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Sleepiness and Head Movements

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Abstract: Sleepiness in working life is critical and strongly associated to work related accidents. The relationship between sleepiness and head movements is poorly investigated. The pattern of head movements over time was investigated in a laboratory study with ten subjects either sleep-deprived or rested. Head movements were obtained by an inclinometer placed on the subject's forehead, and the recording was continuous. Results show that subjects when sleep-deprived moved their head more and had more extreme head movements compared to when rested. An increase of the velocity and the number of extreme head movements over time were noted when the subjects were sleep-deprived and when rested. The increase of head movements was more linear over time in the rested condition, whereas in sleep-deprived conditions most of the increase appeared during the first hour. No significant differences of between forward–backward movements and left–right movements could be found. When rested, the changes in head movements correlated with ratings of sleepiness, EEG activity, and heart rate variability. Head movements can be a used as an indicator of sleepiness.

Key words: Head movements, Sleepiness, Inclinometer, Driving, Indicator

Introduction

Sleepiness plays a critical role in work conducted during long shifts that occur either late at night or early in the morning and where the worker's primary job is to monitor a relatively stable system. Driving a long distance truck is one such activity that has received a fair amount of attention. This type of work illustrates the difficulties of combating the effects of sleepiness and the serious consequences that can occur.

Traffic accident studies related to sleepy drivers show a broad variation of results. The following studies have noted different results with respect to sleep related accidents: Summala and Mikkola[1] report 7–10%; Knipling and Wang report[2] 1.2–1.6%; and Horne and Reyner report[3] 16–20%; and Sagberg[4] reports 1–3% and 3.9%. In a questionnaire study by Hakkanen and Summala[5], about 40% of the long-haul truck drivers reported problems staying alert on average every fifth drive. It has been pointed out, however, that estimates of sleep related accident reports are underestimated and that sleepiness is the largest identifiable and preventable cause of accidents in transport operations[6–8]. For long-distance truck drivers and other occupational groups that must deal with problems of sleepiness, effective methods need to be developed to monitor wakefulness.

Many physiological and subjective methods have produced reliable indicators of sleepiness. For example, electroencephalography (EEG) measures rising alpha and theta activities to indicate sleepiness[9–11]. Hakkanen *et al.*[12] focused on eye blink duration as a measure of sleepiness in on-road driving, concluding that average blink duration was significantly longer for bus drivers with OSAS (Obstructive Sleep Apnea Syndrome). Caffier *et al.*[13] have shown that drowsiness is related to blink duration and reopening time. Devices that warn drivers of their sleepiness are widely used. Although pupillography measures sleepiness[14], it is impractical to use while driving. PERCLOS, percentage of eyelid closure, is a real-time drowsiness-detection system that has shown good correlations with vigilance tests[15, 16]. However none of these types of devices have been widely applied for daily use among transportation professionals. Heart rate (HR) and heart rate variability (HRV) might be able to identify driver fatigue, drowsiness, and/or sleepiness, but these methods have not been sufficiently explored [17–20].

Similarly, subjective ratings of sleepiness produce wide variations as evident in the following studies that use different scales: Hakkanen and Summala[5] used Epworth Sleepiness Scale (ESS); Williamson *et al.*[21] used Stanford Sleepiness Scale; and[22, 23] used the Karolinska Sleepiness Scale (KSS). Recently, van den Berg *et al.*[24] used the KSS and the category-ratio scale (CR-10). To assess fatigue, Nilsson *et al.*[25] used a check list of terms using a Likert-type of scale. The different approaches of rating sleepiness and the use of different scales indicate how difficult it is to measure sleepiness as it relates to work performance.

Head movement related to fatigue/sleepiness has been studied to a much lesser degree. Ji and Yang[26] note that head position can reflect a person's level of fatigue; alert drivers normally look straight ahead, if a driver frequently looks in other directions for an extended time, the driver is either fatigued or inattentive.

In addition to vision, head movements can be used to evaluate fatigue. In research that does not deal with sleepiness related to driving, Hall-effect devices or inclinometers effectively monitor, measure, and analyze head movements[27–32]. Studies that examine sleep and sleepiness during long-haul flights have used inclinometers to measure head movement[33]. During wakefulness it showed activity, whereas during sleep it showed no activity and the authors considered head movement to be more of a general activity rather than an indicator of sleepiness. No analyses of the head movements over time were done. Measuring head movement with a gyroscope while driving has been used by Kito *et al.*[34], but they observed the drivers visual behaviour at an intersection rather than the effect of fatigue on head movements.

Thus head movements could be described as an indicator of fatigue/sleepiness; however, few studies have investigated the relationship of sleepiness and head movement over time. This study investigates head movements over time under sleep-deprived and non sleep-deprived conditions and the aim is to evaluate if there are differences in the pattern of head movements between these conditions.

Method

Subjects

Ten volunteers participated in the study (five men/five women) with an average age of 26 yr (range 21–32 yr). All subjects (students at Umeå University) reported being in good health. The volunteers identified themselves as good sleepers. They also exercised on a regular basis every week, did not use medication, and did not smoke. The subjects received both verbal and written information before participating in the study. Subjects were assured of confidentiality regarding their identity. They were reimbursed SEK 1500 for their participation in all the four separate tests.

Preparations before testing and experimental procedure

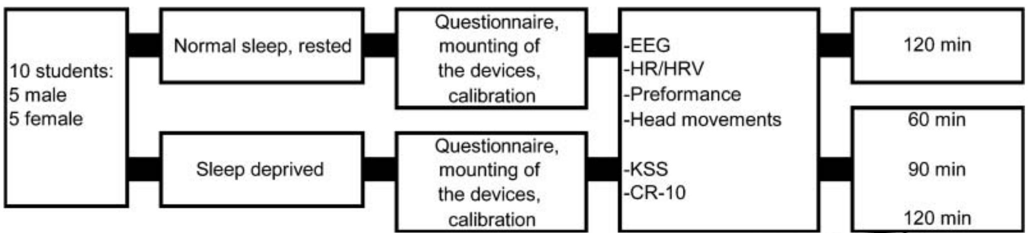
An overview of the study design is presented in Table 1. The experiment for each subject consisted of four test times that varied in length and type of condition: three test times under a sleep-deprived condition (60 min, 90 min, and 120 min) and one test time at rest (120 min). Sleep-deprivation was provoked by instructing the participants to sleep only between 11 p.m. and 3 a.m. the night before the test (i.e., maximum of four hours sleep before 03.00 on the night before the test). For the test condition in a rested state, the participants were permitted to sleep according to their normal pattern. For the 24-h period immediately proceeding each test time, the participants were instructed to maintain normal levels of activity during the morning hours, not to smoke or consume alcohol, to avoid sunlight, and not to watch television the morning of a test. The order of tests was random, and the subjects were not aware of the exact test length only that it would not exceed 2 h. On average the duration between each test was eight days.

Before each test, the participants answered a questionnaire relating to how they had slept the previous night and to their sleep habits for the previous week. Before the sleep-deprived test conditions the subjects slept in average 3 h 59 min (S.D 23 min) while before the rested condition the average sleep time for the subjects was 7 h 25 min (S.D 52 min).

The test was carried out from 8 a.m. to 12 a.m.–1 p.m. depending on the test length, and with no opportunity for the participants to make up for their lack of sleep. The testing session (identical for every the test) began with a baseline registration of the participant's EEG activity, heart rate, and head movements (5 min with closed eyes and 5 min with open eyes). Directly after this registration, which took approximately one hour, the test proceeded. During the test, the subjects were instructed to sit down, to stay awake, to not lean their head on the chair or on their hands, to keep their eyes open, and to focus on the monitor in front of them. The monitor showed a still picture of an empty road in a rural landscape. The participants were also instructed to press a button as fast as possible each time a yellow dot randomly blinked on the monitor screen. Participants made ratings of sleepiness every 15 min throughout test, including immediately before and after each test occasion. The subjects

Table 1. An overview of the study design. Preparation before arriving to and at the laboratory, measures obtained during the test period and the length of the test, which the subjects were randomly assigned to. The lower part of the table shows an example over the first 27 min, describing inclusion of data and the corresponding time block and the activity the subjects are performing

Subjects	Preparation before arriving to the laboratory.	Preparation at the laboratory	Measures obtained during the test	Experiment, test period



Data processing	Excluded	Included	Excluded	Included
Time, min	0 1 2	3 4 5 6 7 8 9 10 11 12	13 14 15 16 17	18 19 20 21 22 23 24 25 26 27
Timeblock		1		2
Subject activity	Rating	Observing the computer screen	Rating	Observing the computer screen

were seated throughout each test with no opportunity to leave the room or consume coffee. After each test, the subjects were placed on a bed placed in a private, screened-off section of the sound proofed lab and allowed to sleep for 60 min. EEG and ECG/HRV monitoring continued during a sleep phase. Results from this analysis are presented elsewhere[20].

Laboratory setup

The investigation was carried out in a soundproofed laboratory with a room temperature between 20°C and 23°C and with low lighting (approximately 5 Lux). Participants sat in a driver's chair with no headrest from a lorry. A table containing the rating scales, questionnaires, and a computer screen were placed in front of the subjects so they could easily access them. To simulate a driver's cab, a sound system in the room reproduced noise from a normal vehicle (approximately 60 dB (A)).

Head movements recording and head data processing

A triaxial accelerometer (ADXL05EM-3 by Analog Devices, Inc. www.analog.com) was used as an inclinometer for recording the forward-backward and left-right head movements. The inclinometer was attached to the subject's forehead with double-sided adhesive tape under the same net-cap that was used for attaching the EEG electrodes (see below). The head movements (one angle measure every second) were recorded during the whole test. The data were stored on a DAT-tape (SONY DIGITAL PC204A) and processed using a computer (PC, Brüel & Kjær LabShop version 6.0). The recorded angle for each second was subtracted from the previous second's angel to calculate angular velocity, degree/s. After processing the data from head movements, the data during the period when the subjects rated their sleepiness were excluded. Excluded data were from the first two minutes, the five minutes around every 15-min interval (for example, minute 13, 14, 15, 16, and 17), and the data from the last three minutes of each test. Included data formed time blocks of 10 min with 601 values each (Table 1). Analyses were made from these values. The 60-min test had four time blocks. The 90-min and 120-min test had six and eight time blocks respectively.

EEG recording

Electroencephalographic recordings were made with silver electrodes and placed according to the 10–20 systems. The EEG signals were transmitted to a preamplifier, and brain waves were amplified and calibrated against a 30 μV wave signal. The amplifier was equipped with an attenuator, which optimally enabled the adaptation of the outgoing signal to an analyser and tape recorder. Simultaneously, the EEG signal was sent to a computer for gathering, processing, and analyzing the data. Alpha (8–12 Hz) and theta (4–8 Hz) power density were analyzed to determine changes in wakefulness. The values of alpha and theta are normalized and expressed as percent of the total power. The EEG data collected when the subjects were performing sleepiness ratings was excluded in the analyses.

Sleepiness rating

Ratings were made on two different scales-the Karolinska Sleepiness Scale (KSS) and the Category-Ratio Scale (CR-10), a scale developed by Borg. The KSS is a 9-point graded, bipolar category scale with the verbal expression "very alert" (value =1) at one end and the expression "Extremely sleepy-fighting sleep" (value = 9) at the other end. The CR-10 scale consists of verbal expressions anchored to a number scale that almost grows exponentially. Although the highest numerical value is anchored with the verbal expression "extremely strong", the maximum lies outside of the number range to allow the subject to rate without the constraint of maximal levels. Subjects use the scale by first finding the verbal expression that matches their experience, and they use the number scale to make adjustments to that rating.

Statistical methods

The statistical analysis was made using SPSS software version 11.0 (SPSS, Chicago, Ill) and conducted using ANOVA for repeated measurements with two within factors (time and condition) when analyzing differences between sleep-deprived and rested condition. For variables with statistically significant changes over time, we also analyzed the type of relationship to time. Huynh-Felt adjustment was used since the sphericity assumption will presumably be violated. To analyze correlations between variables, Pearson's correlation coefficient was used. For statistical tests, an alpha level of 0.05 was used.

Results

Results dealing with EEG, ratings, and heart rate variability have been described in other papers[20]. In addition to the specific results dealing with head movement, this paper includes an analysis about the way in which these changes are correlated to previous reported physiological changes in EEG, ratings, and heart rate variability.

Descriptive statistics

The velocities of the head movement in the forward–backward direction and corresponding velocities in the left–right direction are plotted in Fig. 1. Each value (marked as a circle on the graph) represents one value/second for one of the ten subjects and indicates both the direction and magnitude of velocity of the head movement. In the sleep deprived 60-min test, the forward–backward velocity ranged from –97.0 to 118.3 degree/s while and the left–right velocity ranged from –146.9 to 99.0 degree/s. For the sleep deprived 90-min and 120-min tests, the forward–backward velocity ranged from –107.0 to 115.5 degree/s and –117.8 to 104.5 degree/s respectively. The corresponding left–right velocity ranged from –77.7 to 92.4 degree/s and –94.5 to 134.2 degree/s respectively. During the rested 120-min test, the head movement in the forward–backward direction ranged from –103.9 to 77.8 degree/s and in the left–right direction from –88.5 to 95.3 degree/s. Mean velocity for the forward–backward as well as for the left–right movements were 0.0 degree/s for each test condition respectively (rounding to one decimal). Irrespective to the direction of the head movement, the standard deviation of the velocity ranged from 5.6 to 6.3 for the sleep deprived conditions and 4.6 to 4.7 for the rested condition.

From each subject's forward–backward and the corresponding left–right velocity, a vector was calculated (using Pythagoras' theorem). The mean vector velocities for each subject and the test condition for all subjects during each test condition are shown in Table 2. The distributions of vector velocity for each test conditions are shown in Fig. 2.

To determine how much the subjects moved their head over time during each test condition, all vector velocities were summarised for each subject and time block. The sums were analysed with ANOVA for repeated measurements with two within factors (see below). To describe a more understandable value, the mean vector velocities over time are shown in Fig. 3. During the sleep deprived 60-min test, the average vector velocity increased from 2.5 to 4.2 degree/s. For the 90-min test, the average vector velocity started at 2.8 degree/s, increased to 4.8 degree/s during the first 30 min (corresponding to block 2), and then decreased to 2.6 degree/s. In the sleep deprived 120-min test, the vector velocity first increased from 3.1 to 4.7 degree/s during the first 45 min (corresponding to block 3) and then levelled out at approximately 4.0 degree/s. During the rested 120 min condition, the velocity of the vector started at 2.1 degree/s, gradually increased to 3.6 degree/s, and then decreased to 2.8 degree/s.

As shown in Fig. 2, some vector velocities fall outside the boxes; these are called extreme values. To calculate the extreme values (i.e., extreme vector velocities) and their changes over time, a cut off was determined. These cut offs are based on each subject's IQR (inter quartile range) for the first time block in the rested 120-min test multiplied by 3 (IQR × 3). These cut offs were used to count how many times each subject produced an extreme vector velocity during each time block and test condition. The mean counts of extreme vector velocities for each test condition and over

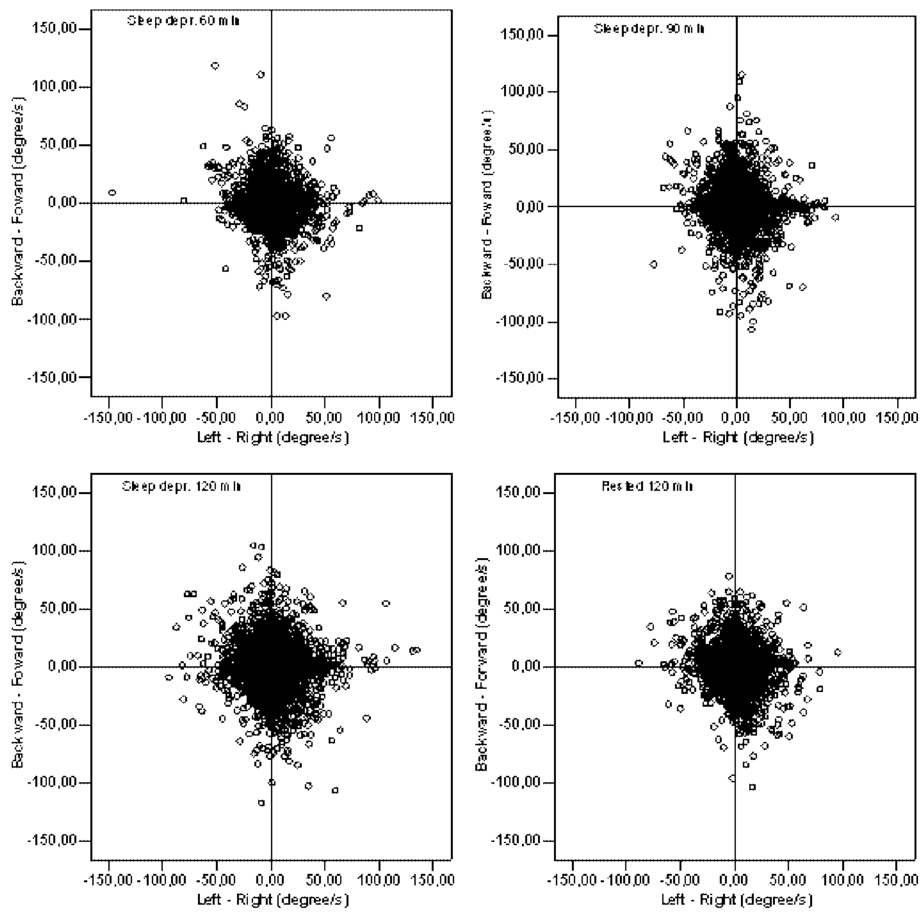


Fig. 1. Four scatter plots for the conditions: sleep deprived 60 min (upper left), sleep deprived 90 min (upper right), sleep deprived 120 min (lower left), and rested 120 min (lower right).
The image is from above the head and the top of the image is the forward (nose) direction. Each circle represents one individual velocity per second for each subject and indicates the direction and magnitude of the head movement. The total numbers of circles are 24,040 (sleep deprived; 60 min), 36,060 (sleep deprived; 90 min), 48,080 (sleep deprived; 120 min) and 48,080 (rested).

Table 2. Mean (m) and standard deviation (S.D.) of the vector velocity (degree/s), for each subject in respective test condition

	Sleep depr.	60 min	Sleep depr.	90 min	Sleep depr	120 min	Rested	120 min
	m	S.D	m	S.D	m	S.D	m	S.D
Subject 01	1.2	3.2	1.6	3.9	3.0	5.9	1.6	4.9
Subject 02	3.6	7.7	4.5	7.7	4.8	8.9	4.9	10.0
Subject 03	6.7	11.3	5.9	9.0	8.2	12.5	4.4	9.2
Subject 04	3.0	5.8	2.5	4.7	3.4	7.4	2.2	3.8
Subject 05	4.8	9.3	5.3	8.4	5.5	11.0	4.0	6.9
Subject 06	1.5	3.0	2.3	3.6	4.4	7.1	2.0	3.5
Subject 07	2.4	3.9	1.4	2.5	1.9	3.8	1.6	3.1
Subject 08	3.1	6.0	3.2	6.2	3.3	6.2	2.7	4.7
Subject 09	2.4	4.1	2.1	3.4	2.6	4.6	1.3	2.6
Subject 10	6.2	11.1	5.7	9.9	2.5	5.1	2.6	5.0
Mean	3.5	2.3	3.5	2.1	4.0	2.5	2.7	1.9

time are shown in Fig. 4.

Analyses of main direction of the head movement

To determine if there were differences between the velocities of the head movement in the left–right and forward–backward direction, the absolute values of left–right velocities were subtracted with the absolute values from the corresponding forward–backward velocities. The results for each test condition are shown in Fig. 5. A positive value indicates that the velocity of left–right movement is higher than the forward–backward velocity. Zero indicates equal velocity; however, differences in velocity could not be statistically confirmed.

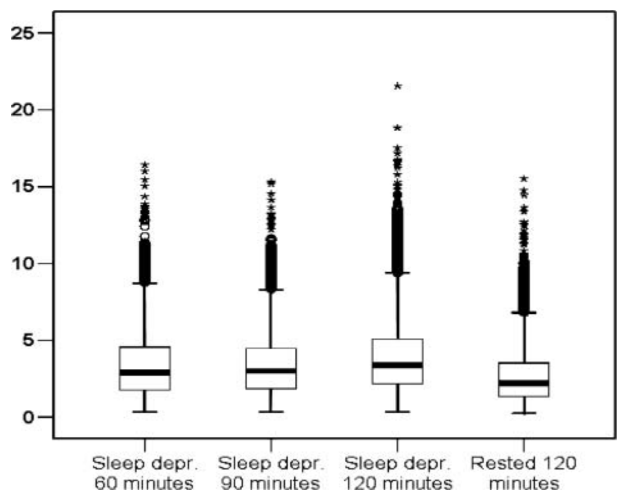


Fig. 2. Box plot showing the distribution of the subject's mean vector velocity per second (Y-axis) during each test condition. Each box represent 50% of the values; the circle (o) and the stars (*) are the outliers are extreme values. Number (n) for each test condition are n = 2,404 for sleep deprived 60 min, n = 3,606 for sleep deprived 90 min, n = 4,808 for sleep deprived 120 min and rested 120 min.

Analyses of the distance of head movement over time

The results of the analysis with ANOVA for repeated measures are shown in Table 3. No significant interaction (time × condition) effects between condition and time for head movement could be found except when comparing the sleep deprived 90-min test with the first 90 min in the rested 120-min test ($p < 0.01$). Significant main effects of time were found in all comparison, indicating that head movements increased over time equally for both sleep deprived and rested conditions. Furthermore, main effects of the condition were only found when comparing sleep deprived or part of sleep deprived conditions with the rested 120-min test or part of the rested condition. This indicates that when the subjects are in a sleep-deprived condition, they move their head (in degrees) more than when rested.

Analyses of the extreme vector velocity over time

Analysis with ANOVA for repeated measures of extreme head movements found no interaction effects (time × condition) except in the analysis of the sleep deprived 90-min test with the first 90 min in the rested 120-min test ($p < 0.01$). Significant effects of time were found in all comparisons, whereas the main effects for condition were found only in comparisons of sleep-deprived conditions and

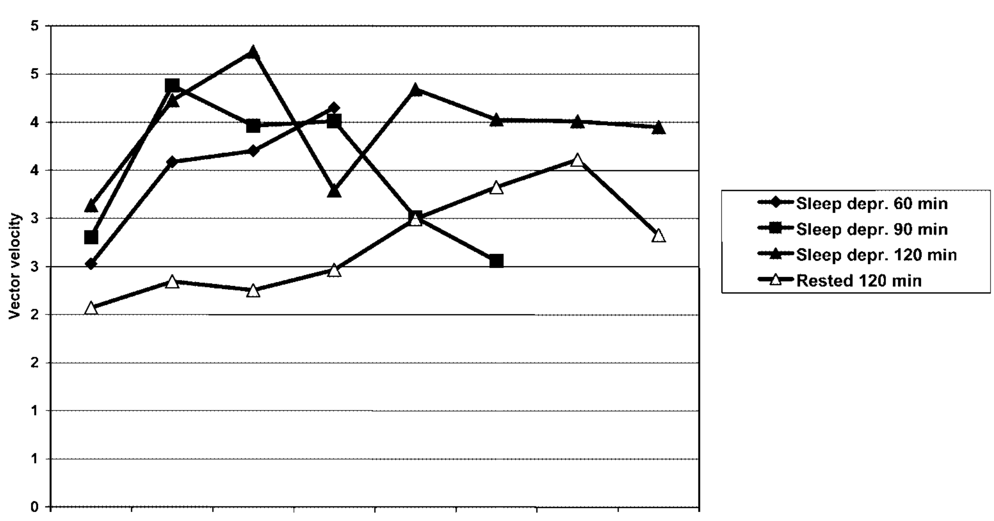


Fig. 3. Mean vector velocity over the time blocks for each test condition. The filled markers are the test condition when the subjects are sleep deprived.

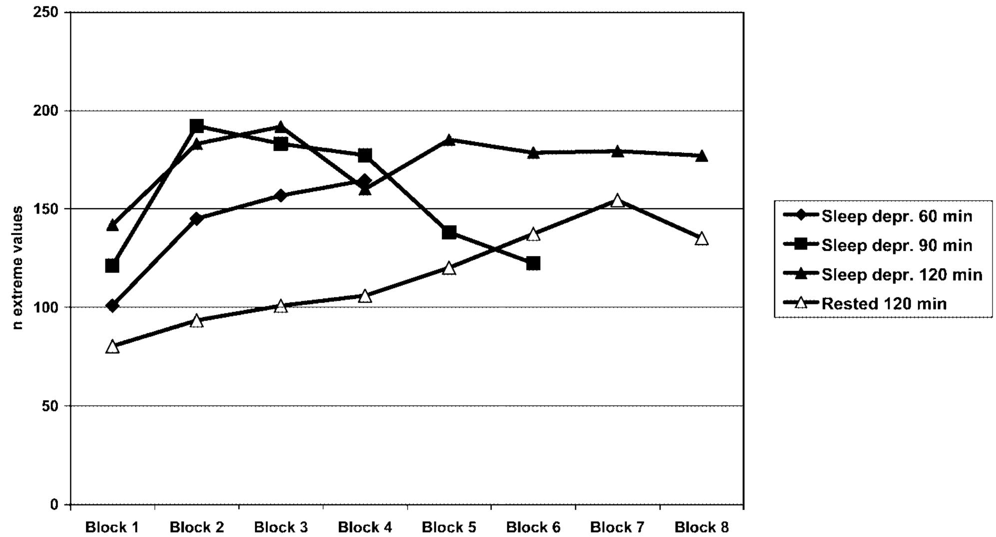


Fig. 4. Number of extreme vector velocities over a cut off.

The subject's individual cut off is calculated from IQR ×3 for time block1 in the rested condition. Velocity is over the time blocks for each test condition. The filled markers are test condition when the subjects are sleep deprived.

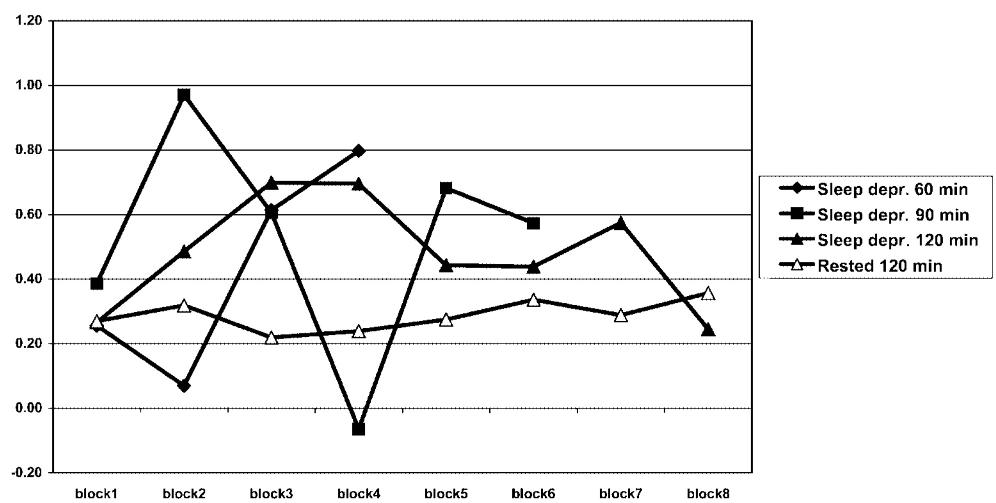


Fig. 5. Differences between the magnitude of the velocity of the left–right movement and the forward–backward movement over time for each test condition.

Positive values (y-axis) indicate that the left–right movement have higher mean velocities than the forward–backward movements.

part of sleep-deprived conditions for the rested 120-min test and part of the rested 120-min test. These results (Table 4) indicate that when sleep deprived, the subjects more often have extreme head movements than when rested and that the number of these extreme head movements increases equally over time in both groups.

Analyses of the correlations between head movements and physiological variables and ratings

The results of the analysis of correlation between head movement (distance and extreme values), physiological variables, and subjective sleepiness ratings are presented in Table 5. The majority of the correlations were in the rested 120-min test. When calculating the correlations over the whole 120 min (Table 5, column A), the coefficient, r, ranges from 0.721 to 0.984. Heart rate shows a negative correlation

Table 3. Head movement (distance in degrees). Results of the separate ANOVAS with the repeated measures of time and condition. Note that the df have been adjusted using the Huynh-Felt correction

Comparisons	Interaction			Time			Condition		
	F	df	*p*	F	df	*p*	F	df	*p*
A									
Sleep deprived 60 min compared to first 60 min in Sleep deprived 90 min	0.7	1.2/11.2	0.44	9.6	2.6/23.2	0.00	1.7	1/9	0.22
Sleep deprived 60 min compared to first 60 min in Sleep deprived 120 min	2.0	2.8/25.2	0.14	6.0	3.0/27	0.00	0.3	1/9	0.59
First 60 min in Sleep deprived 90 min compared to first 60 min in Sleep deprived 120 min	1.2	2.5/22.8	0.32	6.8	1.7/15.1	0.01	0.0	1/9	0.92
Sleep deprived 90 min compared to first 90 min in Sleep deprived 120 min	2.4	5.0/45.0	0.05	4.5	3.9/35	0.01	0.9	1/9	0.38
B									
Sleep deprived 60 min compared to first 60 min in Rested 120 min	2.1	3.0/27	0.13	6.4	2.3/20.6	0.01	6.6	1/9	0.03
First 60 min in Sleep deprived 90 min compared to first 60 min in Rested 120 min	2.3	2.0/17.7	0.13	5.7	3.0/27	0.00	14.0	1/9	0.00
Sleep deprived 90 min compared to first 90 min in Rested 120 min	7.5	3.5/31.4	0.00	3.9	5.0/45.0	0.01	7.2	1/9	0.03
Sleep deprived 120 min compared to Rested 120 min	1.5	4.6/41.0	0.21	3.4	4.8/43.5	0.01	10.7	1/9	0.01

A = Sleep deprived conditions or part of sleep deprived conditions compared to each other.
B = Sleep deprived conditions or part of sleep deprived conditions compared to parts of or the whole rested condition.

to head movements, r = –0.850/–0.966. The correlations in the rested condition are in general not significant during the first hour (Table 5, column B), but they are significant after one and half hours (Table 5, column C). To graphically illustrate the correlations, subjective rating (KSS for ratings) and physiological variables (alpha power, theta power, and heart rate for physiological variables) are plotted against head movement and extreme values (see lower plots in Fig. 6). During the sleep-deprived 60-min and 120-min tests, significant correlations between subjective ratings and both types of head movement measures were found. The correlations between KSS (used as an example) are illustrated in Fig. 6. In the upper two plots, the correlations depend on the dot to the far left (corresponding to the 15 min rating value). If these rating are excluded from the correlation calculation, the correlation ends up non-significant (r=0.920, *p*=0.26 for KSS–Head movement, extreme in sleep-deprived 60 min; r=0.12, *p*=0.81 for KSS–Head movement, extreme in the sleep-deprived 120 min test).

Discussion

The results show increases of the velocity (degree/s) of head movements and the number of extreme head movements over time. The increases over time are statistically equal both when the subjects are sleep deprived and rested. However, the velocity of the head movement and number of extreme head movement are at a significantly higher level when the subjects are sleep deprived than rested at the start of the test. The increase of head movements, both velocities and number of extreme movements, is evident from the beginning of the experiments. When the subjects are sleep deprived, most of the increase appears to occur during the first hour and then levels off for the rest of test. The pattern in the Fig. 3 over time correspond to those seen in the subjective ratings of sleepiness[24, 35].

Table 4. Head movement (count of extreme vector velocities). Results of the separate ANOVAS with the repeated measures of time and condition. Note that the df have been adjusted using the Huynh-Felt correction

Comparisons	Interaction			Time			Condition		
	F	df	*p*	F	df	*p*	F	df	*p*
A									
Sleep deprived 60 min compared to first 60 min in Sleep deprived 90 min	0.8	1.7/15.3	0.43	9	3.0/27.0	0.00	3.7	1/9	0.09
Sleep deprived 60 min compared to first 60 min in Sleep deprived 120 min	1.1	3.0/27.0	0.38	4	3.0/27.0	0.02	1.1	1/9	0.33
First 60 min in Sleep deprived 90 min compared to first 60 min in Sleep deprived 120 min	0.8	2.6/23.6	0.51	4.6	2.2/20.1	0.020	0.0	1/9	0.97
Sleep deprived 90 min compared to first 90 min in Sleep deprived 120 min	2.4	5.0/45.0	0.05	2.8	4.0/35.6	0.04	0.9	1/9	0.38
B									
Sleep deprived 60 min compared to first 60 min in Rested 120 min	1.3	3.0/27.0	0.29	7.9	2.8/25.5	0.00	11.4	1/9	0.01
First 60 min in Sleep deprived 90 min compared to first 60 min in Rested 120 min	2.8	2.3/20.4	0.08	6.5	3.0/27.0	0.00	30.5	1/9	0.00
Sleep deprived 90 min compared to first 90 min in Rested 120 min	8.0	4.0/35.6	0.00	4.3	5.0/45.0	0.00	18.2	1/9	0.00
Sleep deprived 120 min compared to Rested 120 min	0.8	3.8/34.6	0.53	3.3	4.8/43.1	0.01	15.1	1/9	0.00

A = Sleep deprived conditions or part of sleep deprived conditions compared to each other.

B = Sleep deprived conditions or part of sleep deprived conditions compared to parts of or the whole rested condition.

This resembles a "ceiling effect" (which might explain the poor correlations between head movements, ratings, and physiological variables during the sleep-deprived test). One might wonder what is "above the ceiling". The ceiling effect in sleepiness ratings have been discussed earlier[24, 35]. The ceiling effects in these studies can be interpreted as the subject not being able to rate their sleepiness higher without falling asleep because they already struggling hard to stay awake. One might speculate that the higher level of head movements during a sleep-deprived test and especially its signs of leveling off represent the border where the maximum of unconscious head movements occur as one tries to stay awake. Wright and McGown[33] measured head movements among pilots by analyzing head movement during flights. They showed head movement activity during work, but when the pilots fall a sleep, no head movements were shown. This leads to the thought that a sleepy person over time increasingly moves the head more to a certain level and when dozing off the amount of head movement drops. In fact, this goes for sleepiness rating as well as for alpha activity and theta activity. A sleeping person cannot rate their sleepiness. While sleeping, the alpha and theta activity drops and are replaced by delta activity. Thus, the results of this study clearly verify a relationship between head movements and sleepiness. Faster and more extreme head movements are associated with higher rated sleepiness ratings, which hold as long as the subjects stay awake.

When the subjects are rested, the increases over two hours appear to be more linear, an observation that holds for ratings and the physiological variables presented elsewhere[24]. Popieul, Simon, and Loslever[36] measured head movement among voluntary drivers who were not sleep deprived in a driving simulator. They found that the increased head movement appeared clearly after 150 km of a 300 km simulated monotonous driving. Our results, however, indicate that head movement has already increased

Table 5. Correlations between head movements and alpha power, theta power, subjective sleepiness ratings (KSS, CR-10, CR-10 eye), heart rate and total heart rate variability

		Head movement, distance	Head movement, extremes	Head movement, distance	Head movement, extremes	Head movement, distance	Head movement, extremes
		A		B		C	
60 min sl. dep							
Alpha.	r	0.008	0.133				
Theta.	r	0.901	0.860				
KSS.	r	0.962*	0.993**				
CR-10.	r	0.973*	0.95				
CR-10 eye.	r	0.961*	0.962*				
HR.	r	–0.995*	–0.979*				
HRV, pTOT.	r	0.790	0.870				
90 min sl. dep							
Alpha.	r	–0.083	–0.139	0.238	0.100		
Theta.	r	–0.332	–0.232	0.775	0.783		
KSS.	r	–0.056	0.054	0.693	0.753		
CR-10.	r	–0.092	0.025	0.661	0.721		
CR-10 eye.	r	0.054	0.180	0.738	0.800		
HR.	r	0.337	0.262	–0.456	–0.450		
HRV, pTOT.	r	–0.238	–0.133	0.751	0.773		
120 min sl. dep							
Alpha.	r	–0.176	–0.438	–0.225	–0.471	–0.197	–0.435
Theta.	r	0.157	0.228	–0.353	–0.184	0.166	0.275
KSS.	r	0.633	0.806*	0.633	0.788	0.661	0.811
CR-10.	r	0.480	0.661	0.488	0.647	0.518	0.669
CR-10 eye.	r	0.466	0.658	0.453	0.642	0.527	0.686
HR.	r	–0.273	–0.480	–0.326	–0.499	–0.355	–0.529
HRV, pTOT.	r	0.136	0.143	0.078	–0.046	0.134	0.100
120 min rested							
Alpha.	r	0.862*	0.885**	0.08	0.24	0.838*	0.815*
Theta.	r	0.984**	0.946**	0.973*	0.85	0.996**	0.970**
KSS.	r	0.877**	0.933**	0.69	0.92	0.934**	0.981**
CR-10.	r	0.857**	0.892**	0.84	0.94	0.861*	0.930**
CR-10 eye.	r	0.814*	0.823*	0.78	0.971*	0.835*	0.921**
HR.	r	–0.850**	–0.966**	–0.86	–0.999**	–0.911*	–0.983**
HRV, pTOT.	r	0.721*	0.810*	0.90	0.90	0.866*	0.896*

A= Head measures in respective condition vs the other variables in corresponding condition.
B= Head measures the first hour in respective condition vs the other variables the first hour in corresponding condition.
C= Head measures the first1.5 h in respective condition vs the other variables the first 1.5 h in corresponding condition.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

significantly after one hour, whether the person is sleep deprived or not. Furthermore, after one and half-hours when rested, the correlations between head movements, ratings of sleepiness and physiological variables become significant. It thus seems as though the increase in head movements reflects a very early phase of the increase of sleepiness. The results of this study not only confirm the results of Popieul, Simon, and Loslever[36] but also strengthen the statement that head movements are a time sensitive indicator of sleepiness. The increase in head movements reflects the sleepiness ratings while excluding the possible effects related to inattention or distraction.

The relation between head movements and sleepiness is supported also by the differences between subjects when they are rested and when they are sleep deprived. The levels of head movements in the three sleepy conditions are all higher than in the condition of less sleepy. A sleepy person thus changes their head position more than an alert person.

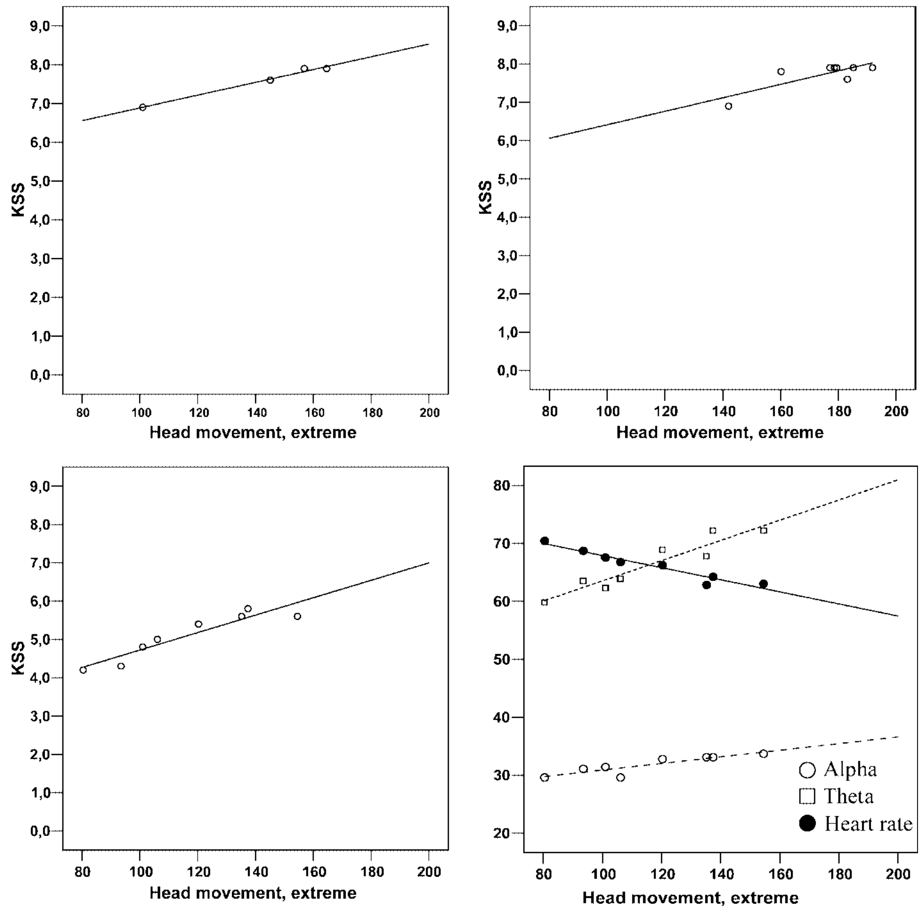


Fig. 6. Four scatter plots to illustrate the correlations between subjective ratings (KSS is used) and physiological variables (alpha power, theta power, and heart rate are used).

In the upper portion of the graphs, two plots of KSS are plotted against head movement–extreme in the sleep deprived 60-min test (left) respectively sleep deprived 120-min test (right). To the lower left, KSS is plotted against head movement–extreme in the rested 120-min test. The lower right plots the head movement–extreme (x-axis) are plotted against alpha power (○), theta power (□), and heart rate (●). Significant correlations are found in all these plots (see Table 5); however, the correlations in the upper two plots both depend on one dot (see text for explanation).

Behavioral activities due to symptoms of sleepiness (i.e., yawning or nodding) or countermeasures to sleepiness (changing head position, stretching, etc.) cause head movement and have shown to increase over time under simulated monotonous driving conditions[37]. Furthermore, a sleepy person also has reduced muscle tone[38], which lead to a less stable head position and might increase head movements.

Eye and head coordination while driving can be predicable when the movements of the eye and head are generated unconsciously[39]. Because the posture condition of the subjects (looking forward at a computer screen with signal blinking at different levels), the direction of the head movements were expected to be dominated by the frontal backwards movements. Furthermore, sleepiness related nodding normally is experienced as a forward–backward movement. Thus, the results from the present study were somewhat surprising since the velocity of the head movements in the forward–backward direction did not differ from the velocity of movements in the left–right direction. The results from this study describe the early sleepiness related movements as a more general non-direction of the head posture control.

The sleepy effect on head posture, developed in a very early stage, is important because of the practical implication of technical systems for registration of sleepiness. A review of the Internet reveals that there are several different technical systems for monitoring head movements. There are small appliances that are put behind the driver's ear and produce a warning signal when the head is tilted to a certain degree in the forward direction. One drawback with such a device is that if the driver nods off backwards against the head restraint the alarm might not go off. Another device that is designed to detect microsleep events occurring in association with head noddings is described by Heitmann *et al.*[40] Even if microsleep can occur in the absence of head noddings, the idea of an optimal indicator is that it indicates severe sleepiness before the driver falls asleep. Another device combines head movement monitoring with analysis of the eye[40–42]. However, despite all the technical innovations of devices that monitor drivers' head movements; there are few field studies that systematically evaluate these devices.

Besides head movement as an indicator of sleepiness, the present study also relates to other indicators of sleepiness; EEG, HR/HRV and subjective ratings. EEG can indicate sleepiness, but the interpreting of the recording demands expert knowledge and further, the device is today to impractical too be implemented as a safety device for e.g. professional drivers. Heart rate might indicate sleepiness; however heart rate variability does not seem to be a relevant indicator of sleepiness[20]. Subjective sleepiness on the other hand, indicates sleepiness, easy to administrated and simple to use. A combination of sleepiness ratings and an objective indicator of sleepiness, that also simple to use, might be a promising safety approach for e.g. drivers. Wireless devices that monitor head movements might not be difficult to build into, for instance, a hat or cap.

One limitation of the present study is the sample size. However due to the time consuming procedure and high levels of discomfort experienced by participants small sample size in studies of sleepiness are not uncommon se [22, 43, 44]. Another limitation is the issue of simulating the actual driving conditions. Failure to simulate actual driving conditions can be a threat to the validity which suggests that laboratory studies should be followed by field studies under realistic conditions. The design of the study with three different test length in the sleep deprived condition could be questioned. Another approach would have been 20 subjects, participating once respectively in the 120 min tests.

In conclusion, this study shows a relationship between sleepiness and head movements. It could be considered as a support for head movements as a sleepiness indicator since the presence of relatively moderate movements even at early stages of sleepiness and a time history of its development. Given the relatively small number of studies of sleepiness and head movement and the fairly mild amount of sleep deprivation in this study, future studies could compare several levels of sleep deprivation (including at least one full night of sleep deprivation) so that a dose-response relationship with head movement could be observed. Furthermore, the practical implication of the findings suggests that field studies are needed to evaluate technical applications.

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