results consists of the time elapsed when the algorithm is stopped, the number of repetitions of the exercise and the time that the user has been active. The algorithm shows more reliability and accuracy than the regular method with the check of the examiner, because, with an accelerometer, it is possible to detect movements impossible to detect by an examiner observing the exercise, *e.g.*, during the tests the person moves slightly against the wall and the examiner doesn't see, but the mobile application detects this and considers it as a fail, invalidating the exercise.

## 3.3 Mobile Application

The mobile application for this work was developed for Android and iOS operating systems, using hybrid development technologies. The platform used for the development, named Cordova (developed by Apache) (Foundation, 2014), allows to develop the application using Web programming languages, such as HTML, JavaScript and XML, which works as a native application running in a WebView using native components to access to the sensors data.

One of the requirements is that the application should have a friendly interface and good usability. The measurement is activated with an easy selection using a big button in the center of the screen, which also shows the state of the capture.

The screens of the mobile application developed are showed in Figure 4.

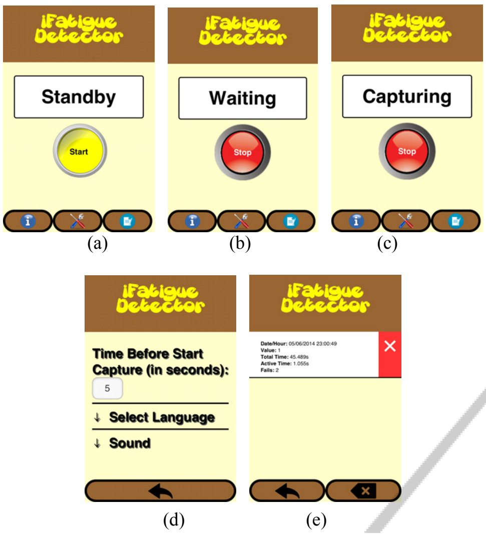


Figure 4: Interfaces of the mobile application.

When the application starts, the state of the mobile application is "Standby", as showed in Figure 4a. When the user press the start button, showed in figure 4a, the status of the mobile application switches to "Waiting" (figure 4b), and this state remains while the user positions the mobile device on the waist, before the beep signal. After this time, the capture and processing of the accelerometer signal will start, changing to the "Capturing" state (figure 4c). During this time, the user must perform the exercises. During the test, the number of the repetitions of the exercise performed will be showed. A beep signal is issued every 2 seconds to control the time when the user must perform the repetitions of the exercise.

In the settings screen, showed in figure 4d, the user is able to change the language of the mobile application, enable or disable the sound and change the time interval that elapses before the capture is started (after pressing the start button). The languages available are English, Portuguese, Spanish and French. The labels related to the state of the capture switch between "Standby", "Waiting", "Capturing" and the number of repetitions of the exercise performed.

In figure 4e, the results of the tests performed are showed and the user can remove the history data of the Heel-Rise Tests performed.

## 4 DISCUSSION

The Heel-Rise Test has easy administration and inexpensive costs. It is used to evaluate the muscle fatigue with simple movements, performing eccentric and concentric muscle actions of the plantar flexor muscles with consecutive elevations maximum heel (Sman et al., 2014, Yocum et al., 2010). This research was done in collaboration between the Assisted Living Computing and Telecommunications Laboratory (ALLab), at Institute of Telecommunications, at the University of Beira Interior (UBI), in Covilhã, and Escola Superior de Saúde Dr. Lopes Dias (ESALD), at the Polytechnic Institute of Castelo Branco.

The experiments of this study were done in several phases. These were: a) the initial phase to identify and validate the accelerometry signal related to the heel-rise movement, and b) a second phase to validate the mobile application.

In the beginning many hypotheses were studied about the measurement of the heel-rise test using sensors. For initial measurements and to verify the reliability of the accelerometer signal to measure the results of the heel-rise test, the participants were tested with a external tri-axial accelerometer, attached to the participant's waist, and a pressure sensor attached to the heel, connected to a bioPlux device (PLUX, 2010), that sends, over Bluetooth, the collected data to a computer device. These sensors were used at the same time that the accelerometer signal was captured with the smartphone, attached to the waist. This allowed to compare the values obtained by external sensors and the accelerometer sensor embedded in a smartphone. Data that was collected by external sensors has a frequency of 1kHz. With these experiments, it was verified that when the value of the magnitude vector is higher than Earth's gravity it corresponds to the time interval that the heel is not on the ground, *i.e.* time of heel-rise repetition, as showed in figure 5.

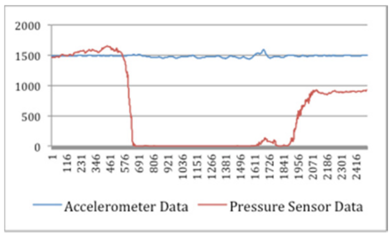


Figure 5: Data collected by a pressure sensor and a tri-axial accelerometer related to a heel-rise repetition.

In continuation, the participants did a few experiences to try to identify the pattern of the accelerometry data related to an exercise of the Heel-Rise Test. The manual measurement of the experiments for this study was performed using a metronome. The participants did the exercises with a mobile device placed on the waist to collect the accelerometry data. The frequency of the collection of the accelerometer data by the mobile application was not possible to manage, but the application collects the data as fast as possible, approximately every 10 milliseconds. The accelerometry data was compared between the experiments to identify a pattern of a heel-rise repetition, which is showed in figure 6.

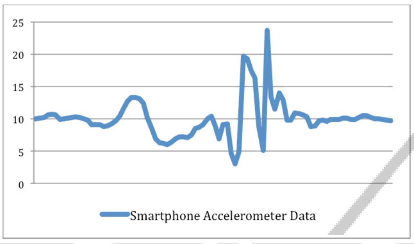


Figure 6: Smartphone Accelerometer Data related to a heel-rise repetition.

In the mobile device, an application previously developed by the author of this document, named as iAccelerometer Capture (Google, 2014a, Apple, 2014a), was used for collecting the accelerometer data and save it to text files.

Then, the automatic algorithm was designed and implemented as a mobile application.

In the last phase, this mobile application, named as iFatigue Detector (Apple, 2014b, Google, 2014b), was tested in a real environment with the same participants of the start phase. During these tests, some issues appeared related to the measurement of the Heel-Rise Test. These were:

- Sometimes the repetition is considered valid by the examiner, but with the accelerometer signal it is invalidated. This was because there was a movement to the front instead of a correct heel-rise exercise with vertical movement;
- Sometimes the person continues in movement after performing the repetition and the mobile application invalidates the exercise; and
- Sometimes, during the movement, the person has some vibrations and invalidates the accelerometry signal.

In the mobile application, the collected data is processed and validated after each two seconds and before the next acoustic signal, applying the validation rules. The time of two seconds between heel-rise has a variation of some milliseconds that corresponds to the delay of the data processing and this is evaluated to accept or reject the exercise and continue or stop the test. Thus, sometimes the algorithm, implemented in the mobile application, stops the test before the examiner, detecting the irregular data in the accelerometry sensor. On the other hand, the mobile application shows to be more reliable than the measurement of the examiner, because it detects some variations not visible to the examiner.

During the experiments, another problem found was where to locate the mobile device at it can vibrate or move during the exercise. It must be attached in a fixed position related to the user's body, preferably on people's waist.

In general, the application implements the algorithm that has been proved correct, but the mobile application needs a more extensive validation with different people, increasing the range of ages, heights, physical conditions, lifestyle and health problems. As a futures work, the validation of the mobile application will be done in order to prove the acceptance of the mobile application by the medical communities.

## 5 CONCLUSIONS

In recent years, the use of mobile equipment has increased. These equipments have embedded many sensors, such as accelerometer, gyroscope and proximity sensors, built-in GPS receiver, camera and others, including possibility to connect to other sensors via Bluetooth. The two most used platforms in mobile devices, such as smartphones, tablets, among others, are Android operating system (owned by Google) and iOS operating system (owned by Apple),.

The Heel-Rise Test consists in an easy, inexpensive and non-invasive test, used to evaluate the muscle fatigue with simple movements, performing eccentric and concentric muscle actions of the plantar flexor muscles with consecutive maximum heel elevations. This test is able to detect some health dysfunctions, but needs preparation of the place and the examiner needs extra attention in order to validate test performance, making use of a metronome to measure the time intervals between heel-rise repetitions.

However, the heel-rise test can be measured using accelerometry and electromyography sensors embedded in a mobile device, which in most of cases are more reliable than the conventional method. During the test, the mobile device should be in a static position related to the body. During this work, a mobile application was created to measure the heel-rise test, which identifies a performance pattern and implements the validation rules related to the accelerometer data and the conventional rules. For the creation and tests of the mobile application, collaboration between ESALD and ALLab was established, which allowed improving the relation between the experts in the health and the computer science areas.

The mobile application created in this research work is multiplatform. The pre-version created during this work is available for iOS operation system (Apple, 2014b) and Android operating system (Google, 2014b). This is a pre-version because this mobile application needs an exhaustive validation in order to be accepted by the medical communities.

Besides, other tests employed in the physiotherapy area can also make use of accelerometry data and other embedded sensors, in order to identify some other health problems.

In conclusion, these tests may have more accuracy than the human eyes to examine the exercises, being the technology very useful to offer support in this type of measurements.

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