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RESEARCH ARTICLE

Posturography as an Indicator of Fatigue Due to Sleep Deprivation

Yair Morad, Bella Azaria, Isaac Avni, Yaniv Barkana,
David Zadok, Reuven Kohen-Raz, and Erez Barenboim

Morad Y, Azaria B, Avni I, Barkana Y, Zadok D, Kohen-Raz R, Barenboim E. ***Posturography as an Indicator of Fatigue Due to Sleep Deprivation.*** **Aviat Space Environ Med 2007; 00:000–00.**

Background: Fatigue is one of the main causes for accidents in transportation. This study was designed to assess the efficacy of a short objective posturographic test as an indicator of fatigue due to sleep deprivation. ***Objectives:*** To assess the efficiency of a short objective posturographic test as an indicator of fatigue due to sleep deprivation. ***Methods:*** Postural control was measured using four-plate posturograhy with eyes open and eyes closed. Over a period of 26 h of sleep deprivation (from 08:00 to 10:00 the following day) 12 subjects were studied 10 times. The posturographic data were correlated with a subjective fatigue assessed by means of the Stanford Sleepiness Score. ***Results:*** Stability and sway intensity while eyes were closed showed a statistically significant circadian pattern with a peak at early morning hours and a recovery at 10:00 the following day. When eyes were open, only changes within the medium-low frequency band (0.1–0.05 Hz), believed to be linked with vestibular function, reached statistical significance. The Subjective Feeling Scale pattern was similar to the postural parameters, but with an absence of recovery at 10:00 the following day. Excluding this point, significant correlations were found between posturography with eyes closed and this scale. ***Conclusions:*** Fatigue caused by sleep deprivation can be objectively assessed by a short, non-invasive, postural test. The vestibular function appears to be relatively more strongly affected by fatigue than the visual and somato-sensory subsystems. Occlusion of vision appears to enhance the effect of fatigue on postural performance. Our results may imply that this test could be used as an efficient screening tool for detection of fatigue.

Keywords: fatigue, sleep derivation, vigilance, posturography.

"PERFORMANCE FATIGUE" is defined by Brown (5) "as the subjective experience of individuals who are obliged . . . to continue working beyond the point at which they are confident of performing their task efficiently." This has become an issue of major concern in technological society, as the majority of contemporary occupations and jobs require optimal attention and alertness during an extended span of time, including night shifts. It was shown that sleep deprivation can cause cognitive and judgmental errors (17). Hence a decline of performance to the extent of failing to respond to critical cues of the operational setting may be fatal (19). Fatigue and weakened vigilance have been reported to be one of the main causes for accidents in aviation as well as in ground transportation (16,26). More specifically, decreased performance related to sleep deprivation and circadian disruption has been implicated in some major disasters, such as the Exxon Valdez and Bhopal accidents (25).

Although levels of fatigue can be subjectively assessed, it was shown that such an evaluation does not reflect the objective, physiological status of the tired person, mainly because subjective reports are biased by motivation, personal factors, experience, training, etc. (18). Hence it is obvious that fatigue must be measured with objective methods. There are several physiological parameters that were reported to be influenced by fatigue, and several of them were actually tested, such as electrocardiogram, electroencephalogram (10,32), rectal temperature (21,30), BP (32), etc. However, none of these assessment methods gained popular use. This is due to several drawbacks such as inconvenience of use, difficulties in interpretation of data, impractical use in field settings, and other reasons that eventually made all these methods non-cost-effective. In light of this, there is an urgent need to find a practicable, non-invasive, but reliable tool to measure fatigue, and especially its critical levels, which involve high risk for accidents.

The postural control system consists of three main subsystems: vestibular, somatosensory, and visual (4). Previous studies done by our group (14) and by others (20,22) have shown that postural control is influenced by changes in vigilance. The computerized posturographic test can measure the activity of each of these three main subsystems (8,27,31), however, the exact effect of fatigue on those subsystems needed to be elucidated. The objectives of the present study were the following: 1) to evaluate the sensitivity of posturographic parameters to fatigue caused by sleep deprivation in healthy subjects; 2) to validate the posturograhic measures of fatigue against an external criterion of established reliability and validity, i.e., The Stanford Sleepiness Test (13); and 3) to investigate the possibility

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that two main subsystems of postural control, i.e., the vestibular and somatosensory, are differently affected by sleep deprivation.

METHODS

There were 12 volunteers (6 men and 6 women ages 20–60 yr) who were recruited for the study. All were healthy and did not take any medication, as verified by medical checkup. Additional exclusion criteria were: postural problems, minor orthopedic abnormalities, and suspected sleep disorders, as assessed by a special questionnaire (33). The Assaf Harofeh Medical Center Ethics Committee approved the study, and each participant gave his informed consent for participation.

Postural control was measured using the FitScan Interactive Balance System (Beamed Medical, Petach-Tikva, Israel, also marketed as Tetrax Interactive Balance System). This method of posturography is based on the assessment of the vertical pressure fluctuations on four independent force plates, each placed beneath the two heels and toe parts of the subject standing on them in upright position. The software of the system measures four basic parameters, obtained by standing in eight positions. The parameters are:

1. Stability index, which is an indicator of the amount of sway. It is an equivalent to the traditional posturographic measures assessing point-of-gravity deviations.
2. Weight distribution, assessed by calculating the percentage of weight put on each of the four platforms.
3. Synchronizations, which are mathematical expressions of the interactions between paired traces obtained by comparing the six possible combinations of the four outputs: heel and toe of each foot (2); the two heels (1); the two toes (1); and the diagonals (2) (heel and contra-lateral toe part). Synchronizations reflect the quality and efficiency of coordination movements of the agonist and antagonist muscle system of the lower extremities.
4. Fourier transformations measure the intensity of sway across a spectrum of sway frequencies ranging from 0.01 to 3.00 Hz, using a sampling rate of 32 Hz during 32 s. This spectrum is broken down into four frequency bands designated as low (0.01–0.1 Hz), medium-low (0.1–0.5 Hz), medium-high (0.5–1.00 Hz), and high (1.00–3.00 Hz). As shown by previous studies (3,8,21,25,29), the power of the low frequencies is linked with visual control, the medium-low frequency band is sensitive to vestibular stress and disturbances, the medium-high frequencies reflect somato-sensory input from the lower extremities, and bursts of high frequencies are signs of postural tremor caused by muscular stress or central nervous dysfunctions.

The standard examination protocol includes eight positions of 32 s duration each. In the present study only two positions were used: standing with eyes open or eyes closed, respectively, for an extended experimental time of 48 s. A more comprehensive and detailed description of the system is described elsewhere (14,15,28).

The Stanford Sleepiness Score (13), a self-rating questionnaire, was used to assess the participant's feeling of sleepiness. The scale contains 7 statements describing a gradually increasing feeling of sleepiness ranging from "Feeling active and vital; alert; wide-awake" (score 1) to "Almost in reverie; sleep onset soon; lost struggle to remain awake" (score 7).

Subjects arrived in the morning, after a normal, full night's sleep and were required to stay awake for 26 h, starting at 08:00 and terminating at 10:00 the next day. They were given posturographic examinations and answered the fatigue questionnaire according to the following timetable: 08:00, 09:00, 10:00, 23:00, 01:00, 03:00, 05:00, and 08:00, 09:00, and 10:00 the following day. This timetable allowed us to compare the three first and three last performances scheduled at identical circadian time points. During the entire study, all subjects were under supervision to ensure sleep deprivation. They were allowed to watch video, read, and eat as desired, but were not allowed caffeine at any form.

The statistical significance of the results was evaluated by computing the non-parametric Friedman's Rank Analysis of Variance for Repeated Measurements, followed by post hoc paired *t*-tests. Correlations were examined using the Spearman Rank Correlation test. All F values refer to Friedman non-parametric one-way test of variance for repeated measurements with degrees of freedom 11–9.

RESULTS

The subjective feeling of fatigue, as reflected by the Stanford Sleepiness Score, is presented in **Fig. 1**. As can F1 be seen, the Sleepiness Scores have a highly significant circadian pattern ($F = 67.5$, $p = 0.0001$) with a conspicuous raise (post hoc *t*-tests, $p < 0.05$) at 05:00, persisting until the end of the experimental period at 10:00. As shown on **Fig. 2A and B**, postural stability shows a F2 similar circadian pattern with a significant peak of destabilization between 05:00 to 08:00 (Post hoc *t*-tests, $p < 0.05$). However, in contrast to the Sleepiness Score,

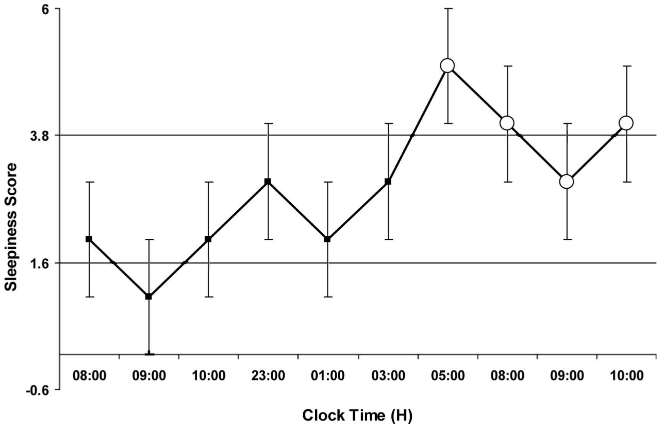

Fig. 1. Subjective Sleepiness Score vs. clock time for the duration of the 26-h experiment. White circles on graph show post hoc differences significant at $p < 0.05$ between designated circadian time points and performance on the morning hours preceding the sleepless night.

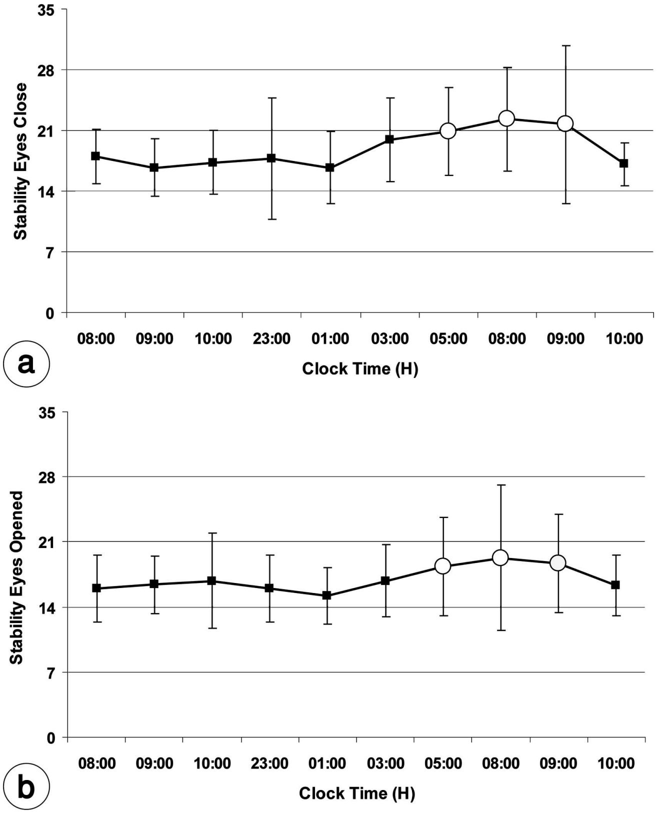

Fig. 2. Stability (mean vertical pressure fluctuation normalized by subject weight) vs. clock time for the duration of the 26-h experiment. A) Eyes open. B) Eyes closed. White circles on graph show post hoc differences significant at $p < 0.05$ between designated circadian time points and performance on the morning hours preceding the sleepless night.

a rather steep recovery occurs at 10:00. Although with open eyes the circadian changes in stability do not reach statistical significance, the same circadian pattern with occluded vision is highly significant (F = 29.7, p = 0.0005). In both Fig. 1 and 2, the standard deviation increases sharply at the peaks of the morning fatigue. This phenomenon is statistical evidence of the individual variability in coping with sleep deprivation.

F3 **Fig. 3** presents the circadian patterns of sway intensity at three frequency ranges of the Fourier spectrum for the position with eyes closed (the circadian pattern of the lowest frequency range—below 0.1 Hz—was not affected by the experimental intervention and is not plotted). The circadian changes of the medium-low frequency range (0.1 to 0.5 Hz) were significant with eyes open (F = 18.3, p = 0.03; data not plotted), as well with eyes closed (F = 21, p = 0.01), while the higher part of the spectrum (0.5 to 3.0 Hz) was affected by fatigue only with occluded vision (F = 23, p = 0.01, F = 19, p = 0.03). Standard deviations are not shown on Fig. 3, as they would interfere with the clarity of the graphical presentation.

As already noted, all posturographic measures show a stage of recovery toward the last test at 10:00 the following morning; however, this recovery is not seen on the Subjective Sleepiness Score. For this reason, correlations between the Subjective Sleepiness Score and posturography were computed with exclusion of the last examination. These correlations were statistically significant for the closed eyes condition. The parameter of diagonal weight shift (**Fig. 4**), while not showing F4 statistically significant changes, revealed a definitive circadian pattern with a raise which started at 23:00, shortly reverted at 01:00, and thereafter followed the trend of the other postural parameters with a peak toward early morning and a recovery at 10:00 the next day. The parameter of synchronization was not affected by fatigue and did not show any systematic circadian trends (data not tabulated).

DISCUSSION

Our results support the first hypothesis, showing that the two basic parameters of stability index and Fourier sway intensities are sensitive to sleep deprivation. This is documented statistically by the significant tests of variance between the repeated measurements, further visible in a conspicuous increase of sway at early morning, and also evident when comparing by post hoc *t*-tests the two examinations at the identical circadian time points at 08:00 and 09:00, one before and the second after a sleepless night. It should be noted that occlusion of vision drastically enhances the effect of fatigue on stability (p = 0.0005), while with eyes open it drops to the insignificant level of p = 0.1. In two studies, one from our group (1) and the other carried out in Japan (22), statistically significant results were also reported for stability measures with eyes open.

A third parameter, diagonal weight shift, which is a derivative of the weight distribution scores, reveals circadian changes which are partly different from those shown by the other two parameters, i.e., the score had started to decline already at 23:00, but otherwise followed the same posturographic trend (Fig. 4). Although these circadian variations were not statistically significant (p = 0.1), we feel that this finding should not be dismissed in light of the outcome of two pervious studies: one reporting significant relationships of this measure with sleep disturbances such as sleep apnea (2), and the other demonstrating significant correlations between weight shift scores and fighter pilot's evaluation of vigilance, concentration, and sensation of stress during flight, as assessed by a self rating scale (11). In both of these studies, as well as in the present one, stress,

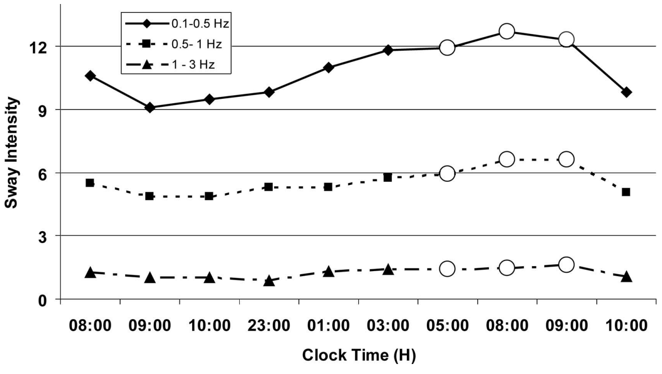

Fig. 3. Three different ranges of postural sway (sway intensity in decibels of pressure fluctuations) while standing with eyes closed vs. clock time for the duration of the 26-h experiment.

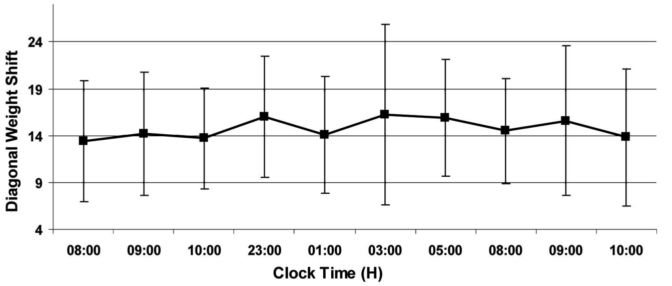

Fig. 4. Diagonal weight shift (differences in weight percentage between left heel and right tow) vs. clock time for the duration of the 26-h experiment.

fatigue, sleep deprivation, etc., are linked with a weight shift from the right toe (anterior right weight displacement) to the left heel (posterior right weight displacement), which can be explained by the decline of vigilance leading to leaning backwards, seeking support on the left "pillar" foot (12).

The correlations found between the postural scores and the universally established Subjective Sleepiness Score represents a satisfactory validation of the postural examination against an external criterion, which is strictly behavioral, albeit completely subjective. The discrepancy between the results of the two instruments at 10:00 of the second day, i.e., the presence of recovery on the posturographic test against its negation in the self-report, is interesting and plausible. A possible explanation for this discrepancy is that the subjective score may reflect what a person thinks "he should feel" after a sleepless night, while the objective postural score tells us the actual situation.

In this context we reported that in our study mentioned above (1), the stability measures correlated significantly with the performance on another independent physiological measure of fatigue caused by sleep deprivation, the Psychomotor Vigilance Test (PVT, Ambulatory Monitoring, Ardsley, NY). AQ: 1 This is a widely used device that was shown to assess cognitive performance during fatigue by measurements of reaction time (9,18). In the same study it was shown that the circadian plots of stability and the plots of circadian variations of body temperature, as reported Nakano et al. (22), overlap. This finding can be interpreted as a genuine, albeit indirect, validation of the posturographic responses in relation to this well-documented physiological response to fatigue caused by sleep deprivation (29).

The differential sensitivity of the postural subsystems to fatigue, as reflected by differences in sway intensities within the Fourier Spectrum were partly confirmed by our findings. When eyes were open, the medium-low frequency band, believed to be linked with the vestibular system, showed significant circadian changes which were absent in the higher part of the spectrum. With occluded vision, significant responses also appeared within the frequency ranges above 0.5 Hz, reflecting somatosensory involvement (Fig. 3B). This observation on the apparent enhanced effect of sleep deprivation on the vestibular subsystem was also documented in our previous study (1), which used conditions designed to create additional stress on the postural system (visual occlusion together with standing on soft pads and toe lifting). During the entire study, the significant predominance of circadian changes in the medium-low frequency band in comparison to the high frequencies was well established. Similar observations were also reported by Shub et al. (23) in his study on 36 h of sleep deprivation while operating a flight simulator. The authors reported that the circadian rhythm of the sway intensity below 0.5 Hz, which was equal to the circadian rhythm of the simulator performance, showed a peak to peak distance of 12 h, while this difference was 24 h for the high frequency range (1.00–3.00 Hz). Interestingly, another study that explored muscular fatigue induced by continuous toe lifting and not sleep deprivation, showed a similar raise in the post-experimental Fourier Spectrum below 0.5 Hz, while the pre- and post-experimental graphic plots above 0.5 Hz completely overlapped (7).

Obviously the above findings, which appear to be congruent, are still far from offering firm and systemic evidence that the main sub-mechanisms of postural control have different thresholds and vulnerabilities to sleep deprivation, fatigue, or stress, with the vestibular system suspected of being the most sensitive. Further research on this issue appears to be of high priority, especially in light of the central role of appropriate vestibular control in pilots during flight (6,24).

Finally, we draw attention to the concomitant increase of SDs of all parameters used in this study with the decline of alertness, which we believe demonstrates the individual variability in coping with sleep deprivation. The conclusion from this phenomenon is, in our opinion, that in order to measure fatigue objectively, these individual differences must be taken into consideration by establishing and storing individual baseline values into the database of the fitness-scanning instrument. In the instrument which was actually developed by our group, this principal is implemented. A baseline posturography value which includes the average values of several posturography tests is stored for each individual, and compared with the results of the posturography results performed when fatigue is analyzed.

In conclusion, the results of this study show that from a pragmatic point of view, posturography has a promising potential to be used as a practical, quick, and easy measure for "Fitness-for-Duty" determinations in occupations where continued alertness on the job is critical, e.g., transportation or heavy equipment operators, control room operators, etc. In addition, from a perspective of basic research, the vestibular function appears to be relatively more strongly affected by fatigue than the visual and somato-sensory subsystems and occlusion of vision appears to enhance the effect of fatigue on postural performance.

REFERENCES

1. Avni N, Avni I, Barenboim E, Azaria B, Zadok, D, et al. A brief posturographic test as an indicator of fatigue. Psychiatry Clin Neurosci 2006; 60:340–6.
2. Ayalon L, Cohen D, El-Dror I, Dayan Y. Weight shifts during upright stance are related to sleep apnea and show diurnal variations. In: Proceedings of the 17th Annual Meeting of Associated Professional Sleep Societies (APSS); 2003; Chicago, IL. Westchester, IL: APSS; 2003.

3. Baloh RW, Jacobson K, Honrubia V. Idiopathic bilateral vestibulopathy. Neurology 1989; 39:272–5.
4. Black FO, Wall C 3rd, Rockette HE Jr, Kitch R. Normal subject postural sway during the Romberg test. Am J Otolaryngol 1982; 3:309–18.
5. Brown ID. Driver fatigue. Hum Factors 1994; 36:298–314.
6. Cheung B, Money K, Wright H, Bateman W. Spatial disorientation-implicated accidents in Canadian forces, 1982–92. Aviat Space Environ Med 1995; 66:579–85.
7. Corbeil P, Blouin JS, Nougier V, Teasdale N. Perturbation of the postural control system induced by muscular fatigue. Gait Posture 2003; 18:92–100.
8. de Wit G. Optic versus vestibular and proprioceptive impulses, measured by posturometry. Agressologie 1972; 13(Suppl. B): 75–9.
9. Dinges DF, Pack F, Williams K, Gillen KA, Powell JW, Ott GE, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. Sleep 1997; 20:267–77.
10. Dussault C, Jouanin JC, Philippe M, Guezennec CY. EEG and ECG changes during simulator operation reflect mental workload and vigilance. Aviat Space Environ Med 2005; 76:344–51.
11. Froom P, Kohen-Raz R. Postural tests before take off predicting fighter pilot performance during mission. Tel Hashomer, Israel: Israel Air Force; 1994. Research Report. AQ: 2
12. Gagey PM, Pied P, Motuer P. Equilibre et Rachis (equilibrium and spine). Paris, France: Frison-Roche; 1998.
13. Hoddes E, Zarcone V, Smythe H, Phillips R, Dement WC. Quantification of sleepiness: a new approach. Psychophysiology 1973; 10:431–6.
14. Kohen-Raz R, Himmelfarb M, Tzur S, Kohen-Raz A, Shub Y. An initial evaluation of work fatigue and circadian changes as assessed by multiplate posturography. Percept Mot Skills 1996; 82:547–57.
15. Kohen-Raz R. Application of tetra-ataxiametric posturography in clinical and developmental diagnosis. Percept Mot Skills 1991; 73:635–56.
16. Krueger GP, Jones YF. U.S. Army aviation fatigue related accidents 1967–1977. Fort Rucker, AL: Aeromedical Research Laboratory; 1978. USAARL Technical Report No. 79–1.
17. Krueger GP, Armstrong RN, Cisco RR. Aviator performance in week-long extended flight operations in a helicopter simulator. Behav Res Methods Instrum Comput 1985; 17:68–74.
18. Krueger GP. Technologies and methods for monitoring driver alertness and detecting driver fatigue: a review applicable to long haul truck driving. Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Research and Technologies Division; 2004 June. Contract Technical Report. AQ: 3
19. Liskowsky DR. Biological rhythms: implications for the worker. Washington, DC: U.S. Government Printing Office, Office of Technology Assessment; 1991 September. Report No.: OTA-BA-463.
20. Liu Y, Higuchi S, Motohashi Y. Changes in postural sway during a period of sustained wakefulness in male adults. Occup Med (Lond) 2001; 51:490–5.
21. Monk TH, Buysse DJ, Reynolds CF 3rd, Berga SL, Jarrett DB, Begley AE, et al. Circadian rhythms in human performance and mood under constant conditions. J Sleep Res 1997; 6:9–18.
22. Nakano T, Araki K, Michimori A, Inbe H, Hagiwara H, Koyama E. Nineteen-hour variation of postural sway, alertness and rectal temperature during sleep deprivation. Psychiatry Clin Neurosci 2001; 55:277–8.
23. Shub Y, Kohen-Raz R, Kohen-Raz A, Ashkenazi I. Combined effect of circadian variations and fatigue-assessment by flight simulator and multiplate posturography. In: Proceedings of the 10th International Symposium on Aviation Psychology; 1999 May 3–6; Columbus, OH. Columbus, OH: The Ohio State University; 1999:896–902. AQ: 4
24. Shupak A, Nachum Z, Stern Y, Tal D, Gil A, Gordon CR. Vestibular neuronitis in pilots: follow-up results and implications for flight safety. Laryngoscope 2003; 113:316–21.
25. Skanavis C, Koumouris GA, Petreniti V. Public participation mechanisms in environmental disasters. Environ Manage 2005; 35:821–37.
26. Summala H, Mikkola T. Fatal accidents among car and truck drivers: effects of fatigue, age, and alcohol consumption. Hum Factors 1994; 36:315–26.
27. Taguchi K. Spectral analysis of the movement of the center of gravity in vertiginous and ataxic patients. Agressologie 1978; 19(B):69–70.
28. Turner M. Evaluation of the Tetrax interactive balance system and Equitest using normal subjects [Dissertation]. Southampton: University of Southampton; 1998.
29. van Eekelen AP, Houtveen JH, Kerkhof GA. Circadian variation in base rate measures of cardiac autonomic activity. Eur J Appl Physiol 2004; 93:39–46.
30. von Zerssen D, Doerr P, Emrich HM, Lund R, Pirke KM. Diurnal variation of mood and the cortisol rhythm in depression and normal states of mind. Eur Arch Psychiatry Neurol Sci 1987; 237:36–45.
31. Yardley L, Burgneay J, Nazareth I, Luxon L. Neuro-otological and psychiatric abnormalities in a community sample of people with dizziness: a blind, controlled investigation. J Neurol Neurosurg Psychiatry 1998; 65:679–84.
32. Zhong X, Hilton HJ, Gates GJ, Jelic S, Stern Y, Bartels MN, et al. Increased sympathetic and decreased parasympathetic cardiovascular modulation in normal humans with acute sleep deprivation. J Appl Physiol 2005; 98:2024–32.
33. Zomer J PA, Rubin E, Lavie P. In: Koella WP, Ruther E, Schultz H, ed. Mini Sleep Questionnaire (MSQ) for screening large populations for EDS complaints. In: Verlag. S-NGF, ed. Sleep 84: Proceedings of the Seventh European Sleep Research conference; September 1984; Holland. September 1984:467–70. AQ: 5

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