2016

Sports Injury Prevention Screen (SIPS): Design and Architecture of an Internet of Things (IoT) Based Analytics Health App

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Abstract

At present, technology-based injury risk screening methods are typically utilized by large and well-funded athletic programs at both the professional and collegiate levels. Such screening is not available to athletes who participate in most scholastic and amateur programs, due to the high cost of testing equipment and the need for oversight by medical professionals who possess the appropriate level of expertise. However, a mobile health app for injury risk screening can eliminate these obstacles, thereby facilitating the availability of systematic injury prevention initiatives to a much larger population of athletes. This study describes the design and architecture of a mobile health app for Sports Injury Prevention Screening (SIPS). SIPS enables athletic programs with limited funding and personnel the ability to conduct individualized injury risk assessments and deploy personalized injury prevention plans that are currently available only at collegiate and professional levels. Even for well funded athletic programs, typical injury screening methods are restricted to assessing either an athlete's musculoskeletal coordination or neurocognitive abilities; assessing both simultaneously is only possible in the laboratory environment. SIPS introduces a novel, dual-task assessment by using two devices simultaneously to measure an athlete's neuro-mechanical responsiveness without the requirements of a laboratory and expert-level domain knowledge. Single device tests, designed specifically to replicate established injury screening techniques using just a mobile phone, are also available in SIPS. Data is collected for all of these tests from devices' motion sensors and is synchronized using Bluetooth® technology. Ongoing work is integrating various predictive analytics algorithms for providing real time feedback to the athlete, medical director and coaches.

Keywords

sensor-based mHealth applications, preventative health, sports injury, analytics

1. INTRODUCTION

Significant effort is expended at the professional and collegiate levels in the United States to prevent sports-related injuries through assessment of an athlete's risk of injury and implementation of targeted interventions for risk reduction. Examples of athletes' attributes and behaviors that are widely documented include neurocognitive capabilities, strength, neuromuscular coordination, postural balance, reaction time, sleep quality, eating habits, etc. The processes and technology required to measure and/or monitor these attributes typically impose practical challenges for athletic programs that lack sufficient resources. Furthermore, dual-task testing provides greatest discriminatory power for identification of athletes who possess greatest risk, which requires even more sophisticated equipment and expertise to administer.

Mobile health (mHealth) apps currently exist that are promoted for prevention and/or management of sport-related injuries, but none currently include the means for accurate quantification of injury risk. An inexpensive means for dual-task assessment of neuromechanical responsiveness (i.e. neurocognitive and neuromuscular capabilities) would provide a valuable guide for implementation of an individualized injury risk reduction program. SIPS, an mHealth application for the Android operating system, provides such a dual-task screening method, which is presented here as an inexpensive, user-friendly, efficient, and accurate means to acquire individualized injury risk assessments for large groups of athletes.

2. Literature Review

MHealth apps are the fastest-growing of all categories of apps [4]. mHealth is an extension of electronic health (eHealth) and comprises health and fitness related practices supported by mobile devices and the IoT [1]. A complete review of mHealth apps is beyond the scope of this study, however, interested readers should begin with Zapata [2] and Aranda-Jan [3]. In 2015 over 100,000 health and fitness-related apps were available to the general public.

Among the increasing number of mHealth apps there has been a recent surge in mobile sports and physical activity-related injury (SPRI) apps. A 2014 review of such apps concluded that the majority made erroneous or false claims, and, that there was an opportunity for developers to work on scientifically-sound apps for the prevention of SPRI [5]. Sports-related mHealth apps [6-9] are now primarily focusing on rehabilitation and prevention exercises for specific injuries. There is a clear paucity of apps that detect injury risk for athletes without previous injuries.

Reviews of mHealth apps for athletes, however, continue to indicate a lack of consensus on the application of evidence-based techniques for injury screening and prevention [10, 11]. Some studies have reported that the measurement of postural stability using trunk-mounted accelerometers is an effective way of distinguishing among subjects for medical purposes [12, 13]. Recently, trunk-mounted accelerometers have demonstrated good correlation with postural stability measurements from force plates for single leg balance assessment [14]. The two posture tests that have provide detailed insight are unilateral wall-sit hold (WSH) and the kneeling horizontal-trunk hold (HTH) provides a means to assess muscle endurance of the back extensors and hamstrings. WSH

Many existing injury screening options and proprietary applications are currently in use by professional and major collegiate sports organizations in the United States, such as those from Dynavision International, Catapult Sports, and Vicon Motion Systems, rely on sensor derived quantitative data for the assessment of an athlete's injury risk levels. The sensors used for collecting this data can include force plates, body mounted inertial measurement units, interactive visio-motor tests, and elaborate high-speed camera arrays.

3. Architecture and Conceptual design

The requirement of expert involvement and integration of evidence-based content during the design phase poses significant challenges for developing effective mHealth applications. This is not only true for general mHealth apps [15], but also extends to mHealth applications that are specifically designed for athletic injury prevention and rehabilitation [9, 16]. The SIPS architecture is comprised of three integrated layers: an application layer, a process layer, and an architecture layer. The various components of these three layers are described in following subsections:

3.1 Application Layer: Injury Screening Tests

The screening tests available in SIPS can be broadly grouped into two basic categories; neuromuscular coordination tests and neurocognitive tests. These two categories of tests can be rendered in three forms: a physical test, a cognitive test, and a combined test. These tests are intended primarily for injury risk assessment of lower extremity injuries and concussion. The coordination tests included in SIPS are similar to established athletic injury screening tests (*i.e.* the Functional Movement Screen [17]), yet differ in that they are able to derive their value from motion sensors in smartphones. The two coordination tests administered are a single leg balance test and a single leg jump test. Each of these tests is to be administered twice for a single subject, *i.e.* separately for each of the legs. This allows for the assessment of differences between dominant and non-dominant extremities, and is significant in determining asymmetry since a large asymmetry can be an indicator of increased risk of injury.

The single leg balance test consists of a timed interval where the subject must balance on one leg. More valuable data can be collected from this test if subjects are instructed to maintain a position of 45° knee flexion and/or elevate the heel of their foot while balancing on a single leg. The accelerometer in the device being used to administer the test provides the most useful data.

The single leg vertical jump test includes a timed interval to jump and regain balance upon landing. The subject is instructed to jump using just one leg, land on the same leg, and return to balance. The height of the subject's jump is less significant than the time required reestablishing postural balance after landing.

A single cognition test is administered in SIPS using the Eriksen flanker task [18]. This test consists of sets of congruent and incongruent stimuli, which are each sets of arrows pointing to the left or right. The subject is instructed to indicate whether the middle arrow points to the left or to the right. The two pairs of congruent and incongruent stimuli are depicted in Figure 1.The flanker task implementation in SIPS is unique in that it does not require touching the screen to identify a stimulus. This is critical in the current context, as it enables a high degree of accuracy with respect to the reaction time. It also offers insight into a subject's indecision and corrective measures when identifying the stimulus.

Independently, the coordination tests can assess an athlete's coordination relative to others as well as the performance disparity between dominant and non-dominant extremities. Independently, the flanker task can be used to screen athletes for concussion or the lingering effects of concussion by gauging the response time and accuracy. Using two mobile devices with Bluetooth® technology, a combined, dual-task test can be administered that assesses both a subject's neurocognitive abilities and neuromuscular coordination simultaneously. The two tests that can currently be administered in unison are the single leg balance test and the flanker task. Together, these two tests can give greater insight into neuromechanical performance abilities than either can independently. These screening tests are most effective when a baseline can be established for each subject when the subject is at an optimal health. This can commonly be done by administering the tests at the beginning of the season, prior to or during the first team practice. The baseline data can then be used for comparison during the season, to monitor the athlete's injury risk level on a continuing basis. Baseline data from the flanker task can be helpful in determining whether the athlete reaction time has suffered a concussion. The test could be deployed during games or practice to identify this condition.

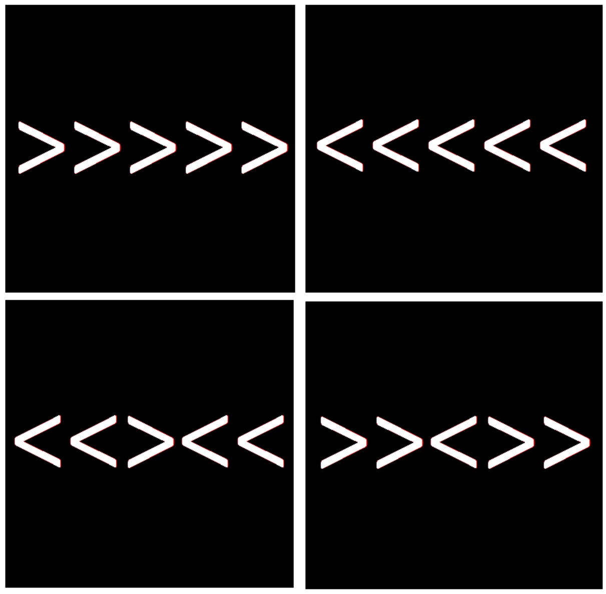

Figure 1: SIPS Flanker Test Task Stimuli (The top left is a congruent left stimulus and the top right is a congruent left stimulus. The bottom left is an incongruent right stimulus and the bottom right is an incongruent left stimulus)

3.2 Process Layer: Testing Procedure

Testing with the flanker task can be conducted without the need for any special equipment. The single leg jump test and the single leg balance test, however, require a lower back mounting strap for holding the screening device still. A strap was customized and crafted just for the purpose of administering these tests using SIPS and is required to keep the device stable during testing, so that sensor measurements exclusively reflect the motion of the subject during screening. The two coordination tests are assessed using data from the devices' accelerometer. The accelerometer outputs acceleration as a vector with axes respective to the device position, thus, the device must remain fixed to the body.

Currently, the accelerometer values from the mobile devices are used to compute root mean square (RMS) values for each of the three vector components collected. These RMS values are indicative of the subject's balance ability as they reflect the ease with which the subject can maintain the desired position during screening. Subjects who have difficulty maintaining stability during the test are prone to moving their bodies more frequently and inconsistently than subjects who maintain the position with ease. The procedure for administering a test begins by opening SIPS on the mobile device. If a lower back mounting strap is required, the device should be mounted prior to opening the menu screen on the device. Ideally, a qualified person familiar with the testing procedure should administer the test. Instructions are also available from the testing screen.

If the device is secured appropriately for the test of interest, and both the subject and administrator of the test are prepared, the administrator can select the desired test from the SIPS' main menu. If the test is a single device test, once selected, the administrator will be able to enter any identification or biometric information for the subject or test that they wish to use later. Some notes to identify the subject and the test are strongly recommended, and consequently, some information is required to begin the test. If user information has been entered, the administrator can press the start button to begin the test. This will begin a short countdown to the test, which allows the administrator to move to an appropriate position, clear of the testing area. During this countdown, a chime is played on the device for each second. The final chime is played at the beginning of the test. The next chime is played at the end of the screening to alert the administrator and subject that testing is complete.

If the test requires two devices, the administrator needs to have both devices prepared for testing. If the devices are previously paired, the primary device should be secured in the lower back mounting strap while the secondary device indicates that it is waiting to begin the test. If the administrator has entered user information, he or she may start the test. At this point, the screen on each device will enter a countdown. The secondary device will only depict a visual countdown, while the primary device, mounted to the subject's back, will also chime during the countdown.

After the testing is completed, SIPS offers the administrator an option to view the results. If the subject or administrator wishes to view the results, a new screen is generated showing the accelerometer results. At the top of this screen are three tabs, one for each of the device's three motion sensors. Upon selection of each of the tabs, a plot of the three axes for the corresponding sensor is displayed.

When leaving the results screen, or if the user selects not to view the results, an upload dialog fragment is generated to determine if the test was successful. This option is extended, if, for any reason, the administrator may wish to retest a subject or invalidate the results from a test; otherwise the test data will be uploaded to the database. The results will be accessible by the administrator or coach in real-time from an online web portal, enabling the administrator to repeat the test, report the results, or make recommendations to the athlete. This procedure is illustrated in Figure 2.

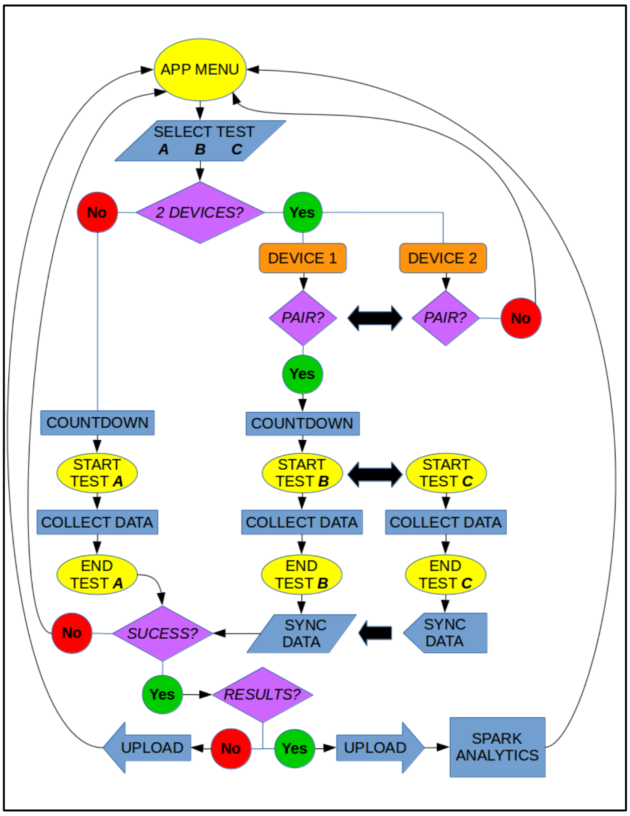

Figure 2. A flow chart depicting the testing procedure for single device and multiple device screening tests

3.3 Architecture Layer: Technical Implementation

This section provides a brief overview of the implementation level details of SIPS' architecture. The app is compatible with devices running Android 4.4 or higher.

For all tests, a countdown precedes the testing period to allow the athlete some buffer time to get positioned and ready for the test. Independent timers are invoked for each of these periods. Upon completion of the first timer, the second timer is initialized and the collection of sensor data begins. Sensor data is collected for the testing period at a rate of 100 Hz. Sensor data collection ceases upon the completion of the testing timer, and the app then queries the user as to whether or not to keep the results.

If the test is considered a success, and the user selects to keep the results, the app attempts to establish a socket connection with the server. All results are first stored locally on the device, and only removed when the app is removed. If the connection is unavailable, the results are queued for upload at a later time when the app can establish a socket connection with the server.

For the two device coordination tests, Bluetooth® technology is used to synchronize the two devices. To pair two devices, a search of nearby devices is conducted. If the user wishes to pair devices, the primary device should initiate the pairing process. After searching for devices, the secondary device should be selected. If the pairing is successful a notification is displayed.

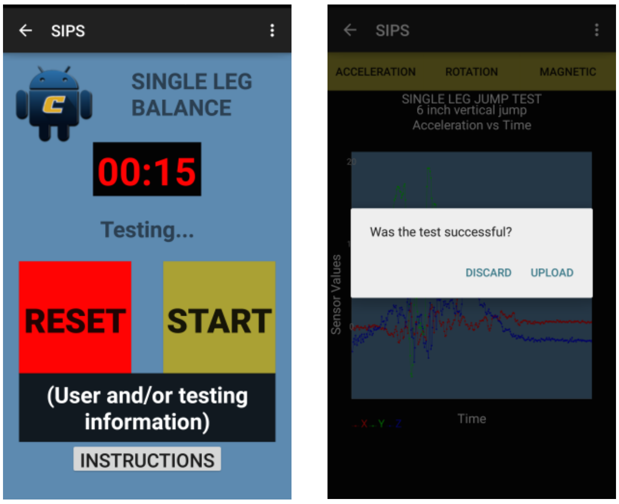

Figure 3 The left image is the testing screen during a single leg balance test. The right image depicts an upload prompt for the user after the results have been displayed**.**

After pairing, both devices will run in a limited mode. They cannot be used to run single device tests until the pairing is broken. If a single device test is selected, a dialog will appear asking if the user wants to proceed and break the pairing established with the second device. If the pairing is broken, a notification is displayed on both devices. The flanker task relies primarily on the gyroscope, as opposed to the other tests relying on accelerometer data. Each test is randomly generated such that an equal number of each stimulus is shown during each test. The test is animated at 60 Hz and administered with the phone on its side, in a landscape position. The entire screen is black during the flanker task, except when a stimulus is being shown. By default, stimuli are displayed at a rate of 1 Hz, or one stimulus per second, and are only visible to the subject for a period of 100 ms. Figure 3 depicts SIPS in use.

Ongoing work is integrating various predictive algorithms that take the IoT data and historical data of the athlete collected through the app and provide real time feedback on an athlete's susceptibility to get injured.

4. Validation

Preliminary validation testing has been conducted for SIPS. This testing was conducted in a motion laboratory using a Vicon motion capture camera system. The Vicon motion capture system is comprised of an array of high-speed cameras surrounding the subject. Visual markers are attached to the subject's body at points of interest. The motion capture system then reports spatial data for each of the markers.

In the preliminary testing conducted using SIPS, four markers were placed in the four corners of subjects' transverse plane at the hips. The Vicon motion capture system does not report data that can be directly compared to sensor data collected from SIPS. In order to approximate acceleration for comparison the second derivative of spatial data was computed numerically for each of the four positions. The mean approximate acceleration magnitude was used for comparison and is depicted in Figure 4 for a single subject. The results depicted in Figure 4 are purely included for qualitative or visual comparison purposes only and not for establishing statistical significance. Detailed validation with significant power and sample size is being designed for establishing statistical significance of various injury prevention related hypotheses.

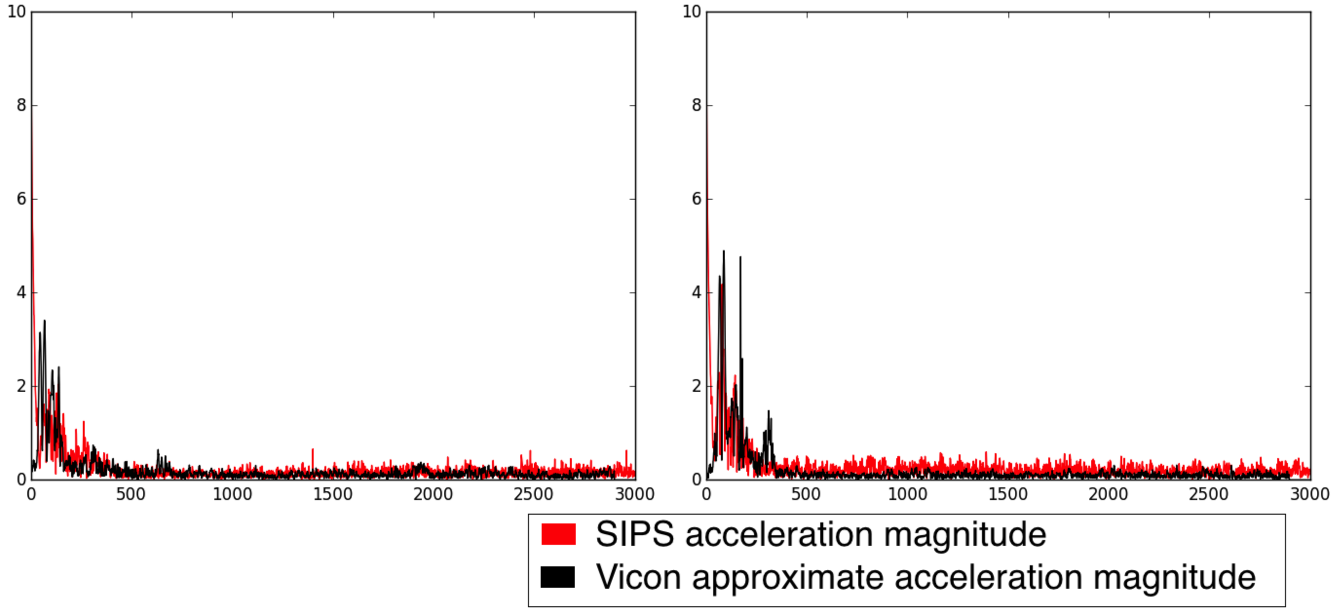

Figure 4 Results from preliminary validation testing.

5. Conclusion

SIPS was developed based on widely used screening methods for injury risk assessment in athletes. These screening tests should be administered first during the initial practice session of the season by the coaches for the team. This effectively establishes a baseline for each of the players on the team. This baseline can be used as a subjective measure of optimal health for each of the players. Coaches can then administer the screening tests periodically, on an as needed basis, or in situations where injury is suspected (*e.g.* concussion). If a player is deemed to be at an increased level of risk for injury, preventative measures can be taken. If coaches are uncertain about a player's injury risk level, a more extensive examination can be conducted.

Future work will involve SIPS to be synchronized with an depth sensing camera for coaches to use skeleton tracking analysis of players during the activity coordination tests administered by the app. This skeleton tracking follows each of the primary joints in a subject's body. This data is recorded and also uploaded to the database and then analyzed using real-time analytics.

SIPS architecture and implementation presented in this article offers the possibility of extending successful, complex technologically advanced injury-screening procedures to athletes of all levels. By enabling coaches of amateur athletics to use technology that is increasingly accessible and more ubiquitous, SIPS can make a significant reduction in the repetitive injuries through scientific screening and prevention for a large athlete population.

Acknowledgment

This research was made possible by funding from the Tennessee Higher Education Commission. A special thanks is due to Dr. Jeremiah Tate, for his assistance in validation of the app and to Joshua Haynes for assistance programming. We also thank Dr. Marisa Colston and Dr. Carrie Baker.

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