Available online at www.sciencedirect.com
SciVerse ScienceDirect
Int. J. Human-Computer Studies 71 (2013) 878–888
International Journal of Human-Computer Studies
www.elsevier.com/locate/ijhcs

Already up? using mobile phones to track & share sleep behavior

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Received 23 May 2012; received in revised form 12 October 2012; accepted 1 March 2013
Available online 15 March 2013

Abstract

Users share a lot of personal information with friends, family members, and colleagues via social networks. Surprisingly, some users choose to share their sleeping patterns, perhaps both for awareness as well as a sense of connection to others. Indeed, sharing basic sleep data, whether a person has gone to bed or waking up, informs others about not just one's sleeping routines but also indicates physical state, and reflects a sense of wellness. We present Somnometer, a social alarm clock for mobile phones that helps users to capture and share their sleep patterns. While the sleep rating is obtained from explicit user input, the sleep duration is estimated based on monitoring a user's interactions with the app. Observing that many individuals currently utilize their mobile phone as an alarm clock revealed behavioral patterns that we were able to leverage when designing the app. We assess whether it is possible to reliably monitor one's sleep duration using such apps. We further investigate whether providing users with the ability to track their sleep behavior over a long time period can empower them to engage in healthier sleep habits. We hypothesize that sharing sleep information with social networks impacts awareness and connectedness among friends. The result from a controlled study reveals that it is feasible to monitor a user's sleep duration based just on her interactions with an alarm clock app on the mobile phone. The results from both an in-the-wild study and a controlled experiment suggest that providing a way for users to track their sleep behaviors increased user awareness of sleep patterns and induced healthier habits. However, we also found that, given the current broadcast nature of existing social networks, users were concerned with sharing their sleep patterns indiscriminately.

Keywords: Sleep; Alarm clock; Social network; Behavior; Awareness; Mobile phone

1. Introduction

The proliferation of mobile devices in everyday life leads to an increasing amount of information about users' personal contexts that can be obtained automatically and made available to third-party applications. Many individuals share details of their life with fellow friends (Alt et al. 2010). Looking at the usage of Google+ or Facebook, it is apparent that keeping friends updated with one's current status through the use of social media has become a popular pastime. It is common for many posts to contain context information about a user. This information is either posted automatically by a third-party service or is posted explicitly by the user. From the perspective of the reader, this information is useful in that, e.g., couples in long-distance relationships are kept updated on what their partner is currently doing, family members are kept up-to-date with each other's activities, and friends might be triggered to meet each other based on posts containing location information.

Here we focus on one of the private, even intimate, pieces of context information available: sleep. Sleeping has been identified as one of the prime activities that contribute significantly to the state of an individual's mental and physical health (Bonnet and Arand, 2003; Everson et al., 1989). There is a mutual relationship between sleep and daily life where

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1071-5819/$ - see front matter
http://dx.doi.org/10.1016/j.ijhcs.2013.03.001

problems in one often impacts the other (Zee and Turek, 2006). There is also a correlation between a lack of sleep and an increase in the number of diseases a person is prone to contracting, e.g., heart disease (Ayas et al., 2003) and diabetes (Gottlieb et al., 2005). Lack of sleep can affect memory (Maquet, 2001; Wagner et al.), cognitive functioning (Faubel et al.), and alertness (Bonnet and Arand, 1995), which can lead to poor work performance and put individuals at an increased risk of injury. As such, increasing individuals' awareness of their own and others sleep habits has the potential to motivate changes in behavior that result in healthier daily practices (Fogg).

While different information and activities have been utilized to assess connectedness and awareness, we only focus on sleep as a daily activity. We aim to investigate how monitoring and sharing sleep information as another type of activity can impact awareness, connectedness, and sleeping behavior. Sleep information, e.g., whether a person has gone to bed or is awake, shows not only one's daily routines but also indicates physical state, reveals one's sleep patterns, and reflects a sense of wellness. This information can be valuable not only to oneself, but also to others. On one hand, knowledge of one's sleeping habits might explicitly trigger healthier sleeping behavior (e.g., if an individual realizes that she did not sleep enough during the past couple of days, she might attempt to catch up on sleep in the near future), on the other hand, being aware that most friends are already asleep might implicitly lead one to go to bed as well. Similarly, sharing this information with one's social network can facilitate social interaction and impact awareness and connectedness, as it indexes one's presence, absence, and availability.

We investigate three high-level research questions (RQs):

1. Is it possible to reliably monitor a user's sleep duration using only her interactions with a mobile phone application instead of using any physical or wearable sensors or devices?
2. Does providing a mechanism to track sleep information impact individuals' awareness of their own sleep habits and, if so, does this increased awareness inspire them to think of starting to engage in healthier sleep behaviors?
3. Does using an alarm clock that enables the sharing of sleep information through a social network impact users' feelings of connectedness and awareness?

To achieve our goal, we implemented a social alarm clock app for Android mobile phones, called Somnometer. The app allows users to rate their sleep quality and specify their sleep status, i.e., gone to bed, snoozed the alarm, and awake. Users can also share their sleep status and quality with their social network. While the quality of sleep is manually obtained from the user, the duration is estimated based on tracking a user's explicit interactions with the mobile application.

We conducted two user studies in an attempt to address our research questions and evaluate the prototype. In a controlled study, we recruited eight participants to use the app for six weeks and provide the research team with qualitative feedback on their experiences. As we were also interested in observing emergent user behavior, we conducted a second parallel study in the wild. To recruit broadly, we distributed the app on Google Play, the official Google Android marketplace, for free over the duration of the study. During the in-the-wild evaluation, of the 725 users who downloaded Somnometer, 173 used it actively over the course of six weeks.

The contribution of this paper is threefold. In this paper we demonstrate that:

- It is possible to monitor users' sleep duration using only an application on the mobile phone instead of using wearable actigraphy devices.
- Tracking and visualizing one's sleep habits impacts knowledge of sleep activity that, in turn, can be used to encourage healthier sleep behaviors.
- Sharing sleep information with social networks impacts feelings of awareness and connectedness among friends.

The remainder of this article is organized as follows. After providing a brief overview of related research projects and commercial products, we present the design and implementation of Somnometer. Next, we describe the experiments and their results. We then discuss the findings and lessons learned from the studies. Finally, we conclude the paper with possible future directions for this research.

2. Related work

Cui et al. reported that “for many people the mobile phone is the first thing that they interact with in the morning, and one of the last objects they use before going to sleep at night” (Cui et al., 2007). Inspired by this, we wanted to explore the possibility of an alarm clock app that is both easy to use for personal sleep analytics as well as having it be socially situated so that users can share their sleep status.

Since the early 1990s, online social sites have enabled users to share meaningful information with others (Bly et al., 1993). Researchers have explored sharing various activities to promote connectedness and awareness (Sahami Shirazi et al., 2011. For example, Hindus et al. analyzed how this concept could be applied to households and family life (Hindus et al., 2001). Kaye et al. explored the effect of simple information sharing among users and realized that even a one-bit communication device is perceived as a rich channel for communicating intimacy among users (Kaye et al., 2005). Bentley et al. reported on how sharing information about whether people are moving or not based on cell data impacts connectedness (Bentley and Metcalf, 2007). Dey et al. developed and evaluated awareness displays that indicated online presence of close friends and reported that the users of such displays can experience increased awareness and connectedness (Dey and de Guzman, 2006). In short, previous work shows that users perceive awareness and connectedness as being meaningful and important. This inspired us to investigate how sharing sleep patterns can impact awareness and connectedness.

We believe that sharing information on personal sleep patterns adds also a new dimension of sharing context both on a personal and a community level. Indeed, sleep patterns seems to have a tight correlation with awareness and connectedness. Interestingly, the bed, as a medium for intimate communication and as a tool for bridging the distance between remotely located individuals, has already been the subject of several projects, e.g., (Dodge, 1997; Goodman and Misilim, 2003). In Mhóráin and Agamanolis employed an augmented eye mask to monitor eye movements and transmit muscle signals of sleeping pattern to a remote device and map them to music. The aim was to increase awareness between non-collocated partners. However, the system was not evaluated through any formal study. *BuddyClock* (Kim et al., 2008) allows users in a small social network to automatically exchange sleep information with each other. It is reported that the alarm clock affected participant behaviors and allowed them to feel more connected to those with whom they shared their sleeping behaviors. By contrast, our app broadcasts an individual's sleep information to one's social network without conveying and exchanging the status of other users in addition to monitor the sleep duration.

When it comes to tracking sleep and helping people wake up or fall asleep at appropriate times, the alarm clock has long been the subject investigated by various researchers. Oznec et al. designed the *Reverse Alarm Clock* for improving children's sleeping behavior (Ozenc et al., 2007). The goal of this project was to help children know whether or not it is a good time to get out of bed. Landry et al. used an alarm clock for supporting personal, routine-based decision-making (Landry et al., 2004). The basic functionality of an alarm clock was challenged in (Schmidt, 2006) and a networked alarm clock was designed that uses other's presence information as a source for setting up the wake-up time. Hemmert et al. designed the *Digital Hourglass* to enable users to set a desired wake up time by the number of hours the user wants to sleep (Hemmert et al., 2009). With this approach users are more focused on the amount of sleep. In contrast to our app, we use explicit interactions between users and the app to implicitly and automatically estimate the amount of night sleep users have.

Audio is the modality most frequently used to wake up an individual using their mobile phone as an alarm clock. Some non-phone-based alarm clocks employ more creative and sophisticated strategies for waking individuals such as using tactile feedback, e.g., vibrating beds (mainly for persons with hearing impairments), visual feedback, e.g., through increasing brightening of lights gradually as with *Philips Wake-up Light*,[1] or simply forcing users to get out of bed to turn off the alarm by jumping from the nightstand and rolling away.[2] Furthermore, there are various products on the market today that can be used to track different aspects of sleep, such as duration, frequency, or quality using non-invasive methods of monitoring, called actigraphy devices. Actigraphs are used to record full circadian rhythm data over the course of multiple, successive days. Accordingly, they have the ability to produce insight in the user's sleep habits and rhythms. Actigraphy devices have been validated and used in the medical community and are also available as consumer information tools (*e.g.,* the *ActiWatch*®[3]).

Fig. 1. Somnometer, a social alarm clock for Android phones.

Several commercial mobile applications are also available that use the phone as a device to manually track users' sleep (e.g., *TYLENOL*® *PM Sleep Tracker*[4]). Some apps employ automatic sensing via accelerometer and orientation sensors to track sleep (e.g., *Sleep Cycle*[5] and *Sleep as an Droid*[6]). *FitBit*[7] monitors how many times and how long the user wake up during the night using a three-dimensional accelerometer and demystifies the user's sleep cycle. Other products have been targeting sleep phase detection specifically in order to wake up users at a more convenient sleep stage, using wearable units such as a headset (e.g., *Zeo*[8]) or a wristband (e.g., *WakeMate*[9]). Several researches also have investigated using body posture detection and movements during sleep as means to measure sleep quality (Van Laerhoven et al.), (Liao and Yang, 2008). However, our app does not use any actigraphy device to monitor sleep. We also refer to Choe et al. for a comprehensive overview on design considerations and challenges of using computing to support healthy sleep habits (Choe et al., 2011).

In contrast to previous projects, we only focus on sleep as a daily activity. Our research investigates the potential of monitoring sleep behaviors using only users' explicit interactions with the mobile phone app instead of using any sensor or actigraph device. The interaction with the app can reveal different information about the user's sleep status. We aim at exploring the feasibility and reliability of using such sleep information to provide feedback and impact their awareness on users' sleep habits. We further study how only sharing sleep activity information with social networks can be used as a way to impact awareness and feelings of connectedness. The app uses existing

[1] http://www.wakeuplight.philips.com/ (accessed May 2012).
[2] http://www.nandahome.com/ (accessed May. 2012).
[3] Actiwatch, Philips Respionics, Andover, MA, USA.
[4] http://itunes.apple.com/app/id317459304 (accessed May 2012).
[5] http://www.mdlabs.se/sleepcycle/ (accessed May 2012).
[6] https://market.android.com/details?id=com.urbandroid.sleep (accessed May 2012).
[7] http://www.fitbit.com/ (accessed May 2012).
[8] http://www.myzeo.com/ (accessed May 2012).
[9] http://www.wakemate.com (accessed May 2012).

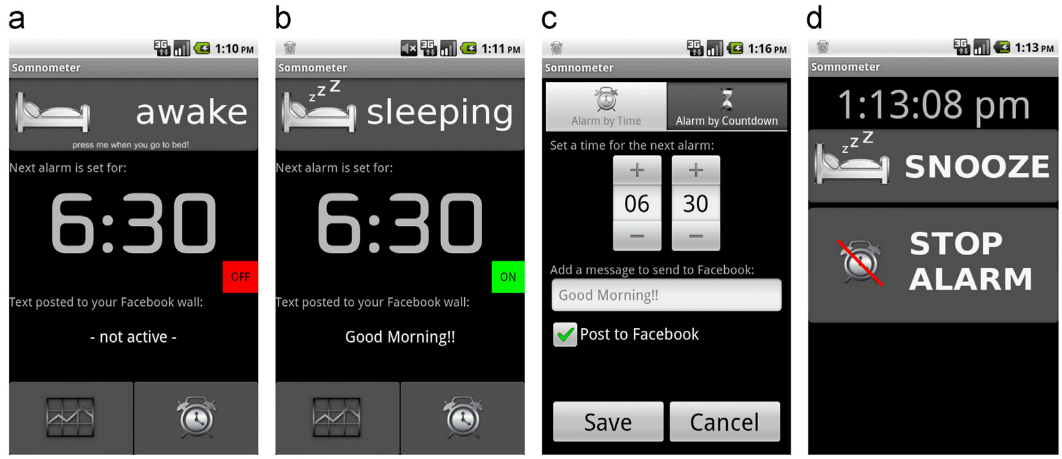

Fig. 2. SOMNOMETER app screenshots: (a) the user is awake and no alarm is set, (b) an alarm is set and the user has gone to bed, (c) setting an alarm in 2 ways: by time and by countdown timer and (d) the alarm can be snoozed or deactivated.

social network, i.e., Facebook for sharing the information and does not convey any information about other users.

3. Somnometer: A social alarm clock app

To answer our research questions we developed a social alarm clock app for Android phones, called Somnometer (see Fig. 1). The app allows users to collect information about their sleep and monitor their sleep behavior. Besides the conventional alarm clock features, users can define their sleep status, i.e., *gone to bed* or *awake*, and rate their sleep quality. Somnometer allows users to share their sleep status (gone to bed, snoozed the alarm, and awake) and quality with their friends through social networks and track their sleep behaviors. While the quality of sleep is manually obtained from the user, the app estimates the duration based on tracking a user's interactions with the app. The app is compatible with Android phones running on OS version 1.6 and higher.

3.1. App functionalities

In detail, the app has the following functionalities:

- Users need to set their alarm daily at any time in order to use this application.
- Provides two different ways to set an alarm: (1) by entering a specific time or (2) by defining a countdown timer (see Fig. 2c), which allows users to set the number of hours they want to sleep.
- Users can also specify their sleep status via a button on the top of the interface (Fig. 2a & b). The button has two states: “awake” and “sleeping”. As soon as an alarm is switched off, the app assumes that the user's status has changed and she is awake, thus the status button displays “awake” (Fig. 2a). On the other hand, when an alarm is set and the user explicitly presses the button, then the button toggles from “awake” to “sleeping” and it is assumed that the user has gone to bed (Fig. 2b). However, this does not mean that the user falls asleep immediately.
- When an alarm is trigged a dialog pops up allowing users to deactivate or snooze the alarm (Fig. 2d). The snooze default duration is 5 min and can be customized.
- Users can associate a message to each button state. The default messages in the app are “Good Night!” when the user goes to bed, “Sleep a bit more” when an alarm is snoozed, and “Good Morning!” when the alarm is deactivated. Users can modify the default messages. Furthermore, when an alarm is deactivated a dialog pops up, asking the user to rate her sleep quality (Fig. 3a). Reporting sleep quality is optional.
- When launching the app for the first time, the user grants the Somnometer access to her Facebook account with a limited set of permissions, enabling Somnometer to post these status messages to the user's Facebook Wall. The button “Post to Facebook” in Fig. 2c enables/disables sharing messages in Facebook.
- There are separate privacy controls available for sharing sleep state (the “awake”/“sleeping” status), the sleep rating, and snoozing. The default sharing setting is no info posted to Facebook. If a user chooses to share her sleep state with Facebook, her messages are automatically posted to the Facebook directly after their assigned states have occurred.
- Users have the ability to also choose to share their sleep ratings with Facebook. Sleep ratings are shared together with the “awake” message in a single status message.
- Since sharing sleep information might create privacy issues, it is crucial that users have a full control over what information is shared with whom. Thus, we provide a feature that enables users to customize the privacy setting of the Somnometer sharing posts and choose friends with whom they want to share their information. If the user does not use this feature, then the default privacy setting of her Facebook account is used.
- Some users prefer to keep mobile phones in silent mode in the bedroom. So in order to minimize disruption, a feature is provided which puts the mobile phone on silent mode when the user toggles the status button to “sleeping”.

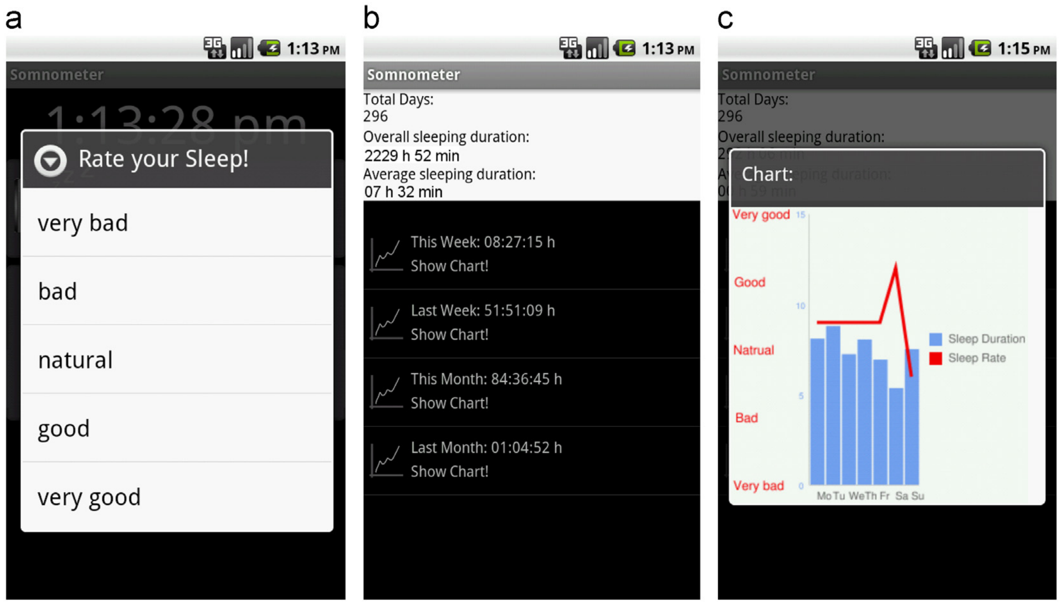

Fig. 3. After the alarm is stopped the user rate her sleep Fig. 4: (a) sleep duration is shown within different time frames (b) a week visualizes of the sleep behavior and quality.

To gather insight into app usage and understanding as to how users interact with the app, an analytics platform for mobile devices, called *Flurry*[10], was used. Moreover, in order to obtain demographic information about our users, we ask the users to enter their gender and age when the app is installed and launched for the first time. We also ask how often and for which purposes they use their phone alarm clock. Answering these questions is optional. All collected data are stored anonymously in an online central database. Somnometer is localized in English and German to target a large and diverse set of users.

3.2. Monitoring sleep behavior

A key feature of Somnometer monitors a user's night sleep duration automatically based on the user's interaction with the app, aimed at answering RQ1. RQ1 challenges the reliability of monitoring a user's sleep duration using only her interactions with a mobile phone application instead of using any physical or wearable sensors or devices. By recording the active status and monitoring changes, it is possible to estimate how long a user has slept. We log the following information:

- time of day when users set an alarm ($t_{\text{alarm\_set}}$)
- scheduled wake up time (t_{alarm})
- time of day when users went to bed (t_{bed})
- number of times an alarm is snoozed (n_{snooze})
- duration of snooze (d_{snooze})
- time of day when alarm is deactivated ($t_{\text{deactivate}}$)

[10]http://www.flurry.com/ (accessed May 2012).

Thus, the sleep duration (d_{sleep}) is estimated by the difference between the times the user went to bed and the alarm was deactivated.

$$t_{deactivate} = t_{alarm} + n_{snooze} d_{snooze}$$
$$d_{sleep} = t_{deactivate} - t_{bed}$$
$$d_{alarm} = t_{deactivate} - t_{alarm\_set}$$

The deactivated time ($t_{\text{deactivate}}$) might differ from the scheduled wake up time (t_{alarm}) if the alarm is snoozed. The time of day when users went to bed (t_{bed}) is the time the user manually presses the status button and changes the button state from “awake” to “sleeping”.

However, there is a chance that the user just sets an alarm as a reminder, forgets to press the status button when going to bed, or took a short nap. In this study we are particularly interested in *nightly* sleep, so we try to filter out irrelevant information by defining following rules: (1) if the sleeping status is not changed and the alarm duration (d_{alarm}) is less than 120 min, we presume the alarm is used as a reminder or she had a nap and ignore this dataset. (2) If the alarm duration (d_{alarm}) is more than 14 h and if the user forgot to change the sleeping status (manually), thus t_{bed} is not available and the calculation of the current sleep duration is ignored. We considered 14 h as the upper threshold, as this is well above the sleep duration of healthy adults.

To gather information about the user's sleep quality, a dialog pops up when an alarm is switched off and asks the user to explicitly rate their sleep on a 5-point Likert scale (1 = very bad, 5 = very good) (see Fig. 3a). This dialog pops up if the calculated sleep duration (d_{sleep}) is more than 2 h. In an effort to provide the user information on her sleep habits, the sleep duration and ratings are visualized using a chart that allows users to toggle between different time frames (week and month) as depicted in Fig. 3b and c.

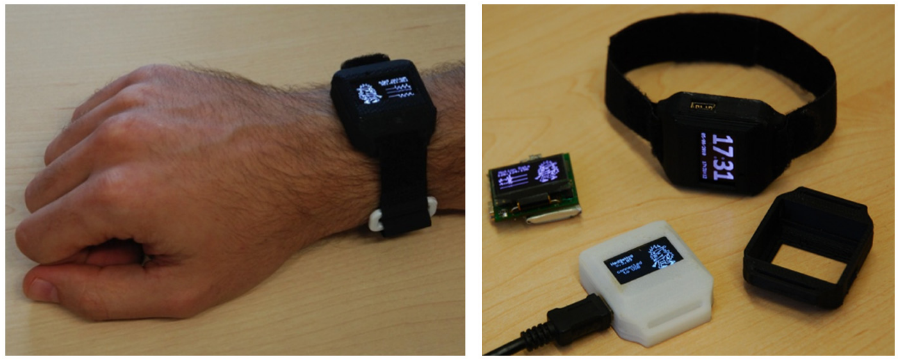

Fig. 4. HedgeHog is a device worn like an actigraph at the dominant wrist records motion, posture, and light data over a long time-span.

3.3. Obtaining ground truth sleeping data

As mentioned above, users' sleep duration is estimated based on their interactions with the Somnometer application. To assess how reliable the estimated sleep duration is, we used HedgeHog[11], an open source device that is worn like an actigraph on a user's dominant wrist and records motion data over a long time-span (Fig. 4). HedgeHog measures three modalities for nightly sleep detection: (1) Light intensity, which is typically low during nightly sleep, (2) Amount of motion using a 3D accelerometer sensor, since movements are rare during sleep, and (3) Time of day, where nightly sleep occurs usually between 11pm and 9am. It uses these three pieces of information as inputs for a Hidden Markov Model (HMM) classifier for automatically detecting sleep sessions. The HMM classifier is already trained with the data gathered from 10 users (2 female and 8 male, average age 33 years) over the course of six months. The device has been previously validated to detect nightly sleep and other sleep characteristics in different research projects such as Borazio and Van Laerhoven (2011); Borazio and Van Laerhoven (2012). This actigraph device can measure the sleep duration and quality more precisely. By using these devices, we gathered ground truth data without users having to annotate sleep segments themselves.

4. Controlled user study

We conducted a controlled study in which we apply a mixed-methods approach to develop a fuller picture of user practices through the use of questionnaires, interviews, and automatic logging. In our controlled study we investigated the feasibility of tracking sleep habits based only on users' interaction with the app without the use of wearable sensors. We assembled several HedgeHog systems and used them as the ground truth for this study. The controlled study also investigated whether sharing sleeping status can impact connectedness and awareness between friends. It investigated the impact of providing feedback about sleep patterns to users on their behavior.

[11]http://www.ess.tu-darmstadt.de/hedgehog (accessed May 2012).

4.1. Setup

Subjects: We conducted a within-subject study for six weeks by recruiting eight students (all male, average age 24 years, SD = 2.5) from different majors at the University. None of the participants reported having any type of sleeping disorder or had participated in any other sleep study. They were compensated with €20 at the end of the study.

Since our target group was users who use their mobile phone as an alarm clock, we recruited participants who had already adopted this practice prior to using the app. During the study we asked our participants to use Somnometer as their main alarm clock and to share their sleep status messages and ratings on Facebook. We deliberately chose participants who were regular Facebook users (spending at least an hour per day browsing Facebook).

Procedure: we divided the participants into two groups of four. The first group started the study by sharing status messages and ratings on the Facebook (G1) while the second group did not share any information (G2). After three weeks the participants were informed to switch groups.

Before starting the study, all participants were invited to the lab and introduced to the study. They were asked to fill in a demographics questionnaire and received a Hedgehog device. We asked participants to wear the device during the entire duration of the study, particularly when they went to sleep. In order to ensure the app worked on their phone properly, we asked them to download and install the app on their phone and to familiarize themselves with the app before leaving the lab. Researchers were available to answer any and all of the participants' questions.

After six weeks, the participants were invited back to the lab to return the sensor. At this time, they completed a questionnaire about their experience with the app and its usage during the study. They were also interviewed and asked to provide feedback about their experience using the app in order to assess the connectedness. They additionally filled in a SUS (System Usability Scales) questionnaire (Brooke, 1996). Apart from collecting data from the app, we also collected the comments on Facebook posts shared by the app during the study.

4.2. Results

Based on the data logs, 336 alarms were scheduled during the controlled study and 347 messages were posted on Facebook (Mean=43.37 messages/participant, SD=3.11). However, we encountered with several issues in recording the information, for example, bugs in the app, no network connection, and running out of battery. Furthermore, participants sometimes forgot to rate their sleep. These issues forced us to only consider 217 data out of 336 for further analysis. This data include complete information about the sleep sessions (duration and rate). The average sleep duration was 7.44 h (SD=1.17) and average rating was 3.45 (SD=1.04).

An ANOVA test revealed that sharing on Facebook had a significant effect on the sleep rating, $F(1215)=5.487$, $p<.05$. Interestingly, the participants rated their sleep worse when they shared it on Facebook ($M=3.31$, SD=1.06) compared to not using sharing on Facebook ($M=3.64$, SD=.99). The results show no significant difference in their sleep duration between groups.

The Pearson correlation analysis revealed a positive correlation between the sleep duration and its rating ($r=.23$, $n=217$, $p<.001$), depicted in Fig. 5. Further analysis indicated that the highest rates, i.e., good or very good, were given to sleep durations between 5.20 and 8.06 h. The questionnaire results revealed that participants found the app very useful and easy to use. The score of 83 out of 100 in the SUS test also reflects the usability of the app. Five out of the eight subjects mentioned that they might use the app further.

4.2.1. Assessment of sleep duration (RQ1)

Unfortunately, the HedgeHog sensor did not always record all sleep information during the study due to a variety of issues (e.g., battery failures, waterproof problems, etc.). These technical shortcomings reduced the amount of the data available for comparison. Therefore, we considered only the sleep duration datasets calculated by the app on the days that the HedgeHog device successfully measured the sleep duration. This resulted in 20 data-pairs. The statistical analysis, interestingly, revealed that on average the duration obtained from HedgeHog (Mean=8.12, SD=1.46) was not significantly differed from our app (Mean=7.98, SD=.87), $F(119)=.22$, $p=.64$, $r=.44$. The start and end time of sleep collected by the sensor and the app also significantly correlate, start time: $r=.57$, $n=20$, $p<.05$, end time: $r=.58$, $n=20$, $p<.05$. No notable individual differences found in the dataset.

4.2.2. Self reflection and behavior change (RQ2)

Based on the qualitative feedback obtained from the questionnaires and interviews, all participants found the analytical chart as the best feature of the app in comparison with other available features such as, the sharing posts in Facebook, set an alarm by the countdown timer, or automatically activate the silent mode. This finding is supported by the fact that participants checked the chart on average once per day during the study. They reported that the chart increase

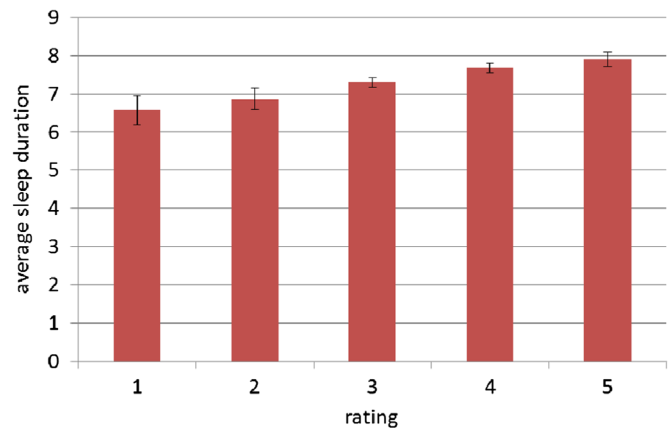

Fig. 5. The analysis reveals that longer sleep session get higher ratings.

their awareness about their own sleep habits and helped them to track their sleep behavior:

P3: “With the chart I was able to check if I slept enough during the last days.” (P4 and P7 also gave similar feedback as P3).

P2: “I tried to keep my sleep duration around 7 h by using the chart.”

P5: “I [found out] that I didn't get enough sleep during the week, so promised myself to sleep longer on Sunday.”

P7: “I never thought such feedback could encourage me to think about my sleep behavior.”

Interestingly, the users reported increase of awareness on their sleep behavior that induced them to change in their sleep behavior but the analysis did not convey any significant difference in the users' sleep patterns.

4.2.3. Sharing sleep information on facebook (RQ3)

We analyzed the Facebook comments received on different posts, i.e., went to bed, snooze, and waking up posts sent by the app. Fig. 6 depicts average number of comments for the different posts. The results showed the 347 posts received 138 comments in total (Mean=17.25 comments/message, SD=14.99). The waking up posts received more comments (Mean=10.93 comments, SD=13.31) on Facebook than other posts sent via the app, i.e., snooze (Mean=.56, SD=.74) and went to bed posts (Mean=2.43, SD=2.8), (P1: “*Good Morning”;* Comment: “*Such a long sleep*”; P1: “*why not once in a while!”*), (P6: “*Good Morning – My sleep was natural*”; Comment: “*mine not:-(*”), (P2: “*Good Morning*”; Comment: “*Oh! You are awake, call you now*”), (P8: “*Good Morning Germany*”; Comment1: “*Good Morning Japan*”; Comment2:*”Good Morning Canada”*). Further, we grouped the posts and looked at their comments. The analysis showed that, interestingly, the posts that included negative ratings, indicating bad or very bad sleep, received 45% more comments. These comments were mainly concerned with why the user had experienced a bad night sleep and if there was something wrong (P5: “*Good morning Facebookers! – My sleep was very bad!*”; Comment: *“why? probably because you woke up too early on weekend;-)”*).

On average participants had 148.5 friends (SD=45.9) on Facebook. The users chose to share their posts with 47% of their

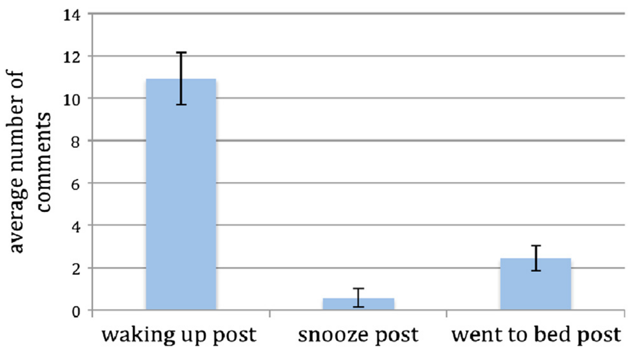

Fig. 6. Average number of comments received on posts sent on Facebook using Somnometer app.

friends on average (SD = 68.6). Six out of eight participants had customized the privacy setting of the messages shared on the Facebook using the app feature. When they were asked with whom they shared the sleep data on the Facebook, participants stated that they mainly shared this information with their partner, best friends, family members, and their colleagues. The participants mentioned that they wanted to share the sleep status only with those individuals who they know well and with whom they are in contact more often as this information might be important for them (P1: "*I shared my status with one of my classmates as we work together on [a project]",* P6: "*I shared the data with my mom to call me when I am awake"*). Meanwhile, they all expressed a belief that sharing this information could invade their privacy.

During the interview, the participants were asked whether sharing the sleep information with friends in social networks impacted their awareness and connectedness. Seven participants experienced the change of awareness among their friends:

P2: "One day I was absent in a lecture. One of my friends checked my Facebook wall and found out I was still asleep. He sent me SMS and reminded me that I missed the lecture."

P5: "My partner told me that before she called me, she checked on Facebook if I am awake."

P6: "I saw friends went to bed and I also went to sleep."

P8: "My friend asked me why I had a bad sleep last night as she knew it from Facebook."

However, they mentioned that frequently sharing this information might irritate their friends. We observed this theme in the analysis of Facebook posts, too (P1: "*Good morning fans! – My sleep was very good",* Comment: "*Do you plan to rate your sleep and share it every single day?:/"*).

4.3. Discussion

The results of the controlled study suggest that it is feasible to monitor a user's sleep duration based just on her interactions with an alarm clock app on the mobile phone. Previously, such sleep monitoring had only been possible using specialized tools such as an actigraphy device. For people who already use an alarm clock app daily, the study suggests that monitoring explicit interactions with the app provided enough information to estimate the user's sleep duration. The statistical analysis showed that the sleep duration acquired from the app is not statistically different than the data obtained from the HedgeHog. Thus, it might be possible to successfully monitor users' sleep duration using just an application on a mobile phone (RQ1). Obviously, for more accurate recording, actigraphy devices are essential.

While asking participants to choose the best feature of the Somnometer app, all participants surprisingly ranked the sleep chart the highest, indicating that users are interested in tracking their sleep behavior. Providing a method of visualizing sleep behaviors is necessary for such applications. Data collected from the interviews and questionnaires revealed that simply providing users with feedback of their personal sleep behavior has the ability to persuade users think about their sleep behavior and start engaging in healthier behaviors (RQ2). Thought, no statistical evidence was revealed in the study. This result aligns well with past work on encouraging exercise (Consolvo et al., 2006). It should be noted that one's sleep behavior can be impacted by many other factors, for example, diet, environment, daily activities, etc. which is not taken into account in this study.

The results further revealed that sharing sleep information with one's social networks impacted awareness among friends (RQ3). Users indicated that they would like to share this information with their social networks. However, users were concerned that sharing sleep information on Facebook had the potential to invade their privacy.

Specifically, our participants expressed that they want to share sleep information with individuals with whom they already have a high degree of social contact as well as with those who they know will find the information useful, e.g., partner, family, close friends, or colleagues. Our participants however expressed that they do not want to share their sleep information with the whole community, as they believe that doing so has the potential to annoy, frustrate, or otherwise bother their friends and colleagues. As such, providing a means to easily administrate with whom sleep information can be shared is crucial. This can be addressed well with recent privacy features in the social networks such as Google+'s circles. Analyzing extracted messages shared via the app and their comments from Facebook revealed that posts with negative ratings received more comments. This supports the idea that friends were concerned about each other and curious to discover the reasons for the low sleep ratings. Good morning messages also received more comments compared to other messages shared in Facebook via the app. This increase in comments might results because if friends knew when a user had woken up, then they knew that she might be available to react and respond to their comments. Consequently this behavior led to an increase in interaction and a feeling of connectedness among friends.

It should be mentioned that controlled studies have certain limitations. Inline with similar research the sample size of such studies are small. Furthermore, the participants use this system only during the study. Long-term usage may reveal other information. The participants in our study were only male, hence there is a probability that the results are gender biased.

5. In-the-wild living laboratory evaluation

With the first study, we wanted to capture users' natural interaction with the application. This is problematic in tightly controlled laboratory-style user studies with a small sample size. As such, we decided to develop and release the app on Google Play, the official Google Android market, and let users download and use the app for free over the course of six weeks. We conducted the in-the-wild study in order to capture emergent user behavior in an effort to better understand how users engaged with the app. Using the Android market allowed us to reach many users and rapidly push new updates to users.

5.1. Setup

We published Somnometer on July 7th 2011 and promoted the app by announcing it via mailing lists, forums, and social networks. We completed data collection on August 18th 2011. The app logged all changes in sleep state and any post sent to the Facebook via the app in a remote central database. As this was an in-the-wild study, there was no manipulation of the variables or features provided by the app. Every participant had the same version of the app and were instructed how to use the app in the same manner. Doing this gave us the ability to observe users' natural behavior. For example, we let each user decide whether or not they wanted to share information with Facebook via the app.

5.2. Results

According to the Android market portal, the app was downloaded 725 times during the six weeks study. Based on the *Flurry* portal, we accrued a total of 3522 sessions of usage (median 2.5 sessions/day). A session was determined to be one use of the application by an end user that typically began when the app was launched and ended when the application was terminated. Furthermore, 55% of users had used the app for only 1 or 2 times over the six-week study period. This left 45% of the participants who used the app more than 3 times.

Based on our database, 173 unique users had set an alarm and at least tried the app, where 166 of them had shared a sleep status message and 165 of them had also shared a sleep rating on Facebook via their use of the Somnometer app. 10 out of 166 users who shared a sleep status message customized privacy settings. The users had on average 258.4 friends (SD = 242.3) on Facebook. Interestingly, only seven individuals chose to share no information on Facebook. Ten people customized the privacy setting, and they chose to share with only 18% of their friends on average.

In total 120 unique users answered the optional survey (72.5% male, average age 29.3 years), with 62% of whom often or always using the alarm clock feature of their phone. Also 85% of all survey participants used the alarm clock as a wake up alarm and 61% as a reminder. In total 454 alarms were scheduled, 86% of which were set by entering a specific time. The mean duration between setting an alarm and pressing the status button ($|t_{alarm\_set} - t_{bed}|$) was 37.6 min. Fifty-five users also checked the sleep chart at least once during the study (Mean = 4.8 times, SD = 1.9).

Since the study occurred in an uncontrolled environment, it was not uncommon for a user to use the app only once or to drop out during the study. To cope with this, we removed data from users who used the app only once or had no night sleep session (a sleep session is the time from when alarm is defined until that alarm is deactivated and the time between the two events is greater than 2 h ($d_{alarm} > 2$ h)). This resulted in 268 sleep sessions from 93 users for the analysis.

We investigated the sleep duration and rating behaviors between the users who shared data in Facebook vs. those who did not share. A one-way analysis of variance revealed significant differences in regard to their sleep duration ($F(1266) = 3.92$, $p < .048$) but not on their rating behaviors ($F(1266) = 3.35$, $p > .82$). While the average sleep duration of those who shared was longer ($n = 151$, Mean = 7.67 h vs. $n = 117$, Mean = 7.34 h), the average rating was lower than those who did not share data in Facebook ($n = 151$, Mean = 3.32 vs. $n = 117$, Mean = 3.46).

Similar to the controlled study, Pearson correlation analysis indicated a positive correlation between the sleep duration and rating ($r = .13$, $n = 268$, $p < .03$).

5.3. Discussion

Almost one hundred participants actively engaged with the application and used the app regularly. They, indeed, demonstrated an interest in tracking their sleep habits and sharing sleep information online with their friends through social networks. The results also revealed that users who shared data with their friends tend to sleep longer. But, interestingly, they rated their sleep lower. This might be a way to redirect friends' attention toward themselves. The correlation between sleep duration and rating was similar to the controlled study. The users recruited from the wild also customized the privacy setting of posts shared in Facebook. This shows that it is important for users with whom this information should be shared. Unfortunately, due to the privacy issues we were not able to gather information about comments on the posts sent via the app from the users recruited in the wild.

While studies in the wild provide this opportunity to test a system out of a laboratory setting with many users but they are conducted in an uncontrolled environment and have certain limitations (Henze et al., 2011). It was inevitable that some users would download the app without using it, use it infrequently, or opt out of participating in the study (Schleicher et al., 2011). Logging users' interactions and behaviors also potentially dissuaded some users from engaging in the study, as they might not be willing to share this information. Furthermore, it is very hard to get information about participants and their context. Therefore, there are uncertainties whether the participants are representative for different age range.

6. Conclusion & future work

In this paper we investigated three research questions: (RQ1) whether it is possible to reliably monitor sleep behavior using simply a mobile phone; (RQ2) how providing users with the ability to track their sleep behavior could empower them to engage in healthier sleep habits; and (RQ3) the impact that sharing sleep information on social networks has on awareness and connectedness among friends.

To address our research questions, we developed a social alarm clock app for Android phones, called Somnometer. Observing that many individuals currently utilize their mobile phone as an alarm clock revealed behavioral patterns that we were able to leverage when designing Somnometer. We conducted two studies: a controlled study and a study in-the-wild. While the controlled study had its own limitations we simultaneously published Somnometer as a free application on the Google Play marketplace and conducted an in-the-wild study to capture natural usage behavior of individuals who had downloaded the app.

Based on the controlled study, we determined that it is possible to monitor users' sleep duration using just an application on the mobile phone instead of have to rely on using wearable actigraphy devices. We also demonstrated that sharing sleep information with social networks impacts feelings of awareness and connectedness among friends. For the participants were important to share the sleep data with those who they find the information has value. Further, sharing of Facebook has significant effect on the sleep rating. Users rate their sleep worse when they share it on Facebook. One reason can be to redirect friends attention toward themselves.

The qualitative results revealed that providing means to track and visualize one's sleep habits impacts knowledge of sleep activity that can be used to encourage healthier sleep behaviors. The investigation of the social alarm clock in-the-wild uncovered desires to share sleep patterns with other. However, privacy concerns pertaining to sharing intimate information on social networks. While in the controlled study most of the participants customized the privacy settings, only 10 users in-the-wild did that which indicate an interesting privacy paradox. In a hyper-connected world, users' desire to connect with each other might include informing each other of minute and even intimate details of everyday life. Doing this correctly is hard, especially in the face of users' privacy concerns. Our investigation here is a glimpse of what that world might be like.

The results suggest that Somnometer had the potential to induce healthier sleep habits. One idea is to provide users with the ability to compare their sleep charts. Comparing sleep charts opens up the possibility of designing games or competitions that could induce modified sleep behavior. Participants' feedback indicates that users would indeed be interested in sharing their sleep charts (P2: “*I'm really interested to compare my sleep chart with friends using the app.”* P3: “*It would be great if I could share the chart with my friends.”*). Understanding how users interacted with their mobile phone alarm clock enabled us to successfully calculate sleep duration by monitoring a user's interactions with the app (setting, snoozing, and disabling their alarm). We are interested in pursuing this same design approach to develop more behavior tracking tools. Further, conducting a longitudinal study to observe much longer-term use of the application can reveal more insights into users behavior.

Acknowledgments

We thank Dr. Niels Henze for the helpful discussions and comments. The project was partly funded from the German Research Foundation within the Cluster of Excellence in Simulation Technology (EXC 310/1) at the University of Stuttgart.

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