Breaking up Long Sedentary Periods of Office Workers through a Virtual Coach using Activity Data

Jasmijn Franke[1,2], Christiane Grünloh[1,2][a], Dennis Hofs[1][b], Boris Van Schooten[1][c], Andreea Bondrea[1] and Miriam Cabrita[1,2,3][d]

[1]*eHealth Group, Roessingh Research and Development, Enschede, The Netherlands*

[2]*Biomedical Signals and Systems Group, University of Twente, Enschede, The Netherlands*

[3]*Innovation Sprint Sprl, Brussels, Belgium*

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Abstract: Office workers often lead sedentary lifestyles, a lifestyle responsible for higher risks of cardiovascular disease, stroke, diabetes and premature mortality. Improvements towards a more active lifestyle reduce cardiovascular risks and thus changing the sedentary lifestyle might prevent chronic illness. The Recurring Sedentary Period Detection (RSPD) algorithm described in this paper was designed to identify recurring sedentary periods using data from an activity tracker, summarise the sedentary periods and pinpoint notification times at which the user should be motivated to get some movement. The outcome of the RSPD algorithm was validated using data from a 10-week period of one typical office worker. Our results show that the RSPD algorithm could correctly identify the recurring sedentary periods, compute fitting daily summaries and pinpoint the notification times correctly. With minor differences, the RSPD algorithm was successfully implemented in the healthyMe smartphone application, one of the supporting services of the SMARTWORK project. Within the healthyMe application, an embodied virtual agent is used to communicate the daily summaries and motivate the user to move more at the identified notification times. Pilots planned as part of the SMARTWORK project will evaluate whether the RSPD algorithm helps to motivate office workers to break up sedentary periods.

1 INTRODUCTION

An active lifestyle contributes positively to both mental (Rohrer et al., 2005) and physical health (González-Gross and Meléndez, 2013). Office workers however, lead a sedentary lifestyle due to prolonged hours of sitting behind a desk, which may lead to significantly higher risks of cardiovascular disease, stroke, diabetes and premature mortality (Parry and Straker, 2013). Especially working people above the age of 55 years old have higher risks of becoming sick or chronically ill (Rogers and Wiatrowksi, 2005). The systematic literature review by Barbaresko et al. showed that healthy lifestyle behaviours (including being physically active) are associated with a reduced risk of cardiovascular diseases (Barbaresko et al., 2018). Thus, certain chronic illnesses may be prevented by changing the sedentary lifestyle of office workers. Currently, there are many available commercial activity trackers connected to smartphone applications, that give insight in the user's lifestyle. However, many of these applications are not user-friendly for the older workers with low digital literacy (Kocsis et al., 2019), are not personalised and their focus is on tracking and visualising activity, rather than coaching. For example, many activity tracking applications have a default daily step-goal of 10,000 steps. Such a goal can be daunting and de-motivating for people with a sedentary lifestyle, as they feel they will never be able to reach it. Thus, a personalised goal that is within reach is necessary to help the user to reach their daily goal.

Setting an appropriate goal is only the first step into changing a person's sedentary lifestyle (Abraham and Michie, 2008), the next step is to coach the person in how to reach their goal. The commonly

[a] https://orcid.org/0000-0003-2319-3186
[b] https://orcid.org/0000-0003-1165-3106
[c] https://orcid.org/0000-0001-8131-6637
[d] https://orcid.org/0000-0001-6757-9406

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available health tracking applications mainly focus on steps taken per day when it comes to goal setting. However, as pointed out also by Barbaresko et al., a physically active person can generally also have sedentary behaviour (Barbaresko et al., 2018). In addition, cramping activity within a small period of time may not be enough to counteract the damage done by the preceding sedentary period (Ekelund et al., 2016). Therefore, to tackle the sedentary lifestyle during the day at the office, it may be better to coach a person to get some movement during prolonged sedentary bouts.

The SMARTWORK project aimed to develop a worker-centric, artificial intelligence system to fully support older office workers in sustainable, active and healthy ageing in their personal and work environment (Kocsis et al., 2019). One of developed systems is the healthyMe smartphone application, that includes various modules (Amaxilatis et al., 2019). This application is used to monitor nutrition and weight and it offers office friendly exercises. Connected to an activity tracker, it is able to track and visualise physical activity, sleep and heart rate. In addition, the healthyMe smartphone application analyses and processes physical activity for personalised coaching, delivered through an embodied virtual conversational agent. The personalised coaching consists of two parts, based on past data of physical activity: 1) setting an appropriate, personalised daily activity goal, and 2) the identification of recurring prolonged sedentary bouts and daily notification times based on past data. This paper focuses on the algorithm behind the second part of the personalised coaching: the Recurring Sedentary Period Detection (RSPD) algorithm. This algorithm was designed to detect recurring sedentary periods per specific weekday, such that data of non-working days do not interfere with working days and vice versa, to optimise the algorithm's accuracy. The aims of this paper are 1) to give a detailed description of how the RSPD algorithm was developed, 2) to evaluate the accuracy of the algorithm, and 3) to describe how it was implemented in the healthyMe smartphone application.

2 DESIGN OF THE RSPD ALGORITHM

The goal of the RSPD algorithm is to identify recurring prolonged sedentary periods based on past physical activity tracked by an activity tracker. Based on the detected recurring sedentary periods, a summary is formulated to raise awareness of the user. Moreover, notification times are pinpointed when the user should be motivated to get some movement to break up the sedentary periods.

The RSPD algorithm will become active once two weeks of activity data are available. Thereafter, it runs every day to determine daily summaries and notification times for the upcoming day.

2.1 Identifying Sedentary Periods

A simplified schematic overview of how the sedentary periods per day are identified is depicted in Figure 1. This first part of the RSPD algorithm uses a sliding-

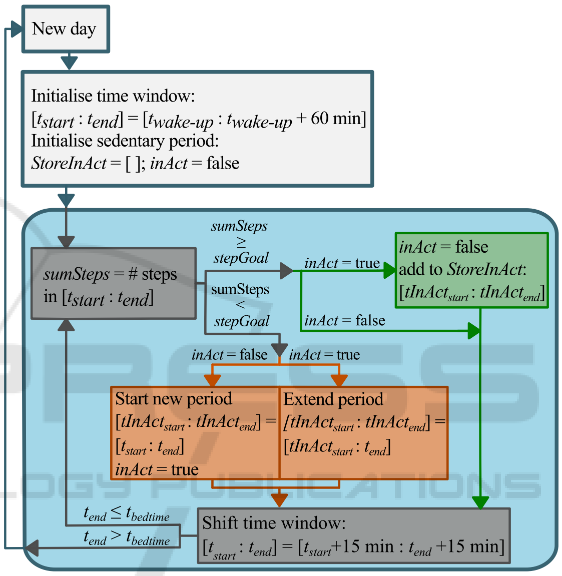

Figure 1: A simplified schematic overview of the first part of the Recurring Sedentary Period Detection algorithm.

window technique to find time intervals in which the hourly step-goal was not met. The contiguous time intervals for which the hourly step-goal was not met are stored and used in the second part of the algorithm. The first sliding-window starts at the time the user woke up ($t_{wake-up}$) and slides through the day in time intervals of 60 minutes, incrementing the start of the window (t_{start}) and end time (t_{end}) with 15 minutes until the user went to bed ($t_{bedtime}$). Within each time interval, it is checked whether steps taken ($sumSteps$) meet the hourly step-goal ($stepGoal$, 250 steps) and if not, the sedentary time interval ($tInAct_{start}$, $tInAct_{end}$) is saved as sedentary period under the specific weekday ($StoreInAct$). Once the algorithm has iterated throughout the day, it proceeds to the next available day, until no data is available any more.

2.2 Identifying Recurring Periods

The variable with the stored sedentary periods per weekday (*StoreInAct*) is used in the second part of the RSPD algorithm to identify recurring periods within the specific weekdays. A simplified schematic overview of how the identification of recurring sedentary periods works is depicted in Figure 2.

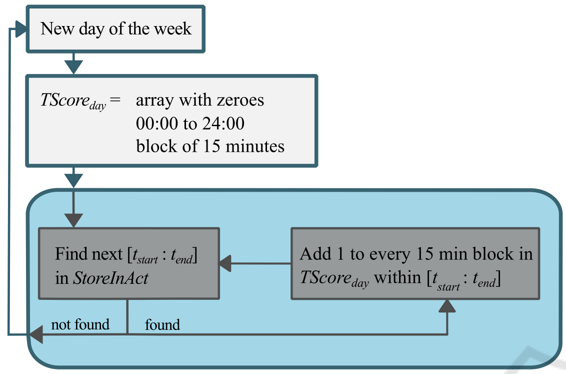

Figure 2: A simplified schematic overview of the second part of the Recurring Sedentary Period Detection algorithm.

A time array with a 15 minute interval is initialised for each day to score when sedentary periods recur ($TScore_{day}$). The algorithm starts with the first entry of the stored sedentary periods and increments each 15 minute interval between the start (t_{start}) and end (t_{end}) of the sedentary period by one to indicate that (another) sedentary period has occurred. If present, the algorithm then proceeds to the next entry of the stored sedentary periods (*StoreInAct*) and repeats the process. After the last available entry, the algorithm proceeds to the next weekday and repeats the process until all days of the week are processed.

2.3 Identifying Appropriate Timing for Coaching

The last step of the RSPD algorithm is to summarise the sedentary periods per weekday and to pinpoint the timing when to motivate the user to get some movement. From the recurring score ($TScore_{day}$), recurring sedentary periods are identified when at least 66% of the time this period is determined to be sedentary. This is determined by dividing the 15 minute interval score ($TScore_{day}$) by the number of days that are present in the data set. Recurring sedentary periods of at least one hour are taken into account in the summary. To prevent lengthy and complicated summaries, recurring sedentary periods that are less than one hour apart are considered as one sedentary period.

Summaries are computed using the start and end times of the recurring sedentary periods in the following way: ‘***weekdays*** *between* $\boldsymbol{t_{start}}$ *and* $\boldsymbol{t_{end}}$*, between* $\boldsymbol{t_{start}}$ *and* $\boldsymbol{t_{end}}$ *and* $\boldsymbol{t_{start}}$ *and* $\boldsymbol{t_{end}}$’. Depending on the number of identified recurring sedentary periods, this sentence is adjusted such that it can be directly used in a dialogue with a virtual coach.

To pinpoint when the user should be motivated, high and low priority recurring sedentary periods are distinguished. Start time of periods that occur during 100% of the time in the data history are stored under high priority notification times. The start time of periods that occur less than 100% and more than 66% of the time are stored under low priority notification times. Low priority notification times that fall within two hours of the high priority notification times are deleted, to prevent overwhelming the user with too many notifications. Moreover, it is not desirable to notify the user close to their usual bedtime and thus, notifications within two hours of their regular bedtime are deleted as well.

3 EVALUATION OF THE OUTCOMES OF THE RSPD ALGORITHM

To test whether the RSPD algorithm correctly identifies the recurring sedentary periods, summarises them and computes correct notification times, a real-life situation with a typical office worker was tested (N=1). In the period from 18-02-2021 to 29-04-2021, a smartwatch (Fitbit Charge HR) was worn 24/7 and this data was used to evaluate the outcomes of the RSPD algorithm.

3.1 Methods

To evaluate whether the RSPD algorithm detected the sedentary periods correctly, cumulative steps taken over each individual day, taken from the activity tracker, were visualised. On all daily graphs, all time intervals computed by the first part of the RSPD algorithm (Section 2.1) during the day were shown, either green (hourly step-goal met) or red (hourly step-goal not met). The resulting identified sedentary periods were depicted in the graphs as orange backgrounds. Periods during the day in which no data was available (non-wear time) were depicted as grey backgrounds. Visual inspections were done to evaluate whether the identified orange sedentary periods from the RSPD algorithm were concurrent at that moment in time with cumulative step count from the activity tracker. If this was the case, the algorithm has identified the sedentary periods correctly.

The recurring sedentary periods were evaluated using heat maps of consecutive 6-week periods of data and comparing these to the daily graphs. For each weekday, a heat map was produced using the percentages of days where a time interval recurred as a sedentary period, resulting from the second part of the RSPD algorithm (Section 2.2). Visual inspections were done to evaluate whether the percentage of the recurring periods concurred with the occurrence of the identified daily sedentary periods (Section 2.1). If this was the case, the algorithm can correctly identify recurring sedentary periods. Lastly, these heat maps were used to evaluate whether the resulting summary and pinpointed notification times (Section 2.3) were correctly produced by the algorithm.

3.2 Results

As example of the outcomes of the RSPD algorithm, the 6-week period between 13-03-2021 and 23-04-2021 was selected. All Fridays during this period are shown in Figure 3.

On Friday the 23rd of March, between 07:15 and 09:30, the cumulative step count increased from 577 to 668 steps. Within this time period, all of the time intervals indicated that the hourly step-goal of 250 steps was not met (red). This period of time was identified by the RSPD algorithm as sedentary. The data suggested non-wear time after 12:00, in which no sedentary periods were detected by the algorithm. All other identified sedentary periods were also inspected and concurred with the cumulative step count and time intervals that were indicated as hourly goal not met. Moreover, in small non-wear periods during the day (e.g. the Fitbit was charging), see Friday the 19th of March between 13:45 and 16:00, no time intervals were initiated and no sedentary periods were identified.

The heat map of identified sedentary periods of the 6-week period is presented in Figure 4. For Friday, two periods in which all Fridays were indicated as sedentary were found, between 08:00 and 08:15 and between 11:15 and 12:00. In Figure 3, these periods all fall within the identified sedentary periods. This also holds for all other weekdays and any other percentage.

The outcomes of the computed summaries and notification times for the 6-week period are presented in Table 1. For the Friday, the summary indicated a recurring sedentary period (more than 66% of the time) between 7:45 and 12:15 and a period between 19:15 and 23:00. In Figure 4, five separate recurring sedentary periods can be distinguished, indicated by orange or red. However, as stated before in Section 2.3, sedentary periods that are less than one hour apart should be aggregated into one sedentary period. Hence, the gaps between the sedentary periods at 10:00, 10:30 and 19:30 should not be regarded in the summary. Taking this into account, the summary computed by the RSPD algorithm was correct. For Mondays, considering gaps of at least an hour, three separate sedentary periods can be distinguished. However, the period between 13:15 and 14:00 was less than an hour and thus not should not be taken into account in the summary and notification times. Verifying this in Table 1, the RSPD algorithm has indeed correctly computed the summary. All other daily summaries were inspected as well and were correctly computed.

The notification times did not always concur with the summaries, see Table 1. For example, on Friday, the summary started with the first sedentary period at 07:45, while the first notification time was at 08:00. However, Fridays at 08:00 were indicated as 100% of the time sedentary and are thus high priority. Since 07:45 fell within two hours of the high priority notification, the low priority notification was suppressed by the RSPD algorithm. On Sunday, there were only two notification times (09:30 and 14:30), even though there was a high priority sedentary period between 21:15 and 22:30. Since the start of this period was within two hours of the subject's regular bed time (23:00), the RSPD algorithm deleted this notification. All other notifications were verified and are correctly computed by the RSPD algorithm.

Taken all results into account, the RSPD algorithm correctly identifies the sedentary periods from the daily cumulative step count. Moreover, it accurately identifies the recurring sedentary periods and computes the summary and notification times correctly.

4 IMPLEMENTATION OF THE RSPD ALGORITHM IN THE SMARTWORK PROJECT

The aim of the SMARTWORK project was to support older office workers in sustainable, active and healthy ageing in their personal and work environment (Kocsis et al., 2019). One of the developed support systems is the healthyMe smartphone application, in which the RSPD algorithm was implemented. Users can connect their activity tracker to the smartphone application and activity data is used

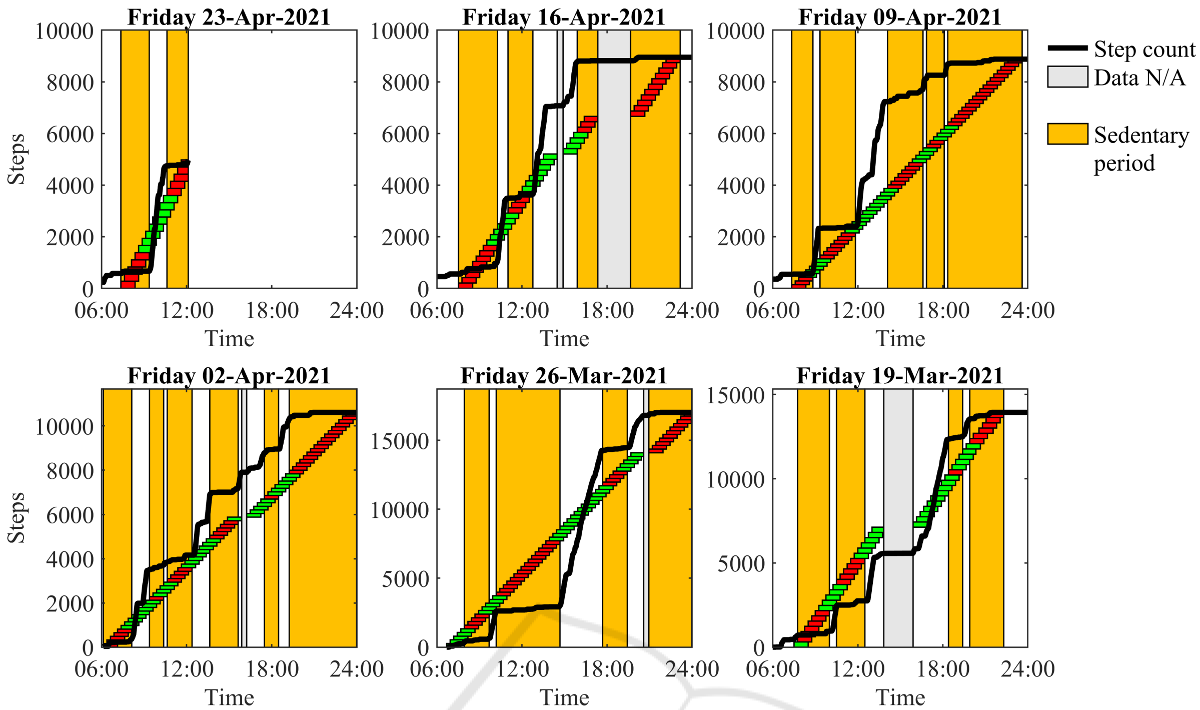

Figure 3: Visualised results of the sedentary period detecting algorithm, for all Fridays during a 6-week period. The boxes represent the intervals in which the hourly step-goal is either met (green) or not (red). Orange backgrounds indicate sedentary periods as determined by the algorithm, non-wear time is indicated with grey background.

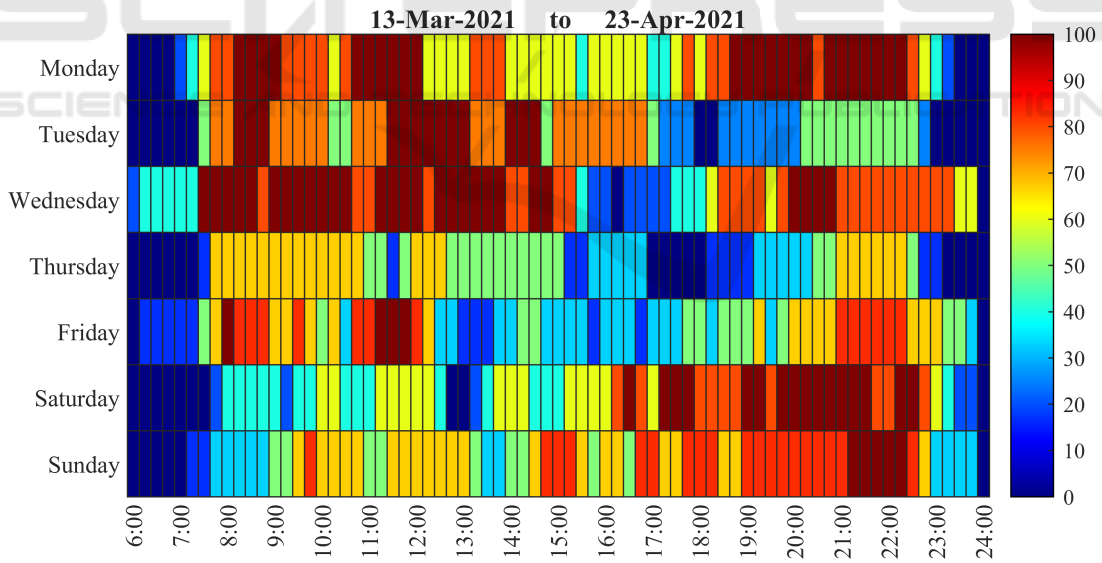

Figure 4: The results of the Recurring Sedentary Period Detection algorithm based on the 6-weeks period of activity data. The colour bar represents the percentage of days during that specific interval that are indicated as sedentary.

as described in Section 2. However, instead of running the RSPD algorithm only once a week, it was implemented such that it runs in a more continuous way. Detected recurring sedentary periods as described in Sections 2.1 and 2.2 are updated every 15 minutes and stored as intermediate result. At the start of each day, the daily summary and notifications are generated for that day, by means described in Section 2.3.

The daily summary is delivered each morning by the embodied virtual agent, Amelia, in the healthyMe smartphone application, see Figure 5. Dialogues were

Table 1: Overview of the computed daily summaries and notification times produced by the Recurring Sedentary Period Detection algorithm. High priority notification times are indicated in bold.

	Daily summary	Notification times
Monday	Mondays, between 07:45 and 12:00, and between 17:45 and 22:30.	**08:15 10:45 18:45**
Tuesday	Tuesdays, between 07:45 and 16:45	**08:15 11:30 14:00**
Wednesday	Wednesdays, between 07:30 and 15:15, and between 18:30 and 23:15.	07:30 20:00
Thursday	Thursdays, between 07:45 and 10:45, and between 21:00 and 22:15.	07:45 21:00
Friday	Fridays, between 07:45 and 12:15, and between 19:15 and 23:00	**08:00 11:15** 19:15
Saturday	Saturdays, between 16:15 and 22:45	**16:30 19:00**
Sunday	Sundays, between 09:30 and 13:00, and between 14:30 and 22:45	09:30 14:30

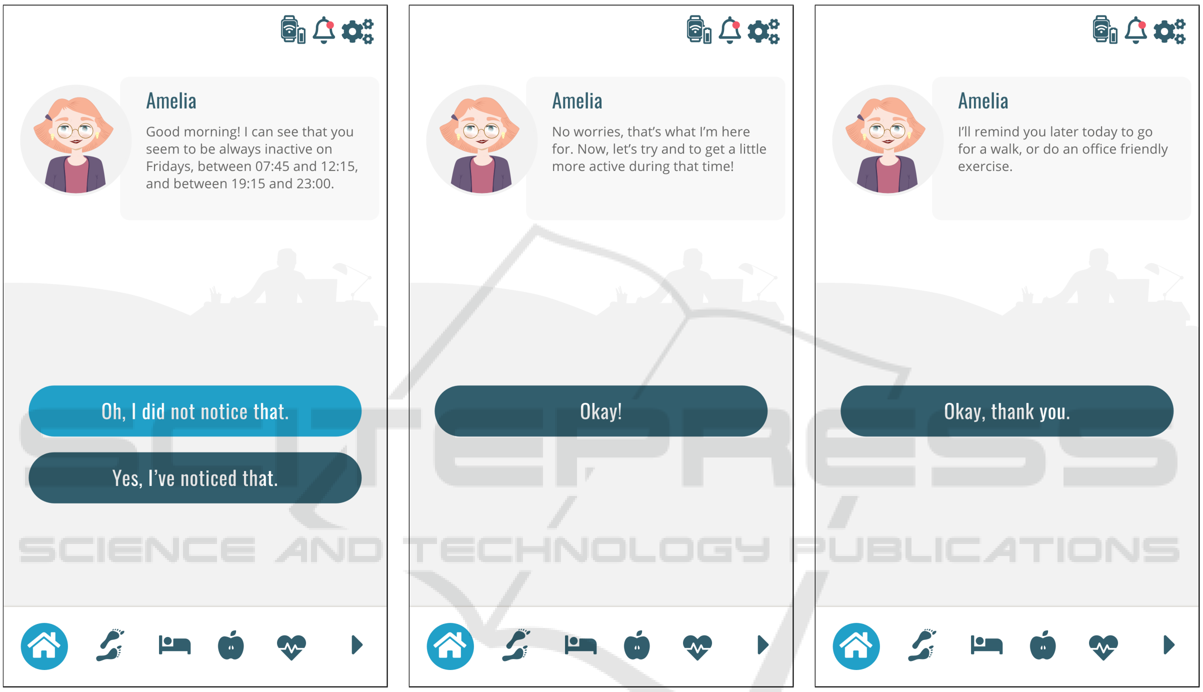

Figure 5: Screenshots of the summary produced by the Recurring Sedentary Period Detection algorithm, given through a dialogue with the virtual coach in the healthyMe smartphone application. Light blue dialogue options indicate the chosen dialogue option.

written in such a way that the user does not receive the exact same text each day. The first part of the sentence, not determined by the algorithm, is chosen randomly from an available set of options.

During the day, the virtual coach will come back to notify the user, at the moments determined at the start of the day, that it is time to get some movement, for example, through the office friendly exercises available in the application. Figure 6 shows a screenshot of the start of the motivating dialogue with the virtual coach in the healthyMe smartphone application. Office workers may have fixed meeting times on some days and thus will be unable to break up that specific period. However, it would be useful to get a notification a little before that time, such that the user can plan to go for a walk before or after the meeting. Therefore, the notifications are triggered 30 minutes before the start of a recurrent sedentary period. Moreover, notifications remain available for the user until the end of the sedentary period. This way, if an office worker does not immediately open the notification, the coach can still motivate them during the length of the sedentary period.

Another important difference between the RSPD algorithm described in Section 2 and its implementation in the healthyMe smartphone application, is that the hourly step-goal is not fixed (i.e., not 250 steps for each hour each day of the week). The Fitbit smartphone application uses also an hourly goal, however, no scientific papers were found what hourly step-goal is appropriate to reduce sedentary lifestyles. As some older office workers

Figure 6: Screenshot of the start of the dialogue with the virtual coach in the healthyMe smartphone application triggered by the pinpointed notification time to break the sedentary bouts identified by the Recurring Sedentary Period Detection algorithm.

may lead extreme sedentary lifestyles (<2500 daily steps) (Tudor-Locke et al., 2011), it may happen that some days are fully indicated as sedentary period, leading to only one pinpointed notification time. Therefore, it was decided to use an outcome of another algorithm supporting personalised coaching of physical activity in the healthyMe smartphone application: the 'Automated Goal Setting' algorithm (AGS). The AGS is used to set *daily* step goals that are achievable for the user to prevent demotivation. It uses past data to flag whether a day of the week is typically 'inactive', 'normal', or 'active' (compared to a person's activity level), determines how many steps the person makes on average for these classifications and then sets the *daily* step goals a bit higher than the average. In the healthyMe smartphone application, the RSPD algorithm uses the same flags, but sets the *hourly* step-goal to 200 steps (less active days), 250 (normal days) or 300 steps (active days).

5 DISCUSSION

The aims of this article were to outline the Recurring Sedentary Period Detection (RSPD) algorithm, to evaluate its accuracy and to describe how it was implemented in the smartphone application of the SMARTWORK project. The evaluation was a N=1 study, with activity data collected over a 10-week period. Visual exploration of the data confirmed that the identified sedentary periods correspond to the time intervals in which the hourly step-goals were not met (Figure 3). Next, the recurrence of sedentary periods throughout the week (Figure 4) were investigated. The recurring sedentary periods were found to correctly correspond to the identified sedentary periods in the daily graphs. Lastly, the daily summaries and notification times (Table 1) were inspected and determined to be correctly computed by the RSPD algorithm. Hence, the RSPD algorithm performs as expected.

During the design of the RSPD algorithm, some parameters were set based on educated guesses, namely the initial period before the algorithm becomes active, the hourly step-goal, minimum duration of recurring sedentary periods and minimum interval duration between two sedentary periods. The two week period before the start of the algorithm might not be representative of the user's activity pattern to provide proper coaching. However, this period allows for a first impression of the type of the activity level of the user to initiate the virtual coaching to encourage the user towards an active lifestyle. Furthermore, the algorithm will continuously update and adapt to the routine of the user throughout time. The hourly step-goal was chosen based on the step-goal used in the Fitbit smartphone application. In addition, the choice of one hour as the shortest sedentary period is in line with features seen in commercial fitness devices that send movement reminders every hour (e.g., Fitbit and Garmin). The decision to aggregate two sedentary periods with less than one hour in between was taken to avoid overwhelming the user with notifications. The RSPD algorithm was designed such that all above mentioned parameters can be easily adapted by developers in future works to improve the context of each specific intervention.

The RSPD algorithm was implemented in one of the support services of the SMARTWORK project, the healthyMe smartphone application. This application uses the outcomes of the RSPD algorithm and delivers the daily summaries through an embodied virtual agent in a dialogue. There were differences in how the RSPD algorithm was described in Section 2 and how it was implemented in the healthyMe smartphone application. The notification time was adjusted to 30 minutes prior to the sedentary period. This allows the user to get some movement before a regular meeting, or plan in time to do so afterwards. However, if the user is already doing this regularly, the sedentary period cannot be broken up, but will still show up in future daily summaries and notification times. This may interfere with technology acceptance and to avoid this, a feature should be implemented in a future version to allow users to indicate specific time slots in which movement is not possible (e.g. recurring meetings). Secondly, the hourly step-goal was based on the AGS algorithm within the healthyMe smartphone application that flags days of the week as typically 'inactive', 'normal', or 'active' days based on past data. These flags were used to set the hourly goal to 200, 250 or 300 steps, respectively. While the hourly goals may not be the same for each day, the goal per flag, however, are still predetermined and fixed. For example, 'active' days for one person could be 8000 steps, while for another it is only 3000 steps. In both cases the healthyMe smartphone application uses 300 steps as the hourly goal, which would hardly be achievable for the latter user. Therefore it is likely that for this person most parts of the day would be indicated as sedentary, because the hourly step goals have not been reached, which was supposed to be avoided by having more personalised hourly step-goals. In future versions of the RSPD algorithm, it is recommended to determine averages of the amount of steps taken within the time intervals that are used. This prevents days from being identified as one large sedentary period, such that the most sedentary periods can be targeted.

The RSPD algorithm implemented in the healthyMe smartphone application will be tested during the SMARTWORK pilots, with office workers aged 50+ in the Summer and Fall of 2021. While the project focuses on older office workers, we believe the RSPD algorithm will be useful to support breaking sedentary periods in all 'couch potatoes' with a sedentary lifestyle, from children to pensioners.

6 CONCLUSIONS

The developed RSPD algorithm correctly identifies the recurring sedentary periods in physical activity data. Moreover, it correctly computes summaries and notification times, that can be directly used in support services such as the healthyMe smartphone application. The next step is to evaluate in pilot studies whether the RSPD algorithm motivates office workers to break up sedentary periods and to evaluate the decisions made for the used parameters. These pilots are planned as part of the SMARTWORK project in the Summer and Fall of 2021.

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