A Personalized Sensor Support Tool for the Training of Mindful Walking*

Rüdiger Pryss[1], Manfred Reichert[1], Dennis John[2], Julian Frank[1], Winfried Schlee[3] and Thomas Probst[4]

***Abstract*— The exploitation of sensor features offered by present smart mobile devices is a trend that becomes increasingly important in various domains. In healthcare, for example, these sensors are used to cheaply gather valuable data for chronic disease management or health care. Regarding the latter, health insurers crave for effective methods that can be offered to their customers. Moreover, smart mobile devices provide many advantages compared to approaches hitherto applied in the aforementioned contexts as they can be easily used in everyday life. Thereby, when taking these advantages properly into account, new mobile application types become possible. Body sensor networks are such an application type that aim at monitoring users in vivo. Furthermore, data gathered with body sensor networks may be a valuable basis to provide user interventions. This paper presents an application that shall support users to walk mindfully. The motivation was to create a mobile tool that can make mindful walking more effective to reduce stress and to target noncommunicable diseases such as diabetes or depression. It is a mobile personalized tool that senses the walking speed and provides haptic feedback thereof. The mindful walking procedure, the technical prototype as well as preliminary study results are presented and discussed in this work. The reported user feedback and the study results indicate promising perspectives for a tool that supports a mindful walking behavior. Altogether, the use of smart mobile device sensors constitutes a promising instrument for realizing mobile applications in the context of health care and disease management.**

***Index Terms*— mHealth, body sensor network, mindful walking, digital health care**

I. INTRODUCTION

Mindfulness has been defined as the intentional and non-judgmental attention to experiences of the present moment [1]. Mindfulness is rooted in eastern meditation traditions and has become highly relevant in basic research [2] as well as in health [3] and clinical science [4]. Many mindfulness exercises applied, for example, in Mindfulness-based Stress Reduction (MBSR) [1] or Mindfulness-based Cognitive Therapy (MBCT) [5] instruct participants to intentionally and non-judgmentally attend to automated body-related processes (e.g., breathing, walking). One of these body-related mindfulness exercises is walking mindfully [6]. The participants are instructed to become conscious of the otherwise automated walking process by walking slowly, taking small steps and by fully focusing on walking. Mindful walking has, for example, been shown to be beneficial for patients with depression [7] as well as for patients with diabetes [8]. During mindful exercises, however, participants often experience that their mind is distracted from being mindful and that they have difficulties to redirect their focus on the mindful exercise, especially patients suffering from depression [9]. Moreover, novices are often insecure how to practice mindfulness. Mobile applications may help users to practice mindfulness as well as to stay mindful and to refocus the attention during mindful exercises. In this paper, a mobile application is presented that supports users to walk mindfully by sensing the individual walking speed and by providing continuous haptic feedback on the individual walking speed during the mindful walking exercise. In general, feedback has been shown to improve performance in various domains [10]. In the context of mindfulness, text message feedback [11] as well as feedback on EEG data to deepen mindfulness was evaluated previously [12]. To support a mindful walking, [13] performed a study and compared visual, auditory, and visual-auditory feedback on the walking. In the current work, the realized prototype consists of mobile applications developed for the Apple iPhone and for the Apple iWatch. The two applications are tightly coupled via Bluetooth and represent the basis for the mindful walking. On the iWatch, a haptic feedback feature was implemented. As other works show [14], [15], such a feature may increase the user experience properly. When concerning the two main goals pursued by body sensor networks, the realized prototype contributes with this features as follows:

> (1) Enable the user to measure his or her usual walking speed *in vivo*. The measurement, in turn, is enhanced by a familiarization phase. (2) Provide haptic feedback (i.e., an *intervention*) to the user if his or her walking speed level exceeds the mindful one, which will be defined by the user during the familiarization phase.

The main motivation behind this work was to develop a mobile application to support individuals in mindful walking - especially those practicing mindfulness is challenging for like novices or patients with depression [9] - with the final aim to increase its benefits for example for stress reduction and the management of noncommunicable diseases [7], [8]. The way how the technical prototype was realized and how the first study with this prototype was conducted will be presented in this paper. Our pilot study investigates 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

*This work was not supported by any organization

[1]Faculty of Computer Science, Engineering and Psychology, Ulm University, Germany
{ruediger.pryss,manfred.reichert,julian.frank}@uni-ulm.de
[2]FOM University of Applied Sciences, Germany dennis.john@fom.de
[3]University Hospital Regensburg, Germany winfried.schlee@ieee.org
[4]Donau Univ. Krems, Austria Thomas.Probst@donau-uni.ac.at

exercise is not statistically different from the target walking speed the participants set for the mindful walking exercise. The obtained results of the pilot study support the hypotheses and indicate that a mobile application for a mindful walking may constitute a proper health care support tool in everyday life. The remainder of this paper is organized as follows. In Section II, the used procedure for the mindful walking is presented, while Section III discusses the technical prototype. Section IV, in turn, discusses study results and Section V the related work, which is relevant in the context of this paper. Finally, Section VI concludes the paper with a summary and an outlook.

II. Mindful Walking Procedure

To support users in exercising mindful walking via the application, the procedure shown in Fig. 1 must be accomplished.

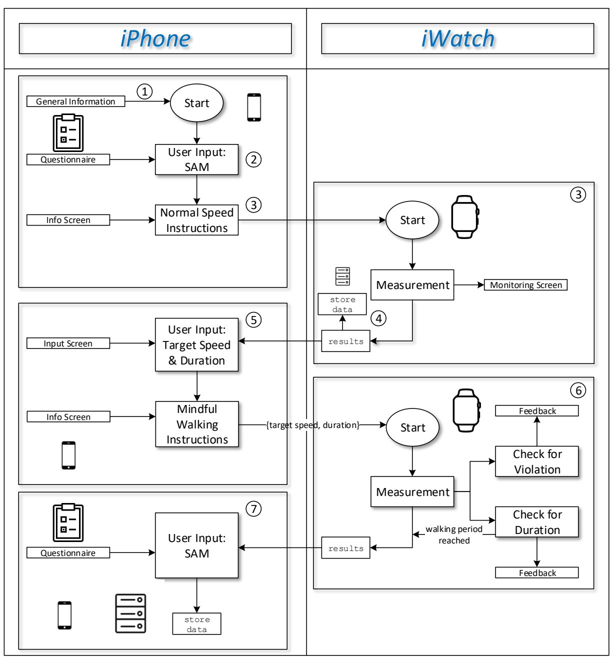

Fig. 1: Mindful Walking Procedure

More specifically, the procedure comprises the following steps in the presented order:

First, a general information on the mindful walking will be displayed on the iPhone application (cf. Fig. 1, ①).

Second, the user rates his or her current valence, arousal, and dominance by the so-called Self-Assessment Manikin (SAM) [16] (cf. Fig. 1, ②).

Third, the usual walking speed of an user will be determined. For this, the user will be instructed by the iPhone application to walk in his or her usual speed for 5 minutes: "Now walk normally for 5 minutes for the measurement of your current walking speed. You will hear a sound as soon as the measurement is complete" (cf. Fig. 1, ③). Then, the user switches to the iWatch application for the 5 minutes measurement.

Fourth, after the 5 minutes, the user receives a feedback on his or her walking speed on the iWatch application (e.g., "Your walking speed is 3.73 km/h"; (cf. Fig. 1, ④)). Then he or she can choose from the following four pre-defined options to set the "target" walking speed for each body walking exercise (e.g., walking speed is 4.0 km/h and users selects 75% reduction (i.e., "target" speed = 1.0 km/h))[1]:

- 10% reduction of the walking speed.
- 25% reduction of the walking speed.
- 50% reduction of the walking speed.
- 75% reduction of the walking speed.

Fifth, again after the 5 minutes, the assessed data (user_id, date, time, SAM, walking speed) are transferred to a database (cf. Fig. 1, ④).

Sixth, in the next step, the participant receives a general instruction on mindful walking (cf. Fig. 1, ⑤). "You are to begin a mindful walking exercise: When walking mindfully, please try to notice at least these four basic components of your steps":

- The lifting of one foot.
- The moving of the foot a bit forward of where you are standing.
- The placing of the foot on the floor, heel first.
- The shifting of the weight of the body onto the forward leg as the back heel lifts, while the toes of that foot remain touching the floor or the ground.

At the end of this step, the user gets the information: "You will get haptic feedback (i.e., a vibration) each time your speed level is higher than the speed level you set as the goal for this exercise. In case you feel the vibration, please try to walk slower. You can stop the exercise at any time, but you should try to walk mindfully for at least 15 minutes. You will hear a sound after each 5 minutes are passed, but you can continue the exercise as long as you want".

Seventh, the mindful walking exercise must be accomplished, feedback on the exercise is provided and questionnaires (e.g., SAM) are administered after each exercise (cf. Fig. 1, ⑥&⑦).

The prototype also includes a feature that enables users to set an individual schedule at which days and times in daily life they want to receive a notification by the application as a reminder to train mindful walking. However, the use of the application is also possible whenever they want to practice mindful walking regardless of the notifications.

III. Technical Prototype

A mobile application was implemented for the Apple iPhone (iOS 11 beta), including the option to run the application also on the Apple iPad. In addition, a mobile application for the Apple iWatch (watchOS 3.2.3) was implemented. The two applications are coupled via Bluetooth. Note that both on the iPhone and the iWatch, a user gets an alert if the coupling was not accomplished. Data, which is produced on the iWatch, is locally stored there and then transferred to the iPhone.[2] Only after a successful transfer is accomplished,

[1] A future version of the application will also include an open entry for the user to set his individual target walking speed for each exercise (prerequisite: target walking speed<usual walking speed).

[2] Note that we are also working on an iWatch version that directly transfers data from the iWatch to a remote database.

the data is erased on the iWatch. All data on the iPhone, in turn, is transferred to a relational database via REST calls. In the following, selected impressions of the two applications are presented. In Fig. 2, two iPhone screens corresponding to the phases ⑤&⑦ (cf. Fig. 1) are shown. Fig. 3, in turn, illustrates two iWatch screens that correspond to the phases ③&⑥ (cf. Fig. 1) of the mindful walking procedure.

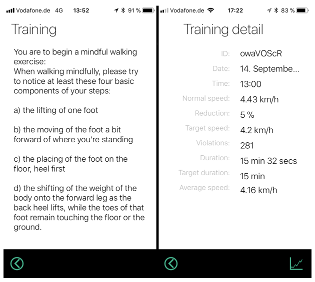

Fig. 2: iPhone Screens: Training Details

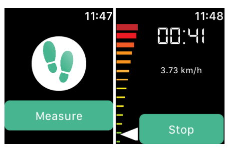

Fig. 3: iWatch Screens: Measurement & Monitoring

IV. Pilot Study Results

In a pilot study, the mindful walking applications were tested in $N = 20$ participants. The participants used the mindful walking applications once; $n = 19$ participants set $15min$ as training interval and $n = 1$ participant set $10min$. The participants usual walking speed as measured by the iWatch application was on average $M = 3.37\ km/h$ ($SD = 0.35$). The average target walking speed the participants set for the mindful walking exercise was $M = 3.16\ km/h$ ($SD = 0.33$), and the average walking speed during the mindful walking exercise as measured with the iWatch application was $M = 3.13\ km/h$ ($SD = 0.28$). A repeated measurement 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 differences 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 ($F(1; 19) = 0.36; p = 0.55$). Finally, we used a paper-based questionnaire to evaluate the overall user experience of the mobile applications. Thereby, the users mainly reported very positive feedback.

V. Related Work

In general, other emerging paradigms exploiting smart mobile device capabilities have already shown that daily life behavior can be properly captured in the context of health care [15], [17]. Concerning the use of smart mobile devices in the context of mindfulness, recent related works have been presented [18], [19]. Despite the advantages of smart mobile devices, their drawbacks must also be carefully considered [20], [21]. Mobile applications that directly cope with a mindful walking have also been introduced. In [22], for example, the authors propose a mobile application using the individual walking speed (accelerometer) as well as the individual breath (microphone) to provide real-time ambient sound at certain frequencies to the user. [13], in turn, described a system for smartphones, which assesses walking in real time and provides immediate visual-auditory feedback to support a mindful walking. However, contrary to our study, no haptic feedback, but visual-auditory feedback was applied and users needed a pair of sensing shoes (to provide feedback on the walking pattern as well). Yet, wearing sensing shoes, looking at the smartphone screen for visual feedback, or hearing auditory feedback (silent surrounding or headphones required) might not always be possible in daily life. Other mobile applications intended to generally foster mindfulness have also been studied, e.g., [23], [24]. In general, the exploitation of smart mobile device sensor features for disease and health care management becomes increasingly important. In the context of tinnitus, for example, sensors in combination with serious games are used to measure the hearing ability of patients [25]. However, such methods have been less considered in the context of a mindful walking. Altogether, neither existing approaches propose a mobile application like presented here for a mindful walking nor do they present the technical procedure in more detail.

VI. Summary and Outlook

This paper presented an application that was developed to support individuals in walking mindfully. The application integrates sensors to measure the walking speed in daily life situations and during mindful walking exercises. Moreover, a feature was implemented to provide immediate haptic feedback on the sensed walking speed. The feedback feature, in turn, was realized as it might prevent individuals from walking faster than intended and from “mind wandering” during the mindfulness exercise. Note that haptic feedback might be more suited in daily life than visual or auditory feedback as it is not always possible to look at the mobile device screen to see visual feedback or to be in silent surroundings / to wear headphones to hear auditory feedback. A pilot study was performed, which revealed 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, [13] reported that their system to support mindful walking 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 feature can be applied successfully. Yet, more evaluations are necessary and future experiments should include a control condition. Without the haptic feedback feature so that more causal conclusions might be possible on whether the haptic feedback feature 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. We plan further studies using psychometric questionnaires (e.g., *Five Facet Mindfulness Questionnaire*) to explore how the feedback feature affects different aspects of mindfulness (e.g., nonjudging of inner experience or nonreactivity to inner experience). Note that only a small sample was investigated and, hence, the generalizability of the results is limited. Larger trials are planned to investigate not only the impact on different facets of mindfulness, but also whether the SAM ratings given before the exercise have an impact on the mindful exercise, and whether the SAM ratings, state body mindfulness [26] and well-being [27] change due to exercising mindful walking with the application. Studies to compare a condition using the mindful walking application, a condition exercising mindful walking traditionally (e.g., guided by an expert, instructions delivered by audio, or video), and a waiting list control condition will be performed. Additionally, further studies are planned in occupational settings (e.g., occupational health management). Finally, we currently evaluate the measured walking speed on more sensors like the Garmin 920XT. 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 presented pilot study results are promising and the mindful walking application offers several opportunities for digital health care.

References

[1] J. Kabat-Zinn, "Full Catastrophe Living: The Program of the Stress Reduction Clinic at the University of Massachusetts Medical Center," 1990.

[2] Y. Tang *et al.*, "The Neuroscience of Mindfulness Meditation," *Nature Reviews Neuroscience*, vol. 16, no. 4, pp. 213–225, 2015.

[3] B. Khoury *et al.*, "Mindfulness-based stress reduction for healthy individuals: A meta-analysis," *Journal of Psychosomatic Research*, vol. 78, no. 6, pp. 519–528, 2015.

[4] ——, "Mindfulness-Based Therapy: A Comprehensive Meta-Analysis," *Clinical Psychology Review*, vol. 33, no. 6, pp. 763–771, 2013.

[5] D. Morgan, "Mindfulness-Based Cognitive Therapy for Depression: A New Approach to Preventing Relapse," 2003.

[6] T. Hanh, *The Long Road Turns to Joy: A Guide to Walking Meditation*. Parallax Press, 2011.

[7] S. Prakhinkit *et al.*, "Effects of Buddhism Walking Meditation on Depression, Functional Fitness, and Endothelium-Dependent Vasodilation in Depressed Elderly," *The Journal of Alternative and Complementary Medicine*, vol. 20, no. 5, pp. 411–416, 2014.

[8] A. Gainey *et al.*, "Effects of Buddhist Walking Meditation on Glycemic Control and Vascular Function in Patients with Type 2 Diabetes," *Complementary Therapies in Medicine*, vol. 26, pp. 92–97, 2016.

[9] K. Rohde *et al.*, "Mindful Attention Regulation and Non-Judgmental Orientation in Depression: A Multi-Method Approach," *Biological Psychology*, vol. 101, pp. 36–43, 2014.

[10] A. Kluger and A. DeNisi, "The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory." 1996.

[11] S. Kraft *et al.*, "Text message feedback to support mindfulness practice in people with depressive symptoms: A pilot randomized controlled trial," *JMIR mHealth and uHealth*, vol. 5, no. 5, 2017.

[12] C. Sas and R. Chopra, "Meditaid: A wearable adaptive neurofeedback-based system for training mindfulness state," *Personal and Ubiquitous Computing*, vol. 19, no. 7, pp. 1169–1182, 2015.

[13] M. Yu *et al.*, "Multimedia-Assisted Breathwalk-Aware System," *IEEE Transactions on Biomedical Engineering*, vol. 59, no. 12, pp. 3276–3282, 2012.

[14] J. Kangas *et al.*, "Gaze gestures and haptic feedback in mobile devices," in *Proc of the SIGCHI Conf on Human Factors in Computing Systems*. ACM, 2014, pp. 435–438.

[15] O. Dehzangi *et al.*, "The impact of vibrotactile biofeedback on the excessive walking sway and the postural control in elderly," in *Proc of the 4th Conf on Wireless Health*. ACM, 2013, p. 3.

[16] M. Bradley and P. Lang, "Measuring Emotion: The Self-Assessment Manikin and the Semantic Differential," *Journal of Behavior Therapy and Experimental Psychiatry*, vol. 25, no. 1, pp. 49–59, 1994.

[17] T. Probst *et al.*, "Emotional States as Mediators between Tinnitus Loudness and Tinnitus Distress in Daily Life: Results from the "TrackYourTinnitus" application," *Scientific Reports*, vol. 6, 2016.

[18] J. Sliwinski *et al.*, "A Review of Interactive Technologies as Support Tools for the Cultivation of Mindfulness," *Mindfulness*, pp. 1–10, 2017.

[19] I. Plaza *et al.*, "Mindfulness-based mobile applications: Literature review and analysis of current features," *JMIR mHealth and uHealth*, vol. 1, no. 2, 2013.

[20] S. Kumar, "Mobile Phone and Adolescents-Addiction a Mindful Check in!" *International Journal of Advanced Nursing Studies*, vol. 3, no. 1, pp. 42–46, 2014.

[21] G. Goggin, *Cell Phone Culture: Mobile Technology in Everyday Life*. Routledge, 2012.

[22] S. Chen *et al.*, "'Ambient Walk': A Mobile Application for Mindful Walking with Sonification of Biophysical Data," in *British HCI Conference Proc*. ACM, 2015, pp. 315–315.

[23] C. Carissoli *et al.*, "Does a Meditation Protocol Supported by a Mobile Application Help People Reduce Stress? Suggestions from a Controlled Pragmatic Trial," *Cyberpsychology, Behavior, and Social Networking*, vol. 18, no. 1, pp. 46–53, 2015.

[24] I. García *et al.*, "Development and Initial Evaluation of A Mobile Application to Help With Mindfulness Training and Practice," *Int'l Journal of Medical Informatics*, 2017.

[25] M. Schickler *et al.*, "Using Mobile Serious Games in the Context of Chronic Disorders - A Mobile Game Concept for the Treatment of Tinnitus," in *29th IEEE Int'l Symp on Computer-Based Medical Systems*, 2016, pp. 343–348.

[26] G. Tanay and A. Bernstein, "State Mindfulness Scale (SMS): development and initial validation." *Psychological Assessment*, vol. 25, no. 4, p. 1286, 2013.

[27] C. Topp *et al.*, "The WHO-5 Well-Being Index: a systematic review of the literature," *Psychotherapy and Psychosomatics*, vol. 84, no. 3, pp. 167–176, 2015.