Scand J Work Environ Health 2007;33(2):148-153

<https://doi.org/10.5271/sjweh.1119>

Issue date: 31 Apr 2007

Electroencephalography artifacts in workplace alertness monitoring

by [Gale J](#), [Signal TL](#), [Garden AL](#), [Gander PH](#)

Affiliation: Sleep/Wake Research Centre, Massey University, 102 Adelaide Road, Newtown, Wellington 6012, New Zealand.
jesse.gale@gmail.com

Key terms: [alertness monitoring](#); [digital signal processing](#); [electroencephalography artifact](#); [night work](#); [shift work](#); [sleepiness](#); [workplace](#)

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/17460803

This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

Electroencephalography artifacts in workplace alertness monitoring

by Jesse Gale, MB ChB,¹ T Leigh Signal, PhD,¹ Alexander L Garden, FANZCA,^{1,2} Philippa H Gander, PhD¹

Gale J, Signal TL, Garden AL, Gander PH. Electroencephalography artifacts in workplace alertness monitoring. *Scand J Work Environ Health* 2007;33(2):148–152.

Objective This study assessed the effect of removing artifacts from workplace electroencephalography (EEG) recordings on power spectra and the consequent interpretation of changes in alertness.

Methods EEG was recorded for 27 air traffic controllers on the night shifts of four roster cycles. On two of the four night shifts, each controller was given a 40-minute opportunity to nap, while on the other two they remained awake (105 shifts in total). Recordings for the last hour of each night shift were screened for artifacts by an experienced viewer (who viewed the EEG in isolation from other electrophysiological recordings). The effects of the nap opportunity on the EEG power spectra were then analyzed in a mixed model analysis of variance in the presence and absence of artifact-contaminated data.

Results Overall, 89.3% of the EEG recordings contained artifacts. Removal of these data markedly altered the interpretation of how the nap opportunities affected the EEG power spectra. The spectral parameters of the artifact appeared to be different when the participants were given the opportunity to nap.

Conclusions Removal of artifacts can dramatically affect the interpretation of workplace EEG recordings. This potential source of error is often unreported.

Key terms digital signal processing; night work; shift work; sleepiness.

Electroencephalography (EEG) is an objective and sensitive marker of neurophysiological arousal that can be used to measure sleepiness without interrupting work (1). However, the workplace can be a poor recording environment, as researchers have less control over recording conditions. This situation creates the potential for large quantities of artifactual signal (eg, from eye-movement, electrode movement, muscle activity, or extraneous 50- or 60-Hz signal). Artifacts can be minimized with the use of good recording technique. Some artifacts can be corrected by mathematical transformation. Any remaining artifact is then identified and usually excluded from the analysis (2, 3).

The exclusion of artifact-contaminated sections of recordings can potentially introduce selection bias, particularly if the artifact and sleepiness are related (ie, if people create different amounts of an artifact when they are tired). Behavior such as yawning and nodding may be initiated to fight sleepiness and could increase

movement artifact. Alternatively, sleepy people may be more sedentary, reducing movement artifact. In either case, the artifact-free data for analysis may not be representative of the recording period of interest.

We could find no published research into workplace EEG artifacts and, despite the potential for bias, workplace studies often make minimal reference to the quantity or management of artifacts (4–6). One workplace study of truck drivers reported 10–15% artifact contamination in its EEG recordings but was not explicit as to the used detection methods or filters (7). Even in controlled laboratory recordings, 16% (8) and 23% of the data have been shown to be contaminated (9).

Our study examined EEG artifacts in a large study of the effects of napping on the alertness of air traffic controllers on the night shift. It was hypothesized that excluding artifacts would reduce the spectral power of the EEG, but would not change the conclusions drawn from statistical models evaluating the effects of napping

¹ Sleep/Wake Research Centre, Massey University, Wellington, New Zealand.

² Capital & Coast District Health Board, Wellington, New Zealand.

Reprint requests to: J Gale, Sleep/Wake Research Centre, Massey University, 102 Adelaide Road, Newtown, Wellington 6012, New Zealand. [E-mail: jesse.gale@gmail.com]

on EEG power spectra. In other words, the spectral characteristics of artifacts were hypothesized to be independent of the participants' level of sleepiness.

Study population and methods

Twenty-seven air traffic controllers participated in a study that investigated the efficacy of napping in improving alertness during a night shift (10). The study received approval from the Wellington Regional Ethics Committee. The average age of the participants was 35.5 (range 26–56) years, and nine were female.

Recordings were made during four night shifts for each participant, two shifts starting at 2230 and two shifts starting at 2330. Each night shift was the last of four shifts in a rapid backward-rotating cycle and was preceded by an early morning shift in the same 24-hour period that finished around midday. On one shift starting at 2230 and on one starting at 2330, the participants had a 40-minute napping opportunity before the last 2 hours of their shift. Data were recorded on a total of 105 of 108 eligible night shifts (three recording failures).

The participants underwent EEG recording during their usual air traffic control work. They were seated in front of a workstation that included a primary radar display with further information and displays to their left and right. Small movements would be required to view this information, and they may have moved to other equipment in the control room episodically.

An Embla ambulatory recorder (Medcare, Iceland) recorded EEG, electrooculography, electrocardiography and electromyography. Grass gold electrodes filled with EC2 conducting paste were applied to abraded skin and secured with adhesive Tegaderm and Hypafix tapes. Four EEG channels were recorded (C_4-A_1 , O_2-A_1 , O_2-O_z , O_2-P_4), and all impedances were less than 5 k Ω prior to the data collection. A mid-forehead electrode was used as the ground. The analogue signal was sampled at 2000 Hz, low-pass filtered at 100 Hz, down sampled to 200 Hz, and stored as a 16-bit resolution digital series. The data were then filtered further (broad band-pass 0.5–90 Hz and a 50 $\pm$ 1 Hz notch filter). Electrodes were attached prior to the beginning of the night shift, and recordings free from movement or equipment artifacts were obtained both before and after the shift (while the participants sat to undertake a performance test). For the analyses, the last hour of each night shift was examined for artifacts.

Polysomnographic recordings of the napping opportunities were scored in 30-second epochs according to the standard criteria of Rechtschaffen & Kales (11).

Recordings from the final hour of the night shift were analyzed for artifact contamination, and their power

spectra were calculated. First, all four EEG channels were analyzed independently for artifacts (using the criteria below) in a random sample of 12 recordings. The O_2-O_z channel contained the least artifact contamination, and, for this reason, it was the only channel analyzed in the remainder of the night shifts.

The O_2-O_z channel was viewed by an experienced EEG researcher (TLS) for the presence or absence of any artifact type using a custom LabVIEW programme (National Instruments Corporation, Austin, TX, USA). Although not normal clinical practice, the channel was viewed in isolation to prevent the scorer from being biased by other recorded sources. The recordings were considered in 5.12-second epochs, incrementing by 2.56 seconds (to provide overlap for spectral analysis using a Hanning window). The epochs were viewed centered in a 10-second section of the recording, which provided context as an aid for artifact identification. The EEG channels were presented with a sensitivity of approximately 4 μ V/mm.

In the absence of standard criteria for artifact identification, an iterative process was undertaken to develop an operational definition for artifacts. Combinations of objective criteria were tested with repeated independent screening by JG, TLS, and ALG until interrater agreement stabilized. We defined an artifact as any of the following: (i) high-frequency components (>20 Hz) with a high amplitude (>50 μ V), (ii) abrupt baseline movement, (iii) spiking (intermittent, nonrhythmic high-frequency waves), (iv) amplitude of any baseline movement exceeding that of surrounding faster activity, (v) baseline movement below 1 Hz accepted as artifact free if the amplitude did not exceed twice that of the overlying activity, (vi) lack of rhythmicity and smooth tracing in any frequency component, (vii) when the artifact occupied less than 5% of an epoch, the epoch was accepted as useable data, (viii) epochs with an artifact that appeared to be exclusively of cardiac origin were widespread in some recordings and were accepted as useable data, (ix) all decisions were conservative, tending toward rejection if unsure.

The manually determined status of each epoch as artifact-free or contaminated was entered into the LabVIEW program and saved alongside the power spectrum of that epoch.

A mixed-model analysis of variance was performed using an SAS program (version 10.0, SAS Institute Inc, Gary, NC, USA). The dependant variables were the absolute power in each of the traditional frequency bands of 1.50–4.00 Hz (delta), 4.02–8.00 Hz (theta), 8.02–12.00 Hz (alpha), and 12.02–16.00 Hz (beta). Delta was truncated at 1.5 Hz, as consistently high power was noted below 1.5 Hz in all sleep and waking states. All spectral data were log_e-transformed to enable parametric testing (12). Fixed factors in the models

were shift start time, nap opportunity, and the primary interaction effect, with participants included as a random factor. Models were run on the data before and after the exclusion of an artifact. That is, before artifact removal, the power spectrum of every epoch was included in the model, and, after artifact removal, only artifact-free epochs were analyzed. An alpha value of 0.01 was used to determine significance.

Results

Approximately 90% of the participants slept in the 24 hours preceding the analyzed hour of the night shift (ie, between the morning shift and the commencement of the night shift), with a mean sleep duration of 2.16 (SD 0.90) hours, estimated with the use of wrist actigraphy. During the nap opportunity, a mean of 17.7 (SD 12.2) minutes of sleep was obtained, and five participants did not sleep.

Across all 105 hours of the recording, there was a median of 10.7 (range 0.4–67.5)% artifact-free data, the percentage of which was not associated with the nap or no-nap conditions.

Before and after artifact removal, the nap opportunity had a significant fixed effect on the power in every frequency band (before artifact removal all $F_{(1,6261)}$ being >13.8 , all $P<0.001$; after artifact removal all $F_{(1,3420)}$ being >30.3 , all $P<0.001$).

The effects of the artifact removal on the mixed-model results are shown diagrammatically in figure 1. The least-squared mean (LSM) estimates of the absolute power in each frequency band are shown, for both the

nap and no-nap conditions, before and after removal of the artifact.

The reduction in spectral power that resulted from removing the artifact was manifold, as indicated by the different scales on the vertical axes in figure 1.

The removal of the artifact resulted in a reversal of the apparent effects of napping on the EEG spectral power, as estimated by the mixed-model analyses of variance. In the models using contaminated data, napping resulted in an increase in spectral power in every frequency band [differences in LSM: delta 22.8 (SE 4.23) μV^2 , theta 11.5 (SE 2.8) μV^2 , alpha 5.4 (SE 1.4) μV^2 , beta 3.2 (SE 0.9) μV^2 ; with 6261 degrees of freedom; all $P<0.001$]. In the models that used artifact-free data, napping resulted in a decrease in spectral power in every frequency band [differences in LSM: delta -0.15 (SE 0.02) μV^2 , theta -0.24 (SE 0.03) μV^2 , alpha -0.65 (SE 0.10) μV^2 , beta -0.18 (SE 0.03) μV^2 ; with 3420 degrees of freedom; all $P<0.001$].

In addition, the removal of artifacts altered the distribution of spectral power across the frequency bands (as shown in figure 1). In the raw data, the power decreased almost exponentially as the frequency increased, irrespective of napping. In the artifact-free data, a peak of power was apparent in the alpha frequency band, particularly in the no-nap group.

Discussion

With the use of a conservative approach to artifact detection, nearly 90% of the workplace EEG recordings in this study were judged to be contaminated with artifacts.

Figure 1. Least-squared mean (LSM) estimates of absolute power attributable to napping, before and after removal of the artifact (LSM $\pm$ SE; * $P<0.001$)

Perhaps unsurprisingly, neurophysiological information was completely obscured by this artifact. Importantly, and contrary to our hypothesis, the amount of spectral power in the artifact differed in the nap and the no-nap conditions. Thus the unscreened data suggested an apparent increase in EEG spectral power in association with napping, while the artifact-free data suggested a decrease in power. These results have important implications for the use of EEG recordings in the workplace, as they suggest that the management of artifacts can alter the findings.

The possible limitations of this study include the possibility that this data set contained an unusual amount or type of artifact contamination. All effort was made to minimize artifacts with a best-practice recording technique and high-quality equipment (3). The work environment was sedentary, and there were no obvious sources of environmental artifact. Nevertheless, all of the recordings contained a large amount of artifact. Our methods for defining artifact may have been more conservative than those used in previous studies. Viewing the EEG channel in isolation is an unusual method, and it made it impossible to determine the sources of the artifact, which would have added important information. However, knowing the sources of the artifact would not have altered the findings presented here. Viewing the EEG channel in isolation was used to reduce scorer bias for artifacts and was unlikely to have overestimated artifacts.

It is necessary to measure sleepiness in the workplace, to identify hazardous work patterns and evaluate fatigue countermeasures (13). Self-reports of sleepiness are known to be unreliable (14, 15). Vigilance and reaction-time tasks interrupt work and provide artificial stimulation. Work-based measures are difficult to generalize to other settings, and error and accident rates are coarse measures of fatigue, due to the infrequency of these events. Only physiological measures, such as EEG, provide continuous and sensitive data on arousal of the central nervous system.

This study confirms that artifacts require careful consideration in studies that use EEG in the workplace. While it is a trivial neurophysiological finding that artifacts can distort spectral data, our results are striking in the context of previous workplace EEG-based sleepiness research, which frequently offers single sentence descriptions on excluding artifacts, without any reports on their amount or distribution (4–6). Our most critical finding was that the spectral characteristics of artifacts seemed to differ with the participants' expected level of sleepiness (at the end of a shift with or without a nap). Indeed, our participants' performance tests indicated that the participants were less sleepy after the nap opportunity: findings which support this possible association (10).

It may be possible to improve EEG monitoring in the workplace. First, the use of different recording equipment may help to reduce artifacts, for example, using well-chlorinated Ag-AgCl electrodes, or finer, shielded electrode wires. However, obtaining cleaner signals will not address the issue of the possible relationship between sleepiness and the spectral composition of artifacts. Second, there may be a potential for increasing the use of reliable and valid artifact-correction techniques, such as blind source or independent component analysis (16). These approaches are difficult to implement in the workplace, as they require a large amount of EEG data and presume that the artifact source is recorded. In the workplace, where environmental, movement, and equipment artifacts play relatively greater roles, it may prove impossible to correct artifacts completely. A third option may be systematic visual sleepiness scoring. Human scorers can potentially ignore brief intermittent artifacts (such as blinks) within a recorded epoch, and draw conclusions from background data. A final option might be to record EEG for analysis under controlled conditions, for example, interrupting work intermittently to record sedentary eyes-closed episodes of artifact-free EEG. This procedure would clearly negate the important benefit of recording EEG during work flow.

In conclusion, it is our contention that artifacts must be carefully considered, managed, and clearly reported in workplace EEG studies to be meaningful. The intention of this paper was to stimulate discussion on these issues.

Acknowledgments

This project was supported by a Wellington Medical Research Foundation studentship to Jesse Gale. Data collection was supported by grants from the Health Research Council of New Zealand, the Lottery Health Board, and Airways New Zealand.

References

1. Mitler MM, Carskadon MA, Hirshkowitz M. Evaluating sleepiness. In: Kryger MH, Roth T, Dement WC, editors. *Principle and practices of sleep medicine*. 5th ed. Philadelphia (PA): Elsevier Saunders; 2005. p 1417–23.
2. Anderer P, Roberts S, Schlogl A, Gruber G, Klossch G, Hermann W, et al. Artifact processing in computerized analysis of sleep EEG—a review. *Neuropsychobiology*. 1999;40 Sep:150–7.
3. Pivik RT, Broughton RJ, Coppola R, Davidson RJ, Fox N, Nuer MR. Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. *Psy-*

- chophysiology. 1993;30:547–58.
4. Richardson GS, Wyatt JK, Sullivan JP, Orav EJ, Ward AE, Wolf MA, et al. Objective assessment of sleep and alertness in medical house staff and the impact of protected time for sleep. *Sleep*. 1996;19:718–26.
5. Neri DF, Oyung RL, Colletti LM, Mallis MM, Tam PY, Dinges DF. Controlled breaks as a fatigue countermeasure on the flight deck. *Aviat Space Environ Med*. 2002;73:654–64.
6. Wright N, McGown A. Involuntary sleep during civil air operations: wrist activity and the prevention of sleep. *Aviat Space Environ Med*. 2004;75:37–45.
7. Kecklund G, Åkerstedt T. Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. *Ergonomics*. 1993;36(9):1007–17.
8. Cajochen C, Khalsa SB, Wyatt JK, Czeisler CA, Dijk DJ. EEG and ocular correlates of circadian melatonin phase and human performance decrements during sleep loss. *Am J Physiol*. 1999;277(3 Pt 2):R640–9.
9. Kinnari K, Peter JH, Pietarinen A, Groete L, Penzel T, Varri A, et al. Vigilance states and performance in OSAS patients in a monotonous reaction time task. *Clin Neurophysiol*. 2000;111(6):1130–6.
10. Signal TL. Scheduled napping on the night shift: consequences for the performance and neurophysiological alertness of air traffic controllers [dissertation]. Wellington (New Zealand): University of Otago; 2002.
11. Rechtschaffen A, Kales A, editors. A manual of standardised terminology, techniques and scoring system for sleep stages of human subjects. Los Angeles (CA): Brain Information Service/Brain Research Institute, University of California, Los Angeles; 1968.
12. Gasser T, Bächer P, Steinberg H. Test-retest reliability of spectral parameters of the EEG. *Electroencephalogr Clin Neurophysiol*. 1985;60:312–9.
13. Walsh JK, Dement WC, Dinges DF. Sleep medicine, public policy, and public health. In: Kryger MH, Roth T, Dement WC, editors. *Principles and practices of sleep medicine*. 5th ed. Philadelphia (PA): Elsevier Saunders; 2005. p 648–56.
14. 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.
15. Owens DS, Macdonald I, Tucker P, Sytnik N, Minors D, Waterhouse J, et al. Diurnal trends in mood and performance do not all parallel alertness. *Scand J Work Environ Health*. 1998;24 suppl 3:109–14.
16. Jung T-P, Makeig S, Humphries C, Lee T-W, McKeown MJ, Iragui V, et al. Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*. 2000;37:163–78.

Received for publication: 6 April 2006