ECE1778 Final Report

HIIT It!

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Introduction

Many Canadians fail to meet national standards of physical activity (Statistics Canada, 2014). 48% report that they are inactive during their leisure time meaning they walk for a half hour or less. This is bad news for the future of the Canadian health care system since there are clear links between exercise and health. Exercise is able to reduce the risk of many health problems including cardiovascular disease, cancer, osteoporosis, diabetes, obesity, high blood pressure, depression stress, and anxiety (Statistics Canada, 2014; U.S. Department of Health, 1996; Keim et al., 2004; Warburton et al., 2006). Statistics Canada (2014) estimates that $5.3 billion of total healthcare costs can be attributed to physical inactivity. We need to find ways of increasing physical activity is to improve Canadians' quality of life, health, and the economy.

People often cite lack of time as their reason for failing to exercise. In 1996, a group of researchers led by Tabata found that for just 4 minutes a day, people could enhance their aerobic and anaerobic fitness more than when performing an hour of moderate intensity exercise (Tabata, 1996). Tabata designed a type of exercise called high intensity interval training (HIIT; other names include "tabata training" and "sprint interval training") that involves alternating bouts of high intensity (all-out) exercise with bouts of low intensity exercise.

A problem is that high intensity exercise is highly unpleasant. Luckily, recent research shows that music can enhance both enjoyment and performance of HIIT (Stork et al., 2015). Additionally, music with rhythmic enhancement can promote adherence to an exercise regime (Alter et al., 2015). Finally, synchronizing one's movements to music can enhance efficiency, thus delaying the onset of exhaustion (Bood et al., 2013).

The goal of our application is to facilitate high intensity interval training using music. Specifically, the application will take a user's self-selected music, add a beat overlay to enhance the song's rhythms, and the timing of the beat overlay will guide the transition from high to low intensity. The beat overlay will be double the rate during the high intensity sections than during the low intensity sections. The application is designed for usage on a stationary bike; however users may use the application with other forms of exercise. The user's task is to synchronize their pedal strokes to the beat overlay. HIIT It! will facilitate their high intensity interval training and subsequently will promote their aerobic and anaerobic fitness.

Statement of Functionality & Screenshots from the Application

The main functionality of the application was the beat extraction and beat overlay. Achieving this main functionality was more difficult than expected since the signal processing toolboxes currently available for Android are lacking adequate descriptions.

Beat extraction is not a trivial task. Few other animals are capable of this feat (Fitch, 2013). It is truly amazing that human brains are able to do this. The auditory scene consists of silence alternated with frequencies varying in amplitude across time. Rhythm is the placement of frequencies in time. From a rhythmic signal, the brain must compare the intensities of the different parts of the rhythm to infer the location of a regular, isochronous pulse—the beat.

Computers use complex signal processing techniques in order to complete beat extraction. We used an open source digital signal processing framework for java called TarsosDSP. Within this framework, there is a beat extraction library called BeatRoot that was originally created separately for usage on computers (Dixon, 2007).

There was no open source Android library for the beat overlay functionality. Instead, we used an open source library designed for computers (Beat Root; Dixon, 2007) to guide the design of our Android implementation.

When a user first opens the application, they are brought to the profile creation/login page (figure 1). Once finished logging in, users are brought to the home screen (figure 2) and they are able to navigate to their music library (figure 3), their workout history (figure 4 & figure 5), and to begin a workout by selecting their workout settings (figure 7). In workout history (figure 4), users are able to select a date to view their past history. For example, one user used HIIT It! to guide their high intensity interval workout twice on December 6th (figure 6). On the workout settings page (figure 7), users are able to specify the length of their high and low intensity intervals (figure 8) and the number of repetitions they wish to complete. Then the user may select a song to accompany their workout (figure 9).Once the music is selected, the beat extraction begins and the user is instructed to stretch and warm-up while the processing takes place (figure 10). Once the beat extraction is complete, the user may begin the workout (figure 11). While the user is engaging in high intensity interval training, synchronizing their movements to the beat of music, they are shown a timer that indicates how much time they have left in each interval, and their current intensity level (figure 12).

Figure 1: Profile creation & login screen

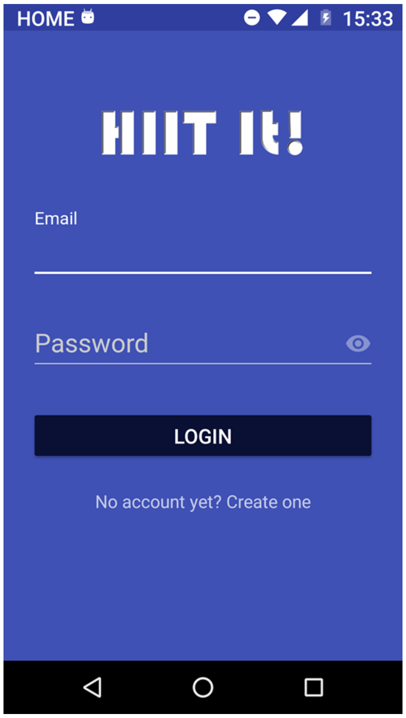


Figure 2: Home screen

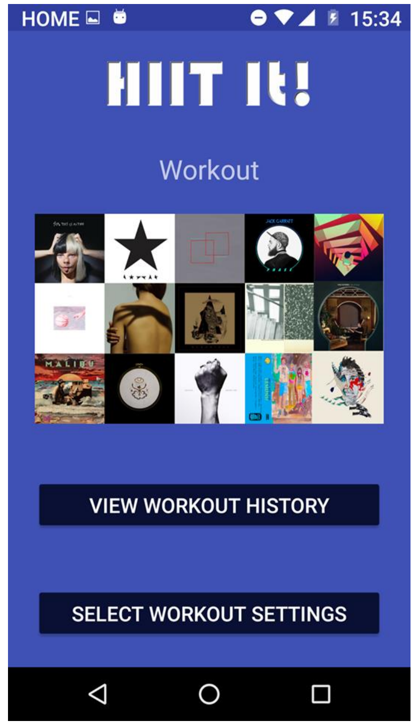


Figure 3: Music library

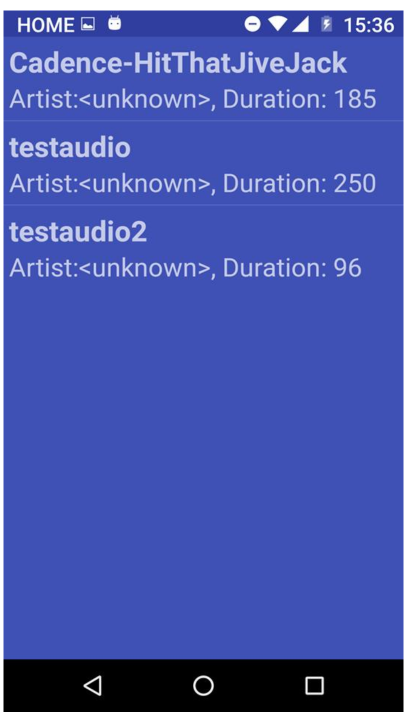


Figure 4: Workout History

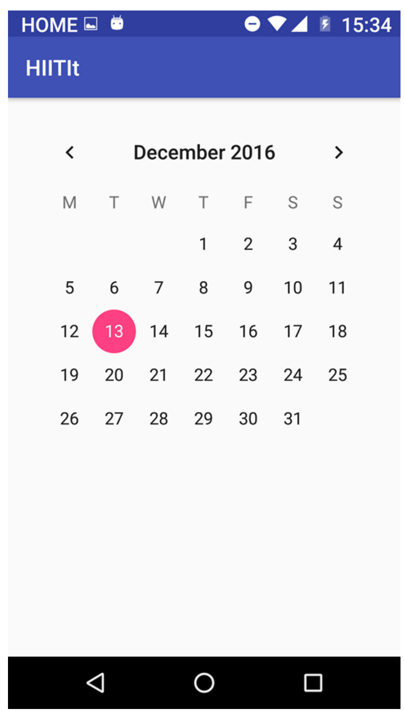


Figure 5: Error message if no workout entry found on a chosen date

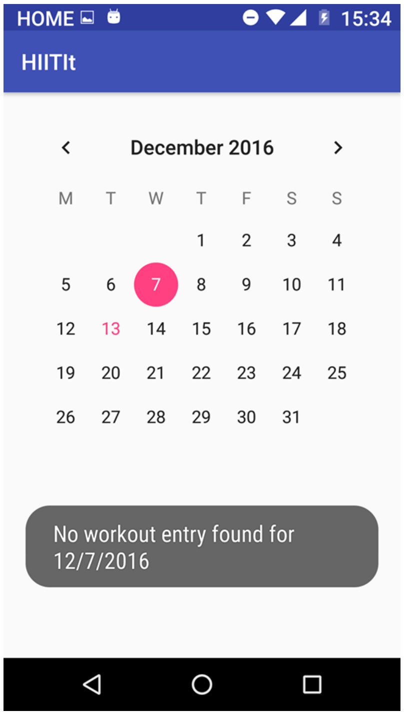


Figure 6: Workout log

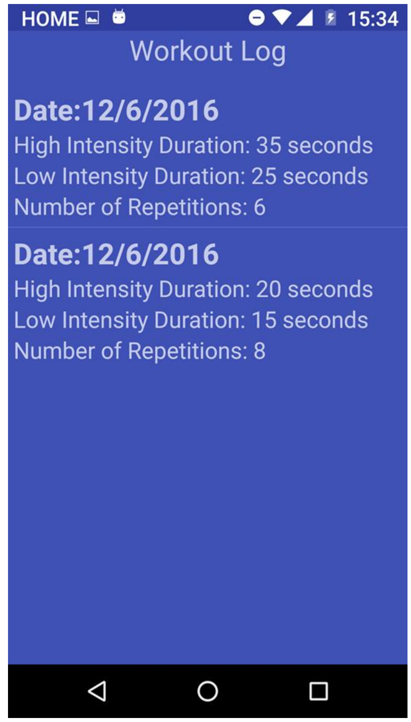


Figure 7: Workout settings page

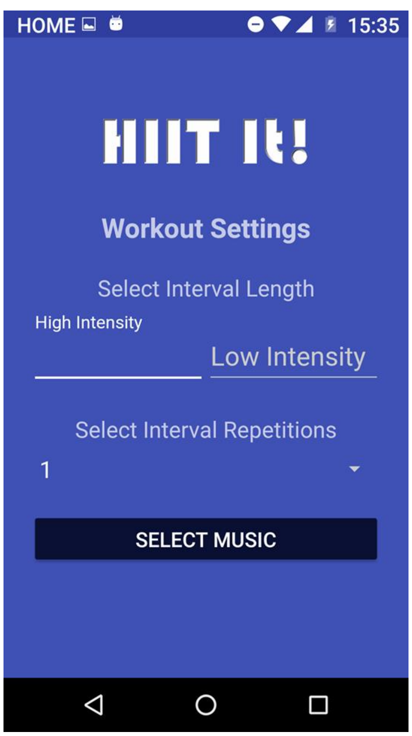


Figure 8: User enters interval length

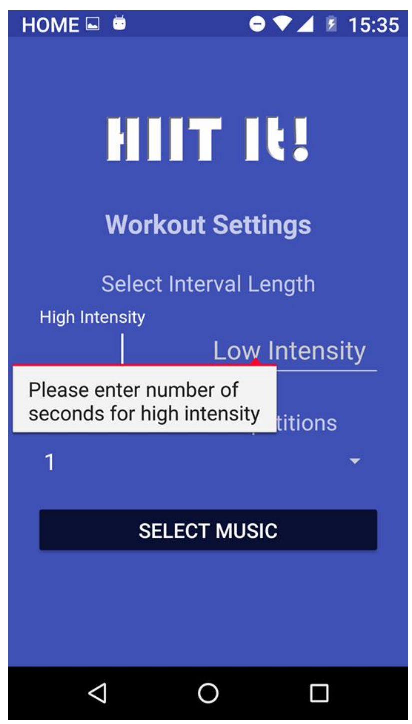


Figure 9: Workout music selection

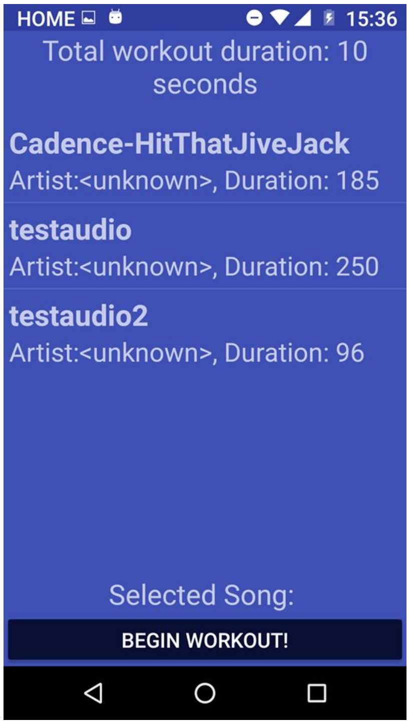


Figure 10: Beat extraction message

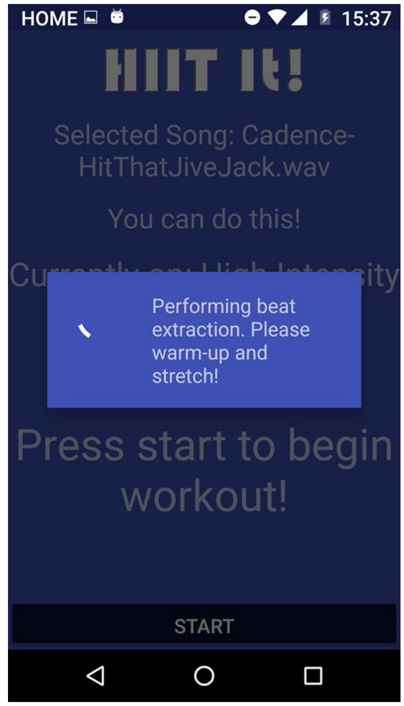


Figure 11: Beat extraction has completed

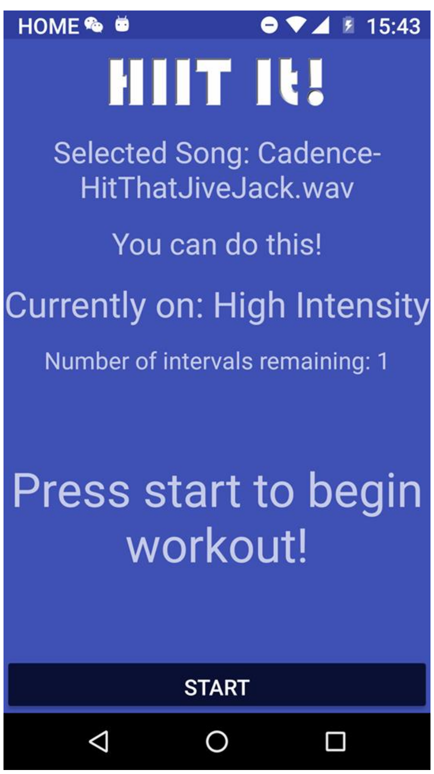
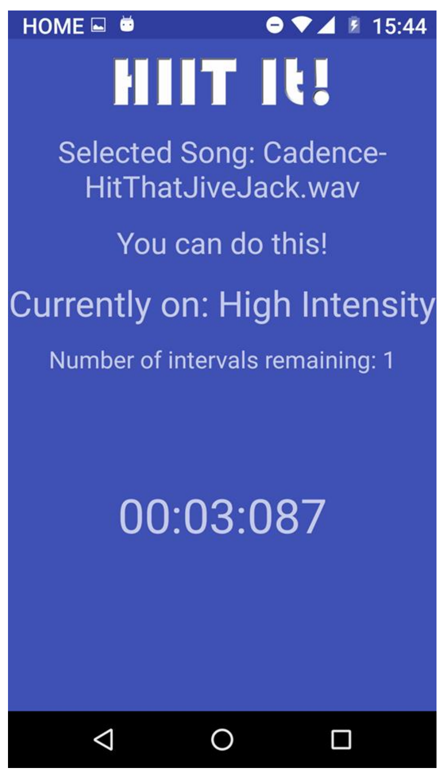
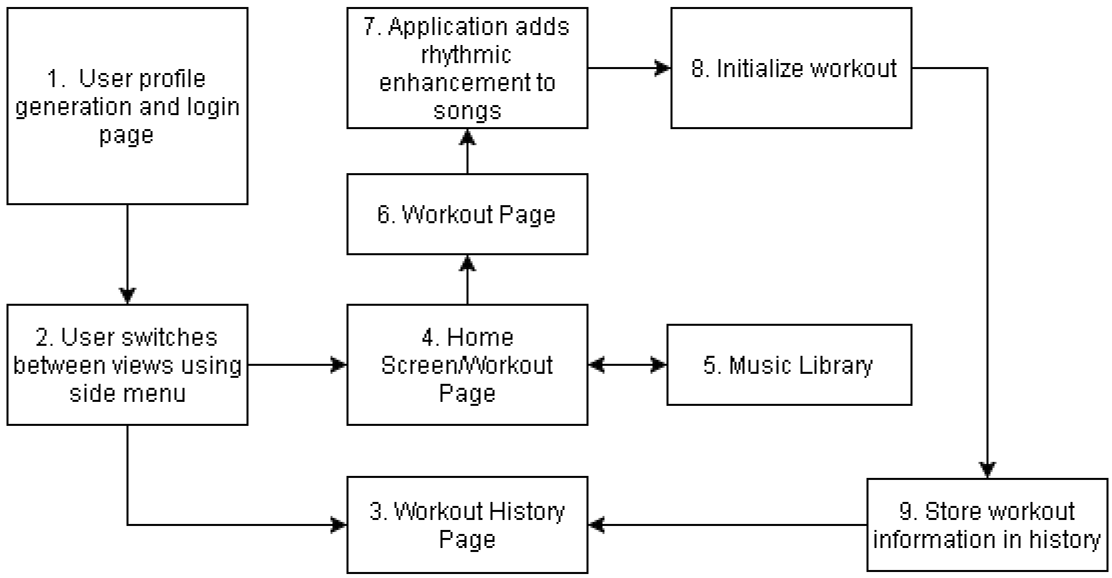


Figure 12: Workout in progress



Once the main functionality was implemented, we attempted to achieve one of our additional goals: to provide users with feedback using a TI sensor tag. There are several reasons that this additional functionality was not implemented. First, we underestimated how challenging implementation of the main functionality would be. The challenges we encountered when trying to implement the TI sensor tag were the high complexity of Android's bluetooth system and the difficulty of integrating this new feature with the previously existing main functionality. For these reasons we decided to delay implementing this functionality until a later date.

Overall design



1. Users will create a profile or will login to their account.

2. Based on the design principles suggested by Android developers, we chose to implement a slide-out menu (also known as a navigation drawer) . The slide-out menu allows for easy navigation between the views.

3. The workout history menu displays a calendar view. Users are able to select a day and view what workout they did on that day.

4. The home screen shows the music selection icon, which navigates to the music selection page, and the option to begin a workout. Selecting the begin workout button brings them to the workout page.

5. Clicking the music selection icon will provide users with the opportunity to select music for their workout from their phone's music library.

6. The workout page prompts the user to select time intervals for the high intensity and low intensity sections and the number of repetitions of the intervals. To start the workout, the user must press the "HIIT It!" button.

7. The location of the beats in the song is determined using beat extraction software (BeatRoot in TarsosDSP). This software performs beat extraction in three main steps: (1) onset detection, (2) tempo induction, and (3) beat tracking. Onset detection involves an an analysis of spectral flux to detect note onsets. Spectral flux is the change in the power spectrum of a signal over time. It is calculated by comparing spectral power in a small window of time to the spectral power in adjacent windows of time. Note onsets are detected when the energy in a window of time is greater than its neighbours. Onsets are selected from the detected notes using a peak finder that identifies which notes have the most spectral power across nearby windows. Tempo induction involves identifying possible tempos based on initial inter onset intervals (IOIs; spacing between onsets). Below is a diagram from Dixon (2007) that shows that once IOIs are calculated, they are assigned to a cluster of similar IOIs.

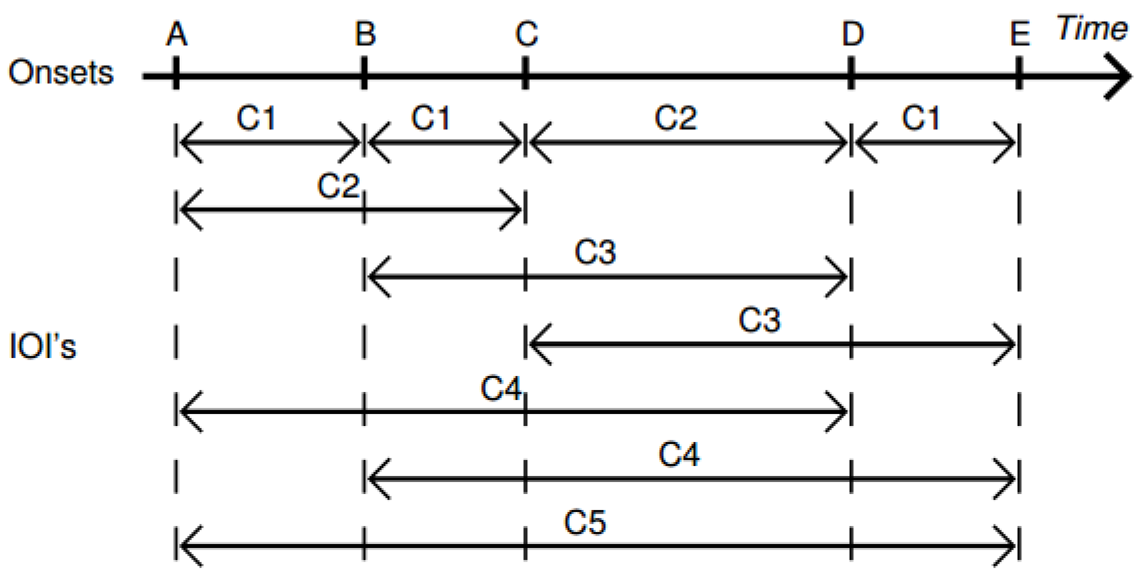


Figure 2. Clustering of inter-onset intervals: each interval between any pair of onsets is assigned to a cluster (C1, C2, C3, C4 or C5)

This clustering analysis accounts for the natural variability present in all human-created music. Cluster information is combined to predict the beat level of each cluster. Given the nature of a beat, clusters will be approximately integer multiples of each other. Clusters are weighted based on the probability that they represent the actual tempo. The beat tracking system is uses a multiple agent architecture. Each agent is assigned a hypothesized tempo. Each agent makes predictions based on their tempo and if an onset falls in the time window of their prediction, it increases the probability that that particular agent's prediction is correct. This process of beat induction progresses from the beginning to the end of the song. (Refer to Dixon's description

(2007) for more details on the mathematical specifications.) Once the beats are identified, drum samples are merged into the original music track. In the high intensity sections, the beat overlay is added at the tempo corresponding to the metrical structure that would provide a high intensity workout. For example, a slow song might have a high intensity section with an overlay double the rate of the beat, while in a fast song the overlay would be the same rate as the beat. In the low intensity section, the overlay is half the pace of the high intensity section (slow song: overlay every beat, fast song: overlay every second beat). The length of the sections are determined by what the user inputted on the workout page.

8. The workout begins once the beat extraction and beat overlay process is completed.

9. Information about the length of the intervals and number of repetitions is stored locally on the device and displayed on the history page.

Reflection

The programmers acquired in-depth technical knowledge of signal processing. In particular, they learned how to process and manipulate audio files in Android and the complexities involved with beat extraction and merging audio files. The specialist learned the limitations of programming on Android and how programming for an application differs from programming for usage on a computer.

We all learned the valuable skill of how to work with people from different academic backgrounds. We learned the challenges of technical jargon and the importance of defining words. There are many cases where a word means one thing in one field and means something completely different in another field. We learned how to navigate challenging interdisciplinary communications, the importance of regular communication, and how to be open-minded.

If we could do this course over again, we would spend more time brainstorming way to achieve our goal. Our goal was to facilitate HIIT training. There are other ways to do this as well. Gathering feedback from members of the class and other colleagues on their favourite idea would have been beneficial during application design. By spending more time thinking outside the box, it is possible we could have generated even more creative ideas. For example, visualization and gamification could have taken the project in different directions. Having a safe time to think alternatively is an important part of any creative process.

Contributions

Eric Zhang

Eric implemented the beat extraction software by learning to use a real-time audio processing framework designed in java (TarsosDSP). He adapted the project to work on a new CPU architecture, assisted Anthony in researching how to implement the beat overlay. Eric explored the possibility of integrating the TI sensor tag using bluetooth on Android.

Anthony Kwan

Anthony implemented the main functionality of the application which consisted of the login screen, preview music player, workout selection, workout history display, interval timer and the workout music player. Anthony researched how to create the beat overlay along with Eric. He created the beat overlay by using the extracted beat timestamps to identify the location of the beats, and then merged two audio files (original music file and beat samples) on Android.

Dana Swarbrick

Dana was responsible for preparing the presentations and providing supportive feedback to Anthony and Eric on presentation style. She completed a literature review that informed the idea behind the application. Dana helped find previously existing software that could perform beat extraction on computers (BeatRoot in TarsosDSP). Dana provided a design of the application interface using Android design principles. Dana prepared most of this final report through consultations with Eric and Anthony. Furthermore, she edited the report to ensure that it was clear and concise.

Daniel Di Matteo

Special recognition goes to Dan Di Matteo for providing design tips and guidance on implementing the overlay functionality.

Specialist context

While I have often introduced this application as useful for everyone, it is particularly useful for those trying to learn movements—whether that is dancers, musicians, or people recovering from injury.

Rehabilitation science is a field concerned with helping people recover following an injury. Rehabilitation relies on neuroplasticity—the brain's ability to change throughout the lifespan (Mang, 2013). For example, after stroke, many cells in the brain die and the brain must rewire itself. Stroke victims struggle to relearn how to move following their stroke. Current rehabilitation techniques that rely only on simple repetition of movements have essentially failed to improve recovery outcomes after stroke (Krakauer, 2015). In order to promote greater recovery, leading researchers have begun experimenting with techniques that can enhance neuroplasticity (Mang, 2013). One method of enhancing neuroplasticity is through the use of exercise.

A growing body of research shows that high intensity interval training after motor practice enhances skill retention (i.e. motor memory) (Roig et al., 2012). High intensity exercise is particularly important for motor learning because this particular type of exercise stimulates anaerobic exertion. Lactate is a by-product of the anaerobic activity taking place in the muscles. When the levels of lactate in the bloodstream exceed those found in the brain, the brain uses lactate as its primary energy source (Coco et al., 2014). Lactate is particularly important for long-term memory formation which is likely why high intensity interval training following motor practice results in better skill retention. An application that facilitates HIIT is useful not only for people trying to become fit, but also for people recovering from a stroke.

My research goal is to evaluate whether high intensity motor learning is capable of enhancing retention of a real-world skill: playing the piano.

Future Work

In the future, we hope to provide performance feedback to the user with the TI sensor tag and with a heart rate sensor. Users would then be able to track how well they synchronize to the beat and have an objective measure of how much physical effort they exerted during the workout. They could observe performance enhancements over time using the heart rate and synchronization data. Finally, we could provide users with more control over the musical rhythmic enhancement by letting them choose the drum sounds that are overlayed on their music.

Permissions

We grant permission for this final report to be posted. We ask that we be able to view the video before agreeing to have it posted online. Finally, at this time, we will refrain from publicly posting the source code as we plan to continue improving our application.

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