Wise – Adaptive fitness instructor based on smartwatch sensor readings

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ABSTRACT
Physical activity and a healthy lifestyle are some of the key aspects regarding the balance of one's life. These days people find less and less time for exercising in their spare time. This can be improved by using wearable devices that guide them and motivate them and make help them get the most out of their time spent on their journey to a more active lifestyle. We propose the development of two applications, one for mobile phones and one for wearable devices, for tracking physical activity and improving its efficiency by giving adaptive feedback based on the age of the user and its preferred training intensity. This paper describes the objectives of the project, the steps that have been followed through the development phase as well as the conclusions we reached after testing the implemented solution.

Author Keywords
Health application; Heart rate tracking; Adaptive feedback; Swift.

ACM Classification Keywords
H.5.m. Information interfaces and presentation: Miscellaneous.

General Terms
Human Factors; Design; Measurement.

DOI: 10.37789/rochi.2023.1.1.6

INTRODUCTION
In a world that benefits from an ongoing and accelerated technological development, smart wearable devices become more and more present in people's daily lives. Thanks to their compact dimensions, those devices can often be found in forms of jewelry, watches, bracelets, glasses and even clothing items. One of the benefits that comes with the size is that they manage to do their work without interfering with the user's routine. The functionalities they offer are often like those of conventional mobile devices, but they are usually better in realizing those tasks thanks of the sensors and specialized components.

People want to maintain an active and healthy lifestyle, which includes both a balanced alimentation and frequent physical activity, aspects that contribute greatly to their wellbeing. Wearable devices can be used as a guidance tool on a path for this lifestyle by monitoring, analyzing and evaluating an individual's level of physical activity. Monitoring health metrics can offer a great contribution to one's lifestyle and physical activity management.

The connectivity between smart wearable devices and smartphones is seen as a catalyst for one's interest in assistive physical activity monitoring. Using mobile apps, the user can analyze centralized data after a training session and can view different statistics about specific metrics used for evaluation. With this kind of technology, an individual can track its progress from day to day, establishing personal objectives whose achievement can improve its lifestyle.

People have the tendency to lose interest in activities that do not bring an immediate and visible benefit. Because of this, consistent practice of physical activity is difficult matter to get into. According to a statistic provided by Vicert [1], 9 out of 10 users of smart wearable devices use those devices to benefit their health, and 88% of them reported that the usage of such devices helped them in accomplishing their proposed goals. Knowing the device they wear monitors their physical activity, a person with such a device is more likely to set goals and make efforts to achieve them, thus resulting in a higher degree of motivation in terms of maintaining an active lifestyle. Assisted physical activity can be described as a way of using technology and smart devices with the aim of supporting and improving a person's experience in practicing physical activities.

Although some complex solutions in assisting physical activity exist, most lack the ability to offer real-time feedback and to stimulate the user in the middle of the workout, relying on metrics computed only after the session is over. Our solution provides a way for the user to get feedback and recommendations in real-time regarding an established objective in order to accomplish it.

RELATED WORKS
The smart wearable devices that are often found within an individual's reach are equipped with a variety of sensors that can be used to monitor different aspects that characterize physical movements. Furthermore, specialized applications that run on said devices can assist the user with multiple types of feedback aimed to motivate him in order to reach a proposed goal.

An attempt to increase physical activity, specifically for older adults, is the application described in [2]. Using a Fitbit tracking device and a companion smartphone application, JitaBug is meant to help adults to maintain or raise their level of physical activity, while the mentioned paper aims to describe the development of the application, its effectiveness and the way it is perceived by users regarding its usefulness. The adaptive aspect of the application is implemented by considering the time of day, physical activity tracking data and the weather conditions in order to deliver recommendations to the user. After testing the effectiveness of the application, the researchers found out that a Just-in-time Adaptive Intervention (JITAI) is a feasible way for supporting physical activity.

Another project designed to improve people's lifestyle is "Monsters & Gold" [3]. This application is designed as a mobile fitness game and its aim is to increase the user's motivation in practicing outside jogging activities. The gameplay is based on defeating monsters and collecting gold as well as different items – spawned based on metric like the user's age, heart rate and exercise phase – in order to increase or decrease the rhythm.

Offering another interpretation of an assistive behavior in an application, Mobile Teen [4] in an application that relies on the motion sensor of the device that it's running on, in order to detect different types of behaviors as physical activity or periods of sedentarism. At the end of a day, the user can review its activity for that day and can label different chunks of behaviors detected by the app.

To combat the "aging in place" phenomenon – referring to living at home regardless of age – Voicu et al. [5] developed a recognition system encapsulated in and Android application, meant to analyze physical activity by collecting data from sensors found on smartphones: gravity sensor, accelerometer and gyroscope. The targeted physical activities are walking, running, sitting, standing as well as ascending and descending stairs. Good accuracy was observed in recognizing all monitored activities, "with especially good results obtained for walking, running, sitting, and standing" [5].

To improve the estimation of energy expenditure, Albinali et al. [6] used a technique involving three wearable accelerometers. They demonstrated that this method could improve energy expenditure estimation by 15% or more compared to other methods. This improvement comes from inferring the type of activity one practices using the acquired data from the accelerometers the processing the data with an algorithm that can run on a mobile device.

Reiss and Stricker introduced in [7] their "idea of a modular activity monitoring system". Using a combination of three modules that make up the system, it offered functionalities like physical activity intensity estimation, heart-rate analysis and activity type recognition. The devices used to track one's activity were accelerometers placed on body extremities as well as a heart rate monitor on the chest. The measured accuracy of physical activity tracking was above 90% for both heart rate monitoring and overall physical activity tracking respectfully.

CONCEPTS

Physical activity refers to any type of movement that benefits health and is recommended for anyone aged 3 or over [8].

Monitoring refers to observing and checking the progress or quality of something over a period of time.

Resting heart rate (RHR) is the number of heart beats per minute at a moment of complete rest, usually measured in the morning, after waking up and before performing any physical activity.

Maximum heart rate (MHR) represents the maximum number of heart beats per minute that the heart can achieve during intense physical effort. The maximum MHR value for a person can be estimated by subtracting their age from 220 [9]. MHR is used as a reference for establishing the intensity zones of the effort.

Target heart rate (THR) depends on the area of effort chosen as an objective in carrying out an activity. These areas correspond to different intensities and objectives.

THEORETICAL FOUNDATION

Physical Activity Monitoring

Physical activity monitoring can be defined as the measurement, analysis and interpretation of information collected by means of specialized devices and various technologies in order to obtain relevant information about various metrics that describe physical activity. There are a variety of metrics that can be analyzed to put the quality of a physical activity into perspective. Each of these metrics can provide valuable information about certain aspects of an activity session. Their importance may differ depending on preferences and intended purpose. Our solution offers the possibility to monitor the active duration of a workout, the traveled distance, the level of energy consumption and the heart rate, the latter being the principal metric that is used for recommending the adjustment of one's effort level.

Heart Rate Framing

Monitoring heart rate during physical activities provides valuable information about the intensity level of movement and cardiovascular health. According to [10], low heart rate values are less associated with mortality from cardiovascular causes. However, this indicator is extremely important in the diagnosis of various medical conditions. Three important variations of this metric stand out due to the data they provide, both in relation to a person's health but also the possibilities and recommendations for him when it comes to physical effort: resting heart rate, maximum heart rate and target heart rate. The significance of each one of this metrics is briefly described in the previous section, while the latter is the one used for analyzing one's level of effort in our activity tracking solution. The selected areas for activity tracking are the very light intensity zone, the fat burning zone, the aerobic zone, the anaerobic zone and the maximum effort zone.

The light activity zone contains heart rate values that are between 50% and 60% of the MHR value. This zone is intended for warming up before considerable exertion or recovery from exertion. This solution refers to this zone as the *Low intensity* zone.

The fat burning zone is between 60% and 70% of the MHR value. Physical activity in this area facilitates the burning of a greater number of calories and is beneficial for weight loss. Wise apps refer to this area as the *Weight control* area.

The moderate zone is found between 70% and 80% of the MHR, and the activity within it improves the body's endurance and cardiovascular health in general. This zone is intended for aerobic activities, where the level of oxygen that the body receives is sufficient to sustain the level of effort made without calling on other sources of energy.

The anaerobic zone requires an effort level where the heart rate values fall between 80% and 90% of MHR. This level of exertion causes the muscles to need more energy than that obtained through breathing, resorting to the breakdown of sugar in the body and the production of lactic acid. Therefore, physical activity in this zone is beneficial for improving performance in activities that do not require great endurance.

The zone that requires the most effort is the maximum intensity zone, with heart rate values between 90% and 100% of MHR. This area is intended for the practice of short-term physical effort by athletes.

Adaptive Feedback; Recommendation Strategies

In order to provide feedback to the user, our solution analyzes the heart rate collected from the watch's sensors in real time and places it inside one of the intensity zones. The user's age can be configured within the Health app available on iOS devices, after which it can be accessed from any app that uses the HealthKit framework. Thus, the Wise app for Apple Watch can compute the MHR and compute the exact limit values for the intensity zones.

There are two recommendation strategies that are used for this solution. Before describing them, it should be mentioned that the project allows the user to configure the feedback frequency. For example, if the user chooses to receive recommendations once every 2 minutes, this feedback will come once every 2 minutes after starting the activity session. Thus, the first recommendation strategy analyzes the user's metrics only at the specific time when the recommendation needs to be made and does not consider the heart rate variation of the past moments. The second strategy, however, involves analyzing the heart rate over a fixed time interval before giving the user a recommendation. The feedback is based on the dominant intensity zone in the analyzed time interval.

WISE – AN ADAPTIVE SOLUTION FOR PHYSICAL ACTIVITY TRACKING

Objectives

This project aims to improve people's experience when it comes to physical activity assisted by smart devices, using the sensors of these devices and the user's preferences to make recommendations to change the level of effort the user puts in. To achieve this goal, two apps have been implemented: a native watchOS app and a companion native iOS app. The watchOS app can be used to start an activity session and see real-time data recorded by the device's sensors, as well as receive recommendations on how to adjust your level of effort. The iOS app can track an activity session, displaying the same metrics and recommendations as the watchOS app. The mobile app can also be used to view activity history along with statistics about each recorded activity session.

Development Tools

XCode

XCode is an integrated development environment used for the development of applications intended for iOS also for other operating systems created by Apple. Important highlights of XCode are as follows:

- Designed to work best with Objective-C and Swift application development.
- The interface builder facilitates the creation of user interfaces in an easy drag-and-drop way.
- Integrates with Swift Package Manager, a command-line tool designed for dependency management.

HealthKit

HealthKit is a framework developed by Apple which offers an API through which applications can extract data collected by watch sensors. According to the official documentation [11], HealthKit uses predefined data types and units of measurement. Thus, the application development process is simplified, as developers know the meaning of the data and how it should be interpreted.

In order to monitor user information and activities, HealthKit stores several categories of relevant data:

- *Characteristic data* represents information that does not change from one activity session to another, such as date of birth, gender, blood type and skin type.
- *Data samples* are the structures in which most of the information about the user's health or activity at a certain point in time is stored.
- *Training data* is data about physical activities or structured exercises. They may specify the type of

activity, the total duration and statistics relating to the entire training period.

- *Data about the source of provenance* describes the device through which a particular data sample was recorded.

Saving and reading this information is done through a Health Store, an access point to all data managed by the library.

WatchKit

The core framework in creating an app for watchOS is WatchKit. It contains several utilities, APIs and resources needed to build an app for Apple Watch devices. The basic elements needed to build a GUI are provided by this library. Moreover, user interaction with the screen and the digital crown are also possible through WatchKit.

WatchConnectivity

WatchConnectivity is the library used by Wise applications to communicate. The library allows developers to build interactive experiences by syncing data between iPhone and Apple Watch. Communication between the mobile phone and the watch can be bidirectional, through a session established between the two devices, a session managed by the framework [12].

Data Persistency

For the user to be able to inspect its activity history, the iOS application needs to implement a method for data persistency.

To store general data related to the metrics of a workout session, HealthKit makes this part easier by offering an endpoint to its internal implementation of a persistency solution. Such an endpoint is called a Health Store and it can be used to create, read and delete information about workout sessions and their specific metrics. This kind of data is stored inside the HealthKit framework and can be accessed on other applications that use this framework or from other devices that synchronize from the same iCloud account.

For the additional workout data registered outside the HealthKit framework, it needs to be persisted even when the application is terminated. To make this possible, our solution uses the Core Data framework provided by Apple. It allows information to be stored as a graph of objects and allows developers to manage the creation, reading, and manipulation of data in an application. The object graph through which Core Data represents application data is made up of instances of classes that represent entities in the Core Data framework, classes that encapsulate the data and behavior of those entities. The model that Core Data uses to represent data is the entity-relationship model, where an application's data models are represented by entities. They define the structure and properties of objects, including their attributes, their type, and the relationships between objects. The additional data is stored exclusively in the iOS application, in a containerized environment and cannot be accessed outside of it.

ActivityKit

ActivityKit is a framework that allows our solution to create real-time updatable widgets – Live activities – containing

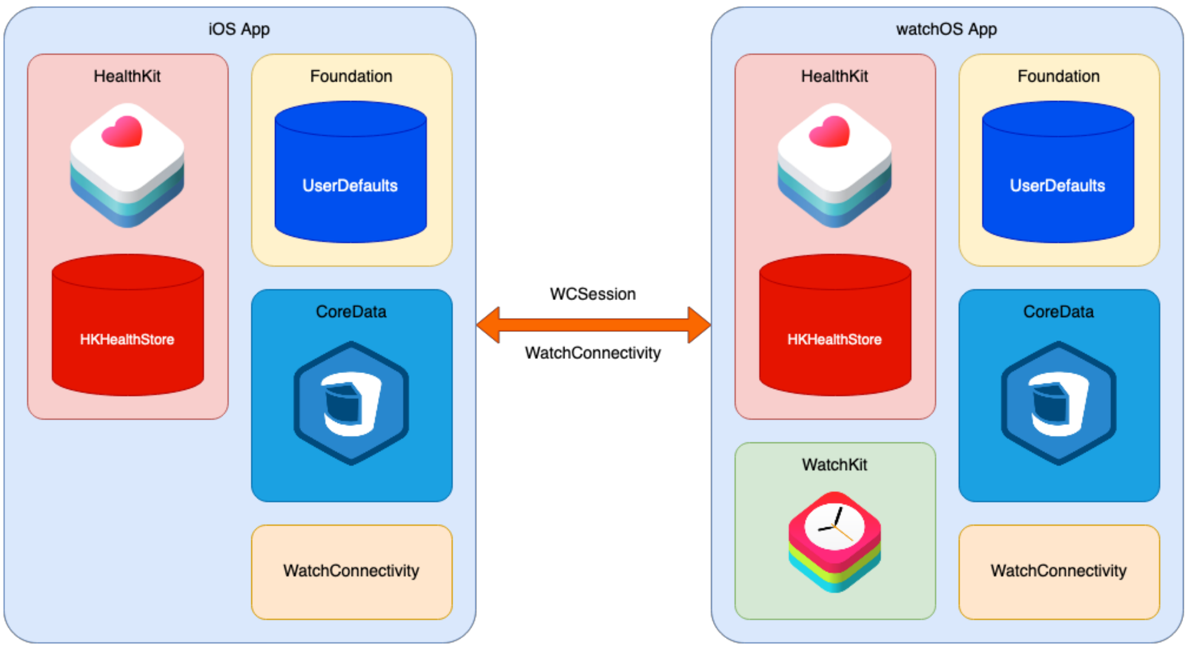

Figure 1. Arhictecture of Wise solution

relevant information about an activity session and display them on the phone's lock screen.

Design and Implementation

System Architecture

Considering the usage of the Wise solution, the two applications were implemented using a monolithic architecture with a MVVM pattern inside, that can be seen in Figure 1. This architecture involves modeling a software program as a self-contained entity independent of other applications and is suitable for developing these applications due to the way the HealthKit and Core Data libraries facilitate local data storing, thus eliminating the need for a web service for persistence reasons. Also, the processing power of devices that meet the needed requirements to run these applications is high enough to perform all computational tasks locally. In our implementation of the MVVM architectural pattern, Manager is a replacement for the ViewModel package, the renaming being due to the main functionality that the classes in this package provide, namely managing device connectivity, activity session, and additional data. Thus, this package contains the essential classes both in terms of application logic and for updating data in real time in graphical interfaces.

Important Entities

Two of the most important entities for the development of this solution are the connectivity manager between the phone and the watch and the workout session manager.

WatchConnectivityManager is responsible with managing the communications between the watch and the phone when an activity session is running on both devices. To be able to transfer information between devices, a connectivity session needs to be established by the manager before any information is sent. This entity is available on both applications, so sending and receiving and receiving actions are bidirectional.

WorkoutManager is the class that manages a workout session, from its initialization, data gathering strategy and termination to the way the additional data is processed and sent to the phone for persistency. This class is available only on the watch application and any valuable information that is needed on the phone app is sent through the established connectivity session. The way sensor readings work on the Apple Watch is based on periodical gathering of samples. A sample is a value registered for a period of time and it can have various types, depending on the metric that it belongs to. When a new sample is acquired by the application, it is processed and then pushed to the user interface where the user can see the new value of the corresponding metric.

Implementation results

Implementing our solution resulted in the creation of functionalities according to expectations. The most important of these are detailed in the following paragraphs.

Monitoring a workout session involves both controlling the state of a workout session and analyzing real-time metrics in order to adjust to the needed effort level. To start an activity session, the user will open the watchOS app and choose one of the available activities from the list on the start interface and then start the session, after which they will be directed to the activity metrics interface.

When receiving adaptive feedback, assuming that the adaptive feedback functionality is activated, the watch will vibrate and modify its graphical interface according to the action that needs to be taken by the user. When the heart rate of the user is within the limits of the chosen workout intensity, a blue indicator with a corresponding message will appear. If the user's heart rate is below the minimum of the chosen intensity, the indicator will turn yellow. When the heart rate is above the maximum of the chosen zone, the indicator will turn red. These visual indicators are accompanied by specific and differentiable vibration patterns that describe the actions that the user needs to take. The feedback on the iOS app can be received both inside the app and on the lock screen, using the live activity that was initiated when the activity session was transferred to the phone. Choosing color as one the predominant means for recommendations can reduce the time that the user needs in order to comprehend the given recommendation.

To analyze previously completed workout sessions, the user can use the iOS app. The latest completed workout and all the workouts from the previews 7 days can be found on the dashboard. When pressing on a workout, a new detailed view will open where the user can see extensive information about the selected workout, like time spent in each intensity zone, total quantity of each measured metrics, the percent of intensity compliance and a heart rate progression throughout the session.

USER INTERFACE

User interfaces are "the point of human-computer interaction and communication in a device" [13]. Because of that, we focused on creating a solution that is intuitive and pleasing for the user.

Figure 2. Starting screen for the watchOS application

Both the phone and the watch app use SF Pro, the system font configured for applications developed for the Apple ecosystem [14]. This way, we offer a consistent experience with the other existent applications in terms of the experience of analyzing information inside the app.

For consistency throughout the offered information, both applications use the same coloring scheme for specific elements. The intensity zones, beside their names, can be identified by their color: cyan, blue, green, orange and red, from least to most demanding in terms of effort. Also, the blob indicator responsible for transmitting feedback has the same color scheme in both applications and its meaning can be seen by accessing the help view in the iOS app.

As for the user interaction, both applications use familiar gestures and types of interactions that can be found in any non-specific iOS or watchOS app, like presenting sheets over existing views or receiving in-app notifications. This way, our solution looks and feels familiar to the user, offering an experience that resembles the usage of other native iOS and watchOS applications.

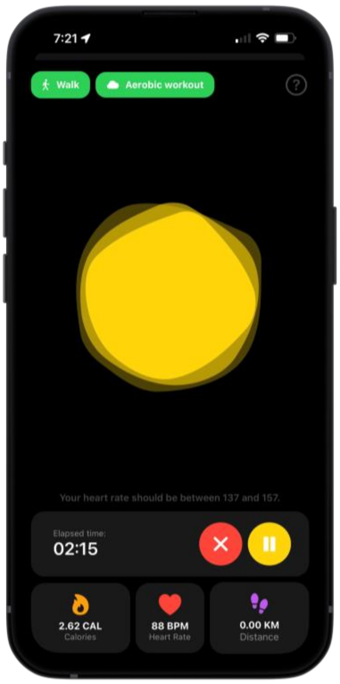

Figure 3. Presented sheet for monitoring view in the Wise application for iOS

TESTING

Experimental testing

During the development of the solution, work-in-progress and finished functionalities have been periodically tested, in different circumstances, to attest their correct operation.

While testing the system's strategy for making recommendations, we concluded that a moment-based strategy may not benefit every individual due to the difference in how one's mind reacts to knowing the way its activity is being analyzed, leading to some cases of poor analytics. The reason for this is the way one user may try to regulate its heart rate only a couple of moments before the time of the next recommendation just to meet the required heart rate for a good recommendation in that moment. This led to the implementation of the period-of-time recommendation strategy, which makes the user aware that its metrics are analyzed every second until the time of the recommendation, not only in that moment.

User testing

Testing the application was meant to verify the effectiveness of the feedback recommendations in controlling the heart rate of the user, in order to stay inside the chosen intensity zone. For obtaining consistent and comparable results, the *Weight control* effort zone was chosen for testing.

The group of testing users consists of two students of 23 years of age, hence the intensity zones limits that can be seen in Table 1. Both applications were installed on their devices for them to be able to practice activity sessions on different occasions. Those activity sessions were realized with recommendations turned off, with "Moment" (M) type recommendations and "Period of time" (PT) recommendations respectfully. The users were encouraged to play with different parameters for PT recommendations to see which one fits their needs better.

Intensity zone	Lower limit (BPM)	Upper limit (BPM)
Low intensity	98	118
Weight control	119	137
Aerobic	138	157
Anaerobic	158	177
Maximum	178	197

Table 1: Intensity zones limits for testing

Results

Activity	Total time	Feedback type	Feedback frequency	Period of time	Success percentage
Walk	64m 2s	-	-	-	45%
Run	29m 47s	-	-	-	43%
Walk	18m 49s	M	2m		51%
Run	21m 15s	M	2m	-	55%
Run	24m 54s	PT	1m	1m	83%
Walk	23m 10s	PT	2m	1m	86%

Table 2. Results from user testing

The testing result were collected from all the participants and were aggregated and presented in Table 2. Those result are promising in the way that they show improvement in the users' success percentage of maintaining their heart rate in the chosen intensity zone, especially for those activity sessions realized using a "Period of time" type of recommendations.

Improvements in the consistency of heart rate values can be seen not only in the resulted percentages, but also in the heart rate progression functionality inside the Wise iOS applications. The heart rate progression presented in

Figure 4 corresponds to the first activity session from Table 2. The heart rate has a wide range of values and fluctuates a lot.

On the other hand, the graphic in Figure 5 describes the heart rate progression from the last activity session. This was realized using "Period of time" feedback, which induces better control of heart rate fluctuations.

Overall, both feedback methods have been shown to bring improvements in the efficiency of an activity session.

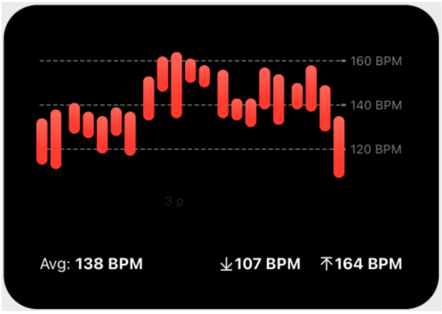

Figure 4. Heart rate graphic for the first activity session in Table 2

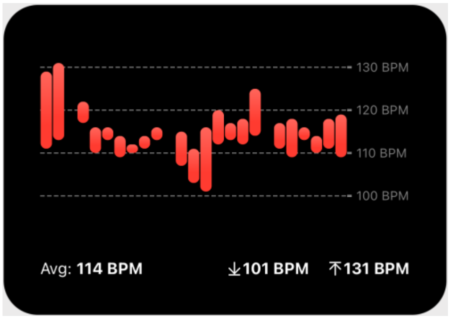

Figure 5. Heart rate graphic for the last activity session in Table 2

User feedback

After testing the solution, both users found the experience of tracking activity sessions with Wise helpful and enjoyable. Moreover, they said that they would further use the application if it was available on the market.

One of the aspects that they both agreed about liking the most was the integration between the iOS and watchOS applications. They said that the way data synchronizes between devices offered more flexibility in terms of tracking the activity metrics in real time. One of them preferred to glance at their metrics on the lock screen of their phone when taking a walk but still rely on the haptic feedback given by the watch. The other one was very pleased that they could prop their phone to something while running on a treadmill and still be able to receive feedback and track his progress and metrics in real time through the interface on the phone. Furthermore, both users liked the way recommendations are based on their age and account for their preferences in terms of strategy and frequency. One of the users confessed that monitoring activity sessions inside a target zone was not one of his chosen ways of tracking physical activity but he reckons that the given feedback reduced the amount of effort he exerted to achieve the proposed goal and that he would like to incorporate this type of activity tracking in his workout routine.

Despite the overall positive experience testing the system, specifically the synchronization between devices, the users were less pleased with some aspects of the applications. The main concern was the occasional synchronization delays between the devices. Sometimes, updating the values of the metrics inside the iOS application with the latest readings from the watch took more than they expected. Also, depending on the length of an activity session, the time it takes for the watchOS application to process the collected data and display a summary grows proportionally. Those delays caused some moments of inconvenience, especially when the users wanted to view their workout statistics right after they completed a session.

In terms of future improvements and recommendations, when asked, both users emphasized that an improvement in processing speed is needed so that the aforementioned inconveniences disappeared. As a recommendation, one of the users expressed interest for more in-depth analytics for heart rate and the inclusion of other metric like moving speed and pace. The other user saw a great potential in incorporating different social features within the app to improve motivation and promote physical activity by practicing group sessions.

CONCLUSION

The goal of this project is to improve the experience of users practicing various physical activities using smart wearable devices to monitor activity metrics and provide recommendations based on their values and user preferences. These improvements help users by contributing to their success rate in achieving a goal, both in terms of training intensity and duration and distance covered in the activity. Moreover, by being able to choose the desired intensity level for an activity and by how the recommendations take into account the settings the users choose, they get a personalized experience which increases their level of motivation.

The project succeeds in achieving its goal of effectively contributing to people's experience of assisted physical activity. The presented work also achieves the less technical goal of promoting physical movement and a healthy and active lifestyle. At the same time, all these beneficial aspects have been implemented considering the best practices used in the development of applications for products in the Apple ecosystem. In this way, users have both the satisfaction of seeing results after using the applications and the satisfaction of the experience of using them.

The development of this project allowed the implementation of an intuitive way of monitoring physical effort, so that the collection of these metrics and their analysis require the user's attention to a lesser extent. In terms of data security, the use of the HealthKit framework ensures the confidentiality and protection of this data through the mechanisms it uses to request and respect the permissions provided by the user. A solution has also been implemented to monitor and retroactively analyze these metrics using the mobile phone paired with the watch as well, using an efficient communication solution between the two devices. Support for real-time activities has also been added to provide flexibility to the user. Thus, activity monitoring on the phone can be done in parallel with various other tasks.

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