Safety and Health at Work 7 (2016) 124–129

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Relation between Multiple Markers of Work-Related Fatigue

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ARTICLE INFO

Article history:
Received 26 January 2015
Received in revised form
3 November 2015
Accepted 7 November 2015
Available online 1 December 2015

Keywords:
fatigue markers
multidimensional construct
workplace

ABSTRACT

Background: Work-related fatigue has a strong impact on performance and safety but so far, no agreed upon method exists to detect and quantify it. It has been suggested that work-related fatigue cannot be quantified with just one test alone, possibly because fatigue is not a uniform construct. The purpose of this study is therefore to measure work-related fatigue with multiple tests and then to determine the underlying factorial structure.
Methods: Twenty-eight employees (mean: 36.11; standard deviation 13.17) participated in five common fatigue tests, namely, posturography, heart rate variability, distributed attention, simple reaction time, and subjective fatigue before and after work. To evaluate changes from morning to afternoon, *t* tests were conducted. For further data analysis, the differences between afternoon and morning scores for each outcome measure and participant (Δ scores) were submitted to factor analysis with varimax rotation and each factor with the highest-loading outcome measure was selected. The Δ scores from tests with single and multiple outcome measures were submitted for a further factor analysis with varimax rotation.
Results: The statistical analysis of the multiple tests determine a factorial structure with three factors: The first factor is best represented by center of pressure (COP) path length, COP confidence area, and simple reaction time. The second factor is associated with root mean square of successive difference and useful field of view (UFOV). The third factor is represented by the single Δ score of subjective fatigue.
Conclusion: Work-related fatigue is a multidimensional phenomenon that should be assessed by multiple tests. Based on data structure and practicability, we recommend carrying out further studies to assess work-related fatigue with manual reaction time and UFOV Subtest 2.

1. Introduction

Fatigue at the workplace is an important issue, as it may adversely affect employees' performance, safety, and health. However, in general, no agreed upon method exists to detect and quantify fatigue, possibly because it manifests in a variety of psychological as well as physiological factors. Past research regards fatigue as a multidimensional construct, with physical fatigue and mental fatigue as two fundamental components [1–4]. Physical fatigue is thought to result from physical exertion and manifests (e.g., as a decreased ability to use the own physical strength, as a feeling of bodily discomfort, and as a change in vegetative functions such as heart rate) [2,4,5]. By contrast, mental fatigue is considered a psychophysiological consequence of lasting cognitive demand, and may manifest as a feeling of reduced alertness and as a decrease in cognitive performance [6,7]. It has therefore been suggested that fatigue cannot be quantified with just one test alone, but rather requires multiple tests to cover as many of its manifestations as possible [8].

This study takes a pragmatic stance. A workplace is not a research laboratory and employees are not experimental subjects; comprehensive testing of fatigue at the workplace is therefore not feasible as time, space, financial resources, testing personnel, and the willingness to be tested are all scarce. It therefore is critical to select as few fatigue tests as possible without a substantial loss of predictive power. A single fatigue test may not be sufficient, however. If work-related fatigue has two or more orthogonal dimensions, testing should include all of them; otherwise, workers may suffer accidents because of fatigue along an untested dimension. Our approach to achieve this goal is based on factor analysis. We decided to administer a battery of popular tests from literature, to determine the underlying factorial structure, and then to select a subset of tests such that each is representative of one factor. Given the distinction between physical fatigue and mental fatigue found

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2093-7911/$ – see front matter
http://dx.doi.org/10.1016/j.shaw.2015.11.003

in literature (see above), we expected to yield at least two factors. However, physical fatigue and mental fatigue may not be uniform constructs, and we therefore expected to identify up to four factors. Should more than four factors emerge, it was concluded that our approach to limit fatigue testing had failed.

Previous research about fatigue at the workplace [3,9] or in a laboratory simulation [2,10] mostly used one single self-assessment tool [11,12]. Some studies, however, registered objective data such as electroencephalogram (EEG) readings [13], heart rate variability (HRV) [14], balance [9], neuromuscular functions [15], cognitive functions [16], or neurobehavioral performance [17]. Only a few authors combined self-assessments with objective tests [2,18], but they did not explore the interrelationships between these measures. Correlations between subjective and objective measures were documented only by clinical studies [19–21], and therefore may not be relevant for the present research, which specifically deals with the fatigue of healthy employees.

Again for pragmatic reasons, we decided to operationalize fatigue as the difference between the end and the start of work, as some other studies did successfully before [9,17] This approach neglects factors such as time awake, sleep–wake history, and circadian phase [22–24], as well as confounders such as sleep quality, food and stimulant intake, and the recent workload. Our reason for focusing on those aspects of fatigue that change from start to end of work (i.e., on work-related fatigue) is that it would be difficult for an employer to assess the additional factors without being charged with intruding the privacy of employees.

2. Materials and methods

2.1. Participants

Twenty-eight employees (14 women and 14 men) of the Leibniz Research Centre for Working Environment and Human Factors were recruited for the study. Their daily work mainly consists of computer data entry, reading, and writing, and thus is characteristic of clerical—as opposed to manual—workers. The participants' age [mean (SD)] was 36.11 (13.17) years (range: 15–64 years). Before testing, participants completed a questionnaire about their actual health status, which was itemized into orthopedic, mental, and chronic diseases. None of the participants reported a limiting disease and all were therefore included in the study. All participants reported normal or corrected-to-normal vision.

All participants gave their written informed consent. The study was approved by the local Ethics Committee of the German Sport University.

2.2. Task design and materials

Each participant was tested once at the beginning (8.30–9.00 AM) and once at the end of the same working day (3.30–4.00 PM). Each session took approximately 30 minutes and consisted of the following five tests: posturography, HRV, distributed attention, simple reaction time, and subjective fatigue. The first two tests are typically considered to measure physical fatigue and the next two tests are considered to measure mental fatigue; subjective ratings probably reflect both physical fatigue and mental fatigue. Between the two testing sessions, participants completed their usual work assignments.

Posturography was implemented using a Nintendo Wii Balance Board (Nintendo, Kyoto, Japan) connected to a laptop via Bluetooth, and using commercially available software (STABLE, pro-WISS, Cologne, Germany). This method to measure postural balance has been validated by several studies [25,26]. Participants stood still with eyes closed for 20 seconds, their feet at hip distance and their arms hanging loosely at the sides of their body. The software sampled raw data from four pressure sensors at a rate of 50 Hz, transformed them into x–y coordinates representing the center of pressure (COP), and later calculated, from the registered COP time series, the parameters path length (mm), velocity (mm/s), anterior–posterior variance (mm), mediolateral variance (mm), and confidence area (mm^2). A comparable method was used in other studies [27–29]. The registration was part of a comprehensive posturography test communicated elsewhere [30], and was reanalyzed for the purposes of this study.

HRV was, due to its easy and time-saving use, measured with a POLAR S810 monitor fastened by a chest strap (Polar Electro Oy, Kempele, Finland), using the beat-to-beat mode. Participants were asked to wear the chest strap and sit still in a quiet room for 5 minutes, and the following time-domain parameters, which were also utilized by other studies [31,32], were extracted from the registrations by a commercial software (Polar Precision Performance 4.0): standard deviation of NN intervals (SDNN) in microsecond, square root of the mean of the sum of the squared differences between adjacent NN in microsecond (also called "root mean square of successive difference" or "RMSSD"), and the mean RR interval in microsecond (mean RR).

Distributed attention was assessed by a computerized version of the useful field of view (UFOV) test [33]. Participants placed their chin on a chinrest at a 60-cm distance from a computer monitor. They were given a short, guided version of the test initially and then participated in three subtests of increasing difficulty. The first subtest measures processing speed and requests participants to indicate by mouse click which of two symbols (silhouette of a car or of a cabriolet) was presented in a fixation box in the screen center. The second subtest measures processing speed under divided attention conditions; this discrimination task is presented concurrently with a target at one of the eight directions 11 cm away from the fixation box, with participants indicating both symbol identity and target location. The third subtest differs from the second in that it includes visual distractors (crosses of the same size and luminance as the symbols) arranged concentrically around the fixation box. Each subtest consisted of 200 trials. Symbols were initially presented for 150 ms; the presentation time decreased by 20 ms after each correct answer and increased by 70 ms after each false answer. Outcome measures were means of all presentation duration of all trials in each subtest.

In the simple reaction time task, which has been used in a variety of research approaches to asses fatigue [17,34–36], participants had to depress the space bar of a keyboard with their dominant hand as quickly as possible after a white dot was presented on a computer monitor against a black background. Fifteen dots were presented at random intervals of 2,500–3,500 ms and the mean reaction time of all responses was used as the outcome measure.

Subjective fatigue was registered by the self-assessment tool of Kim et al [37]. It consists of an 11-point rating scale anchored at 0 = no fatigue, 5 = moderate fatigue, and 10 = maximally possible fatigue. The scale was handed out on paper, and participants were instructed to mark their current fatigue level with a pen. Marks between the scale points were allowed. The distance between the no-fatigue anchor and the mark served as outcome measure.

2.3. Data analysis

As a first step, we performed t tests to reveal differences between morning and afternoon scores for each parameter. In the next step, we calculated the difference between afternoon and morning scores for each outcome measure and participant (Δ scores). To explore the relationships between the measured parameters, Pearson correlations between each of them were correlated. Afterward, all Δ scores from tests with multiple outcome measures were submitted to factor analysis with the inclusion criterion $F > 1$, with no upper limit on the number of factors extracted, and with varimax rotation; the highest-loading outcome measure was selected for further analysis. This procedure effectively reduced the dimensionality of our data, as required for the last step of analysis. In that step, Δ scores from tests with a single outcome measure and selected Δ scores from tests with multiple outcome measures were submitted to factor analysis with the inclusion criterion $F > 1$, with no upper limit on the number of factors extracted, and with varimax rotation.

3. Results

Results of *t* tests revealed differences between morning and afternoon scores for several parameters: a significant increase for SDNN ($t_{27} = -2.118$; $p < 0.05$; $d = -0.566$), RMSSD ($t_{27} = -3.064$; $p < 0.01$; $d = -0.819$), mean RR ($t_{27} = -4.247$; $p < 0.001$; $d = -1.135$), and subjective fatigue ($t_{27} = -6.092$; $p < 0.001$; $d = -1.628$), and a significant decrease for UFOV Subtest 2 ($t_{27} = 2.536$; $p < 0.05$; $d = 0.678$).

Fig. 1 illustrates all Δ scores, and Table 1 shows the Pearson correlations between Δ scores. Correlations were typically strong for parameters derived from a common test, but also for some parameters from distinct tests.

Table 2 shows that the five outcome measures of posturography were reduced by factor analysis to two factors; COP confidence area

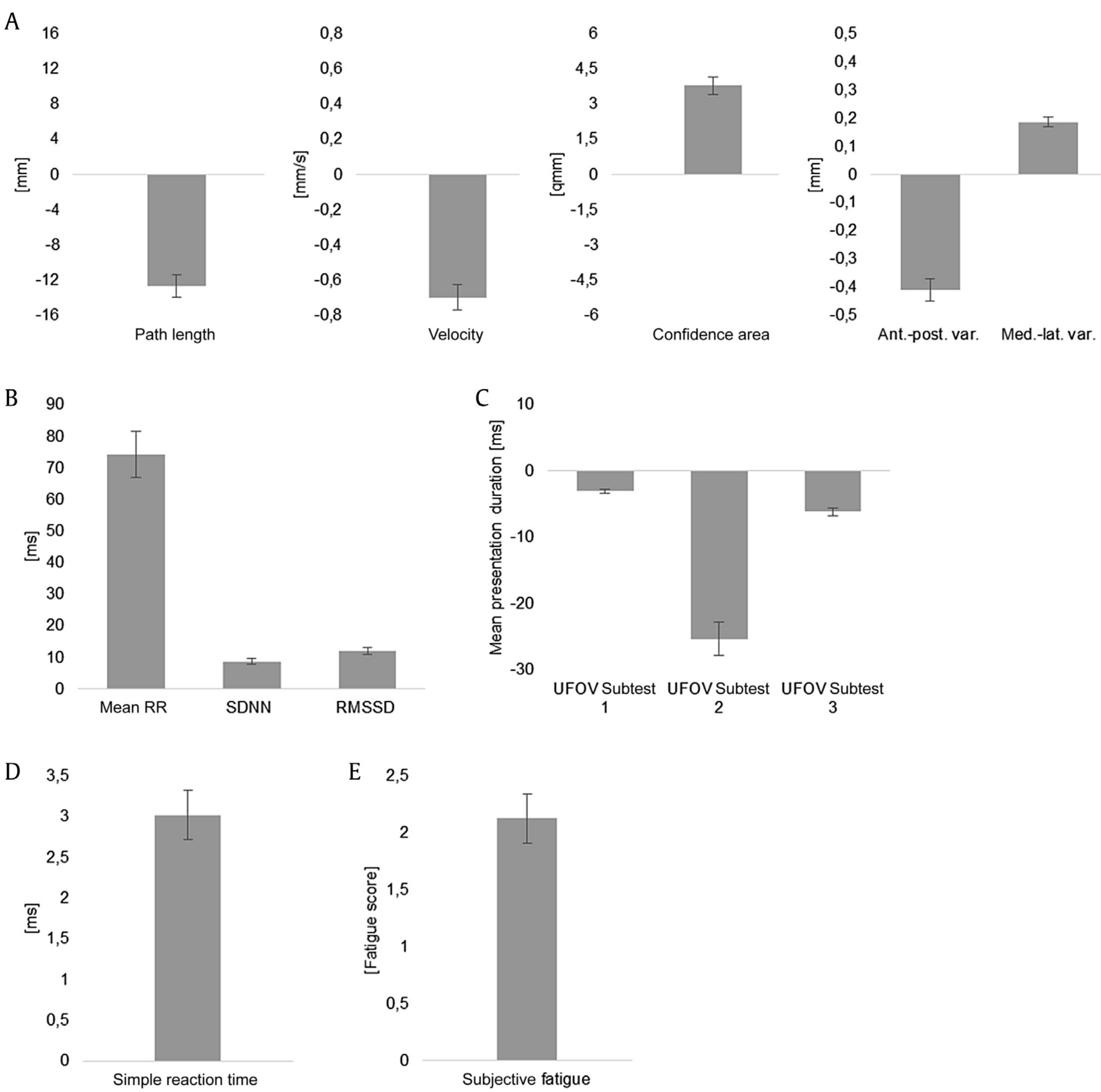

Fig. 1. All Δ scores and standard deviations for (A) the posturography parameters [path length, velocity, confidence area, anterior–posterior variance (ant.-post. var.), and mediolateral variance (med.-lat. var.)]; (B) heart rate variability (HRV) parameters [mean RR interval (mean RR), standard deviation of NN intervals (SDNN), root mean square of successive difference (RMSSD)]; (C) useful field of view (UFOV) parameters (Subtests 1–3); (D) simple reaction time; and (E) subjective fatigue.

Table 1
Pearson correlations (*r*) between Δ scores of all parameters

		Path length	Confidence area	Anterior–posterior variance	Mediolateral variance	Velocity	SDNN	RSMSSD	Mean RR	UVOF 1	UVOF 2	UVOF 3	RT	Subjective fatigue
Posturography	Path length		*0.532*	*0.426*	*0.387*	*0.992*	−0.050	−0.064	−0.071	−0.008	−0.096	−0.058	*0.406*	−0.120
	Confidence area	*0.532*		*0.778*	*0.875*	*0.545*	−0.127	−0.135	0.081	−0.368	−0.142	0.066	0.323	−0.097
	Anterior–posterior variance	*0.426*	*0.778*		*0.486*	*0.456*	−0.148	−0.321	−0.170	−0.248	0.004	0.112	0.163	−0.209
	Mediolateral variance	*0.387*	*0.875*	*0.486*		*0.395*	−0.070	−0.040	0.129	−0.282	−0.134	0.097	0.318	0.012
	Velocity	*0.992*	*0.545*	*0.456*	*0.395*		−0.029	−0.032	−0.073	−0.031	−0.125	−0.044	*0.404*	−0.168
HRV	SDNN	−0.050	−0.127	−0.148	−0.070	−0.029		*0.628*	0.365	0.115	*−0.451*	0.083	−0.302	−0.014
	RMSSD	−0.064	−0.135	−0.321	−0.040	−0.0320	*0.628*		*0.547*	−0.173	*−0.658*	0.087	−0.148	0.022
	Mean RR	−0.071	0.081	−0.170	0.129	−0.073	0.365	*0.547*		−0.372	−0.239	0.063	−0.010	0.170
UVOF	UVOF 1	−0.008	−0.368	−0.248	−0.282	−0.031	0.115	−0.173	−0.372		0.268	0.036	−0.004	−0.183
	UVOF 2	−0.096	−0.142	0.004	−0.134	−0.125	*−0.451*	*−0.658*	−0.239	0.268		0.206	0.024	0.072
	UVOF 3	−0.058	0.066	0.112	0.097	−0.044	0.083	0.087	0.063	0.036	0.206		0.021	−0.121
RT	RT	*0.406*	0.322	0.163	0.318	*0.404*	−0.302	−0.148	−0.010	−0.004	0.024	0.021		0.155
SF	SF	−0.120	−0.097	−0.209	0.012	−0.168	−0.014	0.022	0.170	−0.183	0.072	−0.121	0.155	

Numbers in *italics* represent significance.
HRV, heart rate variability; mean RR, mean RR interval; RMSSD, root mean square of successive difference; RT, reaction time; SDNN, standard deviation of NN intervals; SF, subjective fatigue; UVOF, useful field of view.

had the highest load on factor 1, and COP path length had the highest load on factor 2. Table 3 indicates that the three outcome measures of HRV were reduced to a single factor, with the highest load of RMSSD. Table 4 shows that the three outcome measures of attention also yielded a single factor, with the highest load of UFOV Subtest 2. We therefore selected COP confidence area, COP path length, RMSSD, and UFOV Subtest 2 for further analysis, thus effectively reducing 11 registered variables to four representative variables. Along with the outcome of the fatigue questionnaire and the simple reaction time test, we thus had a total of six variables for further analysis.

As Table 5 illustrates, factor analysis reduced the six remaining variables to three factors. The first factor explains 31% of the total variance and is best represented by COP path length, followed by COP confidence area, and then by simple reaction time. The second factor still explains 28% of the total variance, and is equally well represented by RMSSD and UFOV Subtest 2. The third factor explains only 18% of the total variance and is distinctly associated with one single Δ score (i.e., subjective fatigue).

4. Discussion

This study evaluated work-related fatigue of clerical workers with a battery of fatigue tests. This battery did not include fatigue tests that would be difficult to administer in a workplace scenario, such as EEG, blink rate, or blood parameters, but rather was limited to posturography, heart rate analysis, a test of distributed attention,

Table 2
Factor loadings for the posturography outcome measures

Posturography	Factor 1	Factor 2
Path length	0.249	0.965*
Velocity	0.269	0.961*
Anterior–posterior variance	0.774*	0.273
Mediolateral variance	0.883*	0.149
Confidence area	0.939*	0.306
Percentage of total variance	0.48†	0.41†

* Values greater than 0.7.
† Fraction of total variance explained by the respective factor.

Table 3
Factor loadings for the heart rate variability outcome measures

HRV	Factor 1
Mean RR	−0.759*
SDNN	−0.811*
RMSSD	−0.894*
Percentage of total variance	0.68†

* Values greater than 0.7.
† Fraction of total variance explained by the respective factor.
HRV, heart rate variability; mean RR, mean RR interval; RMSSD, root mean square of successive difference; SDNN, standard deviation of NN intervals.

Table 4
Factor loadings for the distributed-attention outcome measures

Distributed attention	Factor 1
Subtest 1	0.656
Subtest 2	0.802*
Subtest 3	0.531
Percentage of total variance	0.45†

* Values greater than 0.7.
† Fraction of total variance explained by the respective factor.

Table 5
Factor loadings for all selected fatigue outcome measures

Parameter	Factor 1	Factor 2	Factor 3
RMSSD	−0.151	0.910*	0.042
Subjective fatigue	−0.098	−0.002	0.935*
Simple reaction time	0.681	−0.110	0.445
EC path length	0.842*	0.032	−0.101
EC confidence area	0.812*	0.017	−0.136
UFOV Subtest 2	−0.142	−0.909*	0.071
Percentage of total variance†	0.31	0.28	0.18

* Values greater than 0.7.
† Fraction of total variance explained by the respective factor.
RMSSD, root mean square of successive difference; UVOF, useful field of view; EC, eyes closed.

a simple reaction time task, and self-assessment. We conceptualized work-related fatigue as difference between end and start of work, thus disregarding factors such as time awake, sleep quality, and stimulant intake, which influence the level of fatigue but are difficult to assess in regular workplace scenarios. As a third limitation, we used a relatively small sample of 28 because this was the number of individuals who volunteered to participate at the time our equipment was in place and operating.

The test battery yielded 13 outcome measures, which were reduced by test-specific factor analyses to six, and were then reduced by a single, test-overarching factor analysis to three factors. Because all analyses used varimax rotation, the resultant factors are orthogonal, that is, they represent independent processes.

Factor 1, which captures the largest portion of total variance, reflects a reduction of COP path length, an increase of COP confidence area, and an increase of manual reaction time after work. None of these three measures changed significantly from start to end of work when considered alone (*t* tests), but as a group they covaried from morning to afternoon (factor analysis), and thus might represent valid indicators of fatigue. Specifically, a reduced COP path length might reflect a higher postural rigidity after work [30], whereas an increased COP confidence is commonly interpreted as destabilization and an increase of manual reaction time as generalized slowing.

Factor 2 also captures a considerable portion of total variance. It reflects an increase of RMSSD after work, which confirms some [38–40] but not other [41–43] studies on the relationship between HRV and fatigue. Factor 2 further reflects a decrease of UFOV Subtest 2 scores after work, which corresponds to an improved performance. We suggest that Factor 2 represents a higher alertness after work.

Factor 3 captures less variance than the other two factors, and reflects quite selectively an increase of self-assessed fatigue after work. It is interesting to note that subjective ratings load on a distinct factor: it appears that introspective judgments of fatigue are not related to any of the common objective fatigue measures. Although have been studies that focused on fatigue in clinical contexts [19–21], we are not aware of other studies that noticed this lack of an association before.

The emergence of three orthogonal factors indicates that work-related fatigue is not a uniform construct. This supports the notion of fatigue as a multidimensional phenomenon [2,8,44], and suggests that fatigue at the workplace should be assessed by three distinct tests. One of those tests should quantify postural stability or manual reaction time; we recommend the latter, which is much easier to register. A second test should quantify HRV or attention breadth; we recommend the latter for the same reason. Employers might decide to omit this test, because an increased alertness after work is not likely to represent a safety concern. The last test should quantify subjectively perceived fatigue.

Notably, our factor analysis did not confirm the intuitively appealing view that fatigue has two components—physical and mental. Rather two of the calculated orthogonal factors combined measures of both physical fatigue and mental fatigue, and the third orthogonal factor reflected subjective fatigue without any of the physical and mental measures.

The emergence of subjective fatigue as a distinct orthogonal factor is of substantial practical relevance. It implies that employers concerned about safety at work should not rely exclusively on their employees' self-assessment of fatigue: an employee who introspectively feels fully awake may nevertheless be at risk of losing balance, or moving the hand too late. This notion is also confirmed by the Pearson correlations: subjective fatigue shows little associations with the other objective measures of fatigue.

Additional experimentation is needed to find out whether tests not included in the present battery might be more sensitive to the same three factors of work-related fatigue, or sensitive to yet other factors. Additional studies should also determine whether the factorial structure yielded for clerical work also holds for other types of employment (e.g., in the transport sector).

Conflicts of interest

All contributing authors declare no conflicts of interest.

References

[1] Smets EM, Garssen B, Bonke B, De Haes JC. The Multidimensional Fatigue Inventory (MFI) psychometric qualities of an instrument to assess fatigue. J Psychosom Res 1995;39:315–25.
[2] Barker LM, Nussbaum MA. The effects of fatigue on performance in simulated nursing work. Ergonomics 2011;54:815–29.
[3] Veldhuizen IJT, Gaillard AWK, de Vries J. The influence of mental fatigue on facial EMG activity during a simulated workday. Biol Psychol 2003;63:59–78.
[4] Krueger GP. Sustained work, fatigue, sleep loss and performance: a review of the issues. Work Stress 1989;3:129–41.
[5] DeLuca J. Fatigue as a window to the brain. Cambridge (MA): MIT Press; 2005.
[6] Okogbaa OG, Shell RL, Filipusic D. On the investigation of the neurophysiological correlates of knowledge worker mental fatigue using the EEG signal. Appl Ergon 1994;25:355–65.
[7] Leung AWS, Chan CCH, He J. Structural stability and reliability of the Swedish occupational fatigue inventory among Chinese VDT workers. Appl Ergon 2004;35:233–41.
[8] Saito K. Measurement of fatigue in industries. Ind Health 1999;37:134–42.
[9] 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.
[10] Ting PH, Hwang JR, Doong JL, Jeng MC. Driver fatigue and highway driving: a simulator study. Physiol Behav 2008;94:448–53.
[11] Jones G, Hocine M, Salomon J, Dab W, Temime L. Demographic and occupational predictors of stress and fatigue in French intensive-care registered nurses and nurses' aides: a cross-sectional study. Int J Nurs Stud 2015;52:250–9.
[12] Hystad SW, Saus ER, Sætrevik B, Eid J. Fatigue in seafarers working in the offshore oil and gas re-supply industry: effects of safety climate, psychosocial work environment and shift arrangement. Int Marit Health 2013;64:72–9.
[13] Lal SK, Craig A. Driver fatigue: electroencephalography and psychological assessment. Psychophysiology 2002;39:313–21.
[14] Pichot V, Bourin E, Roche F, Garet M, Gaspoz JM, Duverney D, Antoniadis A, Lacour JR, Barthélémy JC. Quantification of cumulated physical fatigue at the workplace. Pflugers Arch 2002;445:267–72.
[15] Yung M, Bigelow PL, Hastings DM, Wells RP. Detecting within- and between-day manifestations of neuromuscular fatigue at work: an exploratory study. Ergonomics 2014;57:1562–73.
[16] Williamson AM, Feyer AM, Mattick RP, Friswell R, Finlay-Brown S. Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance. Accid Anal Prev 2001;33:313–26.
[17] Baulk SD, Fletcher A, Kandelaars KJ, Dawson D, Roach GD. A field study of sleep and fatigue in a regular rotating 12-h shift system. Appl Ergon 2009;40:694–8.
[18] Lorist MM, Klein M, Nieuwenhuis S, De Jong R, Mulder G, Meijman TF. Mental fatigue and task control: planning and preparation. Psychophysiology 2000;37:614–25.
[19] Johansson B, Berglund P, Rönnbäck L. Mental fatigue and impaired information processing after mild and moderate traumatic brain injury. Brain Injury 2009;23:1027–40.

[20] Bailey A, Channon S, Beaumont JG. The relationship between subjective fatigue and cognitive fatigue in advanced multiple sclerosis. Mult Scler 2007;13:73–80.
[21] Johnson SK, Lange G, DeLuca J, Korn LR, Natelson B. The effects of fatigue on neuropsychological performance in patients with chronic fatigue syndrome. Multiple sclerosis, and depression. Appl Neuropsychol 1997;4:145–53.
[22] Lamond N, Dawson D, Roach GD. Fatigue assessment in the field: validation of a hand-held electronic psychomotor vigilance task. Aviat Space Environ Med 2005;76:486–9.
[23] Gribble PA, Tucker WS, White PA. Time-of-day influences on static and dynamic postural control. J Athl Train 2007;42:35–41.
[24] Doran SM, Van Dongen HPA, Dinges DF. Sustained attention performance during sleep deprivation: evidence of state instability. Arch Ital Biol 2001;139:253–67.
[25] Kalisch T, Kattenstroth JC, Noth S, Tegenthoff M, Dinse HR. Rapid assessment of age-related differences in standing balance. J Aging Res 2011:1–6.
[26] Clark RA, Bryant AL, Pua Y, McCrory O, Bennel K, Hunt M. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait Posture 2010;21:307–10.
[27] Jorgensen MG, Rathleff MS, Laessoe U, Caserotti P, Nielsen OB, Aagaard P. Time-of-day influences postural balance in older adults. Gait Posture 2012;35:653–7.
[28] Zech A, Steib S, Hentschke C, Eckhardt H, Pfeifer K. Effects of localized and general fatigue on static and dynamic postural control in male team handball athletes. J Strength Cond Res 2012;26:1162–8.
[29] 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;78:859–63.
[30] Voelker I, Kirchner C, Bock OL, Wascher E. Body sway as a possible indicator of fatigue. Saf Health Work 2015:1–5.
[31] Segerstrom SC, Nes LS. Heart rate variability reflects self-regulatory strength, effort, and fatigue. Psychol Sci 2007;18:275–81.
[32] Egelund N. Spectral analysis of heart rate variability as an indicator of driver fatigue. Ergonomics 1982;25:663–72.
[33] Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR. Visual attention problems as a predictor of vehicle crashes in older drivers. Invest Ophthalmol Vis Sci 1993;34:3110–23.
[34] Loh S, Lamond N, Dorrian J, Roach G, Dawson D. The validity of psychomotor vigilance tasks of less than 10-minute duration. Behav Res Methods Instrum Comput 2004;36:339–46.
[35] Heslegrave R, Angus RG. The effects of task duration and work-session location on performance degradation induced by sleep loss and sustained cognitive work. Behav Res Methods Instrum Comput 1985;17:592–6.
[36] Dawson D, Reid K. Fatigue, alcohol and performance impairment. Nature 1997;388:235–7.
[37] Kim E, Lovera J, Schaben L, Melara J, Bourdette D, Whitman R. Novel method for measurement of fatigue in multiple sclerosis: real-time digital fatigue score. J Rehabil Res Dev 2010;47:477–84.
[38] Abrahamyan HT, Minasyan SM. Normalization of students functional state during academic workload. Chem Biol 2014;3:29–34.
[39] Burger AJ, Chalamb M, Sherman MD. Circadian patterns of heart rate variability in normals, chronic stable angina and diabetes mellitus. Int J Cardiol 1999;71:41–8.
[40] Coumel P, Maison-Blanche P, Catuli D. Heart rate and heart rate variability in normal young adults. J Cardiovasc Electrophysiol 1994;5:899–911.
[41] Cinaz B, La Marca R, Arnrich B, Tröster G. Monitoring of mental workload levels. Proceedings of the IADIS International Conference e-Health 2010, EH, Part of the IADIS Multi Conference on Computer Science and Information Systems 2010 (MCCSIS 2010); 2010. p. 189–193.
[42] Chen JC, Stone PH, Verrier RL, Nearing BD, MacCallum G, Kim JY, Herrick RF, You J, Zhou H, Christiani DC. Personal coronary risk profiles modify autonomic nervous system responses to air pollution. J Occup Environ Med 2006;48:1133–42.
[43] Taelman J, Vandeput S, Vlemincx E, Spaepen A, Van Huffel S. Instantaneous changes in heart rate regulation due to mental load in simulated office work. Eur J Appl Physiol 2011;111:1497–505.
[44] De Vries J, Michielsen HJ, Van Heck GL. Assessment of fatigue among working people: a comparison of six questionnaires. Occup Environ Med 2003;60(Suppl 1):i10–5.