Actigraphy in Diagnosis of Human Operator’s Falling Asleep

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Abstract: Diagnosis of a human-operator’s fatigue remains one of the unresolved problems of modern work physiology. Thus, the objective of this publication was to determine whether it is possible to diagnose falling asleep or falling into the first (relatively light) phase of sleep using forearm actigraphy in a controlled polysomnographic study (PSG). During the study 7 healthy men with the age ranging from 19 to 27 years were observed. The study was carried out from 10 p.m. to 3 a.m. and aimed at modeling of an operator’s typical night-shift positions: standing, sitting on a chair and sleeping while sitting on a chair. The research included PSG and forearm motility monitoring with a 3D Uniscan (Russia) accelerometer. In the standing position the locomotion of the right wrist has been 1100±910 of motility units (MU), in the sitting position- 870±570 MU and 2 minutes of superficial sleep has given 102±51 MU (reliable difference, p<0.01). Thus, using the forearm actigraphy allowed registration of a person’s falling into superficial sleep within the first 2 minutes.

Key words: Antigraphy • Polysomnography • Sleep Diagnosis

INTRODUCTION

Antigraphy is a method of estimation and control of human’s physical activity with accelerometers (antigraphs or inclinometers), sensors, measuring projection of the sum of all the forces, apart from gravity ones, affecting the sensor’s surface [1]. In somnology the accelerometers are commonly used in polysomnographic studies to have a patient’s actinogram [2]. During the last 10 years the antigraphs have been widely used as a simple and convenient method for estimation of the sleep time and sleep pattern [3, 4]. This method allows a longitudinal monitoring of human behavior while sleep. This is what sets this method apart from polysomnography, aimed for diagnosis of pathological and functional disorders in the conditions of special hospitals.

The research of the last years has demonstrated high correspondence between the dynamics of the actinograms and the dynamics of polysomnographic (PSG) key monitoring parameters such as an electro - oculogram and facial electromyogram [5, 6]. It explains why antigraphy is being widely used for physiological monitoring of sleep mainly in healthy people to estimate the functional disorders and to determine the optimum awakening time [6]. Due to the high dependence of human’s functional capabilities on the length of sleep, this method has been widely used in work physiology for monitoring of the workability and alertness in people, whose job is potentially risky and associated with long-term psycho-emotional tension [7]. Systems for monitoring, forecasting and prophylaxis of fatigue have been developed and put into practice [8]. At the same time, diagnosis of a human-operator’s falling asleep remains one of the unresolved problems of modern work physiology and this is the one of the most common reasons of different accidents occurring while driving a vehicle or at a production site “due to the absence of subjective perception by the operator of his/her being somnolent” [9]. The objective of this research was to determine whether it is possible to diagnose falling asleep or falling into the first stage of sleep, applying the actigraphy method.
MATERIAL AND METHODS

During the study, 7 healthy men with the age ranging from 19 to 27 years were observed. The research was carried out in the conditions of a sleep lab of Clinical Hospital at Research Institute of Physiology, Siberian Branch of the Russian Academy of Medical Sciences in the period between 10 p.m. and 3 a.m. and was to model an operator’s night shift. After placing PSG and 3D-accelerometer sensors (this procedure took 45 minutes) and starting monitoring, the trial subjects were left to stand freely in a dark and soundproof room. The subjects were allowed, out of necessity, to move their limbs and body a bit, but they were prohibited to move around the room. They had to stand up in one place. This situation was designated as Stage 1 and related to functional state of “standing”. The length of taking such position was determined arbitrary by each trial subject until he felt he was falling asleep. The following Stage 2 corresponded to the functional state of “physical activity”. To begin the stage the subject sat on a chair and made himself comfortable for sleep putting his head on a cushion fixed to the back of the chair. As soon the subject comforted himself, Stage 3 began that corresponded to the functional state of rest while sitting on a chair without sleep. This was the stage when the subjects were allowed to fall asleep in the same position. The moment of falling asleep and its depth (phase) were determined by a somnologist after processing the data. PSG was carried out with a computerized sleep screener by Grass Technologies with automated data processing. The data processed included EEG; ECG; EMG of sublingual muscle; pulse oxymetry with a sensor by Nelcor (USA); and two-sided EOG of eye bulbs. Simultaneously one carried out monitoring of the movements of the right wrist with an accelerometer by Uniscan (Russia). The software of the device allows keeping track of the sensor’s movements with frequency of 5 points a second and converting the data obtained into motility units (MU).

For the statistical analysis of the quantitative data one applied paired Student's t-test. The results were validated with significance value p <0.05. The research involved no risk for the trial subject’s health in compliance with all the ethical and humanity principles as set forth in the Declaration of Helsinki (2000) and Directive of the European Community 86/609. The research had also been approved by Biomedical Ethics Committee of the Research Institute of Physiology, Siberian Branch of the Russian Academy of Medical Sciences.

RESULTS AND DISCUSSION

The observations for each case were summarized in a visual observation report, where one correlated in time the data from the 3D accelerometer and the key data of PSG, indicating the phases of sleep (Fig. 1). The length of Stage-1, determined arbitrary by the subjects at the moment they were caught by fatigue, has varied from 3.5 to 24 minutes, 13.6 minutes at the average. The length of Stage-3 lasting from the moment the young men comforted themselves and to the moment they fell asleep (1st phase, determined using PSG) has comprised from 2 to 20 minutes. In five cases the sleep has been superficial and lasted from 2 to 20 minutes. In 2 cases the sleep has reached the second stage that continued 15 minutes for one of the subjects. Maximum total sleep time has been 22 minutes. Notice how insignificant has been the time required for the young men to become fatigue at nighttime and to the fact that all the trial subjects have fallen asleep even being seated.

The data presented showed that at nighttime fatigue and a for sleep occur in young healthy men in the first 5 minutes. In this case, standing up freely, all the trial subjects have revealed physiological tachycardia (Table 1), with the heart rate within 95-115 beats a minute. The shift to sitting position (from Stage 1 to Stage 3) has been characterized by statistically significant reduction of the heart rate by 20-25%.

The falling asleep has revealed itself in further statistically significant reduction of the heart rate by additional 10-15%. Thus the difference between the “standing” heart rate and the “sleeping” one has been 30-35%. Such heart rate dynamics fully correlate with the known PSG data [10] and could be easily confirmed with any kind of group analysis. However, for relatively comfortable conditions, the heart rate can not be considered as a parameter providing enough information on the moment, a person falls asleep, if to take into account that the reduction of heart rate by 10-12 beats a minute may well fall within the boundaries of functional heart rate variability [11]. The most reliable measurement here, the gold standard is, of course, PGS with EEG data in particular [12, 13]. But such methods are not appropriate for functional monitoring of falling asleep since they interfere with human operator’s activities.

Statistical analysis of the readings of the 3D-accelerometer has revealed their significant dynamics at different stages of observation (Fig. 2). So, if for the standing position the motions of the right wrist have reached 1100 ± 910 MU, then for the sitting one they have been 870±570 MU.
Fig. 1: Graphical correlation of the 3D actinogram with PSG data. The histogram below reflects the heart rate dynamics. Trial subject A, 22 years old, # 03-09, Date: 14.11.09. The readings of 3D-accelerometer have been correlated with PSG. Time: 1 minute-600 points.

Fig. 2: Graphical comparison of the average readings of 3D accelerometer from the 7 trial subjects at the different stages of the research.

Table 1: Average values of heart rate at different stages of research (M±SD) and significance level of differences between these values

<table>
<thead>
<tr>
<th>Stage</th>
<th>Position</th>
<th>Heart Rate</th>
<th>Difference from Stage 1</th>
<th>Difference from Stage 2</th>
<th>Difference from Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standing</td>
<td>102±9</td>
<td>-</td>
<td>p=0.85</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>2</td>
<td>Sitting on a chair</td>
<td>101±12</td>
<td>p=0.85</td>
<td>-</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>3</td>
<td>Sitting on a chair, not sleeping</td>
<td>80±10</td>
<td>p&lt;0.01</td>
<td>p=0.01</td>
<td>p&lt;0.02</td>
</tr>
<tr>
<td>4</td>
<td>Sitting on a chair, sleeping</td>
<td>68±4</td>
<td>p&lt;0.01</td>
<td>p=0.01</td>
<td>-</td>
</tr>
</tbody>
</table>

Due to the high individual variability the difference between the mean values has been unreliable. At the same time, during the stage of superficial sleep the value has been 102 ± 51 MU, which was 8-10 times less the values indicated above. In this case the individual variability has decreased significantly. All the subjects have demonstrated the actigraphy readings to be within 59-200 MU. It has been so even in cases when the coordinates displaced gradually due to reduced muscle tone of the forearm with the sensor. In a number of cases one has observed 200 MU (maximum-minimum) at Stage 3, preceding to falling asleep. The value of 200 MU was determined as a maximum possible level for «Uniscan» actigraph, where relaxation of the forearm muscles occurred and the trial subject fell asleep. Apparently, the actinogram included time periods (episodes), when the level of motility could be below 200 MU during the period of vigilance. Such a low motility in all the trial subjects has
been registered only at the Stage 3. Its maximum length (before falling asleep) according to PSG has varied from 1 to 4 minutes, 140 seconds at the average. It means if the actigraphy readings are below the level indicated and continue about one minute, a person, more than likely, have fallen asleep. And if they last longer then 4 minutes, one has fallen into superficial sleep.

Thus, a healthy human very quickly develops fatigue and a want for sleep at nighttime. In this case the superficial sleep can come as soon as in two minutes after one changes the standing position to a more comfortable sitting one. It means that any human operator undergoes this ordeal when working night shift or working late at night. At the same time the data presented have revealed that the actigraphy readings have been one order lower then ones for the period of vigilance. It means that one could apply actigraphy as a method for determination of falling asleep during the first four minutes, which could be very useful for development of devices for bio monitoring of human operators, whose activities require long-time alertness, especially at nighttime.

It can be concluded that while standing it takes a healthy person from 5 to 20 minutes to develop a subjective feeling of fatigue and a want to sleep. At nighttime while sitting a healthy person falls into superficial sleep in the first 20 minutes. Using forearm actigraphy one can register a transition from vigilance to sleep within 1 to 4 minutes. This work was supported by the Ministry of Education and Science of the Russian Federation (contract No 13.G25.31.0071).

REFERENCES


