

Circadian activity rhythm in demented and non-demented nursing-home residents measured by telemetric actigraphy

PAULA PAAVILAINEN¹, ILKKA KORHONEN², JYRKI LO'TJÖNEN², LUC CLUITMANS², MARJA JYLHÄ¹, ANTTI SÄRELA³ and MARKKU PARTINEN⁴

¹Tampere School of Public Health, University of Tampere, Tampere;²VTT Information Technology, Tampere, ³IST International Security Technology, Helsinki and ⁴Rinnekoti Research Centre, Espoo, Finland

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SUMMARY There is a need to develop unobtrusive methods for long-term monitoring of sleep/wake and circadian activity patterns in the elderly both in nursing homes and at home settings as sleep is important for health and well-being. The IST Vivago WristCare is an active social alarm system, which provides continuous telemetric monitoring of the user's activity. We examined how the activity signal measured by IST Vivago differed between demented and non-demented subjects living in a nursing home, and how it correlated with the subjective assessment of sleep quality and daytime alertness. The activity signal data together with subjective assessments of sleep quality and daytime vigilance were collected from 42 volunteers (aged 56...97 years; 23 demented and 19 non-demented) for at least 10 days. The demented subjects had lower daytime activity and higher nocturnal activity than the non-demented subjects. Correlations between the activity parameters and self-assessments were weak but statistically significant. We also found correlation between functional ability and diurnal activity. The results are in line with previous studies with demented and non-demented elderly subjects and suggest that the IST Vivago system provides a valid instrument for unobtrusive continuous long-term monitoring of the circadian rhythm and sleep/wake patterns in the elderly.

keywords actigraphy, ageing, circadian rhythm, long-term, sleep, telemetric

INTRODUCTION

Ageing, and also many age-related factors such as medical conditions, medications, psychological and environmental factors and life events have a great impact on sleep/wake patterns and the quality of sleep (Martin et al., 2000). The incidence of sleep disturbances increase with age (Bliwise, 1993; Martin et al., 2000) and sleep architecture becomes more fragmented (Ancoli-Israel et al., 1997a). Adversely, poor sleep has a strong effect on the health and general well-being of the elderly. Poor sleep correlates with health complaints and depression (Phillips and Ancoli-Israel, 2001) and an association between reported sleep problems and the incidence of falls has been found (Brassington et al., 2002). Sleep disturbances may be associated with declining cognitive functions and an early

indicator of dementia (Foley et al., 2001). Sleep problems are also common factors leading to institutionalization (Chenier, 1997; Pollak and Perlick, 1991; Pollalet al., 1990) and sleeping disorders can be predictors of death (Pollalet al., 1990).

Sleep disturbances are highly common for demented patients (Lyketsos et al., 2002; Martin et al., 2000), especially for demented elderly people living in institutions (Ancoli-Israel et al., 1997a). Sleep in demented patients is often fragmented, sleep/wake rhythms are unstable, the frequency and duration of nocturnal awakenings are increased, and wandering and agitation at night are common symptoms for demented elderly people (Ancoli-Israel et al., 1997a; Martin et al., 2000). Demented people also sleep more during the daytime than do non-demented elderly people (Pat-Horenczyk et al., 1998). Sleep disorders also correlate with the severity of dementia (Ancoli-Israel et al., 1997a; Pat-Horenczyk et al., 1998).

Pat-Horenczyk et al. (1998) noticed the need to examine whether the daytime sleepiness and reduced daytime activity of

Correspondence: Paula Paavilainen, Tampere School of Public Health, University of Tampere, FIN-33014 Tampere, Finland. Tel.: +358-3-2157 166; fax: +358-3-2156 805; e-mail: paula.m.paavilainen@uta.

demented subjects causes disturbed sleep at night, or whether fragmented sleep leads to the daytime sleepiness of demented subjects. Voliceret al. (2001) found that longitudinal studies of changes in circadian rhythm are required for achieving "clarifications of the relationships between changes in circadian rhythm and the progression of dementia.

Nevertheless, long-term studies of sleep/wake patterns and circadian rhythmicity of the elderly in institutions and at home for medical diagnostic and treatment purposes have been rare. This is largely because of the lack of appropriate methods. The golden standard for studying sleep has been polysomnography (PSG), which requires laboratory settings and is hence not suited for long-term or large spread use, or use with cognitively impaired subjects. Sleep diaries offer one possible method, but their usability and accuracy are limited, especially when studying cognitively impaired elderly patients. An alternative method suitable for long-term home monitoring is wrist actigraphy, which can be used both for research and diagnostic purposes. Ancoli-Israelet al. (2003) suggested that actigraphy provides information obtainable in no other way, especially in individuals who are less likely to tolerate PSG, such as the demented elderly. Information obtained by actigraphy is reliable for evaluating the sleep patterns and circadian rhythms and effects of treatments (Ancoli-Israelet al., 2003).

There is a need to develop methods for monitoring the circadian rhythm and sleep/wake patterns of the elderly both in clinical settings and at home because of the importance of sleep to health and well-being. This kind of monitoring would be useful for assessing the nature of sleep problems, for evaluating the need for treatment, and for assessing the efficacy of treatments. Monitoring should preferably be continuous and applicable in long-term, i.e. over months or even years to allow the detection of possible changes. Monitoring methods should be suitable for clinical purposes and easy to use for health care professionals.

In this study we used the IST Vivago system (Information Security Technology Oy, Helsinki, Finland; <http://www.istsec.fi>) to study sleep/wake patterns of the elderly. IST Vivago is an intelligent social alarm system with continuous telemonitoring of the user's activity, which is available both for institutional and home use (Särelä et al., 2003). Its primary use is as a social alarm device with a panic button and automatic alarms or notifications for immobility, extended passivity, access control and device usage, but in addition it provides similar performance to standard actigraphy in activity monitoring (Lothjönen et al., 2003). Further, it takes a step forward by providing possibilities for continuous long-term (up to several years) routine monitoring in an unobtrusive way in the normal surroundings and living environments of its users (Särelä et al., 2003). The institutional system is a multi-user system allowing simultaneous monitoring of several users while the home system is for single users only.

The objectives of this study were (i) to determine how the activity signal measured by telemetric actigraphy (Vivago) differs between demented and non-demented subjects living in a nursing home and how it correlates with the subjective

assessment of sleep quality and daytime alertness, and (ii) to develop methods for analysing long-term circadian rhythm and sleep/wake patterns.

METHODS

Subjects and protocol

We conducted the study in two private nursing homes (later institution I and institution II) located in southern Finland. The nursing homes were chosen on the basis of earlier usage of the IST Vivago. The device has been the primary nurse call and alarming system in both nursing homes for some years, and the staff and the residents were experienced in using the device. Participants or their relatives (in the case of severe dementia of the resident) were asked to give their written consent to the study. The exclusion criteria were refusal to use the device continuously 24 h per day throughout the study and chronic conditions seriously affecting wrist movements (e.g. Parkinson's disease and unrehabilitated hemiplegia). The Ethics Committee for Studies in Healthy Subjects and Primary Care of the Helsinki and Uusimaa Hospital District approved the study.

The total number of the residents in institution I was 40. Twenty-eight of them lived in their own flats and 12 in the dementia ward in their own rooms; 27 subjects volunteered to the study but one of them was excluded because of Parkinson's disease. The final study sample consisted of 26 subjects (two men, 24 women). In institution II all 16 residents (15 women, one man) volunteered for the study.

At the baseline, the subjects were screened for dementia with the Clinical Dementia Rating Scale (CDR) (Hughes et al., 1982) and the Folstein Mini-Mental State Examination (MMSE) (Folstein et al., 1975). On the basis of CDR and MMSE scores the subjects were classified as non-demented (MMSE ≥ 20 and CDR ≥ 0.5) or demented (Table 1). As depression is one important factor disrupting sleep/wake patterns in old age (Bliwise, 1993), the subjects were examined for depressiveness by using a five-item Geriatric Depression Scale (GDS-5) (Hoyle et al., 1999). The Barthel Index (BI) (Mahoney and Barthel, 1965) was used for screening the functional ability of the subjects.

Table 1 Distributions of background variables in study groups

	Non-demented I (n = 19)	Demented I (n = 23)	P-value
Age	81.5 \pm 9.0	84.3 \pm 9.5	0.362
MMSE scores	26.2 \pm 2.9	11.6 \pm 5.6	<0.001
CDR scores	0.1 \pm 0.2	1.6 \pm 0.8	<0.001
GDS-5 scores	0.4 \pm 0.7	1.0 \pm 1.1	0.026
Barthel Index (scores)	82.1 \pm 24.1	65.0 \pm 19.4	0.001

Values are given as mean \pm SD. Differences between groups were tested by Mann-Whitney U-test.

MMSE, Mini-Mental State Examination; CDR, Clinical Dementia Rating Scale; GDS-5, Geriatric Depression Scale.

In institution I the data was collected for 10 days and in institution II for 113 days. In the case of missing data for any subject in institution I, data collection was continued until at least 9 days of complete data was acquired. Subjective assessments of sleep quality and alertness in the daytime and in the evenings were collected three times a day at regular times. Furthermore, bedtime, awakening time, number of nocturnal awakenings and time in bed were recorded. Non-demented subjects made self-assessments but a trained staff member made assessments for demented subjects because of their limited cognitive capacity.

Quality of sleep was assessed by using a "five-item classification" (very good to very bad). The total number of awakenings was classified as (i) no awakenings during the night, (ii) 1...3 awakenings, and (iii) more than three awakenings during the night. The Karolinska Sleepiness Scale (Gillberg et al., 1994) was used to assess alertness during daytime and in the evening.

Activity signal acquisition and processing

The IST Vivago system consists of three main components: a wrist unit, a base station, and alarm receiving and routing software. The wrist unit is a wrist-worn alarming device with a manual alarm button, and, in addition to this, it has built-in sensors for activity and usage monitoring. The activity signal, which is constructed from the measured force changes at the unit's movement sensor, is continuously wirelessly transmitted on average once per minute, depending on user's activity level. The activity data is stored by the system allowing online activity monitoring whenever the wrist unit is worn and the user is within the system range (ca. 60 m in open space, inside buildings the range covers a typical apartment with a single base station). For alarming purposes the unit has a manual alarm with adaptive automatic features, which helps to call for help if the wearer is not capable of doing so, e.g. because of loss of consciousness resulting in immobility detected by the device (<http://www.istsec.se>; Säljö et al., 2003).

Vivago wrist unit models WristCare 3001 in institution I, and Vivago 3001 in institution II were used to collect the activity signal. The wrist unit models are similar except for the radio frequency used in wireless communication (WristCare 3001 142 MHz, Vivago 3001 869 MHz). The subjects used the wrist units all the time, except when bathing. If they went out of the nursing home missing data resulted because of the loss of the radio link for data storage; however, this was rare in these studies.

The activity signal was analysed in three periods: for a complete 24 h (from 21:00 to 21:00 hours), day (from 09:00 to 21:00 hours) and night (from 00:00 to 06:00 hours). These "fixed periods were used for simplicity in all individuals despite possible differences in their sleep cycle. The night period was chosen so that the vast majority of the subjects in the institutions were expected to be in bed during this period. For these periods, mean, median and standard deviation (SD) of the activity signal were computed. Night and day (median) activity levels were also computed in normalized units by

dividing them by 24-h median activity level. Median was used instead of mean because of non-Gaussian distribution of the activity data. In addition, to assess the amplitude of the circadian rhythm, ratios of night and day activity (both mean and median) were computed. Furthermore, a sinusoidal model of the circadian rhythm was "fitted to the data, and sine amplitude and acrophase (time of the maximum activity according to the model) were computed (Martinet et al., 2001).

The parameters mentioned above are based on linear system theory, and it is well known that biological systems exhibit nonlinearity. Hence, we applied Poincaré (return) plot analysis for the activity data to allow for the analysis of different complex patterns in the data. A Poincaré plot is constructed by plotting the activity sample $A(t+d)$ as a function of the previous sample $A(t)$, where d is the delay parameter (Fig. 1). This analysis method is commonly applied for beat-to-beat heart rate data for analysis of nonlinear dynamics (Tulppo et al., 1996). By choosing an appropriate delay different dynamics may be studied. Traditionally, $d \approx 1$ is probably most commonly applied, and in this case the parameter SD1 (see Fig. 1) describes mostly short-term variability of the data while parameter SD2 describes long-term variability.

In the case of circadian rhythm, delays of 12 and 24 h are of special interest (Fig. 2). The $d \approx 24$ h plots the current day as a function of the previous day, allowing us to analyse how activity patterns repeat themselves from day-to-day. In case of close resemblance of the days, the data points would appear close to the axis $x \approx y$ leading to small SD1 and large SD2. The delay $d \approx 12$ h presents the data in the counter phase, and in a normal circadian rhythm the data should be grouped in three groups: close to the x - and y -axis (mapping of low night-time activity on high day-time activity and vice versa because of counter phase) and around the middle of the plot (mapping of morning to the evening and vice versa) (Fig. 2). Hence, by comparing especially the differences between $d \approx 24$ h and

Figure 1. A Poincaré plot is constructed by plotting data as a function of itself with a delay d . By using different delays it is possible to study the presence of determinism or randomness in the data. In quantitative analysis of the plot, SD1 is the standard deviation of the data against the axis $x \approx y$, and SD2 is the standard deviation of the data against the axis, which is orthogonal to the axis $x \approx y$ and crosses this axis at the mean value of the data (centre of gravity).

the night/day ratio also showed differences between the groups. In the demented subjects day and night-time activity levels were close to each other and within the 24-h periods activity level was lower than in the non-demented group. Examples of the 24-h activity of a non-demented and a demented subject are given in Fig. 3.

Differences between the groups were also seen in sinusoidal modelling of activity (Table 3). The amplitude of the activity signal differed between groups, but the acrophase did not.

In the 1-min Poincaré analysis both SD1 and SD2 were larger in non-demented than in demented subjects. The Poincaré difference with delays of 24 h and 12 h was significantly larger in the non-demented than in the demented subjects, suggesting stronger circadian rhythm within the non-demented group (Table 3).

Studying all the subjects together, the subjects having better circadian rhythm tended to have better functional ability as suggested by the correlation analysis between activity parameters and Barthel scores (partial correlation, controlled for MMSE scores; $n = 42$). Significant ($P < 0.01$) partial correlations were found between BI scores and night/day activity ratios ($r = 0.55$) (see Fig. 4); normalized day activity ($r = 0.53$); normalized night activity ($r = 0.52$); sine amplitude ($r = 0.46$); Poincaré differences between delays of 24 h and 12 h ($r = 0.42$); Poincaré 1-min SD1 ($r = 0.39$); and 24-h activity SD ($r = 0.39$).

The correlations between daily self-assessments and activity parameters computed for subjects in institution II were low but statistically significant (Table 4). Correlations were found, for example, between the night/day activity ratio and the quality of sleep. The higher the night/day activity ratio was (indicating less difference between night and day

activity levels), the poorer was the quality of sleep. The night/day activity ratio also correlated with daytime and evening alertness: the higher the ratio the poorer the alertness. The Poincaré difference between the delays of 24 h and 12 h correlated with the quality of sleep and daytime as well as evening alertness.

DISCUSSION

We examined how the activity signal differed between non-demented and demented subjects. We found that non-demented subjects had higher daytime and lower nocturnal activity than demented subjects. The variation in activity during the 24-h cycle was lower among the demented subjects. Subjective assessments of sleep quality parameters did not differ between the two groups. However, we evidenced low correlation between the objective (activity signal) and subjective assessments of sleep and alertness in the elderly. Activity data correlated also with functional ability assessed by the BI. Finally, we developed and tested new parameters to quantify the activity signal in long-term recordings.

In the Volicer et al. (2001) study the subjects suffering from Alzheimer's disease had lower daytime activity; higher nocturnal activity, lower interdaily stability of activity and later activity acrophase than healthy subjects. In the Harper et al. (2001) study the diurnal activity of demented patients was significantly lower and the nocturnal activity level higher than in controls, and the mean activity according to sinusoidal model (mesor) of the activity rhythm was lower in demented subjects. The findings of the present study are consistent with these studies suggesting the validity of the IST Vivago for the assessment of circadian activity of elderly and demented subjects.

Figure 3. Examples of the activity signal in a non-demented subject with a clear circadian pattern (upper figure) and a demented subject with no circadian rhythm and high overall activity level (lower figure). The lines under the graphs denote missing data.

surroundings of the subjects, and thirdly, the subjects were familiar with using the device so that the device did not disrupt the sleep and normal functioning of these elderly subjects like some strange devices used only for study purposes.

We combined data from two institutions but we believe this does not introduce a significant confounding factor. In fact, we compared demographical, clinical and activity data from the subjects and found little differences between the institutions (data not shown). Both institutions were quite similar and the time of data collection was approximately the same. Hence, we ended up in lumping these data together.

The statistical power of this study remains limited because of the relatively small number of subjects ($n = 42$). The type of dementia may be a potential confounding factor in our study, because the subjects were not evaluated for their type of dementia. Harper et al. (2001), for instance, found different circadian rhythms between subjects suffering from Alzheimer's disease and other dementing diseases (in that study the classification of dementia was based on postmortem pathology). However, as discussed above, the results are consistent with previous studies, and hence suggest the validity of our study and the applied methods.

Consistent with previous studies, the results showed clear differences between the circadian rhythm of demented and non-demented subjects. The study also suggests potential correlation between functional ability and activity data. Results support the use of the telemetric actigraphy in the long-term screening and follow-up of elderly subjects for sleep and circadian rhythm-related problems associated with dementia and changes in functional capacity.

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