Brief Communication

Effect of sleep deprivation on postural stability

José Haba-Rubio[1]*, Amélie Nater[2]*, Helena Marti-Soler[1], Alexandra Budowski[2], Francis Degache[3,4]*, Raphael Heinzer[1]*

[1]Center for Investigation and Research in Sleep (CIRS), University Hospital of Lausanne (CHUV) and University of Lausanne, Lausanne, Switzerland
[2]University of Lausanne, Switzerland
[3]University of Health Sciences, University of Applied Sciences and Arts Western Switzerland, Lausanne, Switzerland
[4]Department of Physiology, GRISSUL (Group of Research of Institute of Sports Sciences), University of Lausanne, Lausanne, Switzerland

* **Corresponding author**. Center for Investigation and Research in Sleep (CIRS), University Hospital of Lausanne (CHUV), rue du Bugnon 46, 1011-Lausanne, Switzerland, E-mail address: raphael.heinzer@chuv.ch (R. Heinzer)

Abbreviations: AP: anteroposterior axis; BMI: body mass index; CoP: center of foot pressure; KSS: Karolinska sleepiness scale; ML: mediolateral axis; PVT: Psychomotor Vigilance Test; RT: reaction time

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Abstract

Background: Maintaining postural control requires the continuous integration of different peripheral inputs that may be altered by sleepiness. The objective of this study was to assess the effects of 24 hours sleep deprivation on postural stability.

Methods: healthy subjects underwent 24 hours supervised sleep deprivation after a week of stable sleep schedule. Stability was assessed using a posturographic platform allowing to determine the center of foot pressure (CoP) oscillations in mediolateral (ML) and anteroposterior (AP) axis and thereby total XY displacement, the surface area and the mean speed of CoP displacement. Measurements were performed in the morning before sleep deprivation and every two hours during the night. Vigilance and fatigue were evaluated at the same intervals using the Psychomotor Vigilance Test (PVT), and the Karolinska sleepiness scale (KSS).

Results: 30 volunteers (7 men and 23 women, aged 22±2 yo, BMI 18.5-25kg/m^2) were included in the study. When comparing pre-and post-sleep deprivation morning stability parameters, there was significant deterioration in the majority of the postural variables: CoP area ($P<0.05$), AP ($P<0.01$) and total displacement ($P<0.05$) as well as in some PVT's variables: reaction time ($P<0.001$), lapses ($P<0.05$) and in subjective sleepiness ($P<0.001$). During the sleep deprivation night, there was a progressive and parallel deterioration of the stability and vigilance parameters that reached its maxima at 4 a.m., followed by a mild improvement at 6 a.m.

Conclusions: Postural control is significantly altered by 24 hours sleep deprivation and seems to fluctuate in a similar pattern as vigilance and subjective sleepiness.

Keywords: postural control, sleep deprivation, sleepiness, psychomotor vigilance test, posturography

Highlights:

- Postural stability is significantly affected by 24 hours sleep deprivation
- At night, there was a progressive postural control impairment with a peak at 4 am
- Postural control impairment seems to fluctuate in parallel with vigilance and fatigue
- Sleepiness could affect sensory integration necessary to maintain postural stability

Introduction

Maintaining postural control requires the continuous integration of different peripheral inputs including the visual, the proprioceptive and the vestibular systems(1, 2). These functions are integrated in the central nervous system, allowing to determine the position of each part of the body in space and sending back the appropriated signals for maintaining balance. This central sensorial integration can be affected by the vigilance level(3-5). Sleep deprivation can thus be a major contributing factor of postural instability and falls (6). This is of particular concern in modern societies, in which sleep restriction is very common and linked to motor vehicle crashes, industrial disasters, and occupational accidents (4, 5, 7).

The aim of our study was to evaluate the evolution of postural stability during 24 hours sleep deprivation and its relationship with objective measures of alertness and subjective sleepiness.

Methods

Subjects were recruited among the students of Lausanne University in Switzerland. Inclusion criteria were age > 18 years, body mass index (BMI) between 18 and 25 Kg/m^2, regular sleeping/waking cycles with a median sleep duration of more than 7h during the week prior to sleep restriction assessed by actigraphy, no sleep complaints, no intake of medication affecting central nervous system and no chronic alcohol consumption.

Postural stability was assessed using a posturographic platform (Fusyo-Medicapteur, Toulouse, France; Dekra certification), a device allowing to measure the evolution of center of pressure (CoP) oscillations, which represents the central application point of the reaction forces produced by the body to counteract the movements of the center of mass(8). Because the CoP constantly moves around the center of mass to maintain balance, dynamic parameters of the

CoP displacement are commonly used to characterize static postural control. The length of CoP displacement in X- and Y-axis (corresponding to mediolateral and anteroposterior directions), and thereby total XY displacement, surface area and mean speed of CoP displacement were calculated with subjects having eyes open and closed.

Objective vigilance was assessed using a psychomotor vigilance test (PVT), a widespread test that measures reaction time in response to a visual stimulus allowing to objectively assess alertness (9). Subjective sleepiness was assessed using the Karolinska Sleepiness Scale (KSS)(10).

The posturographic assessment as well as the objective and subjective vigilance tests were applied before the sleep restriction in the morning at 7 a.m., in the evening at 10 p.m., at midnight, 2 a.m., 4 a.m., and 6 a.m. During the sleep deprivation night, participants were kept awake at the Center for Investigation and Research in Sleep (CIRS) under constant surveillance by an investigator. They were allowed to watch DVD’s, play board games and to snack between the assessments. Alcohol consumption was prohibited during and 24 hours before the sleep privation, and caffeine was limited to 4 cups during the day with a last consumption at 4 p.m. Driving was prohibited in the day following the sleep restriction night.

Paired t-tests were used to determine differences between the parameters recorded in the morning before and after the 24 hours sleep deprivation, and one-way analysis of variance for repeated measures (ANOVA) were used to assess differences between the 6 consecutive measures. A P value < 0.05 was considered to be statistically significant.

All participants gave their written informed consent and the study was approved by the ethics committee of the University of Lausanne.

Results

30 healthy subjects (7 men and 23 women, aged 22±2 yo, BMI 18.5 -25kg/m2) participated and completed the study.

The main postural parameters, PVT parameters and subjective fatigue's score are described in Table 1. Overall, sleep deprivation altered most postural stability variables: comparing the data before and after the 24-hour sleep deprivation, in open eyes condition, we observed a higher CoP area (+ 32%, P<0.01), a longer Y length (+ 21%, P<0.001), X length (+ 21% P<0.05) and XY length (+14%, P<0.05) and a lower mean speed (- 9%, P<0.05). These differences were however not found in eyes-closed conditions, in which there was even a decrease in decrease in XY length (- 8 %, P<0.05) and in X length (- 16%, P <0.001).

During the sleep deprivation night, ANOVA analysis revealed significant effects of time for postural stability parameters, as well as for PVT variables and subjective sleepiness measured with the Karolinska scale.

For example, the CoP area gradually deteriorated during the 24h sleep restriction (at 7 a.m. before the sleep restriction: 185 +/- 80 mm^2 vs. at 4 a.m.: 294 ± 177 mm^2, P<0.05), followed by a mild improvement at 6 a.m. (272±161 mm^2). As showed in Figure 1, similar evolution patterns were observed for total displacement of CoP (length XY) and anteroposterior direction (length Y).

PVT's variables and Karolinska sleepiness scale scores also showed a similar pattern, with a progressive deterioration during the night. For example, the mean reaction time (RT) reached its higher scores at 4 a.m. (mean RT: 267.5 ± 40.6 msec), and stabilized thereafter at 6 a.m. (mean RT: 267 ± 42.6 msec).

Discussion

The aim of this study was to determine the effects of acute sleep deprivation on postural control, and its relationship with objective alertness and subjective sleepiness.

Our results showed significant variations in postural stability with open eyes condition after a 24h sleep deprivation, as measured by the CoP area, the mediolateral (X-axis), anteroposterior (Y-axis) and total displacement (XY axis) length, as with the mean speed.

CoP area, length of CoP displacement in anteroposterior directions (Y-axis) and total displacement of CoP in anteroposterior and mediolateral plan (Length XY in mm) seem to follow similar dynamics along sleep deprivation, with a progressive deterioration that reaches its maxima instability at 4 a.m., followed by a mild improvement at 6 a.m. Similar evolutive patterns following sleep deprivation were found for mean PVT related variables as mean RT and lapses, as well as for sleepiness scores, suggesting an association between alertness and postural control impairments.

These results are in accordance with previous studies showing that sleep deprivation impairs postural control(4, 11-17), and that it exists a “time-of-day” balance rhythmicity, also in agreement with previous chronobiological studies showing a circadian influence in maintaining posture(3, 11, 12, 16-18).

The similar evolution pattern observed in postural stability and in vigilance is compatible with the idea that sleep deprivation induces dysfunctions in brain areas implicated in both postural control and sustained attention. These areas may be related since both functions seems to be crucial in maintaining stability and that attention is also clearly affected by sleep deprivation

(19, 20). The progressive deterioration in postural stability and in vigilance until 4 a.m. with a trend for improvement at 6 am also suggests a possible circadian effect on both functions, but our study was not designed to evaluate accurately circadian parameters.

As in previous reports, postural control seems more affected after sleep deprivation in the « open eyes » condition than in the « closed eyes » condition(16). This suggests that, after an acute sleep deprivation, there is a slower processing of visual inputs or that the postural control system is unable to integrate visual inputs to adapt balance(16).

Our group also recently showed that not only sleep deprivation but also sleep disruption by sleep disordered breathing can also influence postural control(2). This suggests that not only sleep restriction but also sleep quality impairment can affect postural stability. It is also possible that preventing sleep deprivation and sleep quality impairment could have a positive impact on postural instability-related risk of accidental fall and injury.

There are several limitations in our study that need to be taken into account. First, most measures were performed between 10 p.m. and 6 a.m. which does not allow us to determine fluctuations during the day. Second, the relatively small sample did not allow stratification by age or gender. Further researches are thus needed to clarify the posturographic changes related to sleep deprivation and its fluctuations during a 24 hours' period.

Conclusion

In conclusion, our data confirm that a 24-hour sleep deprivation significantly affects postural stability, which could be the result of a disturbed visual sensory integration, related to a decrease in attentional resources and increased sleepiness.

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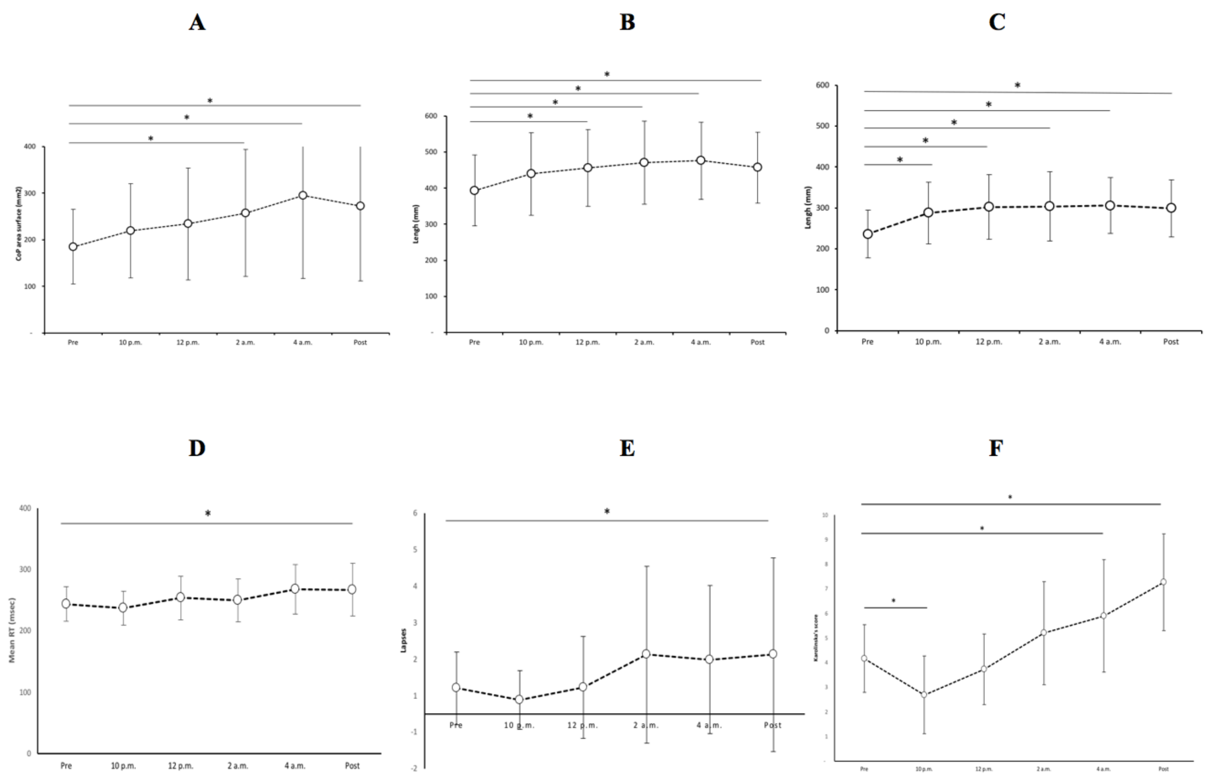
Conflict of interest: The authors have no financial conflicts of interest.

Table 1: Postural stability parameters before and after the 24-hour sleep deprivation (mean±SD), in open eyes' condition.

Postural parameters	Before sleep deprivation (7 a.m.)	After sleep deprivation (7 a.m.)	P-value
CoP area	185 +/- 80	272 +/- 161	**<0.05**
Length XY	394 +/- 99	457 +/- 99	**<0.05**
Length Y	236 +/- 58	299 +/- 69	**<0.001**
Length X	244 +/- 76	275 +/- 70	**<0.05**
Mean speed	10 +/- 2	9 +/- 2	**<0.05**
Mean RT	244 +/-28	267 +/- 43	**<0.001**
Lapses	1 +/- 1	3 +/- 6	**<0.05**
Subjective sleepiness	4 +/- 1	7 +/- 2	**<0.001**

CoP area: center of pressure area (mm^2); Length XY: total displacement of CoP in anteroposterior (Y axis) and mediolateral (X axis) plan (length in mm); length of CoP displacement in anteroposterior directions (Y-axis); length of CoP displacement in mediolateral directions (X-axis); mean speed: mean speed of CoP displacement (mm/s). Mean RT = Mean reaction time using psychomotor vigilance test in milliseconds. Lapses: number of times the subject responded later than 500 ms. Subjective sleepiness: assessed with Karolinska sleepiness scale scores.

Figure 1: Changes in the variables of postural control, in PVT parameters and Karolinska sleepiness scores during the 24-hour sleep deprivation.



A: Center of pressure (CoP) area (mm^2); B: total displacement of CoP in anteroposterior and mediolateral plan (Length XY, mm); C: length of CoP displacement in anteroposterior directions (Length Y, mm); D: Mean reaction time (msec); E: number of lapses; F: Karolinska sleepiness scale scores.

** indicates a P-value <0.05. All data are expressed as means ± SD.*

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