On the Reactivity of Sleep Monitoring with Diaries

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Abstract: The declining costs of wearable sensors have made self-monitoring of sleep related behavior easier for personal use but also for sleep studies. Several monitor devices come with apps that make use of diary entries to provide people with an overview of their sleeping habits and give remotely advice. However, it could be that filling in a sleep diary impacts people's perception of their sleep or the very behavior that is being measured. A small-scale field study about the effects of sleep monitoring (keeping a sleep diary) on a cognitive and a behavioral level is discussed. The method was designed to be as open as possible in order to focus on the effects of sleep monitoring where participants are not given a goal, motivation or feedback. Some behavioral modifications were observed, for example, differences in total sleep time and bedtimes were found (compared to a non-monitoring week and a monitoring week). Nevertheless, what the causes are of these changes remains unclear, as it turned out that the two actigraph devices used in this study differed greatly. In addition, some participants became more aware of their sleeping routine, but changing a sleeping habit was found challenging because of other priorities. It is important to know what the effects may be of sleep monitoring as the outcomes may already have an effect on the participant behavior which could cause researchers to work with data that do not represent a real life situation. In addition, the self-monitoring may serve as an intervention for facilitating healthier sleeping habits.

1 INTRODUCTION

Self-monitoring your sleep is becoming increasingly accessible to the general public. An already large number of smartphone applications and dedicated devices are available on the consumer market that help track sleep related behavior, (e.g., sleep duration, waking up during the night, etc.) reflecting the current trend towards the 'Quantified Self' which seeks to empower individuals to collect information about themselves, to help them approach health professionals already informed by an initial analysis, and to support health interventions with monitoring their behavior and overall well-being (Swan, 2012).

Actigraphy devices and traditional sleep diaries are widely used in sleep related research as they are low cost and allow monitoring sleep behavior in real life (Carney et al., 2012; Sadeh, 2011). Researchers have often been concerned with studying correlations between the two as they provide subjective and objective measures of sleep quality, e.g., see (Lockley et al., 1999). However, such works do not consider the potential effect of self-monitoring of sleep on a behavioral or cognitive level. Will people adjust their habits and more importantly will self-monitoring lead to healthier habits? Or perhaps it is just knowing that one is being monitored that makes one feel to adjust his or her sleeping habits?

Self-monitoring has been researched thoroughly in the past, especially when it is used as an intervention (Amato-Zech et al., 2006; Burke et al., 2011; Butryn et al., 2007; Helzer et al., 2002; Hufford et al., 2002; Martin et al., 2006; Matevey et al., 2006; O'Kane et al., 2008; Wang et al., 2012). The effects found in these studies differ greatly and make self-monitoring effects ambiguous. The effect self-monitoring may have on a cognitive and behavioral level pertains to the *reactivity* of self-monitoring. Reactivity is a phenomenon that emerges when persons alter their performance or behavior due to the awareness of being observed (Korotitsch and Nelson-Gray, 1999) Kazdin (1974) investigated different aspects of self-monitoring, such as response desirability, goal setting and feedback upon people's performance on a sentence-construction task. It turned out, amongst others, that:

1) *administering a performance goal or feedback amplified the reactive effects of self-monitoring,*
2) *monitoring one's own behavior or being monitored by someone else was equally reactive,*
3) *the process of self-recording provoked behavior change independently of observing the results.*

These findings indicate that the very act of self-monitoring as such may result in reactive behavior (As earlier described in Goelema et al. (2014).)

That reactivity is related with self-monitoring has been shown in the study of Motl et al. (2012). The purpose of the study was to test a behavioral intervention for persons with multiple sclerosis (MS). However, the average steps per day was higher during the baseline period compared to the first week of the behavioral intervention. One possible explanation for this result may be that during the baseline period the participants wanted to make as many steps as possible to make a good impression. This study is a perfect example of the need to interpret carefully results pertaining to the potential reactivity of self-monitoring.

As for the traditional way of sleep monitoring, keeping a diary, there is little known about the reactivity effects. Bolger et al. (2003) concluded that there is insufficient evidence that reactivity forms a threat to diary validity. Litt et al. (1998) reported that although their participants became more aware of the monitored behavior, the self- monitoring was not reactive. Still, this study only monitored the urge to drink and not assessed a full diary. Specifically for sleep monitoring, the effects of keeping a diary have not yet been investigated. Only a recent study of Todd and Mullan (2014), reported that keeping a sleep diary (combined with a response inhibition intervention) made people avoid anxiety and stress-provoking activities before going to bed. However, since the study of Todd and Mullan includes an intervention, any effects on behavior may not be attributed to the self-monitoring per se. Nevertheless, cognitive behavioral therapy is often supported by keeping a diary and thereby shaping awareness (Okajima et al., 2011).

We performed a first study (briefly reported in Goelema et al., 2014), expecting that tracking behavior with actigraphy would impact sleep related behavior. This was not confirmed, and as it turned out it was the act of keeping a diary that seemed to impact on the cognitive level though less on a behavioral level. This finding prompted the current study where we investigated the effects of keeping a sleep diary. The set-up of study 1 was reverted for this study. During the whole three weeks participants wore an actigraphy device and filled out only in the second week a sleep diary. We hypothesized that between the first week of non-filling out a diary and the week of keeping a diary the sleep efficiency (SE) and total sleep time (TST) increases and wake time after sleep onset (WASO) and bedtime (BT) decreases in the second week. Secondly, we hypothesized that when comparing week 2 with week 3 the results would be the reverse, namely a decrease of SE and TST and increase of WASO and BT.

2 METHODS

2.1 Participants

To safeguard the reliability of our results, we decided to recruit participants aged between 40 and 60 years old. The reason for choosing this age range was that Monk et al. (2003) found a significant association between lifestyle regularity and good sleep. Moreover, previous research has shown irregular sleep quality and rhythm amongst school-aged children, youngsters, and adolescents (Dahl and Lewin, 2002; Monk et al., 1994; Sadeh et al., 2000). To assess whether completing a sleep diary affects people's lives, a population is needed that normally would show regular sleeping times. Considering this, the target group was set to age 40-60, assuming that people around this age have the most stable daily routine and sleep rhythm.

Because of practical constraints relating to the availability of devices, two groups of 10 subjects were made, originally resulting in 20 participants for this study. Participants wore a different device in each group (see heading measures) and one group started two weeks later. The process of recruitment was the same for each group. The intended fifteen nights of data per participant (total of 300 data records as opposed to the eventual 203 records) was reduced greatly because of several circumstances. These circumstances included failure of data recording from the devices, failure of setting 'In and Out Bed Times' (software related issues), failure of following instructions by participants and the irregularities in the sleep pattern of participants (emergencies, illness, parties, deadlines, that have led to exceptional bed times). The loss of data ruled out five participants, eventually resulting in a total of 15 participants for this study.

2.2 Measures

Participants were asked to fill in the Pittsburg Sleep Quality Index (Buysse et al., 1989) to determine their normal sleeping behavior. The PSQI contains 19 self-rated questions, which are combined to form seven 'component' scores, each ranging from 0-3 points ('0' indicating no difficulty and '3' indicating severe difficulty). The seven component scores together form a 'global' score, ranging from 0-21 points, '0' indicating no difficulty and '21' indicating severe difficulties in all areas.

The 'Consensus Sleep Diary' (CSD) was used only in the second week, which contains questions about initiating and maintaining sleep as well as a global appreciation of sleep (Table 1) (Carney et al., 2012) Sleep diaries are effective tools to get an insight in participants' sleeping behaviour and discover changes in sleeping patterns.

Table 1: Consensus Sleep Diary - Core

Consensus Sleep Diary – Core
1. What time did you get into bed?
2. What time did you try to go to sleep?
3. How long did it take you to fall asleep?
4. How many times did you wake up, not counting your final awakening?
5. In total, how long did these awakenings last?
6. What time was your final awakening?
7. What time did you get out of bed for the day?
8. How would you rate the quality of your sleep? (Very poor, poor, fair, good, very good)

At the end of the study, a short interview was held with each participant. Amongst others they were asked if and how the CSD influenced their behaviour. Did they go to bed and get up earlier or later because of the diary? Did they change any rituals and were they more aware of the hours of sleep they should be getting? Furthermore they were asked about their sleep experience during the whole period of the study, and more specifically whether they slept better or worse comparing the different phases of the study. In addition, questions regarding the effect of wearing an actigraphy device during sleep were also assessed. The closing interview also took care of certain irregularities that might have occurred in the data (e.g., occasions that might have disturbed a good night's sleep, or events that required the participant to go to bed much later or get up much earlier than regularly). Lastly, during the closing interview we revealed to them the actual goal of the study (investigating the reactivity effects of a sleep diary).

Participants in Group 1 (participants 101-107) were given the Philips Actiwatch Spectrum (Philips Respironics, Inc, Murrysville, USA), while participants in Group 2 (participants 108-115) were given the ActiGraph device (ActiGraph, LLC, Pensacola, FL). Both devices make use of an accelerometer to detect and log wrist movement, also known as actigraphy. They were set to a standard data sampling rate of 120 per hr (every 30 seconds), providing ample data per night.

2.3 Procedure

The participants were instructed to wear an actigraphy device on their non-dominant hand from Sunday-Monday night to Thursday-Friday night for 3 weeks straight, excluding the weekends and including the wake-up-times on working days. Participants were asked to fill out the CSD each morning, only during the second week.

Many actigraphy sleep–wake scoring algorithms rely on sleep diary information to set scoring periods for sleep onset and offset. In this study, participants were instructed to start wearing their device when they were trying to fall asleep. In case of going to bed earlier to read a book, watch television, etc. they were told not to wear the actigraphy device until they actually wanted to go to sleep and then to put it on the wrist. Furthermore they were instructed to take off the actigraphy device right after their final awakening. For the Actiwatch the same procedure was applied, only the function of the marker button to indicate that someone wanted to fall asleep was explained extra, but eventually barely used by the participants.

2.4 Data Analysis

'In Bed' and 'Out of Bed' times were determined by analyzing the beginning and endings of the activity graphs. One participant reported to have forgotten to take the ActiGraph off. This omission and other mistakes were corrected by using the 'In Bed' and 'Out of Bed' times indicated in the diaries. In case of unreliable indications, data was removed from the calculations. The sleep efficiency was calculated as ratio of the total minutes of sleep time (TST) divided by the total minutes of time in bed (TTB).

Statistical analyses were conducted using SPSS IBM 20. New variables were computed to extract the mean of the SE, WASO, TST and BT of each week to take care of missing values. Repeated measure analysis was conducted, with time (the phases of the experimental study) as the within subject factor. The contrast repeated was used, to compare week 1 with week 2 and week 2 with week 3. The assumption of sphericity was met, meaning that the level of dependence between experimental conditions was roughly equal. However, the assumption of normality was not met and therefore the outcome of the Greenhouse-Geisser test was used. The repeated measures analyses were done for each parameter (SE, TST, WASO and BT), and for the complete group. First, we looked at whether there was a main effect for time and if so, then pairwise comparisons were examined. For each group separately paired-sample t-test or Wilcoxon signed ranked test was conducted. Statistical significance was set at $p < 0.05$.

3 RESULTS

The characteristics of the sample are listed in Table 2. The average age of the sample was just under 52 years and 10 out of 15 were women. For group 1, the average amount of sleep time was 5.89 hours (SD =0.9 hours) and for group 2 it was 6.55 hours (SD = 0.82 hours). The average PSQI score was a little above the cut-off score of 5, this would indicate that the participants experienced slight sleeping problems.

Table 2: Demographic data and sleep characteristics of the samples

	Group 1 (N = 7)	**Group 2** (N = 8)
Age	51.14 (5.8)	50.9 (3.9)
Gender ♂	5	5
Bedtime	24:05:49 (41:13)	23:25:29 (36:51)
TST	353.23 (54.3)	393 (48.9)
WASO	58.11 (23.2)	36.9 (20.6)
SE %	81.5 (6.4)	91.3 (4.7)
PSQI	6 (2.5)	5.7 (2.4)

Note. Values are mean (standard deviations) or percentage of cases. Bedtime = (hh:mm:ss)/ (mm:ss)TST = total sleep time (min), WASO = Wake time after sleep onset (min), SE = Sleep efficiency and PSQI = Pittsburgh sleep quality index.

First all data from both groups were analysed using the mean value for each week per participant. For the complete group no significant results were found, between baseline and week 2 or week 2 and week 3 (for example: SE, mean week 1 = 85%, mean week 2 = 87%; df = 2, F = 2.54, p = .097, Figure 1).

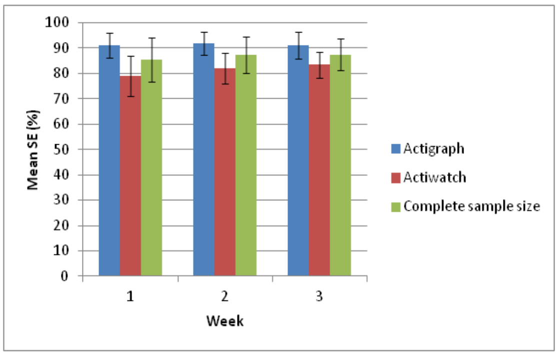

Figure 1: Mean sleep efficiency (SE) for each week, displayed for each group separately and for the whole sample, including error bars (1 +- SD).

When testing the hypotheses for only the participants who wore the Actiwatch no significant results were found for SE and WASO. There was a significant difference between baseline and week 2 for TST (Z = -2.197, p = .028; mean TST: week 1 = 328, week 2 = 361, Figure 2). This means that during the week of filling out the sleep diary the total sleep time was longer than during baseline. Moreover, a difference in mean bedtimes was observed between week 2 and week 3 (Z = -2.366, p = .018; mean BT: week 2 = 24:09:14 week 3 = 23:47:27, Figure 3). This indicates that in the last week of the study participants went to bed earlier than during week 2.

For the ActiGraph group no significant results were observed between baseline and week 2 or week 2 and week (For example: WASO, Z = -,98, p = .327; mean week 2 = 35,74, mean week 3 = 36,91, Figure 4).

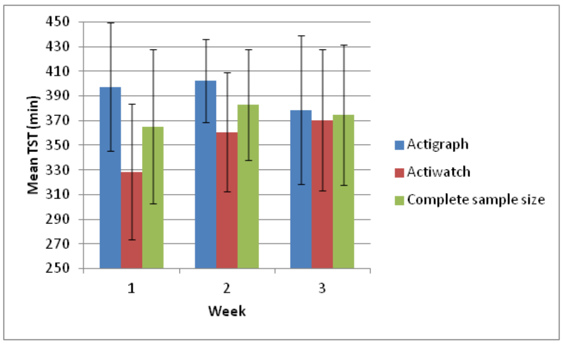

Figure 2: Mean total sleep time for each week, displayed for each group separately and for the whole sample, including error bars (1 +- SD).

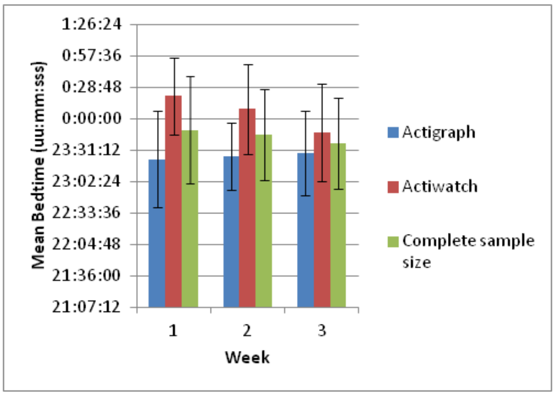

Figure 3: Mean bedtimes for each week, displayed for each group separately and for the whole sample, including error bars (1 +- SD).

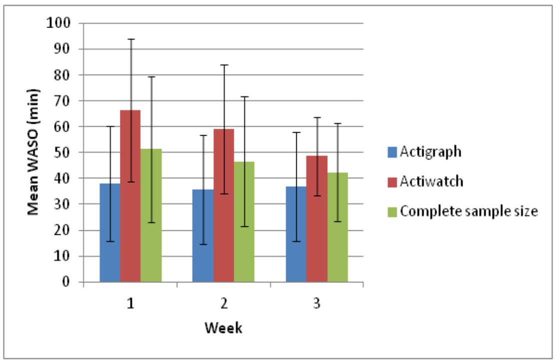

Figure 4: Mean wake time after sleep onset (WASO) for each week, displayed for each group separately and for the whole sample, including error bars (1 +- SD).

3.1 Closing Interview

The closing interview revealed that it was difficult for the participants to notice any difference in sleep quality on a weekly basis. The participants did not change their sleep routine based on filling the diaries. They did not go to bed earlier or changed their alarm clock settings. However, a handful of participants indicated that filling in the diary made them more aware of their sleeping habits.

Five participants reported that they did have to get used to the actigraphy devices during the first few days of the experiment. They indicated that this might have had a minor influence when falling a sleep the first few days. Except for one participant who reported very bad sleep during phase 2 according to that subject of wearing de actigraphy device. What did become apparent, was that as the study evolved wearing the actigraphy devices became an automated process of which the participants were less aware than in the beginning.

4 DISCUSSION

A significant effect was found when comparing TST of week 1 with week 2 and between bedtimes of week 2 and week 3 of the Actiwatch group. The increase of the TST was expected while the decrease of bedtimes in week 3 was not anticipated, as we had expected the opposite effect. It could be that the decrease in bedtimes in week 3 is caused by keeping the diary which may have had longer lasting effects (the week after). No significant results were found with the overall group or the Actigraph device. Because of trends seen in the graphs, we also compared the baseline with week 3, and found significant effects between total sleep time and bedtimes in the Actiwatch group, however, what the cause of these effects could be remains unclear. Participants indicated during the closing interview, that they experienced worse sleep only in the first one or two nights of the study, because they had to get used to the actigraphy device and the general idea of participating in a sleep related study. Moreover, no differences were found in the outcomes between good and bad sleepers based on PSQI scores (≤ 5 is considered as good).

In this study important differences were found between the results of the Actigraph and the Actiwatch devices. The reliability and validation of actigraphy is a much discussed topic and it may have played a role in this outcome. Related reports support the validity of data recording with the Philips Actiwatch (Gironda et al., 2007; Hyde et al., 2007; Weiss et al., 2010), whereas the Actigraph seems to be less reliable (Hjorth et al., 2012). The golden standard for sleep studies is considered to be polysomnography (PSG). Although actigraphy and PSG tend to correspond reasonably well (Ancoli-Israel et al., 2003; Tryon, 2004), research reports measurements errors in actigraphy (Blackwell et al., 2008). Therefore it could be that the found results are caused by the use of different devices. (We found significant differences between the Actiwatch group and the Actigraph group, for instance, mean TST week 1, $Z = -2.32$ $p < .021$). As a result, conclusions based on the objective measures (actigraphy) of this data set could not be made.

However, based on the closing interview, participants mentioned they did not change any sleeping habits, but some of them were more aware of their sleeping routines because of filling in the the sleep diary. This confirms the findings by Goelema et al.(2014), where some participants did change or tried to change their pre-bedtime rituals, probably caused by filling in the sleep diary. These studies suggest that presumably motivation or a significant alteration in the daily routine of a person is a necessary prerequisite for influencing sleeping behaviour through self-monitoring.

A remarkable side-note on the failure of following instructions by participants, is that during the diary week, hardly any missing data was recorded while in week 1 and week 3 there was considerably more missing data. This confirms earlier investigations on wrist actigraphy adherence research by Carney et al. (2004), who suggests that combining actigraphy monitoring with diaries can increase the likelihood of adherence to sleep instructions.

The behavior of sleep is deeply rooted in one's daily routine and modifying this behavior will have a large impact on the rest of the daily rhythm. Vice versa, ‘other factors’ influence sleeping behavior greatly. This means that probably one needs to be motivated to actually adjust a sleep behavior. When participants are motivated for adjusting a behavior, in the majority of studies, significant results have been found, at least for the short-term (Bouffard-Bouchard et al., 1991; Zimmerman and Kitsantas, 1999). Although these studies were all conducted on different topics, such as improving learning skills than on changing sleeping habits, there is a high likelihood that the same will be true for adjusting a sleeping behavior or thought. This would mean for sleep monitoring, that when individuals are motivated they are more eager to adjust their sleeping behavior and this could lead to alterations in the daily routine of that person. Moreover, it will increase the level of self-control and could contribute to a healthier lifestyle, as it becomes more known that sleeping well is essential for health, psychological well-being and daytime functioning (Totterdell et al., 1994).

The importance of motivation for self-monitoring can be integrated into a theory of self-regulation, however several versions of the self-regulation theory are proposed (Ajzen, 1991; Fishbein, 1979). Schunk and Zimmerman (2008) argue that motivation is an essential dimension of self-regulation learning, while other theories put more emphasis on the self-efficacy beliefs and discrepancy in costs and benefit it may have on the short or long term.

In addition, this motivation may be affected by the feedback a monitoring device gives. When the insight into a certain behavior increases, this will make a person more aware of their behavior and therefore the feedback could turn into an agreeable argument to get motivated to adjust that behavior. If feedback could have been given immediately then the outcome might have been different, as has been found in several other studies (Gajar et al., 1984; Kazdin, 1974). Most consumer-level devices available in the market supply feedback to their users, giving users a great insight in their monitored behavior. Moreover, persons are encouraged to set personal goals, to acquire a healthier lifestyle. For persons with already a high desire of self-control this would serve as a handle to gain control of one’s life.

This study is the first study that makes an attempt to explore the reactivity of sleep measures in a quantitative way. The effect size found of the significant result between TST 1 and TST 2 for the Actiwatch group was medium: .587. However, whether this effect size is significant for clinical purposes remains unknown. On average a person sleeps between 7 and 8 hours, but what the acceptable deviation from 7 a 8 hours is, is not known. There is no clear clinically relevant effect size within the sleep field operationalized. Moreover, an individual situation is probably more important for disparity in total sleep time, as sleep is very interlinked with the daily routine it can have a significant effect for one individual and not for another individual.

As mentioned in the method section, there was a difference in the expected 300 data records and the eventual 203 data records, because of unforeseen circumstances. The loss of data should be accounted for and possibly be prevented. Future research, could attempt to replicate these results during a longer study. To adjust behavior, and especially (sleep) behavior that is incorporated in the daily routine, it probably takes more time to adjust. In addition, a cross-over design or adding a control group that is not subjected to a diary is another way to control and justify temporal effects. Moreover, a distinction between persons who already want to improve their sleep and those who are just curious about their sleep should be made. This will give an insight into the motivation level of a participant before starting with the study, which is an important factor on their thoughts and behavior. Lastly, the influence of feedback should also be accounted for by the study method, to find out what the effects are of feedback on sleep monitoring.

To conclude, objective behavioral changes were observed in the Actiwach group whether this is due to the device that was used or a real behavior change remains inconclusive. Nevertheless, higher awareness due to filling in the diary was observed in both of our studies. It is important to know what the effects can be when self-monitoring your sleep, as the prospect is that monitoring physiological features will become more and more normal and more advanced devices will be available. This can lead to more awareness of the behavior that is being monitored. Moreover, the effects of sleep monitoring need to be taken into consideration when someone is coached remotely, as data that is presented may not represent real life information.

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