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Original Article

Relation between Multiple Markers of Work-Related Fatigue

Ina Völker*, Christine Kirchner, Otmar L. Bock

German Sport University Cologne—Institute of Physiology and Anatomy, Cologne, Germany

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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.

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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

* Corresponding author. German Sport University Cologne—Institute of Physiology and Anatomy, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany.
E-mail address: i.voelker@dshs-koeln.de (I. Völker).

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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

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