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Automatically Captured Sociability and Sleep Quality in Healthy Adults

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Abstract— **Sleep and social interactions have been shown to have a considerable public health impact. However, little is known about how these affect each other in healthy individuals. This research is first to propose the exploration of the bidirectional relationship between technologically sensed sleep quality and quantified face-to-face social interactions. We detail a pilot study designed to study the relationship of sociability and sleep quality, both measured and perceived, of healthy adults. We capture real-world social interactions and measure sleep in a naturalistic setting using wireless sensing technologies. We find that it may not be the device-defined sleep quality (ZQ score) but our perceived sleep quality which affects our following day's sociability. Further, we also find perceived sleep quality is more strongly correlated to normalized ZQ scores than the actual scores. These intriguing insights raise several questions on how an individual's social life could be affected by sleep and indicate the usefulness of mobile sensing technologies in understanding public health phenomena.**

I. BACKGROUND AND MOTIVATION

Sleep with its considerable role in public health, has led to several studies trying to understand its impact on both physical and psychological health including social well-being [1-3]. The role of social relationships and its importance in maintaining health and well-being has also been discussed in earlier studies [4-6], yet little is known regarding the relationship between an individual's real world social interactions and sleep quality.

Previous studies attempting to understand the effect of social interactions on sleep have focused on loneliness, social isolation and depressive symptoms and have not been able to capture the dynamic nature of real world interactions in healthy individuals. Due to limitations of gathering rich social interaction data, these studies relied on self-reported social information collected through surveys, which is prone to inaccurate, biased and incomplete data.

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With the improvement in technology, it is now possible to capture this data ubiquitously using mobile phones. Features such as Bluetooth, GPS on these mobile devices enable reality data mining, measuring who an individual interacts with and the frequency of these interactions. This attempts to capture an objectively measured picture of an individual's complex social behavior within a community. This research uses such rich dynamic data to quantify an individual's social behavior using mobile technology to study its relationship with sleep, both quality and quantity. Recent studies have suggested that behavioral effects such as weight gain seems to show stronger relationships with such interactions than self-report social information [7, 8] and so we would like to take this opportunity to study the relationship of these rich interactions with sleep measured in a naturalistic setting.

Sleep has a considerable public health impact and poor sleep has been shown to have adverse health effects from psychiatric illnesses such as depression to physical health risks such as obesity and diabetes [9-11]. It can also lead to behavioral consequences such as sleepiness, impaired cognitive function, low job performance, accidents resulting in both health and financial losses [12, 13].

Most studies either use self-reported sleep information or use methods such as laboratory PSGs for objective assessment of sleep which can disturb and change an individual's usual sleep quality and quantity. In-home studies have utilized methods such as actigraphy which can only detect sleep/wakefulness patterns and are prone to inaccuracies by misinterpreting quiet wakefulness as sleep [14]. With this research, we plan to study quantified sleep quality in a real-home environment using a wireless mobile technology and study its relationship with sociability.

It is important to study these factors in the 'wild' because that is how people live in the real world. Sleeping in an unfamiliar environment and out-of-routine can disturb and change an individual's usual sleep quality and quantity from that under habitual conditions. An animal study on mice showed that these exhibit significantly different activity rhythms in the field when compared to laboratory environment [15]. This suggests that laboratory experiments and survey collected information prevents us from capturing and understanding the real world dynamics of these factors.

This is the first study designed to explore the bidirectional relationship between sleep quality and quantified face-to-face social interactions. It will be interesting to study how these two factors affect each other since studies have suggested that self-reported social ties can have a significant effect on the spread of health related behaviors such as

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obesity [16]. A study involving undergraduate students found lonely individuals reporting poorer sleep than non-lonely individuals [2] and another interesting study showed that social ties with close friends influenced sleep loss in adolescent social networks [17]. In this work, we wish to uncover the associations between real world interactions and sleep quality. One of our earlier studies found that subjects whose mood was significantly affected by previous night's sleep tended to have greater sociability [18]. However, that study included only self-reported sleep duration information. In this work, we include quantified sleep quality as sleep quality has been shown to be a better indicator of health and well-being than just sleep quantity [19] and reduced sleep quality parameters have been shown to influence diabetes and hypertension [20, 21]. We also gather information about perceived sleep quality through traditional surveys, which may not be easy to capture automatically.

In this work, we leverage the opportunity to gather rich social and sleep quality information together and study how these affect each other in healthy individuals. We believe that such rich sleep and sociability data will provide us novel insights into if these factors captured from the 'wild' are related to each other.

II. EXPERIMENT

A. Study Population

This study was conducted in a real-world setting and included 20 healthy subjects, 10 couples, living in a graduate dorm. The subjects included 14 students (10 males and 4 females). The remaining subjects were spouses that were not students. The subjects ranged from 20-35 years of age with a mean age for males of 28 years and mean age for females of 26.8 years. The study was approved by the Institutional Review Board (IRB) of the university and participants provided informed consent as approved by the IRB.

B. Data collection

Data was collected over a period of two weeks in March and April 2011. The dataset used in this work includes a combination of automatically captured face-to-face interactions, objectively measured sleep quality and self-reported sleep quality. Fig. 1 shows an overview of the methodology.

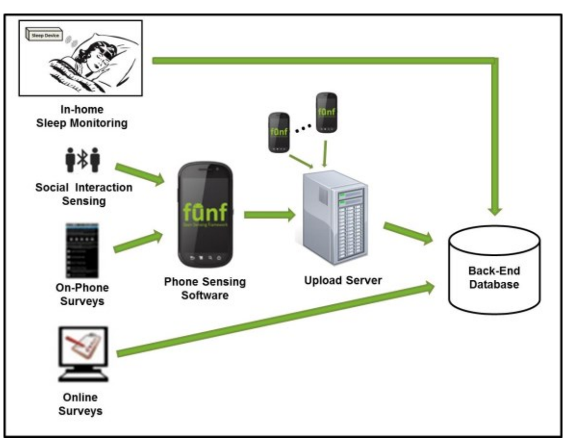

Figure 1. Methodology Overview

C. Social Interaction Data

All subjects were provided with Android operating system based mobile phones augmented with a software platform which sensed and recorded proximity to nearby phones and other Bluetooth devices. This allowed us to track face-to-face interactions through Bluetooth proximity sensing. The subjects were asked to use the study phones as their primary phones for the length of the study. The phones also had a survey application which allowed them to answer survey questions. This study was part of a larger study where detailed description of the data collection platform and the technologies used are available elsewhere [22].

Since most participants were students, the social interaction time a person had on a particular day is considered to be between 4 am to 4 am on the next day to include post mid-night interactions, common in a student community. Social interaction time defines how social an individual has been on that day. Sociability was defined as the total amount of social interaction time a person had on a particular day. This measure considers both the actual time a person spent interacting and the number of people with whom there were interactions. For instance if a person is interacting for 10 minutes with 3 different people, the social exposure is taken as 30 (3*10). Sociability was normalized per subject by converting each subject's values to a normalized value between 0-1 with a value closer to 1 indicating that the sociability on that day is close to the highest sociability observed for this individual over the period of this study. A value closer to 0 indicates the opposite: the daily sociability is close to the lowest observed value for that individual. Sociability was normalized to understand its variations within subjects.

Participants whose social interaction times were very low and did not reflect their average sociability during the larger study were eliminated from the analysis. Causes for such anomalies include technical failures and subjects traveling away from the community. This resulted in elimination of 7 subjects. Subjects who had less than five data points of overlap between their sociability and sleep nights were eliminated from the analysis. This resulted in the exclusion of two additional subjects. The remaining 11 subjects were analyzed. These included 7 males and 5 females. These subjects provided N=123 subject nights, with sociability and sleep data. Details of sleep capture are described in the next section.

D. Sleep

Sleep was monitored using an automated wireless system, Zeo Bedside Sleep Manager which includes an elastic head-band and a bed-side unit [23]. It is a commercially available device and has been validated for reliable and accurate monitoring of sleep in healthy adults [24]. Sensors are embedded on the headband which allows dry contact with the forehead and does not require any adhesive like that in PSG electrodes. The sensors detect frontal EEG (electroencephalographic) signals and a neural network algorithm uses these to classify the signals into the various sleep stages. The headband wirelessly communicates with the bedside unit which stores the sleep stage architecture (hypnogram) data onto the SD card. The data can then be exported for analysis. The raw EEG data is not stored by the device.

Participants, following their normal routine, were asked to use the Zeo head-band for 14 nights in their homes. Participants could view their previous night's hypnogram every morning on the alarm clock display and also check how long they spent in the various sleep stages through the bed side unit. The device also provides an over-all sleep quality indicator, ZQ score which is a single measure of sleep quantity and quality. It is calculated from the total sleep time along with adding and subtracting points based on restorative and disruptive sleep. The device-defined indicator ZQ score was used as the measured overall sleep quality. Nights with ZQ scores below 21 and when subjects reported the head-band falling off were eliminated from the analysis.

Subjects were asked to complete a questionnaire each day about their perceived sleep quality (the options provided ranged from 1 to 7 where 1: very poorly; 4: Neither poorly nor well; 7: very well).

III. Data Analysis and Results

Nights with high (good) and low (bad) sleep quality were separated based on (1) survey reported sleep quality and (2) measured Zeo data. Sociability for good and bad sleep quality nights were compared using a Wilcoxon Rank Sum test.

Nights with high and low reported sleep quality were determined based on the 1-7 reported sleep quality scale, where bad nights were defined with reported sleep quality of 1-3 (n=33) and good nights were defined with reported sleep quality of 5-7 (n=68). To analyze across subject variations in ZQ scores, nights with ZQ scores above 80 were defined as good nights (n=59) and nights below 60 were defined as bad nights (n=37). Within subject variations in ZQ scores was analyzed by normalizing each participant's ZQ score by dividing each observed value with the median ZQ value of that individual. Nights below normalized score of 0.85 (n=32) were defined as bad nights and those above 1 as good nights (n=69). As with reported sleep quality scale of 4, slept neither poorly nor well, we determined the range of 0.85 to 1 in normalized ZQ score as representative of the same middle range.

Fig. 2 shows the following day's sociability box plot distribution for good and poor reported sleep quality.

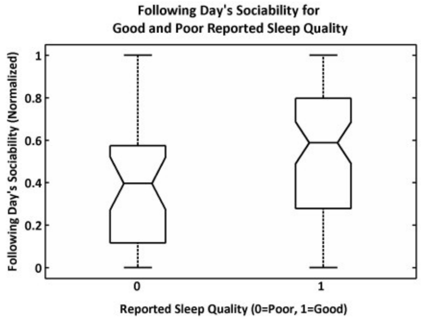

Figure 2. Reported Sleep Quality is associated with Following Day's Sociability

The median sociability after nights in which a participant reported poor sleep quality and the median sociability after nights when good sleep quality was reported were significantly different (p=0.038), where the median sociability was higher when good sleep quality was reported for the previous night. No significance was found with previous day's sociability and sleep. Median sociability after nights with low ZQ scores and nights with high ZQ scores showed no significant differences.

To understand how survey reported sleep quality compared with technologically measured Zeo sleep quality indicator ZQ, we ran a Spearman Rank test using the daily reported sleep quality, measured ZQ and normalized ZQ scores. Correlating normalized ZQ scores with reported sleep quality showed a significant spearman rank correlation (rho=0.4; p<0.0001) (Fig. 3). The correlation with actual ZQ score was lower (rho=0.3; p<0.001) than that with normalized ZQ score.

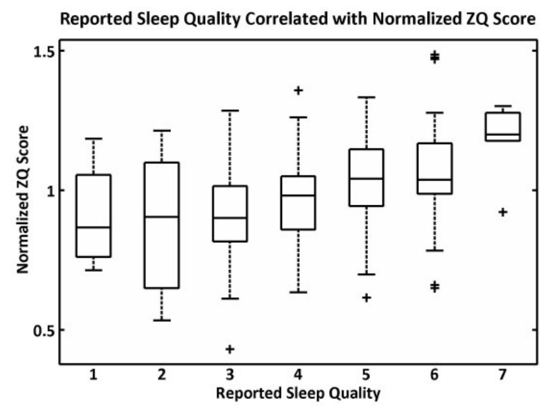

Figure 3. Reported Sleep Quality is associated with Measured Sleep Quality

IV. Discussion and Conclusion

Interestingly, this study suggests that sociability is different for high and low reported but not measured sleep quality, even though reported and measured sleep quality are significantly correlated. This suggests that it may not be the device defined sleep quality, but our perceived sleep quality that affects our following day's sociability. This result is novel and has not been reported prior. Another interesting result is that perceived sleep quality was found to be more strongly correlated with normalized ZQ scores than the non-normalized scores. This suggests that the perception of how well one slept is affected by within individual differences in scores more than the actual score. This is an intuitive finding since a person who gets better sleep than his usual would perceive it as very good, irrespective of how another person might be sleeping with that same ZQ score. However, since the correlations we found are not very high, this suggests that our perceived sleep quality may not be fully explained by objectively measured sleep quality. Our perception may be dependent on a number of external factors. These intriguing results raise further questions on how an individual's sociability might be linked to specific sleep quality parameters and how our perception of our sleep is affected by these factors.

These interesting insights would not have been possible without the novel use of smartphones to quantify face-to-face interactions of subjects. Moreover, the ability to capture sleep data in a real world setting provides us with a more reliable way to study these relationships. This integrated approach of social computing and wireless sensing allowed us to understand some relationships between sleep quality and sociability. These results are important because they indicate the usefulness of social sensors and wireless sensing in understanding public health phenomena. It also indicates the importance of sleep quality to an individual's sociability and requires moving beyond a pilot and pursues further studies to delve deeper into these relationships.

Sleep has been shown to be affected in depressed people but these findings suggest that even in healthy individuals their sleep quality could be associated with their day to day social life. The small sample size is a limitation in this study and further larger studies are required to validate these results. Missing data was also an issue for a number of subjects resulting in their exclusion from analysis. Future studies attempting to capture real-world data should consider the problems of missing data and should be designed to minimize these. For example, subjects should be asked to report their usage and times they were outside the community so that their data can be used accordingly. The software platform only detects interactions within this community. These limitations potentially can be mitigated by conducting experiments involving larger populations. Since ZQ score is an overall measure of sleep quality, the relationship of the different sleep phases with sociability may bring deeper insights. Capturing real-world data comes with its problems of missing data but despite these limitations, this study brought novel insights. With the increasing advancements in technology to capture dynamic real-world data and availability of home sleep monitoring, studies run in the 'wild' will provide key insights into our understanding of how these factors affect our health.

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