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A personalized support tool for the training of mindful walking: The mobile “MindfulWalk” application

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Abstract

Digital health prevention is a trend that becomes increasingly important in various domains. Health insurers crave for effective methods that can be offered to their customers. Moreover, smart mobile devices pose many advantages as they can be easily used in everyday life without being burdensome. Taking these advantages into account, completely new applications become possible. This thesis presents an application that is intended to support users to walk mindfully. It is a mobile personalized tool that senses the walking speed and provides haptic feedback thereof. The procedure of mindful walking, the technical prototype as well as preliminary study results are presented and discussed. The reported user experience and the study result indicate promising perspectives for a tool that supports a mindful walking behavior. Altogether, the use of modern smart mobile device sensors paves the way for useful mobile application in the context of health prevention in particular and health care in general.

Contents

1 Introduction

Mindfulness has become the focus of interest in psychology and medicine more and more [Mar12]. Chronic diseases are often treated with mindfulness-based therapies [CBM+12, SES+12] and the state of mindfulness is significantly related to several indicators of psychological and physical health [CBM+12, SES+12, KSR11]. Mindfulness is a skill that can be obtained by regular training while intentionally and non-judgmentally paying attention to the present moment. Mindfulness can be exercised by anyone to reduce stress (mindful-based stress reduction; MBSR), calm anxiety, sleep better, improve focus and more. Due to its growing popularity, many mobile applications emerged to support and track mindful exercises. The focus of a mindful exercise can be any experience of the present moment like objects (e.g., chair, plant, etc.), environmental influences (listening) or body-related processes (breathing, walking). Mindful walking as proposed by Thich Nhat Hahn [Han] has the advantage of easy integration into our every-day life. Everyone walks every day. Walking is usually just a way of getting from one place to another. Therefore mindful walking has the potential of giving everyone daily access to mindfulness practice without having to learn new techniques. A mobile application can remind people on a regular basis to walk mindfully and to observe and track the exercise, giving real-time interactive feedback using sensor measurement.

1.1 Motivation

We live in a very busy world, the pace of life is often frantic and we're always doing something. The mind doesn't get any rest since it's always occupied. But we rely on our mind to be happy, content, emotionally stable as individuals and also kind thoughtful and

considerate with others. We need our mind to stay focused, creative, spontaneous and to perform at our best. But instead, we get stressed with all the thoughts and difficult emotions going round that we don't know how to deal with and the result of that is that we are not longer present in the world we live in; we miss out on the things that are most important to us.
The goal of mindfulness is the appreciation and experience of the present moment in order to get less distracted and not lost in thought by stepping back and looking at thoughts and emotions from a different, non-judgmental point of view.

Mindfulness can be described as the intentional and non-judgmental attention to experiences of the present moment [KZ90]. Mindfulness is rooted in eastern meditation traditions and has become highly relevant in basic research [THP15] as well as in health [KSRF15], and clinical science [KLF+13]. The body is the focus of many mindfulness exercises applied for example in Mindfulness-based Stress Reduction (MBSR) [KZ90] and Mindfulness-based Cognitive Therapy (MBCT; [SWT02a]). In these exercises, the participants are trained to intentionally and non-judgmentally attend to automated body-related processes (e. g. breathing, walking). The aim of these exercises is to gain the ability to flexibly switch from the "doing mode" into the "being mode of mind", which is characterized by the concrete and accepting perception of moment-by-moment experience and allows disengagement from dysfunctional cognitive processes [Wil08]. The ability to disengage in turn is considered to reduce depressive symptoms. One of these body-related mindfulness exercises is walking mindfully [Han]. The participants are instructed to become conscious of the otherwise automated walking process by walking slowly and taking small steps. Mindful walking has, for example, been shown to be beneficial for patients with depression [PSTS14] as well as for patients with diabetes [GHTS16].

Mindful walking can be exercised anytime by anyone. Hanh even proposed to walk mindfully all the time, anywhere we go [Han]. All one has to do is walk slowly and notice each step. Explicitly attend to breathing and walking and nothing else. It takes a little practice and some may find it hard to integrate such mindful exercises in today's hectic world. Also, participants often experience that their mind wanders away from being mindful and they have difficulties to redirect their focus to the mindful exercise, especially patients suffering from depression [RADM14]. Moreover, specifically novices are often insecure on whether they practice mindfulness the way it is intended. Applications providing support in practicing mindfulness may help to stay mindful and in refocusing the attention during mindful exercises, in turn, might be helpful to address these problems. Almost everyone has a smartphone and it can help people to walk mindfully. A mobile application could manage user-created schedules and notify the user to start a mindful walk training. It could support the user during the training by ensuring the user isn't walking too fast so that he is actually walking mindfully. As a bonus, a mobile application could measure and collect walking data during the exercise to let the user review past exercises and monitor progress. Since mindful walking has to be trained, an app could help inexperienced users to get into mindful walking, to stay focused during the exercise and to train mindful walking on a regular basis. Since mindfulness isn't only beneficial for patients with acute illnesses, a mobile application could also attract younger individuals which may be hard to get in contact with from a clinical setting [PPL+17b].

The hereby developed underlying mechanism enables mindful walking to be integrated with a mobile crowdsensing service like TrackYourTinnitus [PPS+17, PSLR17]. This way longitudinal data could be collected under real-life conditions using ecological momentary assessment [SPP+16] to observe a variety of other factors which may affect test results and are not covered in this work like e.g., time-of-day dependency [PPL+17a].

1.2 Related work

1.2.1 Computer-supported mindfulness

Most studies of computer-supported mindfulness involved mindfulness as a component of a broader therapeutic intervention. Also, most of these studies only presented mindfulness techniques without providing interactive practices. The content was presented using videoconferencing [GNBBG08] or web pages, sometimes enriched with audio or video [AK04, EABP08, LFV+10, TWO+10, KCKW12]. Some researchers utilized web-pages on smartphones [KFE+11, NDE+12] or actual smartphone applications [MKL+10]. Glück and Marcker [GM11] investigated an interactive web-based mindfulness training for thought distancing where participants imaginarily labeled clouds with distressing thoughts or sensations on a screen with a blue sky to watch the clouds move across the sky and out of sight. The application was designed to support affect labeling and thought distancing but it basically just moved a cloud across the screen when hitting the spacebar. The participants had to do all the work with labeling distressing thoughts and associating the labels with the moving clouds. The experiment of [BEC+12] included a mindfulness technique in a virtual environment for mood induction. Participants reported low levels of difficulty to use and also high levels of satisfaction although the technique didn't provide an interactive component. Another study utilizing a virtual environment was conducted by [SGS07] of the Meditation Chamber where participants had to focus on their breath while an interactive feedback based on the user's skin conductance, respiration, and blood volume pulse was projected into the VE in form of an abstract video.

1.2.2 Smartphone-supported mindfulness

There are countless mindfulness-based mobile applications (MBMAs) on the market. Studies have shown that most of these apps are simply guided meditations, reminders, and timers but most importantly the almost complete lack of evidence of the efficiency of those applications [MKHS15, PDHM+13]. A sample search among the top-rated MBMAs on the App Store during the course of this study has confirmed that these results are still valid. All tested apps (Mindfulness [Min], Headspace [Iim], ZMeditations [For], SimpleHabit [SH], 7Mind [7Mi] and Buddhify [Eve]) provide audio-guided meditations and most of them offer reminders (Mindfulness, Headspace, SimpleHabit, 7Mind and Buddhify). Some apps show mindfulness exercises based on goals such as sleep better, reduce stress, calm anxiety or improve focus (Headspace, SimpleHabit, Buddhify) but still, all exercises consist only of an audio track with no interactive feedback or measurement. Only one tested app provides an optional Watch app to measure the heart rate before and after an exercise (Mindfulness) and one application has a self-assessment rating of mindfulness, concentration, and balance at the end of an exercise (Buddifhy). Besides the limited feedback and interactivity, many apps only provide a basic set of meditations. All other meditations or sets of meditations are chargeable per exercise or subscription plan. Across all tested MBMAs in this and other studies, there is almost a complete lack of interactive feedback and sensor measurement as well as evidence of usefulness.

During the research for this study, only two interactive mindful walking apps have been found. The Breathewalk-aware system [YWLH12] uses a complex net of sensors to raise the user's awareness of walking and breathing behaviors by providing multimedia guidance on the smartphone.

The AmbientWalk App also takes breathing into account and generates a real-time ambient sound based on the user's breath and walking pace.

Both apps are research prototypes and not targeted at end users. Also, both apps provide a quite intrusive audio-visual feedback to the user which can disturb the actual mindful exercise.

1.3 Approach

The practice of mindfulness can be difficult for people with no or minimal experience with meditation [KZ05, SWT02b]. A supportive tool must be easy to understand and use, otherwise "naive meditators" will be discouraged to start practicing and will eventually abandon practicing. Mindful walking is all about walking and intentionally attending to the automated process of walking. This exercise should not be disturbed by attending to a phone. To make a supportive tool for mindful walking as little intrusive as possible the mindful walk app is split onto a smartphone and a smartwatch. All interactions can take place on the phone benefiting from the larger screen while during the actual mindful walk exercise nothing more than the watch has to be carried. The watch doesn't need to be attended to during the entire exercise so one can fully attend to walking.

Mindful walking can be best exercised when walking slowly so one can consciously perceive every single motion of the walking process. The MindfulWalk app sets a target speed for the mindful walking exercise which is slower than the "normal" walking speed by a selectable percentage. This way everyone can select an individual walking speed for the exercise but it will always be *slower* than the normal walking speed. In order not to exceed the target speed during the exercise the application must provide a gentle non-intrusive feedback. The smartwatch can perform various haptic feedbacks from a slight tap on the wrist up to vibrating so the user can keep attending to walking and doesn't have to look at a screen.

Since emotional states, as well as emotion dynamics, can mediate the effects of the exercise [PPLS16b, PPLS16a], the experienced emotions on the dimensions *affective valence, dominance* and *arousal* are also captured before and after the exercise using the Self-Assessment Manikin [BL94].

1.4 Structure

The following chapters present how the prototype app was developed, how the pilot study was designed and conducted and finally discuss the study results and give an outlook how the app could be developed further. Chapter 2 focuses on the implementation of the prototype, where first all requirements are analyzed and structured (cf, Sect. 2.1) and then a concept is presented how to realize the latter (cf. Sect. 2.2). In the following Section details of the implementation of both the iPhone App and the Apple Watch Extension are presented. Finally the defined requirements are validated against the finished prototype (cf. Sect. 2.4).

In Chapter 4 the details of the pilot study are described which was conducted to examine the usefulness of the app. Section 3.1 explains the method used whereas in Section 3.2 the results are evaluated.

Finally, a summary and outlook is given.

2

Implementation

In order to conduct the study, a mobile application was developed. This application consists of two parts. A smartwatch app and a smartphone app. This way the user can comfortably interact with the questionnaires on the phone on a larger screen but doesn't need to carry the phone or look at it while walking since he gets feedback over the watch on his wrist.

This chapter comprises the applications requirements, the concept to realize them and a summary of the actual implementation followed by a concluding analysis of the final app regarding the requirements but also limitations.

2.1 Requirements analysis

2.1.1 Functional requirements

For a simple and easy-to-learn usage, the app will be divided into three sections, which will be available in the main menu. These sections are:

1. General information
2. Schedules
3. Start

Each section must provide certain functionalities, which will be defined in the following. For later on reference, the single requirements are labeled with (FR#1).

General information

FR#1.1 Display App information: The user can view general information on the app itself as well as instructions on how to use it. The instructions should give an overview of the functionalities of the app and cover every use-case. The wording should and be easily understandable for all user groups.

FR#1.2 Display General information: This section serves general information on mindful walking. What it is, why the user should train it and how to train it using this app.

Schedules

FR#2.1 Create new schedule: The app should be able to notify the user to train mindful walking. The time and frequency of these notifications can be managed by the users through schedules. When creating a new notification schedule the user can set the day, time and interval (daily, weekly, every X hours) of the notification. The user can create infinite schedules.

FR#2.2 Edit schedules: Existing schedules can be edited and deleted. In the edit-mode, the user can tweak the same variables as in the create-mode.

Start

This section is where the actual mindful walking training starts. The training consists of several steps and each step has to meet certain functionalities.

FR#3.1 Mood evaluation: Using a self-assessment manikin[BL94] the user can rate his/her mood.

FR#3.2 Normal walking speed measurement: To measure the "normal" walking speed, the user is instructed to walk normally until he hears a feedback sound to indicate that the measurement is successful.

FR#3.3 Save data: The collected data (mood and normal walking speed) should be saved to a database locally as well as remotely along with a user ID to identify the participant and a timestamp.

FR#3.4 Choose target speed: Before the training starts, the user can select a target walking speed based on the measured normal walking speed. The choice consists of 10, 25 or 50% reduction of the normal walking speed.

FR#3.5 Save target speed: The chosen target speed should be saved to the database as well. Additional parameters like user ID and timestamp should be saved too, to correlate the datasets later.

FR#3.6 General instruction: Before the actual mindful walking training, general instructions on how to walk mindfully should be displayed.

FR#3.7 Mindful walking: During the mindful walk training the app should constantly measure the current walking speed and notify the user whenever the current walking speed exceeds the target speed. The training should last at least 5 minutes and the app should notify the user when 5 minutes have passed but the user can cancel the training at any point, before or after the 5-minute recommendation.

FR#3.8 Finish training: When the user finishes the training the collected data should be saved to the local and remote databases. The dataset should include: start time, finish time, feedback frequency, feedback timestamps and average walking speed.

2.1.2 Non-functional requirements

The non-functional requirements specify the quality and performance expected from the app as well as the error handling. A comprehensive documentation of the implementation of requirements and a good feasibility and flexibility.

NFR#1 - Quality

The Application should be *correct*. It may not show false information and all functionalities should work correctly and as expected. It should be *reliable* and still work under adverse conditions. *User-friendliness* is a major part of the quality including *consistency* regarding the design, language, and navigation. Well-know navigation- and design concepts of mobile applications should be preferred. The user should easily reach all functionalities and shouldn't be disturbed or even restricted by the app. It should rather be seen as a tool to conduct the mindful walking study. In terms of *security* the app must collect all data anonymously. The privacy of the user must be preserved and the participants should be informed about all data the app is saving. Data - user matching only happens by a random and anonymous user ID. Last but not least the application must be *robust* and should not crash after wrong or unexpected user input or measurement data. This also affects the data upload to the remote database. If no network connection is available the data is only saved locally and sent to the server as soon as a connection is possible.

NFR#2 – Performance

Essential performance features are *response time behavior*, *computing expense* and *data throughput*. This means the app should quickly respond to user input and not freeze. Computationally expensive operations should be avoided to keep down CPU usage and thereby save battery life. The data throughput through network transactions should be kept low by reducing the saved datasets to the essential parameters to save the user's data allowance. Also, weak network connections can lead to longer responding times if the data packages are too big.

NFR#3 - Error handling

In case of an error or application failure, understandable and usable error messages should be given to the user, for example in form of a dialog. Common errors in this context are database and network errors but also measurement errors because of hardware (e.g. gyroscope) disturbances.

NFR#4 - Documentation and Flexibility

Good software design includes appropriate flexibility, expandability, and feasibility. By a modular design, the single components of the application can be delimited and handle distinguished tasks (cohesion) while relying on each other as little as possible (coupling). This supports easy editing of individual components.

Last but not least the compliance of the defined requirements has to be traceably documented in the implementation.

2.2 Concept

Even though the main purpose of the app was to conduct the study, it is designed to be easily extendable to make it usable for everyone in everyday use. In this case, it would be a personal tool to measure mindful walking exercises and to review his own data. For the study though, all subjects will be using the same app on the same hardware. This has an impact on the underlying data structure. Instead of one user with many exercises there are many users with one exercise each. To make the app usable for the study but also easily alterable with little effort the data model in Fig. 2.1 was developed.

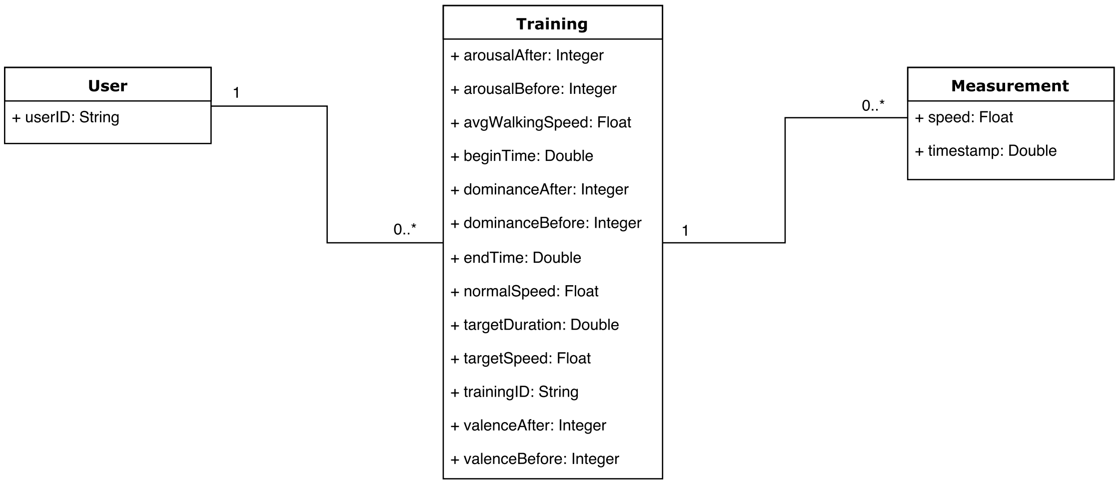

Figure 2.1: Data Model

This way every subject has a distinct user for the study and the app can be altered for a single user by omitting the user creation and creating a singleton user instead.
All training relevant data is stored in the training object. The single measurements during the exercise are referenced in another table since there can be many of them for each training.
The user itself is handled anonymously and is only identifiable by a randomly generated string for the sake of the study. The user object can easily be extended with personal information if needed. Not shown in the data model are the schedules, which are similar to the training objects referenced by the user. They are left out in this figure since they are not necessary for the study.

To make the application as easy to use for the subjects there is a big “Start”-Button on the home screen of the app which directly creates a new user and starts a new training. For the training itself, the user switches between phone and watch. The training starts

with the first self-assessment manikin on the phone after which the user is instructed to walk normally for a while to determine his normal walking speed. To minimize false data of the user standing, the user himself must start the measurement when he is ready to walk by tapping a button on the watch. When the normal walking speed is determined the user is notified on both the phone and the watch and the phone app automatically switches to the next screen where the user can then select his target speed and duration of the training.
After this initialization process, the user himself can start (and stop) the training by tapping the button on the watch. The phone is not needed during training since the measurement happens on the watch. During the training, the user can observe the current duration and speed. The speed indicator doesn't show the actual walking speed of the user since this is not particularly of interest and could even be distractive. Instead, it shows the current speed in relation to the target speed on a numberless speedometer to give a hint on how much the user is walking too fast. When the target duration is reached or the user is walking too fast he is notified by a slight vibration of the watch so the user doesn't even have to look at the watch once and can fully concentrate on the mindful exercise.

When the user finishes the training by pressing the button on the watch, the measurement data is transferred to the phone and the phone app automatically switches to the next screen with the concluding self-assessment manikin.

The other features of the app are not targeted for the subjects. They comprise the whole data management (creation and deletion of users, exercises and schedules) as well as statistical insights into single exercises and static information about the app. The data is represented in lists where the first page is a list of users, selection of a user shows the users list of exercises and the selection of a training shows the details of this training.
All data can be transferred to a remote database for further investigation and statistical calculations. For an end-user version of the app, this process needs to be automated to ensure regular backups.

2.3 Implementation

The app was developed on an iPhone SE (running iOS 11 beta) and an Apple Watch Series 1 (running watchOS 3.2) using Xcode 9 beta and Swift 4. All data is created and persisted using the CoreData framework which is based on the scheme shown in figure 2.1. CoreData creates so-called managed objects based on this scheme which are mutable objects of the defined entities with all their attributes and relationships.
The core of the application though is the walking speed measurement. The CoreMotion framework provides access to the system-generated live walking data. The current pace is calculated utilizing a step counter over time. This is as precise as it gets working with the available sensors of the phone/watch. It has its limitations when it comes to very slow walking speeds since the pedometer cannot distinguish single steps anymore and returns a pace of zero.

During a mindful walking training data has to be transferred back and forth between the phone and the watch. Since live communication between phone and watch requires both applications to be active and in the foreground there had to be a fallback solution since this case cannot always be ensured. As soon as the user lowers his wrist the watch screen turns off and the application switches to background mode. During training phone and watch can get out of reach if the user walks without carrying the phone. The phone screen turns off, switching the app to background mode if the user doesn't interact with it for some time. When the phone (or the watch) wants to send data to its counterpart application it has to be checked for reachability first, meaning the counterpart app is active and in the foreground. If this is not the case, data will be sent to a background queue and delivered as soon as the counterpart app becomes active again (for instance when the user raises his wrist to look at the watch) and can be shown immediately.

```
public func send(messages: [String : Any]) {
  if !session.isReachable {
    sendInBackground(messages)
      return
  }
  // send message in foreground (live)
  session.sendMessage(messages, replyHandler: nil) { error in
    // handle errors
    print("error sending message: \(error)")
  }
}

private func sendInBackground(_ message: [String : Any]) {
  // WKSession must be activated
  if session.activationState != .activated {
    return
  }
  // cancel outstanding transfers
  // only the current one is relevant
  if session.outstandingUserInfoTransfers.count > 0 {
    session.outstandingUserInfoTransfers.forEach {
      $0.cancel()
    }
  }
  // queues message on the other device
  session.transferUserInfo(message)
}
```

Listing 2.1: Sending data to the counterpart

2.3.1 iPhone App

The iPhone app is storyboard-based, meaning all screens are predefined in a storyboard with a distinct ViewController for each screen. The screens are connected through segues (transitions from one screen to another). This way the whole infrastructure of the application could be built quickly, enabling the user to navigate through all available views.

The goal was to make the single steps of the training as self-explanatory and simple as possible and to avoid wrong input. The user can navigate linearly through the steps of a training session and go back at any point to correct his or her input. Every screen shows instructions on what to do.

The self-assessment manikin uses well-known radio buttons and can only be finished after the user selected a value of each of the three dimensions.

After the self assessment-manikin, the normal walking speed is measured. The user is instructed to switch to the watch for measurement and walk normally until the measurement is complete which is signaled with a haptic and an acoustic feedback on the watch while the phone automatically switches to the next screen.

On the following two views, the user can select both reduction of speed as well as the duration of the training in a similar way on separate screens to maintain readability. The last screen of the actual training shows to instructions to mindful walking. At the same time, the user input is sent to the watch. The actual training then takes place on the watch so the user doesn't have to carry the phone.

When the phone receives the training results it automatically switches to the final self-assessment manikin (i.e., which works exactly like the first one) and the results are presented to the user while the training data is saved to the database. If the training is interrupted at any point and doesn't reach this final step, data will not be saved ensuring only complete training objects.

2.3.2 Watch App

The watch app consists of two views: the normal speed measurement and the training view. The user only interacts with the what to start and stop the measurement as soon

as he is ready. All other interactions take place on the phone because of the bigger screen. The first view only shows a disabled button to start the measurement for the normal walking speed. It is enabled after the user finished the first questionnaire. Once tapped it disappears and the message “Start walking” is shown. The user also receives a feedback and a message when this measurement is completed. During measurement, the pedometer measures ten speed values greater than zero and then calculates the average which is considered the *normal walking speed*. This way some variations in the subjects walking speed are taken into account but also the measurement doesn’t take too long (about half a minute).
The calculated result is sent to the phone app and after receiving the user input the watch automatically switches to the training view where the user can start and stop the training while observing the current training time and speed. The interface is kept quite simple to not distract the user from the mindful walking exercise. A speed indicator shows when the user is walking too fast but stays at the same position when the subject is walking too slow since this is not considered a mistake during the exercise. The user will receive a feedback when his selected duration passed but the training will continue until the user taps the stop button which he can do at any time even if the target duration is not yet reached. At this point, all measurement data is sent to the phone and the training is complete.

HealthKit

WatchOS apps are considered Foreground apps; they run only while the user interacts with one of their interfaces. This is also due to the limited battery duration of the watch. One problem when measuring live walking data on the Apple Watch is that the application switches to background mode as soon as the user lowers his wrist (i.e., which everyone does during walking). When in background mode, all processes of the application are paused and tracking APIs like the pedometer won’t receive updates anymore. The only exception tasks allowed to run in the background are URL sessions for networking tasks, audio player to play audio in the background and the HealthKit WorkoutSession which specifically targets workout tasks like walking. Using the WorkoutSession requires the

user to explicitly grant the application access the HealthKit framework. The HealthKit framework tracks and saves all kinds of health information and the user can specifically decide which information the application can read or write.
For the purpose of the mindful walk exercise the app doesn't need to read or write any health data, it just needs access to the HealthKit framework itself in order to instantiate a *HKWorkoutSession* enabling the application to keep tracking in the background. The *HKWorkoutSession* also fine tunes the Watch's sensors for a specific activity, in this case walking to generate higher-frequency data samples.

2.4 Validation and Limitations

2.4.1 Functional requirements

General information

FR#1.1 Display App information: Not yet implemented.

FR#1.2 Display General information: Not yet implemented.

Schedules

FR#2.1 Create new schedule: The user can create new schedules by tapping the "+"-Button in the schedules menu. Start date and time, as well as the repeat interval, can be configured using iOS-PickerViews.

FR#2.2 Edit schedule: All created schedules are shown in a list view. If the user selects an existing schedule from the list it can be edited similarly to the creation.

Start

FR#3.1 Mood evaluation: When starting a new training a self-assessment manikin is shown which the user has to complete using radio buttons in order to get to the next screen.

FR#3.2 Normal walking speed measurement: The phone app shows instructions on what to do (switch to the watch, press start and start walking normally) while the watch app measures the walking speed. When the measurement is complete a feedback sound along with a vibration is played on both the watch and the phone to notify the user.

FR#3.3 Save data: The measured walking speed is transferred from the watch to the phone and saved to the training object. It is not yet saved to the database since the training object is saved as a whole at the end to guarantee consistent data.

FR#3.4 Choose target speed: The user can select the target speed for the mindful walking training relative to the measured normal walking speed. The choice reaches from 1% to 50% in 1-percent-steps and can be selected using a picker view. In the same manner, the duration of the mindful walking training can be selected in 1-minute-steps starting from 5 minutes.

FR#3.5 Save target speed: The target speed is saved to the training object. It is not yet saved to the database since the training object is saved as a whole at the end to guarantee consistent data.

FR#3.6 General instruction: After the target duration is selected an instruction screen appears, explaining the mindful walk training, how to walk and what to pay attention to. No next button is displayed, instead, the user is instructed to switch to the watch to start the measurement.

FR#3.7 Mindful walking: During the mindful walking exercise, the watch constantly measures the user's current walking speed. Whenever this exceeds the target speed plus a small threshold the user is notified by a vibration of the watch. The user can also observe the current duration of the training and gets a feedback from the watch when the selected target duration (during the study: 15 minutes) is reached. However the training can be stopped at any time before or after the target duration has been reached by pressing the "Stop"-Button on the watch.

FR#3.8 Finish training: After completing the post-training self-assessment manikin the training is saved to the device storage. The data set includes start and finish time, both SAM-results, normal, target, and average walking speed, target duration as well all speed measurements during the training along with timestamps. The data can be transferred to a remote database by pressing the button in the statistics menu.

2.4.2 Non-functional requirements

The non-functional requirements were constantly taken into account during implementation yet some ratings may be subjective.

NFR#1 - Quality

All displayed information is *correct* in the sense of instructions and explanations. As of measured training data, false information is avoided by not saving incomplete (aborted) training objects. A mindful walking training has to be completed as a whole and cannot be paused and resumed later since this would not only corrupt data but also tear the subject from its mindful state.
Since mindful walking can be exercised anywhere anytime the application must *reliably* work under diverse conditions. Speed tracking with the pedometer is independent of any GPS-signal and also works while walking on staircases or similar. No internet connection is required, only the Bluetooth connection between watch and phone and even that is required only at the start end at the end of the training. Since the application only is a support tool and the main focus of the user should be on the mindful walking exercise, *user-friendliness* is critical. A mindful walking training can be started by simply tapping the big “Start”-Button on the home screen of the app. Navigation within the app follows a well known horizontal page-to-page concept, allowing the user to go back and forth at any time. The navigation bar at the bottom of the screen is available throughout the app to *consistently* guide the user. No personal data is collected and the users are referenced only by a random ID to avoid *security* issues. The app is *robust* since false user input is prevented by strict input constraints. Data transmission between phone and watch is assured by the background queue fallback. All data is saved locally on the

device, no internet connection is needed. The data can be transferred to an external database if a network connection is available.

NFR#2 - Performance

The app provides a quick *response time behavior* to user interactions during navigation within the app. Small delays can occur during the data transfer from the watch to the phone after the training when all measurement data is sent to the phone. Also during walking, feedback to sudden speed changes can be delayed due to the tracking mechanism with the pedometer which retroactively calculates the speed every few steps. The *computing expense* is kept low, the application doesn't perform any expensive computations. This is especially critical on AppleWatch since apps using too much CPU will be suspended by the operating system [Inc] due to the limited battery capacity of the device. *Data throughput* to external services so far only happens manually by pressing a button in the app. A network connection has to be assured beforehand, otherwise, no data will be transferred. Besides that data transfers only happen over Bluetooth between watch and phone. Since the measurement takes place on the watch, all measurement data has to be transferred to the phone at some point which may lead to a small delay depending on the duration of the training (up to 2 seconds for a 15-minute training).

NFR#3 - Error handling

Has yet to be implemented since it was not necessary for the study which was conducted under supervision.

NFR#4 - Documentation and flexibility

The development of the application followed the model-view-controller pattern for efficient code reuse. This pattern is also well supported by the Xcode IDE. While the CoreData framework handles the model layer and the views visually are created in Interface Builder, one can concentrate on writing the controllers for the single views. This way the application can easily be maintained and expanded.

The single controllers rely on each other as little as possible (coupling) while every component handles a distinguished task (cohesion). In addition to well-documented source code flexibility is guaranteed.

2.4.3 Limitations

Speed measurement using a pedometer has some limitations going along with it. First, sudden changes in speed can't be noticed instantly since the current speed has to be calculated retrospectively based on the number of steps taken in the last seconds so user notifications about speed changes are always delayed. Second, speed measurements lack precision since the step-length of the user isn't determined and also won't be constant. This could be corrected to a certain degree by providing an input field for the average step-length during mindful walking. Third, a certain minimum speed is required for the speed measurement to work properly. If the walking speed during the exercise is too slow (e.g., the subject already has a slow normal walking speed and chose a fairly high reduction) most speed measurements will return zero (which is again ignored by the app).
Further, the phone app, as well as the watch app, is required since they form a unit. One app won't work without its counterpart.

3 Study

To evaluate the usefulness of the MindfulWalk app a practical study was conducted (mostly at Ulm University) from September to October 2017.

3.1 Method

3.1.1 Participants and design

The sample consisted of 30 participants (3 female) which were recruited via Email and direct messages. Participation was voluntary and without any compensation. Most participants were graduates and postgraduates. No personal information was raised. This study used a one-group pretest-posttest design even though not only the change in mood but also the participantś behavior during the exercise was of interest.

3.1.2 Procedure

First, participants were told what mindful walking was about and how to walk mindfully. Also, a brief overview of the procedure was given. Next, the devices (iPhone and Apple Watch) were handed out with the apps running. Participants then had to complete the procedure shown in Fig. 3.1. They started the exercise themselves by tapping the "Start"-Button① on the home screen which led them to the pre-exercise 5-point Self-Assessment Manikin② [BL94] (cf. Fig. 3.2).

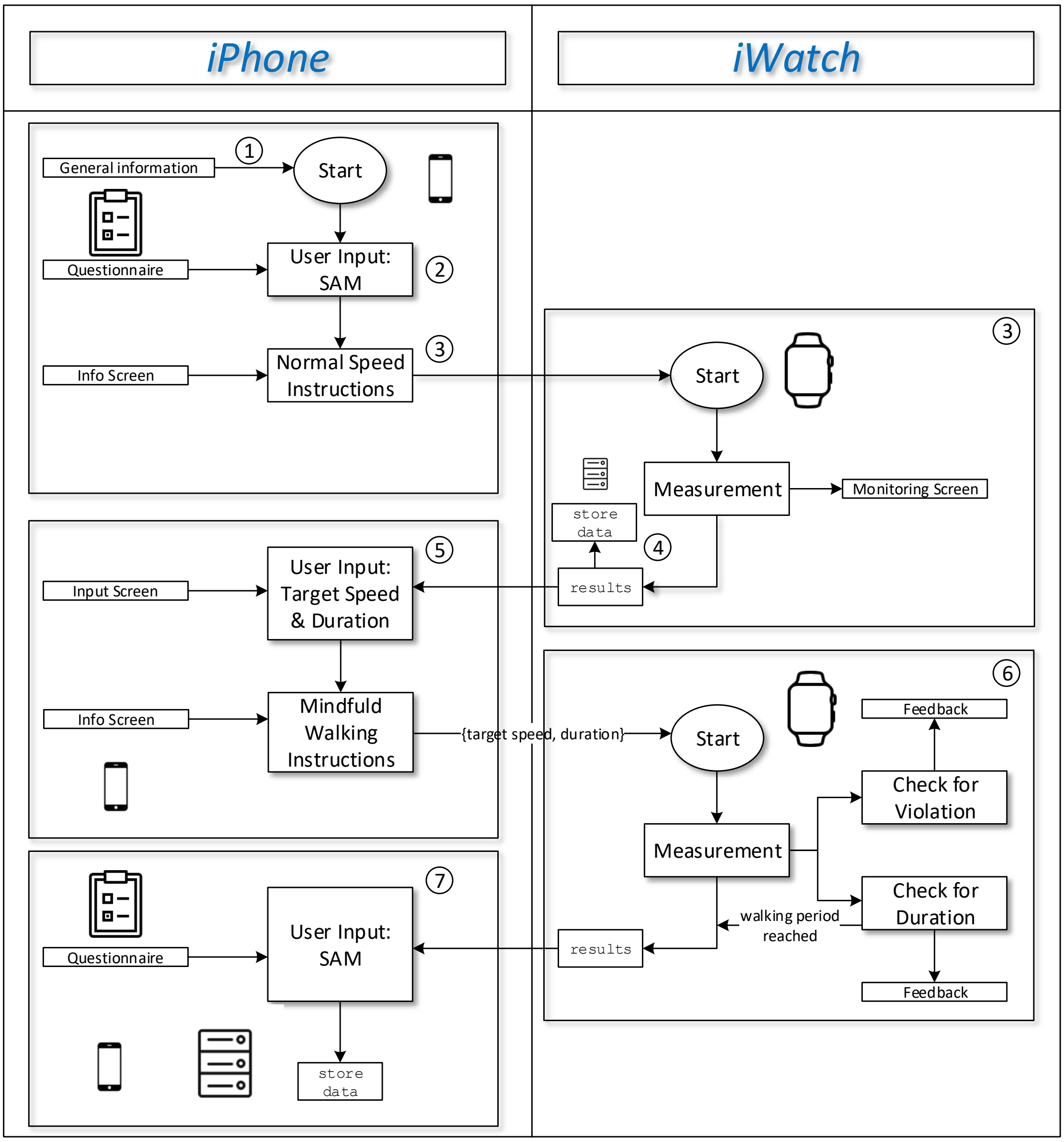

Figure 3.1: Walking Procedure

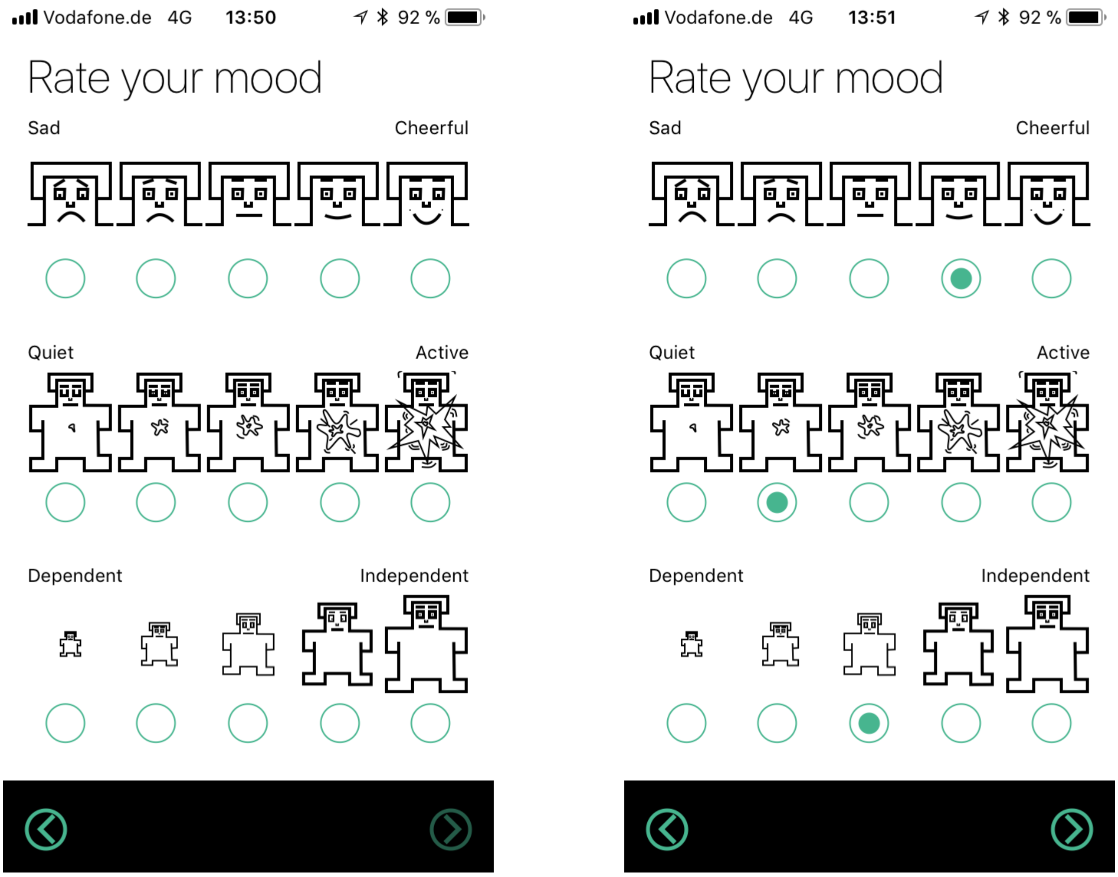

Figure 3.2: Self-assessment manikin selected and unselected

After completing the questionnaire an instruction to walk normally was displayed③ and the participants had to start the measurement with a button on the watch③ (which is enabled after the SAM has been completed) (cf. Fig. 3.3).

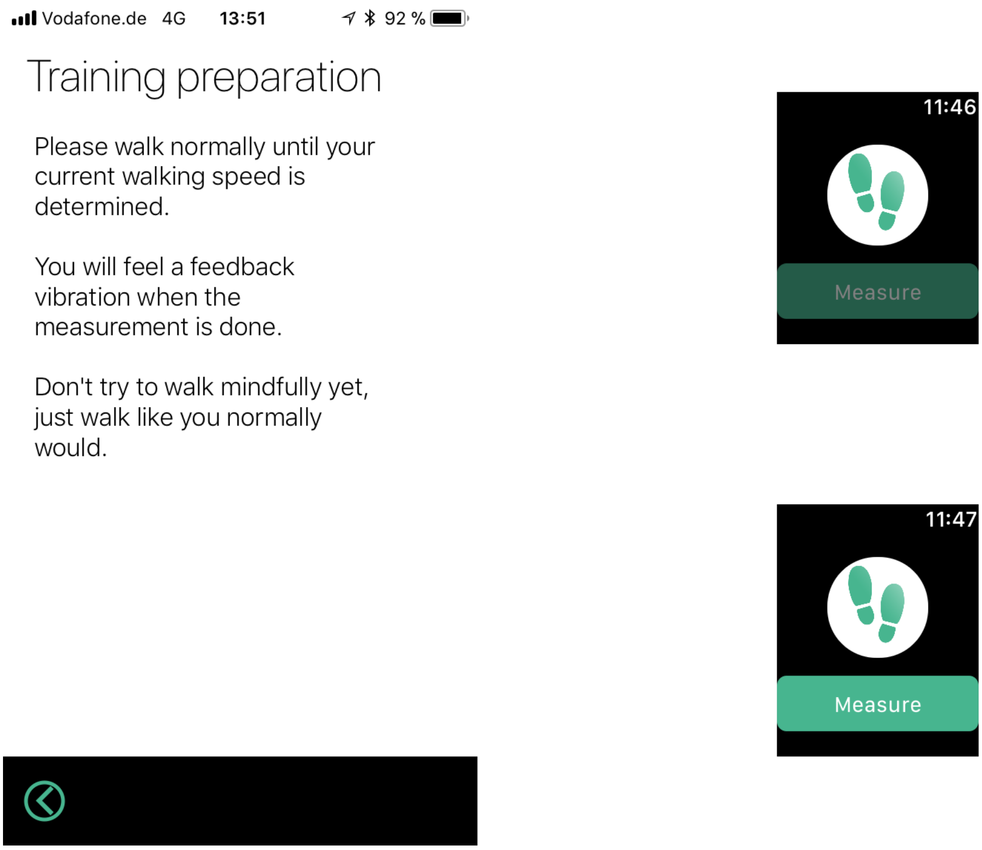

Figure 3.3: Normal walking instruction on the phone (left) and start screen on the watch with disabled (top) and enabled (bottom) button to start the measurement

The participants then walked normally for about a minute until they received feedback in form of a sound a vibration, also a message on the watch was shown to return to the phone since the phone was not carried during walking (cf. Fig. 3.4). The resulting normal walking speed was then transferred to the phone via Bluetooth④

Before the actual mindful walking exercise, the target speed and duration had to be selected⑤. This was done for the participants to avoid too slow target speeds since the speed selection depended on the normal speed and could therefore lead to very slow

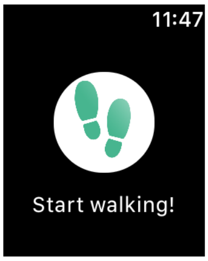

Figure 3.4: Instruction to start walking after tapping the Measure-button (left) and feedback message after the measurement (right)

target speeds if too much reduction was selected. The selected target speed ranged from 91-95% of the normal walking speed. The target duration was also selected for the participants since all subjects were asked to walk for at least 15 minutes (cf. Fig. 3.5).

Next, the participants were again instructed how to walk mindfully and not to exceed their target speed which will be indicated by a vibration of the watch. The measurement was again started by the participant on the watch who could then walk anywhere for at least 15 minutes. Most participants decided to walk outside. During the exercise, subjects could monitor their current speed and time on the watch (cf. Fig. 3.6). Whenever the current walking speed exceeded the target speed the participant received a haptic feedback on the watch⑥.

Finally, after tapping the “Stop”-Button on the watch, the participants had to complete the post-exercise self-assessment manikin⑦.

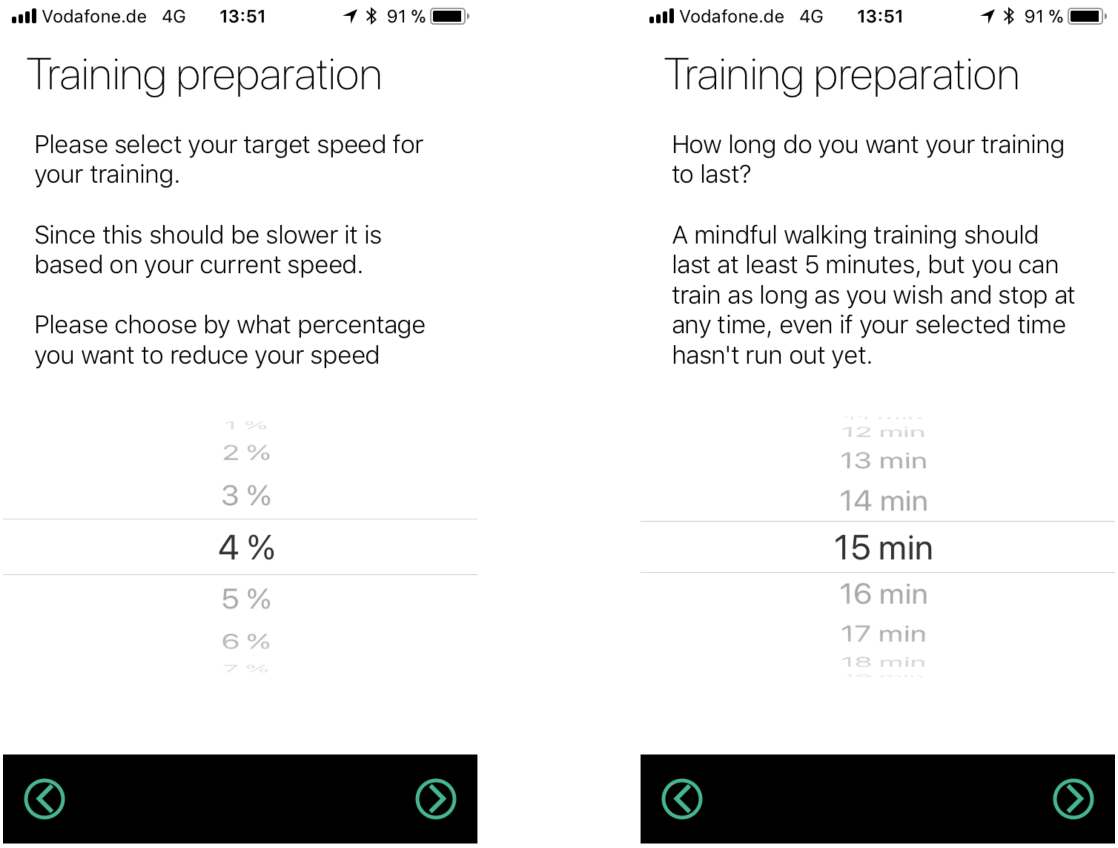

Figure 3.5: Target speed (left) and duration (right) selection

Figure 3.6: Speed and time monitor during the exercise

3.2 Results and Evaluation

In the pilot study, the mindful walking application was tested in $N = 20$ participants. The participants used the mindful walking application once; $n = 19$ participants set $15min$ as training interval and $n = 1$ participant set $10min$. The participants usual walking speed as measured by the Apple Watch application was on average $M = 3.37km/h$ $(SD = 0.35)$. The average target walking speed the participants set for the mindful walking exercise was $M = 3.16km/h$ $(SD = 0.33)$, and the average walking speed during the mindful walking exercise as measured with the Apple Watch application was $M = 3.13km/h$ $(SD = 0.28)$. A repeated measure analysis of variance (rANOVA) was conducted in *SPSS 24* to test whether the usual walking speed, the target walking speed, and the walking speed during the mindful walking exercise are significantly different. The rANOVA (Greenhouse-Geisser corrected) produced a statistically significant result indicating relevant difference between the three walking speeds (usual walking speed, target walking speed, and walking speed during the mindfulness exercise): $F(1.09; 20.67) = 29.13; p < 0.01$. Moreover, simple contrasts (with the walking speed during the mindful walking exercise as reference) were performed within the rANOVA to evaluate the hypotheses whether the usual walking speed is faster than the walking speed during the mindful walking exercise as well as whether the walking speed during the mindful walking exercise is not statistically different from the target walking speed the participants set for the mindful walking exercise. The results were in correspondence with the hypotheses: The walking speed during the mindful walking exercise was significantly slower than the usual walking speed $(F(1; 19) = 30.48; p < 0.01)$ and the walking speed during the mindful walking exercise was not significantly different from the walking speed the users set as target for the mindful walking exercise $(F(1; 19) = 0.36; p = 0.55)$.
The results of the single participants are shown in Table 3.1.

VB[1]	AB[1]	DB[1]	normalSpeed	targetSpeed	targetDuration	average	VA[2]	AA[2]	DA[2]	duration	SD[3]	speedDifference	reduction
1	1	1	3,3326	3,1327	00:15:00	3,1308	-1	-1	-1	00:15:48	0.2399	0.06%	6%
1	-1	1	3,6609	3,4413	00:15:00	3,2416	-1	1	-2	00:15:26	5.069	0.11%	6%
1	0	1	3,3972	3,1594	00:15:00	2,8710	-1	1	0	00:17:17	0.4132	0.15%	7%
1	0	1	2,8813	2,6796	00:15:00	2,8782	2	1	1	00:15:19	1.2153	0.00%	7%
2	1	1	3,1246	2,9683	00:15:00	2,8598	-1	-1	0	00:15:50	0.3560	0.08%	5%
1	2	1	3,8577	3,5105	00:15:00	3,5536	2	-1	-1	00:16:27	0.5202	0.08%	9%
0	-1	1	3,3984	3,1945	00:15:00	3,3311	-1	1	0	00:27:27	0.4630	0.02%	6%
1	-1	1	3,3849	3,0803	00:15:00	2,9131	-2	1	1	00:00:00	0.8324	0.14%	9%
0	-2	1	2,9659	2,8177	00:15:00	3,0046	-1	-2	1	00:19:00	0.3764	0.01%	5%
1	-1	0	3,5547	3,3059	00:15:00	3,3760	-2	1	2	00:15:00	0.1846	0.05%	7%
1	-2	0	3,1330	2,9450	00:15:00	3,0311	-1	1	2	00:15:45	0.3795	0.03%	6%
2	-1	0	3,1966	3,0367	00:15:00	3,0019	1	-1	-2	00:15:33	0.5744	0.06%	5%
0	1	0	3,8879	3,6546	00:15:00	3,5313	-2	1	2	00:15:01	0.6937	0.09%	6%
-1	-2	0	4,0832	3,8790	00:15:00	3,4158	-1	1	-2	00:15:27	0.3818	0.16%	5%
1	-2	0	3,0755	2,8602	00:15:00	2,7641	-1	-1	2	00:15:11	0.4409	0.10%	7%
-1	-1	0	2,7749	2,5807	00:15:00	2,5684	-1	2	1	00:16:17	0.3930	0.07%	7%
1	0	1	3,7325	3,5086	00:15:00	3,4896	-2	1	2	00:16:16	0.5000	0.07%	6%
-1	0	-1	3,1076	2,9211	00:10:00	3,2245	-1	-1	-2	00:10:09	0.9117	0.04%	6%
1	-1	0	3,5788	3,3998	00:15:00	3,4546	-2	1	2	00:16:49	0.2514	0.03%	5%
1	0	0	3,3208	3,0884	00:15:00	3,0451	-2	1	0	00:15:05	0.3229	0.08%	7%

Table 3.1: Study Results

[1] VB/AB/DB = valence/arousal/dominance before exercise
[2] VA/AA/DA = valence/arousal/dominance after exercise
[3] MSD = standart deviation of single speed measurements

4

Summary and Outlook

In this work, an application developed to support individuals in walking mindfully is presented. The application integrates a sensor to measure the walking speed in real life situations and during mindful walking exercises. Moreover, a tool is implemented to provide immediate haptic feedback on the sensed walking speed. This feedback was integrated as it might prevent individuals from walking faster than intended and from “mind wandering” during the mindfulness exercise. Haptic feedback might be more suited in daily life than visual or auditory feedback as it is not always possible to look at the smartphone screen to see visual feedback or to be in silent surroundings / to wear headphones to hear auditory feedback. A pilot study was performed which showed promising results. The data of the walking speed sensor showed that the participants usual walking speed is faster than the walking speed during the mindful walking exercise. In line with this result, [YWLH12] reported that their system to support mindful walk also slowed down the walking speed. Moreover, the sensed walking speed during the mindful walking exercise was not different from the walking speed the participants set as target speed for the mindful exercise. The result that the participants could achieve their intended “slow speed” might suggest that the haptic feedback function could be applied successfully.

Yet, more evaluations are necessary and future experiments should include a control condition. The latter without the haptic feedback function of the application, in turn, would allow for more causal conclusions on whether the haptic feedback function of the application is indeed helpful to walk mindfully as slowly as intended and to stay mindfully during the exercise. It could also be possible that the feedback distracts the participants from being mindful. Moreover, feedback of any kind could create a judgmental stance towards the walking, which is against the mindfulness principles. An option in the application to turn the feedback on and off would not only be useful for a follow-up study with a control condition but also give end-users the possibility to walk mindfully without any distractions and only use the app as a silent tracking tool, if they chose to do so. Also the stored data should also be synced with a cloud-based database on regular basis to ensure backups. Further studies using psychometric questionnaires (e.g., *Five Facet Mindfulness Questionnaire*) are needed to explore how the feedback function affects different aspects of mindfulness (e.g., nonjudging of inner experience or nonreactivity to inner experience). Note that only a small sample was investigated limiting generalizability of the results.

Larger trials could investigate whether using the mindful walking application can improve mindfulness or also well-being in general. Additionally, further studies are needed to investigate the health-related effects as well as the acceptance of the mindful walking application in occupational settings (e.g., occupational health management). Further comparisons between a condition using the mindful walking application and a condition exercising mindful walking traditionally (e.g., guided by an expert, instructions delivered by audio, or video) would reveal if the haptic feedback (and the mindful walking application in general) are beneficial for walking mindfully. In summary, the newly developed mindful walking application has been successfully applied to sense the walking speed and to provide immediate feedback on the current walking speed. The results of the pilot study are promising and the mindful walking application offers several opportunities for digital health prevention.

List of Figures

List of Tables

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Erklärung

Ich erkläre, dass ich die Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

Ulm, den ....

Julian Frank