Supporting Activity Pacing with Continuous Feedback using Smartwatches

Students
Silvan Kübler (silvan.kuebler@uzh.ch)
Michael Wagner (michael.wagner2@uzh.ch)
Samuel Eiben (samuelchristian.eiben@uzh.ch)

Supervisors
Dr. André Meyer: Main Supervisor
Prof. Dr. Thomas Fritz: Supervisor
Dr. med. Carlo Cervia: Co-Supervisor
Isabelle Cuber: Co-Supervisor

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Abstract

Activity pacing is used to control fatigue and exhaustion as well as a worsening of various other symptoms set off by physical activity. Among others, long term symptoms after COVID-19 infections can be a cause for the need of activity pacing. One approach to perform activity pacing is to manually try to restrict physical activity, which can be cumbersome as patients have to remember to take measurements themselves because with this approach they do not get notified about increased measurements, e.g. when their heart rate spikes. Some patients are using smartwatches to manually keep track of some of their body factors, such as their heart rate. However, these smartwatches are built to activate and push people to be more active, contrary to what patients suffering from long COVID should do. We introduce MindfulPacer, an application for smartwatches and smartphones intended to support the process of activity pacing. MindfulPacer allows to create alarms which are triggered under predefined circumstances. Being tailored towards activity pacing, MindfulPacer further allows to analyse recorded data and events in hindsight. After initially collecting a set of useful features for MindfulPacer and implementing the application, a qualitative field test was conducted to learn about its everyday applicability in the real world. While we have identified some limitations of the used smartwatches, initial results were promising and users generally appreciated using smartwatches with the alarm-based approach for activity pacing. We conclude by suggesting further steps to continue developing MindfulPacer such as to improve battery consumption or extend MindfulPacer to a wider range of models and operating systems.

1 Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has led to about 760 million infections as of June 2023 [49]. Upon infection, patients can develop coronavirus disease 2019 (COVID-19) ranging from asymptomatic disease to severe disease leading to hospitalization and, in some patients, death [44]. About 5-20% (depending on the source) of COVID-19 patients experience long-term symptoms [33,36]. This condition is commonly referred to as long COVID and is increasingly recognized as an emerging burden for both patients and the healthcare system. Among others, symptoms include fatigue, shortness of breath, cognitive impairment, and Post Excertional Malaise (PEM) [4,7]. Although long COVID manifests as heterogenous disease, it shows many similarities to myalgic encephalomyelitis/chronic fatigue syndrome (ME/CFS), a condition affecting under 1% of the total population [7,15,35]. Nevertheless, both patient subsets have in common that they can suffer from debilitating fatigue, PEM, and exhaustion, triggered by physical activity [5]. Further, a recent study showed that the immune system of female ME/CFS patients struggled to recover from physical activity when compared to a healthy group [30,47].

A common strategy applied by patients to avoid so called "crashes" is activity pacing [22]. Activity pacing is a common form of energy management, which allows individuals to limit (i.e. "pace") their activity (e.g. heart rate, number of steps, etc.) to a specific level or predefined goal, and avoid exhaustion. Activity monitoring during physical activities (sports, work, household) provides biofeedback that promotes symptom awareness and control, and helps to avoid exertion and overtaxing one's body [2]. Thus, pacing can be useful for various scenarios, e.g. in pain management, for sports training, and also people suffering from long COVID or ME/CFS. Our approach to track those activities will be using activity trackers, more specifically smartwatches, which provide a multitude of sensors for physical data.

While many patients perform manual pacing without any aids, some have started using activity trackers, such as the Fitbit wristwatches that can be easily worn and provide reliable (but not medical grade) measurements, such as heart rate and number of steps [26]. However, smartwatches generally tend to motivate users to be more active, which is the opposite of what long COVID patients are trying to accomplish [42,43].

In this project, a smartwatch application paired with a companion application for smartphones (the MindfulPacer application) was created to support the currently rather manual activity pacing approach. MindfulPacer allows users to create activity alarms as well as to log events and gain additional insights into their physical activity. Compared to other solutions, MindfulPacer is tailored towards activity pacing by offering support for being less active. It further acknowledges that each user has slightly different requirements by incorporating a suite of alarm settings for individual adjustments.

MindfulPacer aims at helping to answer the following research questions:

[RQ1] How can today's commercially available smartwatches be used for activity pacing? (technical feasibility)

[RQ2] How do users use the activity pacing smartwatch and companion app to (a) identify individual exertion thresholds, (b) receive alarms, and (c) log events to learn more about causes of crashes? (qualitative feasibility)

[RQ3] Can users who have tested our activity pacing smartwatch and companion app over a few weeks imagine using it over extended durations for their activity pacing, and which improvements are necessary for a successful long-term use? (applicability, long-term use)

To answer these research questions, a prototype of an activity pacing app was developed for Android smartwatches and smartphones, and evaluated using a field test.

2 Related Work

There already exist several applications and research around activity pacing. This section discusses some of them and displays the differences to MindfulPacer.

2.1 Activity Trackers used to Motivate Activity

One use-case of activity trackers is to motivate being fit or increasing physical activity. For example by showing achievements or comparing recorded activities with data uploaded by others [10].

A specific area where activity trackers are used to be more active is with diabetes patients. One small-scale study explored how useful Fitbit smartwatches are to motivate patients for being more active (in contrast to activity pacing) [25]. Another diabetes related application for Fitbits is called Sentinel and is intended for parents to monitor diabetic children [6]. While the use-case is rather different to MindfulPacer, the feature set is somewhat overlapping, as Sentinel also allows to set upper thresholds and the possibility to show graphs and use alarms.

Another example of activity trackers motivating activity can be found with Garmin and Samsung smartwatches. Both manufacturers offer alerts based on minimum/maximum thresholds of heart rate. However, this feature is sub-optimal for activity pacing as the thresholds are tailored towards exercising (for example, some models require the user to stay above a chosen threshold for at least 10 minutes before the heart rate is registered) [12,41]. Further, some models try to motivate users to be more active, which is the opposite of activity pacing [13,43].

2.2 Long COVID and ME/CFS

In the domain of long COVID and ME/CFS, activity pacing has been successfully applied to help dealing with low energy levels [15]. It has been shown that it can be difficult for long COVID patients to return to pre-COVID personal activity levels [50]. However, pacing activities in a structured way can help to reduce certain post-COVID symptom episodes [37].

2.3 Existing Solutions for Activity Pacing

This section provides an overview of some existing solutions which apply activity pacing in different areas. Similarly to the examples discussed in section 2.1, some of the solutions shown in table 1 also make use of smartwatches. However, in contrast to the solutions from section 2.1, most of them do not promote activity but instead try to support pacing physical activity, showing some similarities with our intended approach. Each entry lists some characteristics, which are compared to MindfulPacer in the following paragraph.

Comparison to MindfulPacer Compared to our intended goal, the solutions from Visible Health Inc as well as the Sentinel application (as mentioned in section 2.1) and the Pulsalarm App showed the most similarities among the solutions we could identify. Namely, those solutions also made use of a smartphone combined with a wearable device. While Sentinel and Pulsalarm do not focus on activity pacing, Visible Health Inc has a similar goal to MindfulPacer.

However, MindfulPacer offers additional functionality, such as to automatically or manually create events for later analysis or a range of settings to enhance customizability of alarms. We were unable to identify another solution that offers this kind of flexibility when defining alarms for activity pacing. Further, MindfulPacer offers to track the step count additionally to heart rate measurements and allows to analyse both using a built-in analytics page.

Name	Devices	Characteristics
Pain ROADMAP [28]	Smartphone, Wearable (accelerometer), Web	Tracking activities with manual entries to manage chronic pain (rather than long COVID).
Visible Health Inc [29, 34]	Smartphone (IOS, Android), Wearable (armband)	Measuring heart rate and postural data with smartphones and armbands to support ME/CFS and long COVID patients [45].
Pulsalarm [40]	Smartphone (IOS, manage settings), Smartwatch (Watch OS, show measurements)	Setting heart rate thresholds to support active people (contrary to focusing on activity pacing).
HRPacing (Fitbit) [1] *Pacing (Apple Watch)* [38]	Smartwatch	Support activity pacing by using simple thresholds.
ME/CFS Pacing App [8]	Smartphone (IOS, Android)	Allowing to manually enter daily activities to help identify where too much energy was spent.
Track and Pace activity diary [27]	Smartphone (Android)	Allowing to manually track daily activities for an overview over the personal health.
Manually checking heart rate and step readings [26]	Smartwatch (Fitbit)	Manually reading heart rate and step measurements and writing field notes as a reflection.

Table 1: Existing solutions for smartphones / smartwatches

3 Approach

To get an understanding for the scope of the approach, activity pacing literature was complemented by expert interviews (conducted prior to this project) as well as feedback from a long COVID researcher (Dr. med. Carlo Cervia).

This revealed the following aspects to be important in order to support patients with activity pacing:

- Patients should automatically receive alarms when they are too active.
- It needs to be possible for users to create and tailor alarms towards their personal situation. For example, statistics can show which alarms were shown at the right point in time and help users to define better alarms.
- The solution should allow users to amend collected data and complement it with additional information, such as performed activities or energy levels.

The following section further describes our solution to support these goals.

4 Implementation

To implement the approach, we created a prototype ("MindfulPacer") consisting of a smartphone application used to configure alarms and analyse data as well as a smartwatch application to display current measurements and trigger alarms.

Since the implementation started at an early point, we have used an iterative, user-feedback-driven process where feedback from testers could be included and the features could be continuously improved in regard to user experiences and the approach.

The following goes further into detail on how MindfulPacer can be used as well as some design decisions which were made, before moving on to further describe various findings in section 5.

4.1 Workflow

Generally, MindfulPacer is intended to be run on a smartwatch throughout the day. A smartphone can be used to help set up the smartwatch and later modify and analyse collected data. Figure 1 gives additional insights on how a possible workflow can look like, with specifics described below. Further, figures 2 and 3 show MindfulPacer on the smartwatch and smartphone at various steps in the workflow.

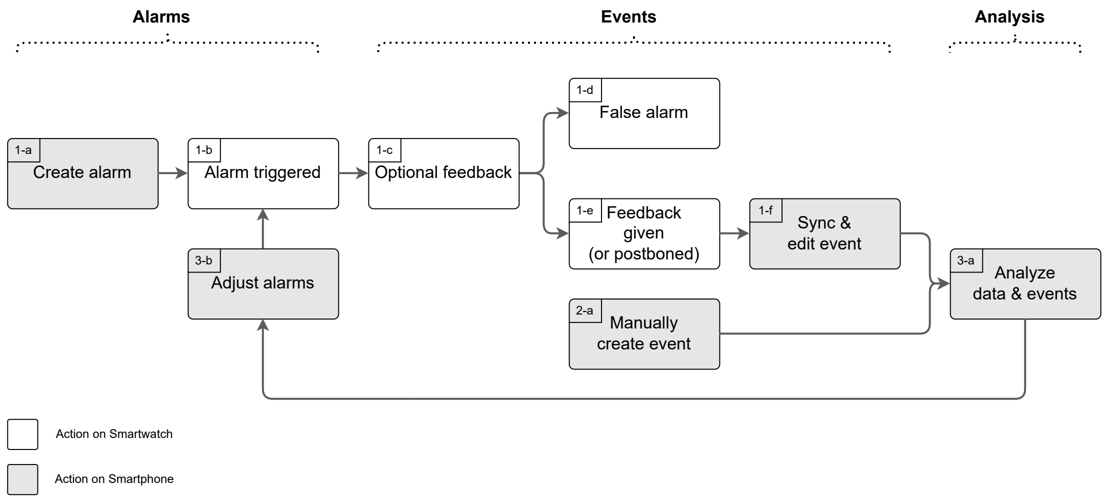


Figure 1: Workflow when using MindfulPacer

Using MindfulPacer on the smartphone, users can create heart rate as well as step alarms. Different alarm settings can be specified before saving the alarm, where MindfulPacer will attempt to automatically sync it to the smartwatch (a manual sync option is provided as well) (1-a).

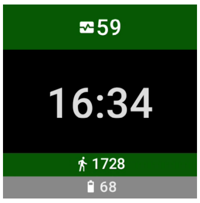
Once the alarm conditions are met, the smartwatch will notify the user according to their preferences (e.g. using vibrations, sound or a flashing display) until the alarm is dismissed (1-b).

When dismissing an alarm on the smartwatch, the user has the option to give feedback by specifying an activity that caused the alarm. At this point, the user is informed that an event will be created on the smartwatch (unless the user classifies this alarm as a false positive) (1-c,1-d,1-e).

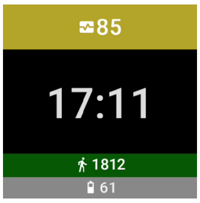
If the user wants to specify additional details on the event at a later point, this can be done on the smartphone application. When opening MindfulPacer on the smartphone, events and recorded data will be updated automatically if possible and optionally further events can be created (1-f,2-a).

MindfulPacer further offers an analytics page on the smartphone. Here, users can look at measured data and created events, with the intention of helping to identify relations between data and events. This is achieved by including event icons and measured data in the same chart (3-a).

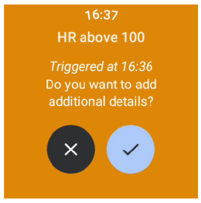
While MindfulPacer includes recommendations and explanations for the different values on the smartphone, there are no definite values and each user thus has to adjust their alarms according to their personal liking (3-b).



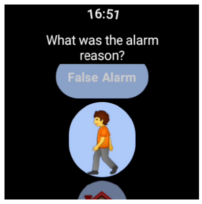
(1-b) Main screen



(1-b) Light alarm

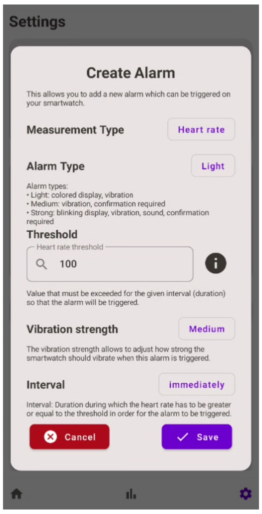


(1-b) Medium alarm

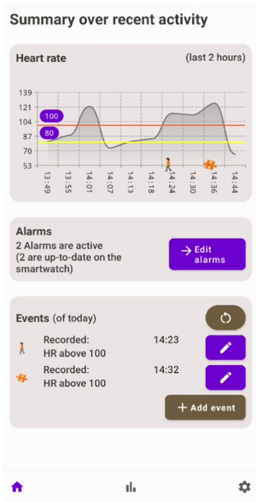


(1-c,1-d,1-e) Feedback

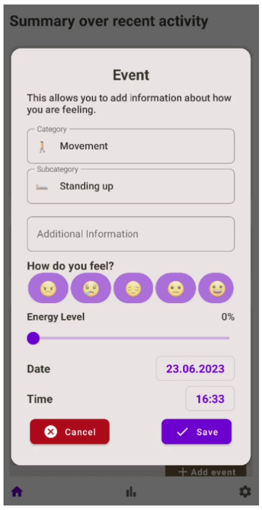
Figure 2: MindfulPacer smartwatch application screenshots



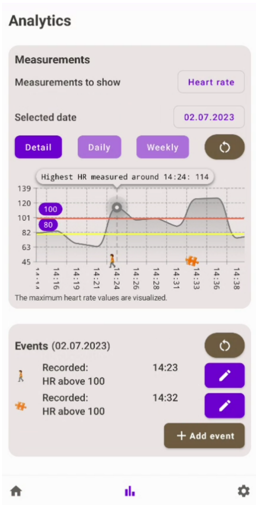
(1-a,3-b) Alarm creation



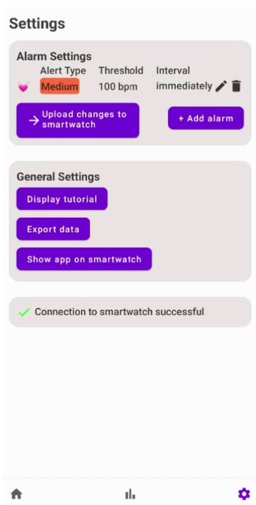
(1-f,2-a) Home screen



(2-a) Creating an event



(3-a) Analytics screen



(3-b) Settings screen

Figure 3: MindfulPacer smartphone application screenshots

4.2 Platform Choice

MindfulPacer was implemented for Android Smartphones and Wear OS smartwatches. Before initiating the development phase, multiple other platforms were evaluated and compared against each other by doing research and small proof of concepts to verify the main functionality (one requirement being that MindfulPacer should not upload collected data online without user interaction). The advantages of the chosen platforms can be split into user experience as well as technical nature.

User perspective Since the same Google Play Store entry can be used for both applications, users can install them at the same time [17]. Further, different manufacturers support Wear OS and more might join in the future, reducing the restriction of a single vendor [16]. There also exist other convenience features that allow for an easier setup (for instance, the smartwatch automatically uses the same language as the smartphone and the same user accounts might be used depending on the device manufacturers).

Technical perspective Android and Wear OS offer good support for communicating and sending data between devices [21]. Considering the global market share (of 2021), Apple Watches are clear leaders [39]. However, because of a lack of test devices (the smartwatches themselves as well as iPhones, which are required to set up Apple Watches [3]), Apple Watches and an IOS app were not further looked into. Instead, we decided to choose Wear OS, which is used by some Samsung devices (among others) - Samsung being second on the list. Another option would have been to use Fitbit devices. However, the architecture of Fitbit would have likely required our data synchronization to use the internet [9, 31]. Lastly, the viability of Garmin smartwatches seemed comparable to Wear OS devices, offering the added benefit of long battery life [14]. However, because of the rather high price of some Garmin models and the good support for communication between Android and Wear OS we decided to choose Wear OS instead [11].

4.3 Smartwatch App vs. Watchface

Another design decision relating the smartwatch application was the choice between implementing a full application or a watch face. A watch face can be thought of as the main screen when using the smartwatch, which typically displays the time plus some additional information such as the current step count for example [18]. A smartwatch app on the other hand can be launched from the list of apps, similar to smartphone apps.

MindfulPacer was developed as an app rather than a watch face. This allows to have more control over the frequency of data updates (an important aspect of MindfulPacer). Further, apps provide better support for user interactions. A watch face on the other hand is limited in terms of data update rate and can only support basic user interactions [19, 20]. However, using an app with frequent data updates comes with the drawback of higher battery consumption. Another drawback of using an app is that it might be accidentally closed (e.g. by clicking a button to return to the main screen). This was partially alleviated by vibrating the smartwatch when MindfulPacer is closed to get the attention of the user. Further considerations that could be explored to improve battery life as well as other technical design decisions have been documented outside this report [1][2].

5 Field Test and Learnings

This chapter first describes the field test that was used to evaluate MindfulPacer, before going into further detail on collected data and learnings.

[1] Notes regarding battery life: https://github.com/HASEL-UZH/ActivityPacing/issues/113

[2] Design decisions: https://github.com/HASEL-UZH/ActivityPacing/blob/master/docs/design_decisions.md

5.1 Field Test

To evaluate MindfulPacer, a qualitative field test with 5 participants (recruited from personal networks) was performed (however, as P1 has not been able to provide any feedback, this tester is excluded from the analysis). The field test consisted of two surveys - one towards the middle of the field test (n=3) and one at the end (n=1) [3]. Depending on the energy level of participants, the second survey was replaced with an interview (n=2) and additional feedback was collected individually throughout the field test. The total duration of the field test was four weeks.

Table 2 shows an overview of the participants and the different device models that were used:

ID	Age	Work situation	Smartwatch Model	Feedback
P2	39	on sick leave	Galaxy Watch 5	S1, S2
P3	24	working part time	Google Pixel Watch	S1, INT, data export
P4	60	on sick leave / working	Galaxy Watch 5 (44mm)	S1, INT, data export
P5	37	working part time	Galaxy Watch 5 Pro	data export

Table 2: Field test participant demographics (S1=first survey, S2=second survey, INT=interview)

The participants were conducting activity pacing at various levels before using MindfulPacer and had long COVID symptoms of different severities. While this allowed to get insights from multiple perspectives, we were unable to receive responses from all participants consistently.

5.2 Data Collection and Analysis

There were multiple sources of feedback. Feedback for possible improvements and issues was given throughout the field test (using the approach that was easiest for the respective testers regarding their current symptoms) and was collected in a single document to allow for a better overview and analysis. The goal of the surveys on the other hand was to gather qualitative data about the research questions, usage of alarms, events and the analytics page as well as the System Usability Scale. Results from surveys could be easily analysed using the results view of the survey tool. Interviews were conducted with two participants to gather additional data about their usage of MindfulPacer and to follow up on answers given in the first survey. The interviews were automatically transcribed and complemented by manual notes.

Overall, the findings can be classified into suggestions to improve user experience and personal experiences using the app. Changes to improve user experience and important bugs were implemented and rolled out during the field test.

Users could further opt-in to provide technical activity logs and recorded data which MindfulPacer collected during the use of the application. These exports included data to support technical analyses as well as certain usage patterns. As the activity logs used a simple JSON format, analyses could be done by writing functions to filter the data per tester/activity.

The following goes into further detail regarding insights of using MindfulPacer.

5.3 Smartwatch adequacy for activity pacing

To gain insights in regard to RQ1, multiple questions regarding the suitability of smartwatches and MindfulPacer in terms of activity pacing were asked during the first survey (n=3), as shown in figure 4.

[3]The survey questions can be found here: https://github.com/HASEL-UZH/ActivityPacing/blob/master/docs/survey/Survey_Masterproject.pdf

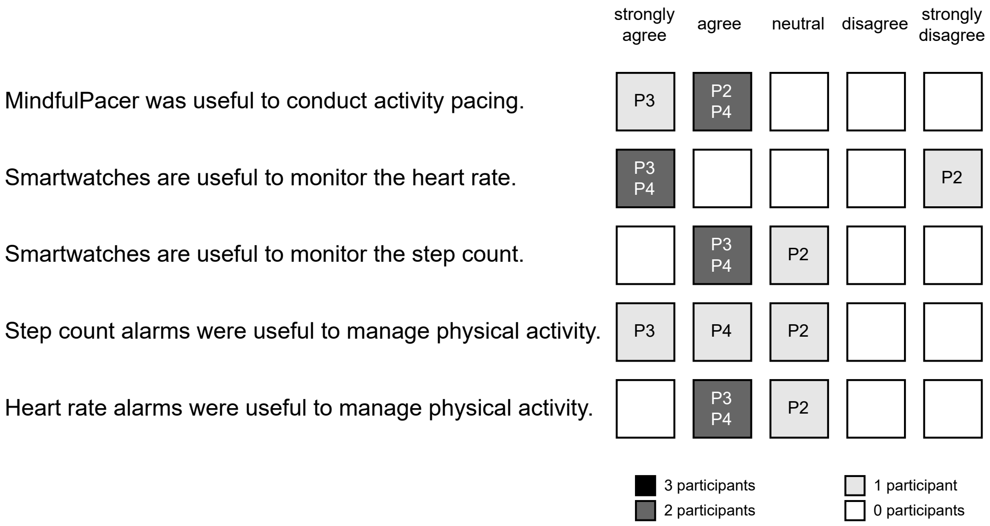


Figure 4: Likert results for suitability of MindfulPacer/smartwatches for activity pacing

Overall, the responses from the participants were positive. However, one participant (P4) mentioned that they perceived the step measurements to be only loosely connected to feeling fatigued. Further, one answer from participant P2 regarding their experience with smartwatches and heart rate measurements stood out. P2 reported that the heart rate measurements were completely inaccurate when compared to their own perceptions and Fitbit measurements.

Among the three participants, P2 had strong symptoms and was highly sensitive to the alarms. They did not find the step alarms useful as their movement throughout the day was generally low. On the other hand, P3 also experienced some inaccurate measurements, according to the recorded data, but still found MindfulPacer useful. P3 specifically mentioned that by utilizing the alarm feature, they were able to reduce the intensity of an upcoming crash.

> „Although I had a very stressful week and was therefore very inconsistent with pacing, the alerts helped me notice and catch the crash I was heading towards a little earlier, so I only had a 'mini crash'." (P3)

Perceived accuracy of measurements It should be pointed out that the participants were informed about the possibility of receiving inaccurate/too high heart rate measurements in advance. Because such inaccurate measurements were already experienced during development (with all of the tested smartwatch models), an indicator was added in case a smartwatch detected inaccurate measurements. Multiple other people have reported similar behavior online [48]. The indicator might have helped to partially reduce the impact of false-positives on the testers.

Encouragement for activity Another aspect regarding RQ1 is that the tested smartwatches themselves generally encourage activity rather than pacing it (as already mentioned in section 2.1). Some examples include:

- Encouragement to do activity when not moving for a certain amount of time.
- Encouragement when achieving a predefined step goal.
- Automatically recording activity when doing sports.

Participants were therefore instructed on how to disable such features [42,43].

Battery life Because MindfulPacer constantly measures the heart rate, there is a significant battery consumption. First tests have shown usage times of around 10-12 hours, which was confirmed by one user. While these numbers heavily depend on the used smartwatch model as well as the chosen settings (e.g. the Samsung Galaxy Watch 5 Pro has a significantly larger battery), they can be limiting to some users. Some options for improvement are described in section 6.3.

Detection if the Smartwatch is worn In rare cases, some Samsung smartwatches have wrongly detected whether they were worn or placed on a desk. To clarify times of paused heart rate measurements, the heart rate number was hidden while not being worn. However, P3 was the only participant that noticed such behavior and it did not cause any false alarm.

5.4 User behavior

In regard to RQ2, testers were further asked about how they use specific features of MindfulPacer.

Setting individual exertion thresholds In order to find optimal heart rate thresholds, MindfulPacer displayed a formula to calculate possible thresholds, which was used by one user. After using the app, this user made adjustments to the heart rate as well as step thresholds according to personal experiences made before and during the field test. Another user further based their threshold values on prior experiences from using a Fitbit device.

Alarms Testers generally found the personalized alarms useful. As mentioned in 5.3, one tester was able to reduce a crash by using the alarms. A sensitive tester further reported that the smartwatch accidentally vibrated when they fell asleep and another feedback was to allow for more control over vibration strength of alarms (the application was adjusted to support both requests).

Alarm feedback on the smartwatch When being asked about which information was most relevant to collect at the time of an alarm, two of three testers responded with the activity performed during the alarm (with the third tester classifying the activity as second most important). Due to these responses, users can now select an activity if they decide to give feedback on an alarm (compared to previously being able to select an emotion-icon, which was classified as less important).

Another option for feedback was to specify an alarm as false-positive, which was not used very actively. However, this does not necessarily indicate strong accuracy because the users could also choose to give no feedback to an alarm at all. For example, P5 gave no feedback to 162/451 alarms (over 15 days) and P4 gave no feedback to 15/122 alarms (over 8 days). Alarms of light intensity are not included as MindfulPacer only asked users for feedback on medium and strong alarms. This data was evaluated before changing the feedback from emotions to activities. Additionally, multiple improvements to the intuitivity, such as an automatic alarm synchronization or displaying the alarm trigger time on the smartwatch, were implemented based on received feedback.

Events & Visualizations Most users mainly used automatically created events (which were created by the smartwatch when an alarm was triggered). Further, two out of three users reportedly used the visualizations on the smartphone multiple times per day while all three users found the charts with the integrated event icons of the smartphone app rather useful to analyse alarms. Two users further found the approach of creating events rather useful and P3 mentioned to like the possibility of creating events but rarely used it because their main smartphone (an iPhone) was not supported.

Overall, two out of three users would like to continue to use MindfulPacer, with the other user having a neutral standpoint (RQ3). Additionally, the System Usability Scale was evaluated, which resulted in an average of 72.5 of 100 points (with samples 85, 77.5 and 55 (one answer missing)) [46]. However, the meaningfulness of this number should be carefully interpreted due to the small sample size and the fact that the medical conditions of potential users have a broad range.

6 Discussion

The field test has shown that supporting activity pacing using MindfulPacer can positively affect its users. This last section summarizes the findings and provides a possible outlook.

6.1 Personalization

For answering RQ2, our results indicate that the users appreciated the amount of configuration options. One upcoming crash could be reduced using alarms and one user further mentioned that the colored display and optional sound of alarms were helpful during interactions with other people as those people quickly understood that a break was necessary without much explanation.

However, there are some areas where users desired further customizability, such as to specify the vibration strength per alarm (which was later implemented), the possibility to manage an activity calendar or to add custom event categories. Another extension could be to automatically adjust alarms using machine learning, optionally letting users opt-in to provide training data.

6.2 Gaining Insights into Collected Data

Users generally reported the visualizations to be helpful. However, further support was requested for using the application. For example, this could be accomplished by an experienced professional which could accompany users to help find suitable alarm thresholds as well as to analyse data in hindsight. For the analysis, the existing export could be extended to be less technical and additionally include the charts, which might further help to identify causes of crashes as asked in RQ2. One user additionally asked to compare data of different days to help with the analysis and to incorporate data on oxygen saturation, which is offered by some smartwatches [23,32].

6.3 Using Smartwatches for Activity Pacing

In regard to RQ1, we found that smartwatch notifications can be disturbing to users with strong symptoms. This includes encouragements to be more active as well as notifications about smartphone connectivity or low battery, which can cause vibrations and sounds. While encouragement messages can be disabled, not all of the other notifications could be fully deactivated.

Despite that, users generally reported MindfulPacer to be useful in regard to activity pacing. For answering RQ3, we have identified that that reducing bright colors and only using short texts are possible improvements for users with strong symptoms. One user further suggested to add a break mode which could be activated after a crash (e.g. to reduce brightness and disable sounds).

Further, currently not all users can be fully reached by MindfulPacer due to the lacking support for iPhones and the relatively low battery duration (RQ1 and RQ3). Having more smartwatch models to choose from would help support more users, e.g. depending on their preferences or budget but also in regard to measurement accuracy and battery life. Further models could include the TicWatch 5 Pro for Wear OS or other platforms such as Apple or Garmin smartwatches [24]. If the battery life can be improved, introducing a night mode (during which alarms are paused) could further be added for additional reflections and data collection.

Lastly, MindfulPacer currently needs to be run in the foreground on the smartwatch to function properly. Implementing a background service could further improve battery life. As mentioned in section 4.3, possibilities of approaching this have been documented outside this document.

Overall, while activity pacing can already be successfully supported using MindfulPacer, an extended range of supported devices as well as further steps towards improving the battery life have been identified as extensions which would further benefit patients with activity pacing[4].

[4] Some addutional possible extensions to MindfulPacer have been documented here: https://github.com/HASEL-UZH/ActivityPacing/issues

References

[1] allyann. Hrpacing by allyann | Fitbit app gallery. https://gallery.fitbit.com/en-gb/details/240bd0c9-5c5a-4dc3-9a1b-b738c26c5143. Accessed June 22nd 2023.

[2] D. Antcliff, P. Keeley, M. Campbell, S. Woby, A.-M. Keenan, and L. McGowan. Activity pacing: moving beyond taking breaks and slowing down. *Quality of Life Research*, 27(7):1933–1935, Feb. 2018. Accessed January 1st 2023.

[3] M. Casserly. All the things an apple watch can do without an iPhone | Macworld. https://www.macworld.com/article/676595/does-an-apple-watch-work-without-an-iphone.html, November 2022. Accessed June 18th 2023.

[4] Centers for Disease Control and Prevention. Long covid or post-covid conditions. https://www.cdc.gov/coronavirus/2019-ncov/long-term-effects/index.html/, 2021. Accessed January 1st 2023.

[5] Centers for Disease Control and Prevention. Myalgic encephalomyelitis/chronic fatigue syndrome (me/cfs) | CDC. https://www.cdc.gov/me-cfs/index.html, May 2023. Accessed June 28th 2023.

[6] R. Chen. Ryan chen. http://www.ryanwchen.com/sentinel.html. Accessed June 22nd 2023.

[7] H. E. Davis, L. McCorkell, J. M. Vogel, and E. J. Topol. Long COVID: major findings, mechanisms and recommendations. *Nature Reviews Microbiology*, 21(3):133–146, Jan. 2023.

[8] Emerge Australia Inc. Me/cfs pacing app – Emerge Australia. https://www.emerge.org.au/news/mecfs-pacing-app-2, August 2021. Accessed June 22nd 2023.

[9] Fitbit LLC. Companion guide. https://dev.fitbit.com/build/guides/companion/. Accessed June 18th 2023.

[10] T. Fritz, E. M. Huang, G. C. Murphy, and T. Zimmermann. Persuasive technology in the real world: A study of long-term use of activity sensing devices for fitness. In *CHI 2014*. ACM, Apr. 2014.

[11] Garmin Ltd. Fitness watches | sport watches | smartwatches | Garmin. https://www.garmin.com/en-US/c/wearables-smartwatches/. Accessed July 7th 2023.

[12] Garmin Ltd. Heart rate monitoring | Garmin technology. https://www.garmin.com/en-US/garmin-technology/health-science/heart-rate-monitoring/. Accessed June 22nd 2023.

[13] Garmin Ltd. How are intensity minutes earned? | Garmin customer support. https://support.garmin.com/en-US/?faq=pNU9nnDzzGAHmEavp9rpY8. Accessed June 22nd 2023.

[14] Garmin Ltd. How long will my garmin smartwatch battery last? | Garmin blog. https://www.garmin.com/en-US/blog/general/how-long-will-my-garmin-smartwatch-battery-last/, September 2022. Accessed June 21st 2023.

[15] A. Ghali, V. Lacombe, C. Ravaiau, E. Delattre, M. Ghali, G. Urbanski, and C. Lavigne. The relevance of pacing strategies in managing symptoms of post-COVID-19 syndrome. *Journal of Translational Medicine*, 21(1), June 2023.

[16] Google LLC. Wear os by google | the smartwatch operating system that connects you to what matters most. https://wearos.google.com/intl/en/. Accessed June 21st 2023.

[17] Google LLC. Distribute to wear os | android developers. https://developer.android.com/distribute/best-practices/launch/distribute-wear, December 2022. Accessed June 21st 2023.

[18] Google LLC. Build fatch faces | Android Developers. https://developer.android.com/training/wearables/watch-faces, May 2023. Accessed June 18th 2023.

[19] Google LLC. Expose data to complications | android developers. https://developer.android.com/training/wearables/tiles/exposing-data-complications, February 2023. Accessed June 18th 2023.

[20] Google LLC. Handle taps in watch faces | Android Developers. https://developer.android.com/training/wearables/watch-faces/interacting, February 2023. Accessed June 18th 2023.
[21] Google LLC. Send and sync data on wear os | Android Developers. https://developer.android.com/training/wearables/data/data-layer, June 2023. Accessed June 18th 2023.
[22] Halldorsson. Unable to walk and housebound at the age of 12 – the extreme consequences of long covid. https://www.who.int/europe/news-room/feature-stories/item/unable-to-walk-and-housebound-at-the-age-of-12---the-extreme-consequences-of-long-covid, May 2023. Accessed June 28th 2023.
[23] M. L. Hicks and C. Lynch. Best smartwatches that can measure blood oxygen saturation levels 2023 | Android Central. https://www.androidcentral.com/best-smartwatches-can-measure-blood-oxygen-saturation-levels, June 2023. Accessed July 7th 2023.
[24] HK SMARTMV LIMITED. Ticwatch 5 pro - powerful, inside and out. https://www.mobvoi.com/us/pages/ticwatchpro5. Accessed June 22nd 2023.
[25] W. Hodgson, A. Kirk, M. Lennon, and G. Paxton. Exploring the use of Fitbit consumer activity trackers to support active lifestyles in adults with type 2 diabetes: A mixed-methods study. *International Journal of Environmental Research and Public Health*, 18(21):11598, Nov. 2021.
[26] S. Homewood. Self-tracking to do less: An autoethnography of long covid that informs the design of pacing technologies. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI '23, New York, NY, USA, Apr. 2023. Association for Computing Machinery.
[27] Imobisoft. Track and pace activity diary – apps bei Google Play. https://play.google.com/store/apps/details?id=com.imobisoft.painapp, December 2017. Accessed June 22nd 2023.
[28] D. Ireland and N. Andrews. Pain ROADMAP: A mobile platform to support activity pacing for chronic pain. *Studies in health technology and informatics*, 266:89–94, 2019.
[29] C. Johnson. Visible: The 1st long-covid and me/cfs activity/pem tracker is here - Health Rising . https://www.healthrising.org/blog/2022/11/19/visible-app-long-covid-chronic-fatigue-syndrome/, Nov. 2022. Accessed November 23rd 2022.
[30] C. Johnson. Exercise triggers major immune system letdown in me/cfs - Health Rising. https://www.healthrising.org/blog/2023/06/17/exercise-immune-system-letdown-chronic-fatigue-syndrome/, June 2023. Accessed June 30th 2023.
[31] jtlapp. Solved: Re: Storing time, hr, and gps information from fit... - Fitbit community. https://community.fitbit.com/t5/SDK-Development/Storing-time-hr-and-gps-information-from-fitbit-device/m-p/2189223/highlight/true#M180, Nov. 2017. Accessed July 5th 2023.
[32] T. Kerns. Spo2 tracking is quietly making its way to some Google Pixel Watch users. https://www.androidpolice.com/google-pixel-watch-spo2-tracking-limited-availability/, June 2023. Accessed July 7th 2023.
[33] I. Kryuchkov. Post covid-19 condition (long covid). https://www.who.int/europe/news-room/fact-sheets/item/post-covid-19-condition, December 2022. Accessed June 30th 2023.
[34] H. Leeming. The next step: Our beta launch. https://www.makevisible.com/blog/the-next-step, Nov. 2022. Accessed November 23rd 2022.
[35] E.-J. Lim, Y.-C. Ahn, E.-S. Jang, S.-W. Lee, S.-H. Lee, and C.-G. Son. Systematic review and meta-analysis of the prevalence of chronic fatigue syndrome/myalgic encephalomyelitis (CFS/ME). *Journal of Translational Medicine*, 18(1), Feb. 2020. Accessed January 1st 2023.
[36] V. Nittas, M. Puhan, A. Raineri, M. Gao, E. West, and O. Bürzle. Long covid: Evolving definitions, burden of disease and socio-economic consequences. https://www.bag.admi

n.ch/dam/bag/en/dokumente/mt/k-und-i/aktuelle-ausbrueche-pandemien/2019-nCoV/Literaturrecherchen/literaturrecherchen_long_covid_20220608.pdf.download.pdf/FOPH_LitReport_Covid-19%20LongCOVID_20230124.pdf, Nov. 2022. Accessed June 30th 2023.

[37] M. Parker, H. B. Sawant, T. Flannery, R. Tarrant, J. Shardha, R. Bannister, D. Ross, S. Halpin, D. C. Greenwood, and M. Sivan. Effect of using a structured pacing protocol on post-exertional symptom exacerbation and health status in a longitudinal cohort with the post-covid-19 syndrome. *Journal of Medical Virology*, Dec. 2022.

[38] Q_PERIOR AG. Pacing on the App Store. https://apps.apple.com/app/pacing/id6448513970, May 2023. Accessed June 22nd 2023.

[39] F. Richter. Chart: Apple several ticks ahead in the smartwatch market | Statista. https://www.statista.com/chart/15035/worldwide-smartwatch-shipments/, Sept. 2022. Accessed July 5th 2023.

[40] B. Rudmann. Pulsalarm app on the App Store. https://apps.apple.com/app/pulsalarm-app/id1516619515?platform=appleWatch, February 2022. Accessed June 22nd 2023.

[41] Samsung Electronics America, Inc. Monitor your heart rate on your Samsung smart watch. https://www.samsung.com/us/support/answer/ANS00083511/. Accessed June 22nd 2023.

[42] Samsung Electronics America, Inc. Use automatic workout detection on your Samsung smart watch. https://www.samsung.com/us/support/answer/ANS00083510. Accessed June 21st 2023.

[43] Samsung Electronics Australia Pty Ltd. Disable inactive time alerts on Samsung watch | samsung australia. https://www.samsung.com/au/support/mobile-devices/disable-smart-alarm-on-samsung-watch/, October 2021. Accessed June 21st 2023.

[44] A. Synowiec, A. Szczepański, E. Barreto-Duran, L. K. Lie, and K. Pyrc. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): a systemic infection. *Clinical Microbiology Reviews*, 34(2), Mar. 2021.

[45] The Visible Team. Why we've chosen to focus on me/cfs and long covid. https://www.makevisible.com/blog/why-we-have-chosen-focus-on-me-and-long-covid, Sept. 2022. Accessed July 5th 2023.

[46] U.S. General Services Administration. System usability scale (SUS) | Usability.gov. https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html. Accessed June 22nd 2023.

[47] D. J. Van Booven, J. Gamer, A. Joseph, M. Perez, O. Zarnowski, M. Pandya, F. Collado, N. Klimas, E. Oltra, and L. Nathanson. Stress-induced transcriptomic changes in females with myalgic encephalomyelitis/chronic fatigue syndrome reveal disrupted immune signatures. *International Journal of Molecular Sciences*, 24(3):2698, Jan. 2023.

[48] Wes1000. Samsung galaxy watch 4 measures heart rate at double actual - Samsung community. https://eu.community.samsung.com/t5/wearables/samsung-galaxy-watch-4-measures-heart-rate-at-double-actual/td-p/5221274, Apr. 2022. Accessed June 30th 2023.

[49] World Health Organization. WHO coronavirus (covid-19) dashboard | WHO coronavirus (covid-19) dashboard with vaccination data. https://covid19.who.int/, 2023. Accessed June 22nd 2023.

[50] J. Wright, S. L. Astill, and M. Sivan. The relationship between physical activity and long covid: A cross-sectional study. *International Journal of Environmental Research and Public Health*, 19(9):5093, Apr. 2022.