MYWALK

FINAL REPORT

ECE1778 Creativity and Programming for Mobile Devices

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I. Introduction

The **purpose** of the *MyWalk* app is to help its users **detect and reduce the occurrence of step-time asymmetry (STA)**. Since gait is a fairly symmetrical movement pattern [1], STA is a feature of atypical gait patterns and is caused when individuals spend an uneven amount of time on one foot relative to the other (Figure 1) [2]. Consequently, it is an indicator of poor gait control [3] and manifests in a wide-range of patient populations, including Parkinson's disease [4], hip osteoarthritis [5], and predominantly stroke, due to its high prevalence in Canada [6,7]. Although initially benign, STA is problematic because it leads to severe, long-term medical consequences. These consequences may include inefficient energy use during gait, balance difficulties, reduced overall activity levels, increased joint degeneration, and musculoskeletal pain [8]. Therefore, effective management of STA is necessary to prevent the development of these negative outcomes.

Fortunately, the effects of STA are preventable, since this abnormality can be reversed prior to the onset of severe consequences. Patterson et al (2010) demonstrated that active, real-time feedback about STA, during gait training exercises, could be used to significantly reduce the magnitude of the asymmetry in stroke patients [9]. However, once patients are discharged from a hospital, they are no longer provided with regular feedback on their gait patterns. In the long run, STA tends to deteriorate, particularly after four years post-stroke [10]. Nevertheless, the costs of administering repetitive clinic-based training procedures would be exorbitantly high for such a large patient population. Therefore, there is a need to explore alternative methods of monitoring and training individuals affected by STA, for example, through the use of mobile device technology, which has the capacity to enhance mobility outcomes [11].

II. Overall Design

Structure

The app was designed with two main components: **user interface** and **back-end support** (Figure A). The user interface consists of Menu Activity, Training Mode, Community Mode, and Progress History Mode. The back-end support consists of the Internal State Machine, Gait Symmetry Analysis, Data Storage, and Communication. It handles incoming data from sensors, processes gait data from the accelerometer, and provides feedback to the user in form of display, sound, and vibration.

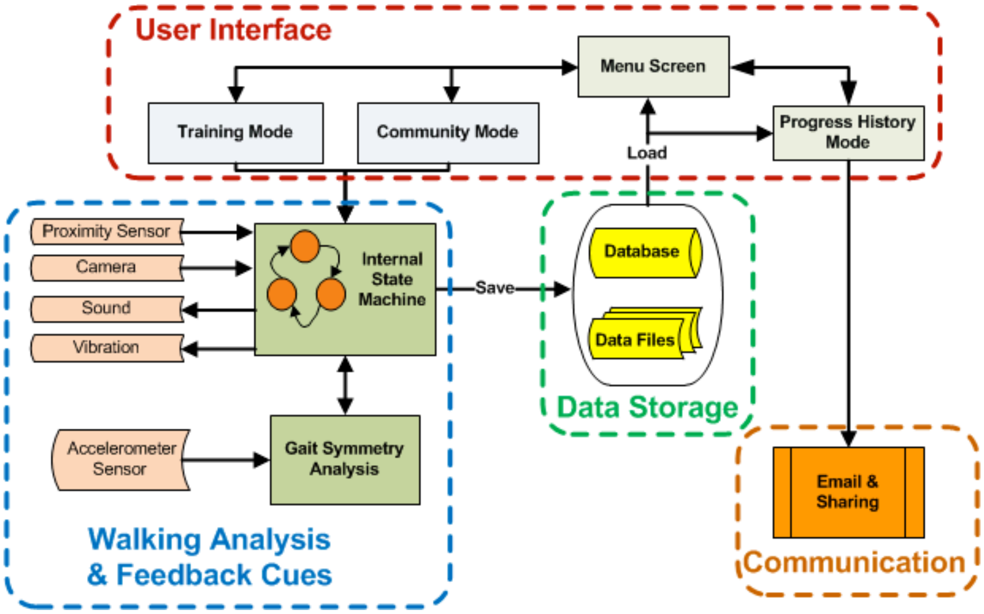


Figure A. **Block Diagram of the *MyWalk* App**

The **Internal State Machine** directs the progression of the app through the walking tests. It guides the user with instructions on the display, checks for the positioning of the device with the proximity sensor, detects walking pattern to start data analysis, and displays results at the end of the test.

The **Gait Symmetry Analysis** is called for processing and interpretation of accelerometer data. The methods written for this purpose include linear interpolation, low-pass filtering, and autocorrelation. Android devices sample with varying time intervals and vertical gait acceleration has random fluctuations, introducing both spatial and temporal noise. Thus, in the pre-processing stage, linear interpolation is used to resample the data with fixed time intervals between samples. A 4th order Butterworth low-pass filter with a cutoff frequency of 5 Hz is used to further reduce noise. In this app, the method suggested by Yang (2011) is modified to the performance of a mobile device [12]. Data with a time window of 3.5 seconds are sampled from the accelerometer for the input into autocorrelation every 200 milliseconds. This provides high temporal resolution for gait analysis. Autocorrelation of vertical gait acceleration provides two dominant peaks, by taking the ratio of the time between each peak location, a symmetry value is found.

Design

The following features are highlights of the **user design principles** that were adhered to during the planning of the GUIs:

- **Top-down structure**: information was arranged to go from top-level views (e.g. menu screen), to category views (e.g. progress history list screen), to specific views (e.g. results screen) [13]
- **User experience**: the menu screen puts forward content that is useful for both new and frequent users [14]

- **Navigation**: navigation is simple: e.g. action bars in progress history mode are consistent between tests (i.e. buttons are located in the same position) [13]
- Other principles include: **Branding** [14], **Proper Button Sizes** [13], and **Use of Gestures** [13]

III. Statement of Functionality & App Screen Shots

MyWalk has **three modes of operation**: 1) **Training**, 2) **Community Walk**, and 3) **Progress History**. In the **training** mode, the user can conduct short (1 minute), repetitive exercises to improve their gait symmetry. With the **community walk** mode, the user can identify how different environments affect his/her gait symmetry. Lastly, in the **progress history**, the user can track how their gait symmetry has changed over time and navigate to previous training/community results. Figure B outlines how users can navigate through *MyWalk*.

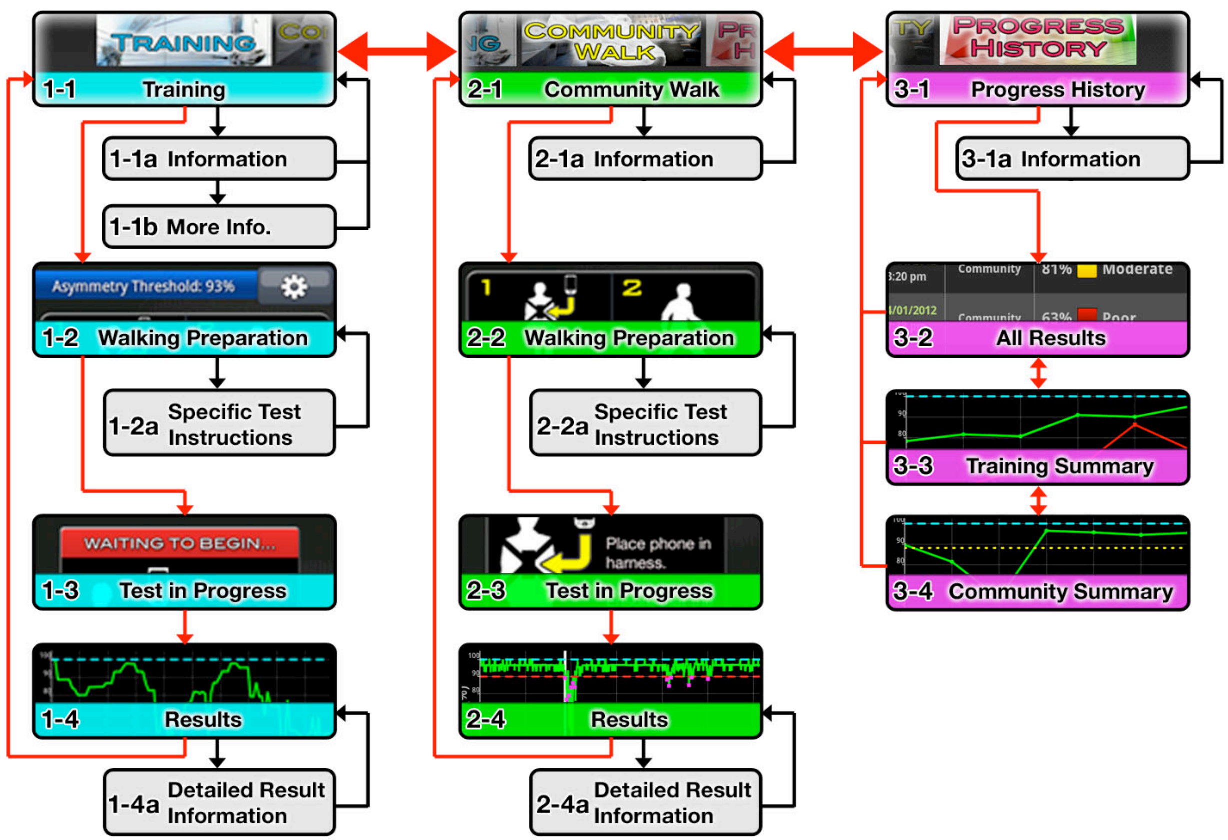
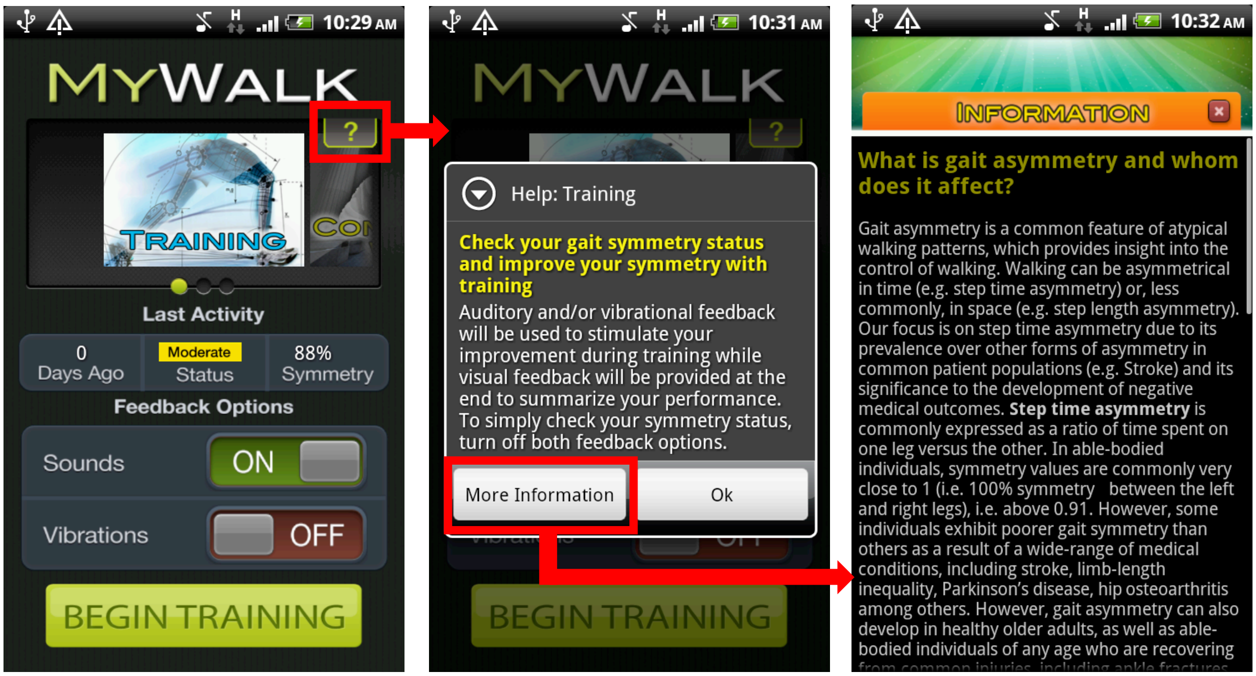


Figure B. **Navigation of the *MyWalk* App**

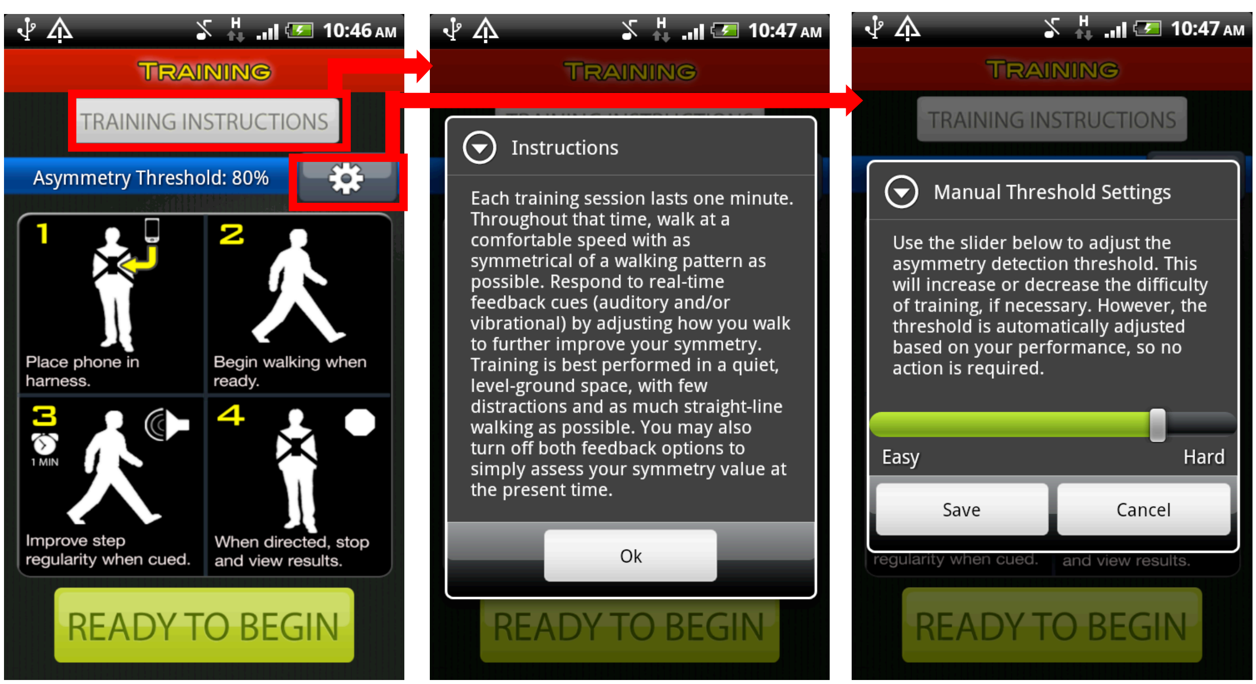
Training Functionality

The training menu screen (**1-1**) allows the user to view scores from the last training session and change feedback options. Help is available (**1-1a**, **1-1b**).



1-1 **1-1a** **1-1b**

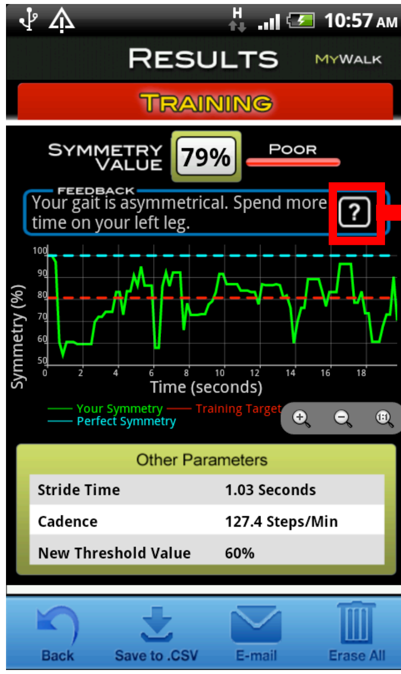
After selecting "begin training", the user is shown instructions of how to conduct training (**1-2**). Detailed instructions are available (**1-2a**). Also, the threshold of gait symmetry that triggers feedback can be manually adjusted (**1-2b**).



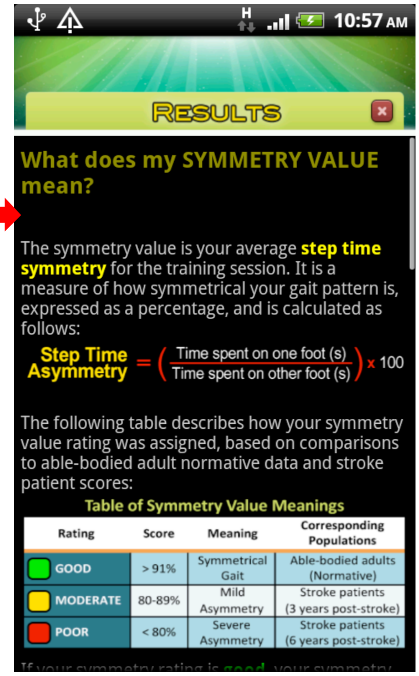
1-2 **1-2a** **1-2b**

After pressing “ready to begin”, the user must place the phone on their body mid-line and begin walking. A voice prompt is played when the app has detected proper phone positioning (proximity) and walking (accelerometer). During training, gait symmetry is calculated in real-time. If symmetry is below the threshold, feedback prompts are played. The user may quit the training at any time (**1-3**). Or a voice prompt will inform the user when 1 minute is over and the results will be displayed (**1-4**).

1-3



1-4

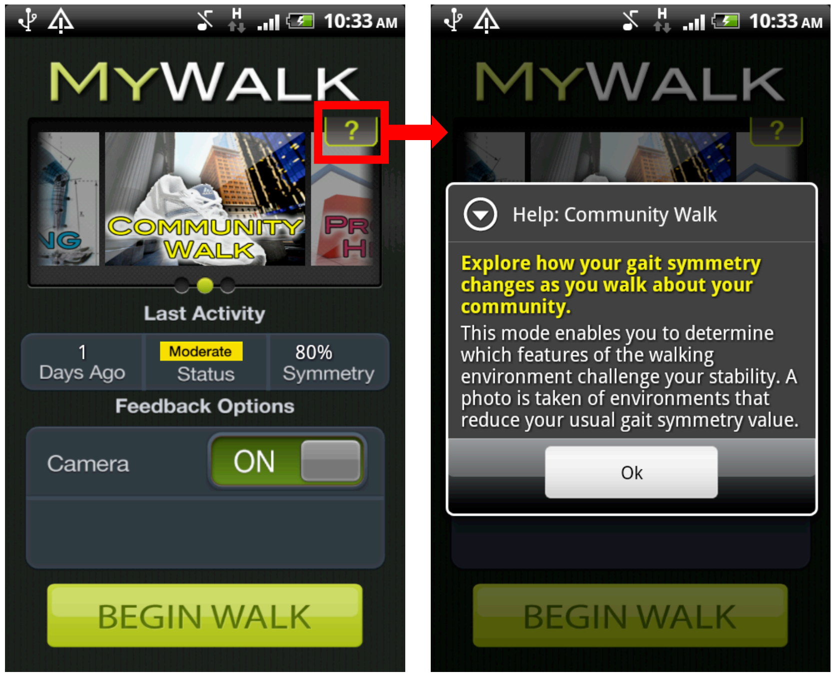


1-4a

Results show (**1-4**): the average gait symmetry of the session, feedback (which can indicate which leg to spend more time on), a graph of symmetry vs. time, and other walking parameters. Help to interpret the results is also available (**1-4a**). After each training session, a new threshold is automatically calculated based on user performance.

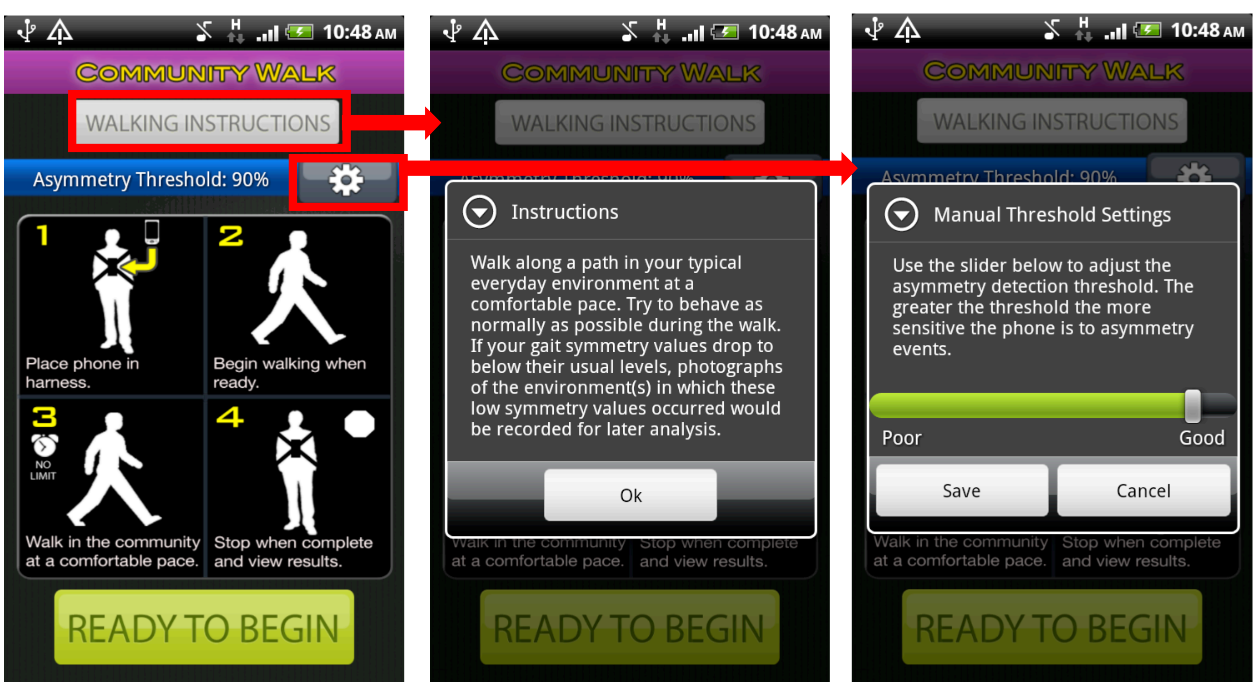
Community Walk Functionality

The community menu screen (**2-1**) can be transitioned to by swiping the gallery. Users can see their last activity, feedback options, and help (**2-1a**).



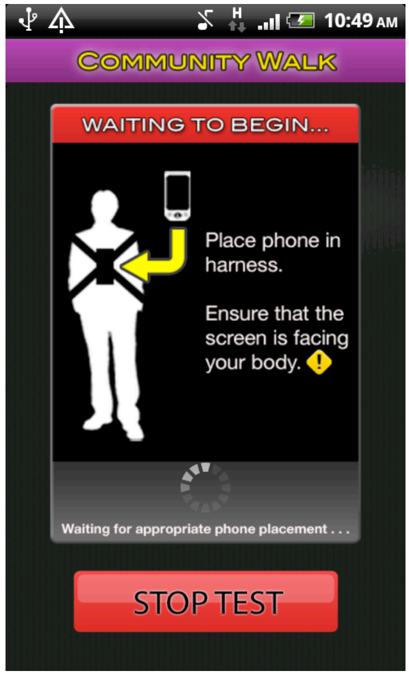
2-1 2-1a

By pressing "begin walk", the user is shown instructions (**2-2**, **2-2a**) and threshold options (**2-2b**) that are slightly different to the training mode.



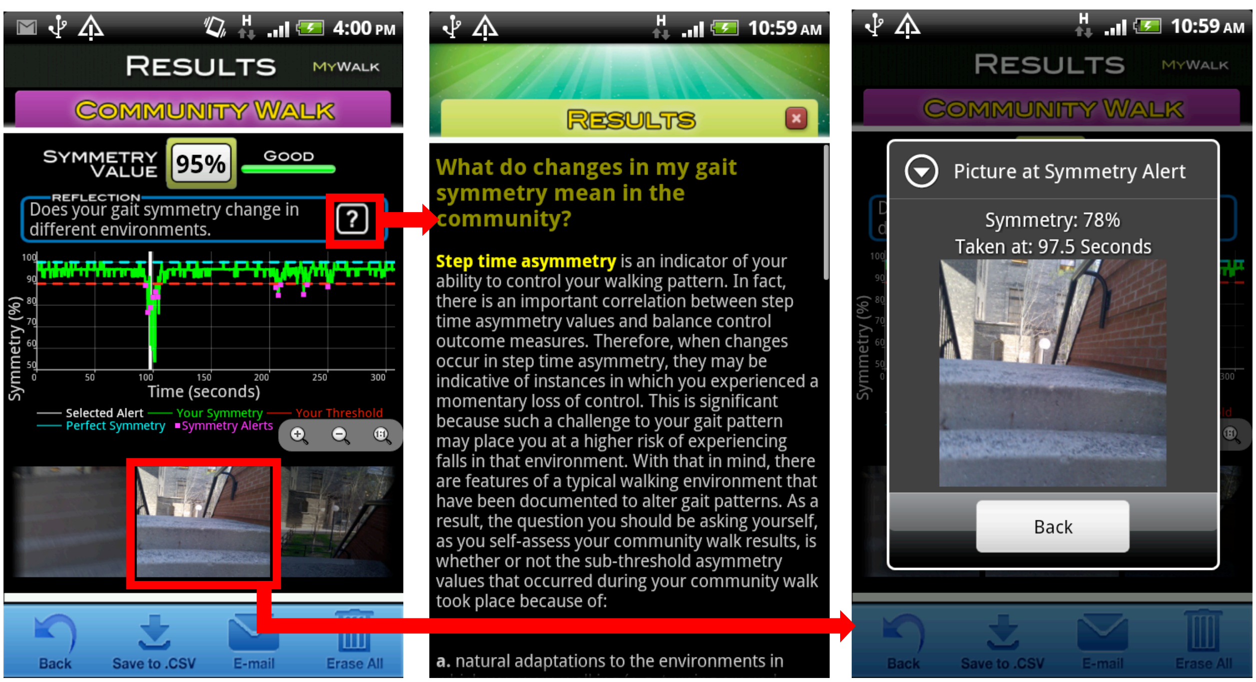
2-2 2-2a 2-2b

When walking in the community mode a picture is taken when symmetry is below the threshold. There is also no time limit, so the user must "stop test" to complete the session (**2-3**).



2-3

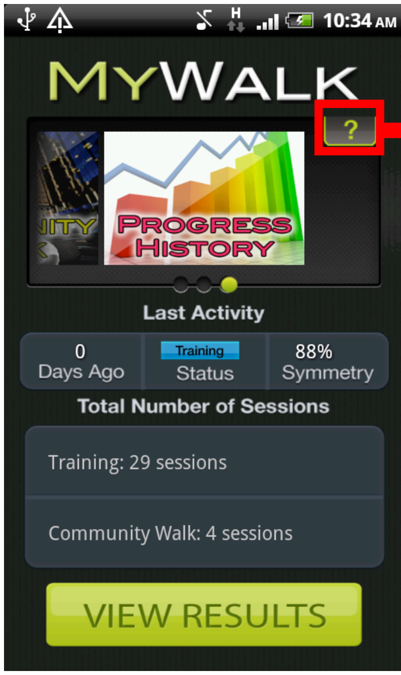
Community results (**2-4**) show: average symmetry, a graph of symmetry vs. time, and pictures taken in the session. The selected picture is highlighted in white on the graph. Additional help (**2-4a**) and picture enlargement (**2-4b**) is available.



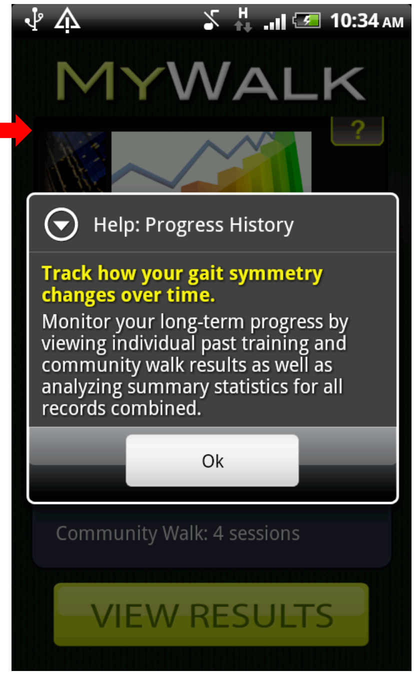
2-4 **2-4a** **2-4b**

Progress History Functionality

The progress history menu screen shows session statistics (**3-1**) and help (**3-1b**).

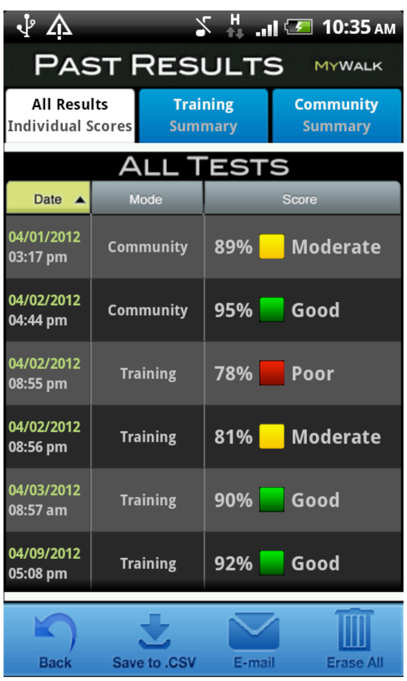


3-1

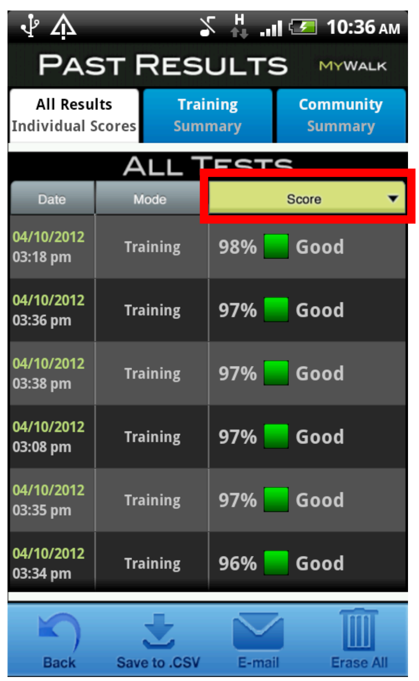


3-1a

Upon pressing "view results", the user will see a list of all previous walking sessions (**3-2**); these can be sorted by date, mode, and score. When the user selects a list item, the corresponding result screen will open (**1-4**, **2-4**).

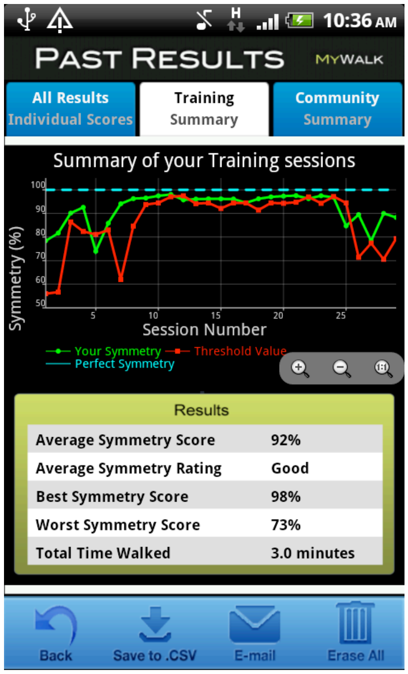


3-2

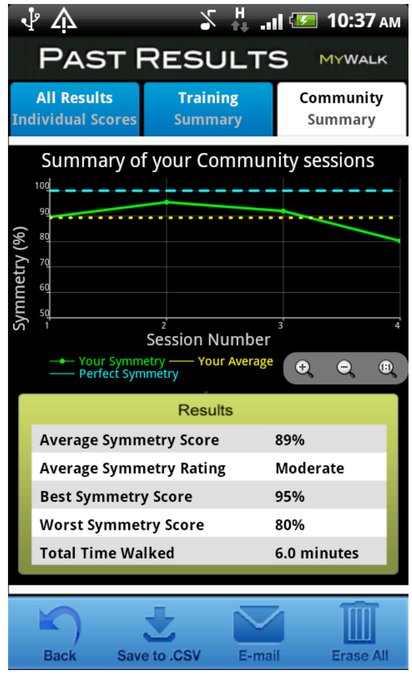


Sorted by descending score

The user can change tabs to view summaries of training (**3-3**) and community (**3-4**) modes.



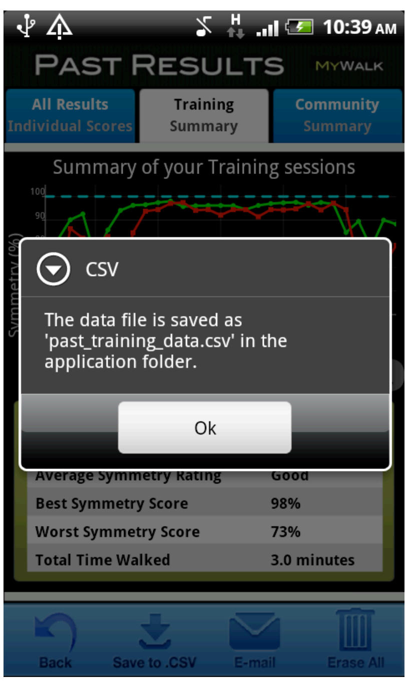
3-3



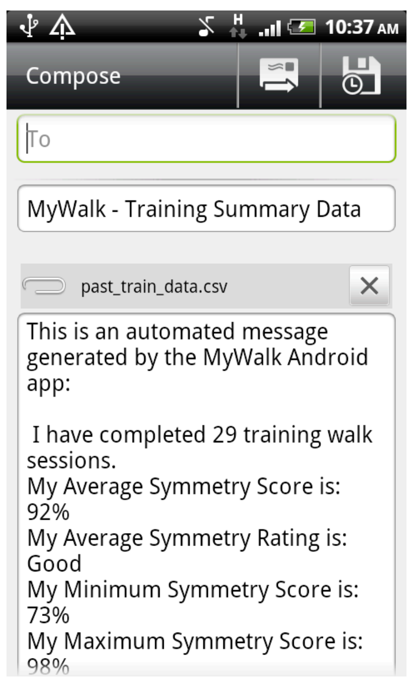
3-4

Navigation Bar Functionality

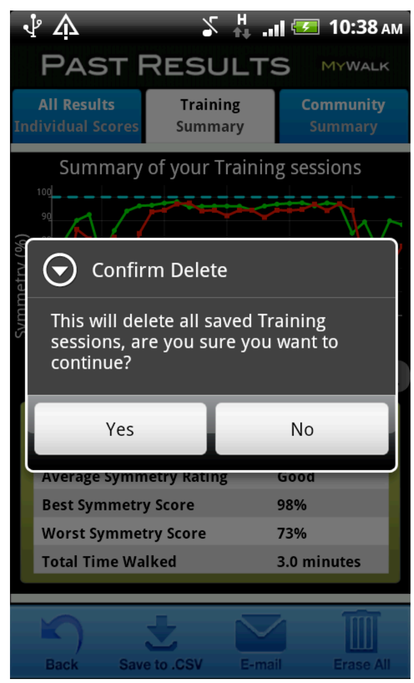
Every result screen has a bottom navigation bar that can: 1) go **back;** 2) save graphs to **CSV**; 3) send statistics and graphs via **e-mail**; and 4) **delete** the results.



Save to CSV



Send with E-mail



Delete

Accuracy and Sensitivity of *MyWalk*

The *MyWalk* STA algorithm was validated against a high-precision VICON® MX Motion Capture System (Vicon, CO, USA) by measuring STA using both techniques simultaneously. (Figure Ci.) One able-bodied young male (age: 25) walked across an in-laboratory pathway ten times at his preferred gait speed. The position of toe and heel markers (Figure Cii.) were tracked by Vicon (at 100 Hz), labeled manually, and used to calculate a reference symmetry value in Matlab. The average root-mean-square difference between the *MyWalk* and reference symmetry values computed was 0.02 units, which is smaller than the STA variability exhibited by stroke patients (i.e between 0.02-0.11 units) [8]. This indicates that *MyWalk* is sufficiently accurate to detect significant changes in this population.

Furthermore, the sensitivity of the *MyWalk* app (i.e. its ability to detect meaningful changes in STA) was investigated by comparing the gait patterns of: 1) an able-bodied young male (age: 28) walking normally; 2) a middle-aged female (age: 61) with atypical gait resulting from bilateral reconstructive foot surgery; and 3) the able-bodied male simulating STA. As depicted in Figure D, the results were as expected [i.e. normal gait with highest symmetry (95%); atypical-symmetrical gait middle-range (85%); simulated-asymmetrical gait with lowest symmetry (79%)]. Eighty steps from the two walking conditions performed by the young adult were confirmed against the Vicon system, which found between-technique differences of only 0.03 and 0.01 units for the normal and simulated patterns respectively. Thus, the *MyWalk* app is both sensitive enough to detect between- and intra-individual gait pattern changes with good accuracy.

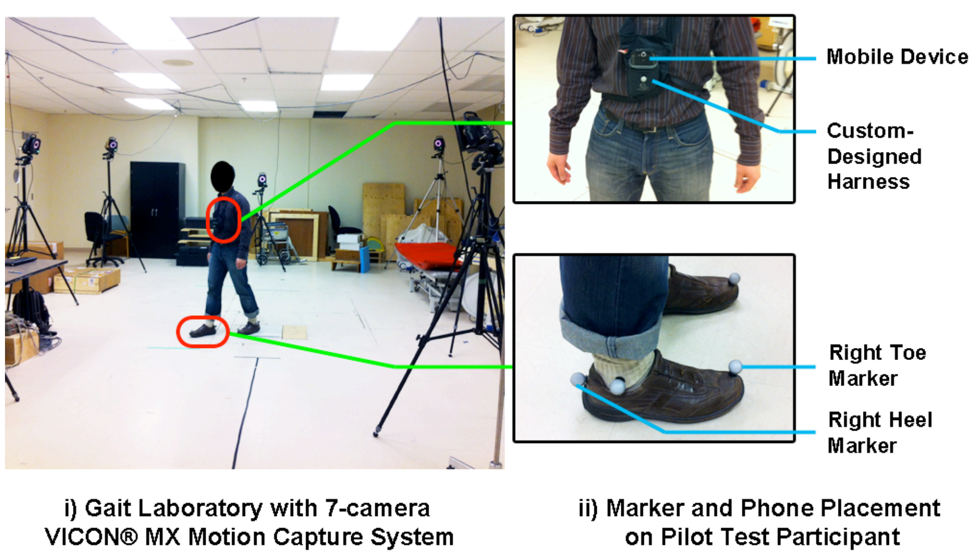


Figure C. **Validation Testing**

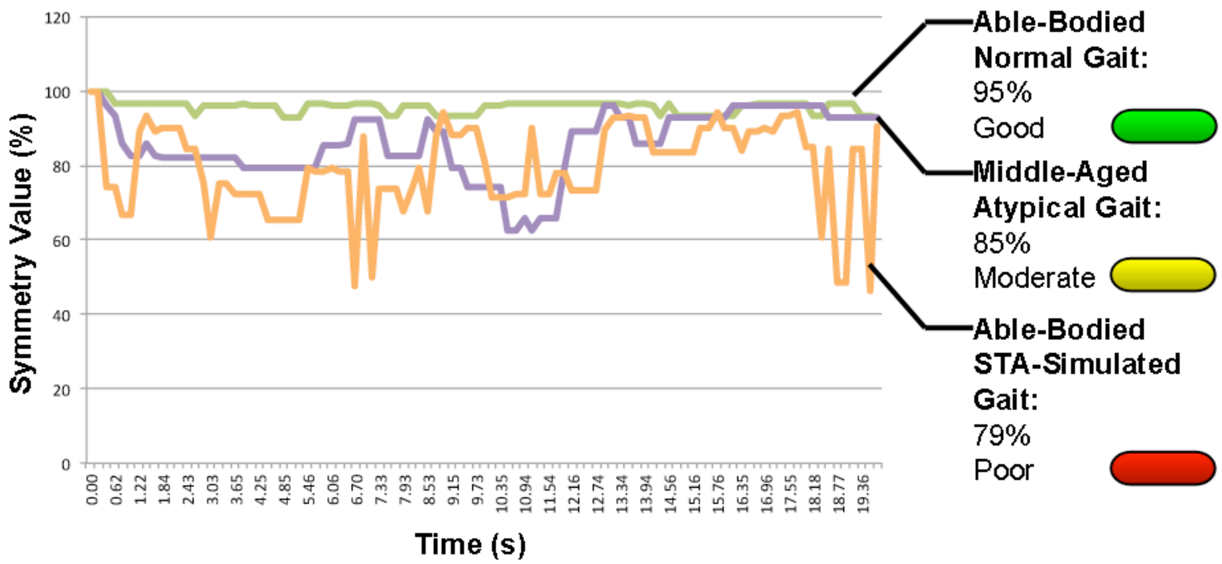


Figure D. **Sensitivity Testing**

Known Issues

- Accurately **measuring distance** traveled from accelerometer data is difficult due to accumulating noise over time (e.g. orientation of phone changes, gravity components difficult to remove completely, temperature noise on raw signal) [15]. As a back-up, the Apper and validated a walking velocity estimate against the Vicon system; however, there was no time to implement this parameter.
- Need to **validate other gait parameters** calculated from autocorrelation (i.e. stride time, cadence).

IV. Key Learning

The key personal learning accomplishments are summarized in Table 1. Our key lesson learned relates to project planning. Due to the difficulties in implementing a distance measure in the later spirals, we realize that it is better to complete essential parameters in earlier stages so there is time for adjustments as needed.

Table 1. **Key Personal Learning Accomplishments**

Team Member	Accomplishment(s)
Eric	1. Learned to measure and analyze gait with an accelerometer 2. Used digital signal processing skills in a practical application
Justin	1. Learned to make Graphical User Interfaces (GUI) using design principles for mobile devices 2. Learned how to convey field-specific knowledge to programmers in a way that is comprehensible and constructive to idea development and implementation.
Tuck	1. Developed intuition to make Android apps (on all aspects back-end to GUI implementation) 2. Learned Java

V. Contribution by Group Members

Each member of the group made invaluable contributions to all aspects of App development. Table 2 summarizes the role of each member.

Table 2. **Individual Contributions**

Team Member	Roles and Responsibilities
Eric	• Set up and maintained subversion server for version control of source code • Developed DSP algorithms for preprocessing, gait detection, and data analysis • Designed access methods to data storage • Coding for user interface and back-end support
Justin	• Assumed role as project manager • Designed UI graphics according to user design specifications for iOS and Android devices • Wrote detailed in-app help literature • Assembled presentation graphics and slides • Validated STA and velocity parameters against a Vicon Motion Capture System • Performed app usability testing, sensitivity testing (on a pilot subject), and error determination • In-depth literature searches to establish background and clinical relevance; determine gait parameter calculations; and compare *MyWalk* parameter results to published values • Built custom phone harness
Tuck	• UI implementation and assisted Justin in defining UI graphics • Development of e-mail, graphing, data processing, and sensor integration functionality • Help validate STA against a Vicon Motion Capture System • Primary debugger of the app: worked closely with Eric to ensure correct functionality • Conceptualized camera integration into the community mode

VI. Apper's Context: *MyWalk*'s Contribution to Rehabilitation Science

Rehabilitation Science is concerned with investigating the means by which movement-related impairments can be prevented, and physical activity can be maintained, enhanced, or restored. As a result, not only does the goal of *MyWalk* align well with that of Rehabilitation Science, but it also helps us to push the boundaries of what is possible in both clinical practice and research in this field.

MyWalk can impact **clinical practice** by providing clinicians with access to how their patients are progressing at home (e.g. the rate of gait improvement). It enables this by: 1) accurately quantifying clinically-relevant gait parameters at home; and 2) facilitating the sharing of test results between patients and clinicians by e-mail. Clinicians would, thus, be able to better tailor their therapy prescriptions to the individual patient's needs and update those prescriptions exactly when needed, not merely during periodic clinical visits.

Furthermore, *MyWalk* can influence a **patient's perception** of his or her control over the rehabilitation process. The app differs from existing interventions, which do not provide direct feedback, require a clinician to interpret the results, and thus, contribute to an overall feeling of helplessness. The *MyWalk* training mode gives patients an objective tool with which to assess their gait characteristics (e.g. step-time asymmetry). Training with feedback (e.g. auditory cues) also provides them with a beneficial, self-care instrument that they can employ to actively improve their step-time asymmetry. In addition, the summary graphs in the progress history mode and the detailed explanations of results enable patients to independently monitor their progress over time and understand the meaning of those results. *MyWalk* can, therefore, make a meaningful difference in the quality of life of its users beyond that made by reducing gait asymmetry.

Lastly, **rehabilitation research** itself will be highly impacted by *MyWalk*, which uses mobile device technology to revolutionize the collection of gait characteristics outside of the typical laboratory- and clinic-based models of assessment. Presently, our understanding of gait is limited, because it is based on assessment models in which: 1) patients are on their best, not usual, behaviour (i.e. Hawthorne effect); and 2) walking conditions are ideal (i.e. a level, even-surfaced, straight walkway under good lighting), not realistic (i.e. containing both physical and cognitive demands). There is a wide-range of features in an individual's walking environment that can influence his or her gait characteristics. The *MyWalk* app can be used to determine which environments challenge an individual's stability by taking a photo of those environments that increase step-time asymmetry. Since step-time asymmetry is indicative of the control of walking, researchers can also use the magnitude of symmetry changes, provided by the app, to probe the factors responsible for those changes and, ultimately, improve fall prevention strategies for patients.

Overall, *MyWalk* makes use of the best tools and functionality that mobile devices have to offer to the understanding of gait. In doing so, the app is helping to usher in a new era for Rehabilitation Science research and practice.

VII. Future Work

We hope to augment the *MyWalk* app in several exciting ways going forward. For instance, we will explore integrating **other gait parameters** into the app (e.g. gait speed), which are commonly used in clinical gait tests. If these tests can be conducted with *MyWalk*, then this would enable patients (and their clinicians) to more effectively monitor their general mobility status outside of the clinic. Furthermore, we will look at **integrating social media** to enhance communication of results, and to increase the **number of positions** in which the phone can be placed during walking (e.g. pants pocket) by developing new position-specific gait algorithms. Lastly, **validation and usability testing** in the stroke population will be performed to confirm the accuracy of our gait algorithms and determine the feasibility of applying the app as part of therapy. We will also consult clinicians on the feasibility of the app.

VIII. Business School Marketing/Entrepreneurship Opportunity

No.

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