DIFFERENCES IN LIGHT SLEEP AND DEEP SLEEP MEASURED WITH IST VIVAGO® WRISTCARE

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Abstract: Activity monitoring is a widespread alternative to polysomnography (PSG) in studying sleep/wake patterns because it enables inexpensive long-term monitoring and does not require laboratory conditions for recording. IST Vivago® WristCare is a wrist worn activity monitoring device, which has been found to produce similar results to traditional actigraphs in sleep/wake detection. The movement sensor of Vivago® is more sensitive to low intensity movements than that of traditional actigraphs. We compared activity measured with IST Vivago® during deep sleep, light sleep and awake. The results showed that average ($p<0.001$) and standard deviation ($p<0.00001$) of activity are significantly lower in deep sleep than in light sleep. However, minute-by-minute classification of sleep level was not successful. In conclusion, Vivago® activity gives indication of the overall sleep quality, but does not allow sleep stage classification.

Introduction

Sleep problems are becoming increasingly common, especially among senior citizens. Over 50% of people over the age of 65 years have at least one chronic sleep complaint [1]. Sleep problems are due to various factors, for example, medical and psychiatric conditions, medication side-effects, and age-related changes in circadian patterns [2, 3]. Poor sleep correlates with health complaints, mental problems, poorer subjective quality of life, and increased risk of accidents and falls [1, 3, 4]. Most sleep problems are treatable, but about 50% of sleep problems are not diagnosed by primary care physicians [5]. Diagnosis is typically done based on the patient's subjective assessment of his/her sleep quality. This can be done with a simple questionnaire, sleep log. Sleep log is a very convenient and inexpensive method for assessing sleep quality, but also inaccurate due to its subjective nature. Furthermore, sleep logs do not provide information about sleep stages [6].

Polysomnography (PSG) is the golden standard in the diagnosis of sleep problems. PSG recordings consist of the measurement of several physiological signals, for example: brain electric activity (electroencephalography; EEG), heart electric activity (electrocardiography; ECG), eye movements (electrooculography; EOG), and muscle activity (electromyography; EMG). PSG recordings are expensive and sensitive to artifacts, and therefore unsuitable for long-term and out-of-laboratory use.

Actigraphy is a popular alternative to PSG in the study of sleep/wake cycles. Movement sensors in the wrist device measure the activity of the user, and the detection of sleep is based on the finding that there is less movement in the wrist asleep than awake. The agreement between actigraphy and PSG in discriminating between wakefulness and sleep is reasonable, typically above 90% [7]. In addition, actigraphy is unobtrusive, inexpensive, and suitable for use over prolonged periods. IST Vivago® Wristcare (Vivago®; IST International Security Technology Oy, Helsinki, Finland) is a wrist worn activity monitoring device, which has a movement sensor particularly sensitive to low intensity movements [8].

The objective of the present study was to study the differences in the wrist activity measured with Vivago® during deep and light sleep (defined by PSG). The focus was on finding out whether wrist activity provides information on the quality of sleep.

Materials and Methods

The data set used in the present study has been previously used in Lötjönen et al. [9]. The data consisted of one-night wrist activity and PSG measurements from 28 subjects (6 males and 22 females) with mean age 62 years (range 26-87 years, SD 19 years). One subject was excluded from this study due to suspected timing error between Vivago® and PSG data. The study group was divided into three groups for analysis. The first group contained all subjects (N=27). The second group consisted of middle-aged subjects under the age of 65 (N=13, mean 44 years, SD 10 years). The third group consisted of senior subjects over the age of 65 (N=14, mean 78 years, SD 7 years).

Vivago® was used for measuring activity for one night from the non-dominant wrist. Vivago® is an intelligent social alarm system, which in addition to the manual push button alarm also generates automatic alarms based on sensor data. The system consists of a wrist unit (Figure 1), base station, and alarm-handling software. The wrist unit measures the activity of the user, and transmits it to the base station over a radio link thus making the data available online [8].

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Figure 1: Vivago® wrist device for activity monitoring.

The Vivago® activity data are similar to traditional actigraphy, but the movement sensor in Vivago® is more sensitive to low-intensity movements than traditional actigraphs (Figure 2). Vivago® has also been found to perform equally to actigraphs in sleep/wake detection; Lötjönen et al. found agreements of about 80% between Vivago® and PSG [9]. It has also been shown that Vivago® activity differs between demented and non-demented subjects [10].

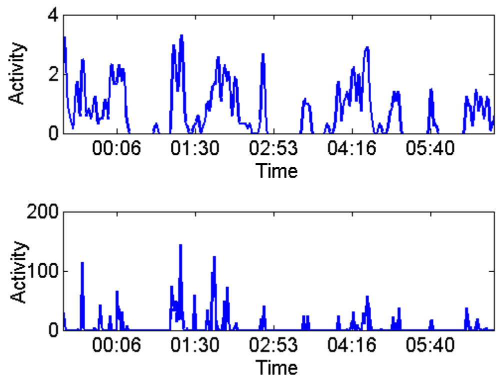

Figure 2: Vivago® activity signal (above) and traditional actigraphy (Actiwatch, Cambridge Neurotechnology, AW4) over one night.

In addition to wrist activity, PSG signals were recorded over night. The PSG in 30-second segments was scored using the standard Rechtschaffen and Kales criteria [11]. Then, the data were transformed to one-minute segments by rescoring a segment as "wake" if both wake and sleep states were present [12]. In the present study, sleep stages 3 and 4 are called "deep sleep", and stages 1, 2, and REM (rapid eye movement) are called "light sleep".

Only activity measured in bed simultaneously with PSG was studied, thus "awake" means "awake in bed". First, total sleep time during the study night and the proportion of deep sleep based on PSG classifications were calculated for the three groups. Mean and standard deviation of Vivago® activity in segments of deep sleep, light sleep, and awake were also calculated for all groups. The differences in mean and standard deviation parameters between sleep stages and subject groups were compared statistically.

Classification of sleep stages based on activity was attempted with the following procedure. First, activity signal was classified as sleep and wake as described in Lötjönen et al. [9]. Sleep segments with activity equal to or lower than a threshold A were classified as deep sleep. Ratio between deep sleep time and total sleep time was calculated and compared to that calculated based on PSG classifications. Five values (0, 0.1, 0.2, 0.3, and 0.4) for threshold A were tested.

SPSS 12.0 software package was applied for statistical computations. Wilcoxon Signed Ranks test was used for comparing variables due to the small number of subjects in the study.

Results

Subjects slept on average 5.2 hours (range 3.2-7.1h, SD 1.2h) during the recording night. Middle-aged subjects slept longer (mean 5.8h, range 3.7-7.1h, SD 1.0h) than senior subjects (mean 4.7h, range 3.2-6.5h, SD 1.1h; $p=0.02$). On average, deep sleep constituted 25% (range 6-49%, SD 11%) of total sleep time. The proportion of deep sleep of total sleep time was somewhat smaller for middle-aged subjects (mean 23%, range 6-40%, SD 8.5%) than senior subjects (mean 27%, range 9-49, SD 13%; ns).

For all three groups, average (middle-aged: $p=0.02$; senior: $p<0.001$; all subjects: $p<0.001$) and standard deviation of activity (middle-aged: $p < 0.001$; senior: $p<0.001$; all subjects: $p<0.00001$) were significantly smaller in deep sleep than in light sleep. The differences in these parameters between the groups were not statistically significant (Figure 3). Thus, the results are presented for the first group (all subjects) only. The data for individual subjects are presented in Figure 4.

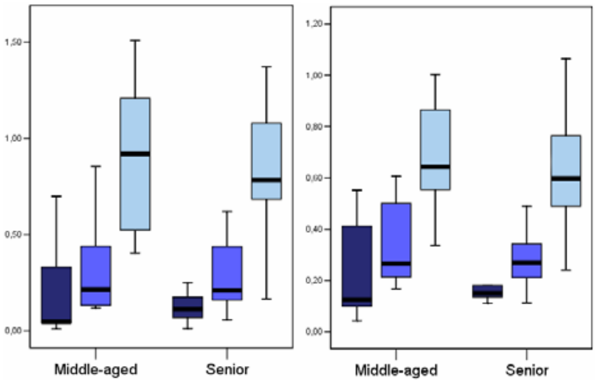

Figure 3: Box-and-whiskers plot depicting different distributions for average activity (left) and standard deviation of activity (right) in deep sleep (dark blue), light sleep (blue), and awake (light blue) for middle-aged and senior groups. Thick lines indicate the median, box edges represent the 25-75% quartile range and the whiskers indicate the overall range.

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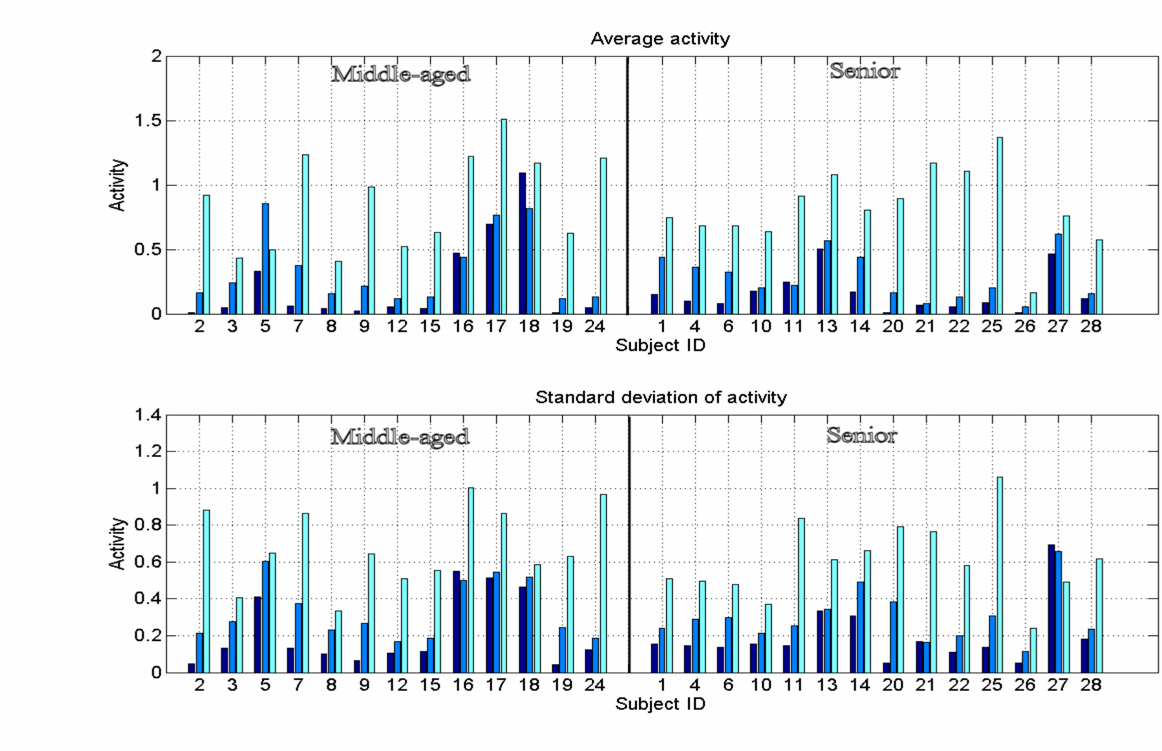

Figure 4: Upper picture: average activity for each subject in deep sleep (dark blue), light sleep (blue), and wake (light blue). Lower picture: standard deviation of activity in different states. The 13 bar groups on the left represent the middle-aged subjects, and the 14 bar groups on the right represent the senior subjects.

For 22 out of 27 (81%) subjects both average and standard deviation of activity were smaller in deep sleep than in light sleep. The ratio of deep sleep to light sleep average activity was on average 0.50 (SD 0.36) and the ratio of standard deviations was on average 0.61 (SD 0.27). Altogether five subjects had higher average and/or standard deviation of activity in deep sleep than in light sleep. Two subjects (11 and 18) had higher average activity, and two subjects (21 and 27) had higher standard deviation of activity in deep sleep than in light sleep. In addition, one subject (16) had both higher average and standard deviation of activity in deep sleep. Furthermore, one subject (5) had higher average activity in light sleep than awake, and one subject (27) had higher standard deviation of activity in both deep and light sleep than awake.

Figure 5 presents the Vivago® signals and PSG classifications for subjects 2 and 3 from the middle-aged group. Subject 2 slept 6.6 hours during the study night and had 1.8 hours (27%) of deep sleep. The ratio between deep sleep and light sleep average activity was 0.06 and the ratio of standard deviations was 0.22. Subject 2 had three periods of deep sleep, which were also seen as low Vivago® activity. Activity in light sleep was higher, and activity in wake the highest. Subject 3 slept 4.9 hours during the night and had one hour (21%) of deep sleep. The ratio of averages was 0.19, and the ratio of standard deviations was 0.48. Subject 3 had a long period of deep sleep in the beginning of the night. Vivago® activity was also low during this period. Generally, subject 3 had higher activity in light sleep than in deep sleep, but there were also some light sleep periods with very low activity.

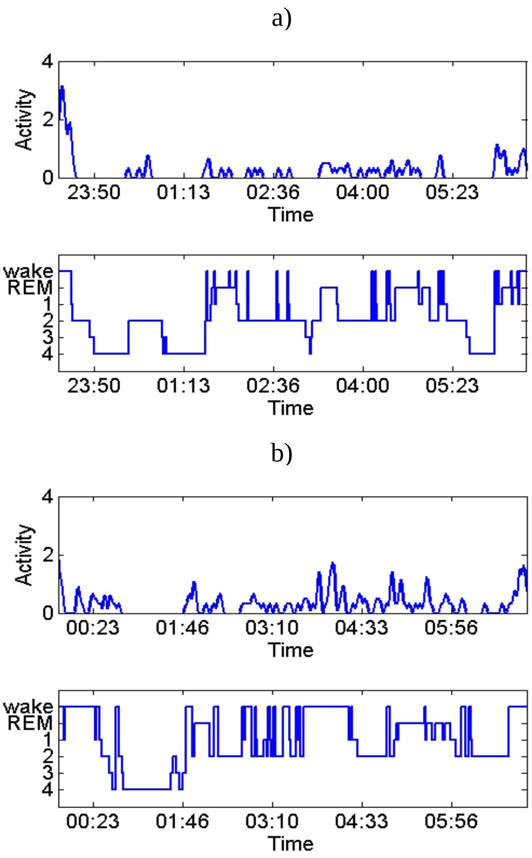

Figure 5: Vivago signals and corresponding PSG classifications for subject 2 (a) and subject 3 (b) from the middle-aged group.

Figure 6 presents the Vivago® signals and corresponding PSG classifications for subjects 16 (middle-aged) and 11 (senior). Subject 16 slept 5.8 hours during the study night and had 1.6 hours (27%) of deep sleep. The ratio between deep sleep and light sleep average activity was 1.1, and the ratio of standard deviations was 1.1. Subject 16 had some deep sleep periods in the beginning of the night. During these periods also Vivago® activity was low. However, there were also light sleep periods during the night where Vivago® activity was as low as in deep sleep. For the last hours of the night, Vivago® activity remained relatively high. Subject 11 slept 3.3 hours during the night and had 0.3 hours (9%) of deep sleep. The ratio of averages was 1.1, and the ratio of standard deviations was 0.58. Subject 11 had very little deep sleep during the night; there were only few very short periods of deep sleep seen in the PSG. There were no quiet periods in activity signal during the night. However, light sleep periods had lower activity than wakefulness.

a)

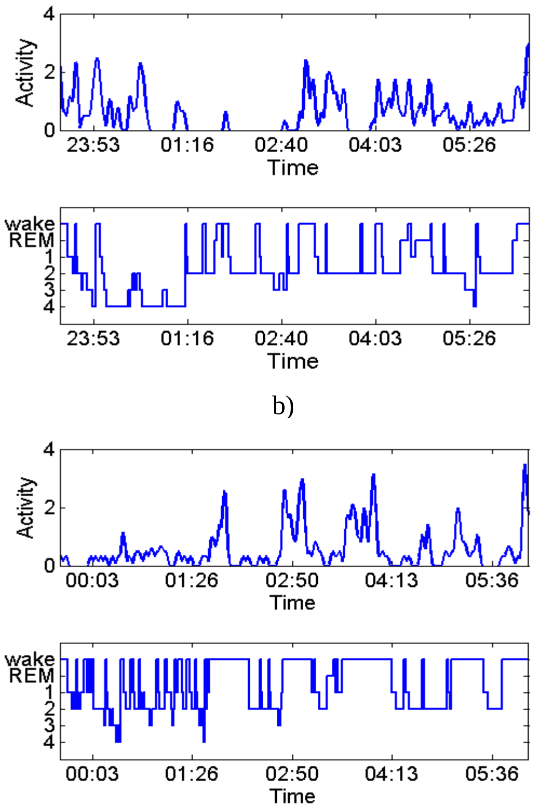

Figure 6: Vivago signals and corresponding PSG sleep stages for middle-aged subject 16 (a), and senior subject 11 (b).

Despite the significantly different activity levels in deep sleep and light sleep, the classification produced low correlations (< 0.08) between deep sleep detected by Vivago® and PSG.

Discussion

The main finding in the present study was that wrist activity measured with Vivago® is significantly lower in deep sleep than in light sleep. However, some subjects have long periods of low activity in light sleep, as well. Therefore, reliable minute-to-minute sleep stage classification cannot be done based solely on wrist activity. However, even if not capable of exact sleep stage classification, activity monitoring may provide valuable qualitative information about sleep duration and quality. Similar conclusion was made in a study by Kaartinen et al. [13]. Instead of a minute-to-minute dissection of sleep, activity monitoring may provide a more generic view on sleep.

The so-called first night effect (FNE) is often encountered in PSG recordings. It means the alteration of the sleep structure in the unfamiliar environment of the sleep laboratory and is characterized by, e.g., increased wakefulness [14]. In the present study, the laboratory recordings were performed over one night only. The total sleep time for the whole group was short, the subjects slept on average 5.2 hours during the study night. Average deep sleep duration for all subjects was 1.3 hours, which is only 25% of total sleep time. Thus, there is reason to suspect that the FNE had an effect on the duration and quality of sleep of the subjects. Some subjects had very little deep sleep (e.g., subject 11 in Figure 6 b had only 9% of deep sleep, and subject 18 had 6% of deep sleep), making the parameters calculated based on activity in different stages unreliable.

The results indicate that Vivago® signals provide information on the quality of sleep. If a person has no low-activity periods during the night and no neurological disease that is causing the extra movements, there is reason to suspect that the person does not have sufficient deep sleep periods. However, the occurrence of low-activity periods does not necessarily mean there is deep sleep. Thus, the method alone cannot be used for diagnosing sleep problems but could be used for screening and follow-up of sleep quality.

Conclusions

Activity measured with Vivago® is significantly smaller in deep sleep than in light sleep. However, the activity distributions of sleep stages overlap, which makes minute-to-minute classification of sleep stages unreliable.

The results indicate that Vivago® signals provide information on the quality of sleep. The method could be used for screening and follow-up of sleep quality.

Acknowledgement

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