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Original Article

Body Sway as a Possible Indicator of Fatigue in Clerical Workers

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ABSTRACT

Background: Fatigue has a strong impact on workers' performance and safety, but expedient methods for assessing fatigue on the job are not yet available. Studies discuss posturography as an indicator of fatigue, but further evidence for its use in the workplace is needed. The purpose of the study is to examine whether posturography is a suitable indicator of fatigue in clerical workers.
Methods: Thirty-six employees (Ø 34.8 years, standard deviation = 12.5) participated in postural tasks (eyes open, eyes closed, arm swinging, and dual task) in the morning and afternoon. Position of their center of pressure (COP) was registered using a Nintendo Wii Balance Board and commercial software. From registered COP time series, we calculated the following parameters: path length (mm), velocity (mm/s), anterior–posterior variance (mm), mediolateral variance (mm), and confidence area (mm^2). These parameters were reduced to two orthogonal factors in a factor analysis with varimax rotation.
Results: Statistical analysis of the first factor (path length and velocity) showed a significant effect of time of day: COP moved along a shorter path at a lower velocity in the afternoon compared with that in the morning. There also was a significant effect of task, but no significant interaction.
Conclusion: Data suggest that postural stability of clerical workers was comparable in the morning and afternoon, but COP movement was greater in the morning. Within the framework of dynamic systems theory, this could indicate that the postural system explored the state space in more detail, and thus was more ready to respond to unexpected perturbations in the morning.

1. Introduction

Fatigue is a serious safety risk for workers who operate vehicles or machinery. It also is a critical issue for clerical workers: fatigue reduces vigilance and productivity, and it increases the probability of mistakes [1,2]. Unfortunately, an assessment of fatigue on the job is not easy to accomplish. Many studies used questionnaires; however, these do not provide objective data [3–5]. Others used objective measures such as electroencephalography [6], heart rate variability [7], or cognitive function tests [2,8]. These methods are expensive and time consuming, and/or they interfere with normal job performance. The present study, therefore, focuses on another indicator of fatigue: posturography. This method is relatively quick, unobtrusive, and, with the advent of posturographic gaming hardware, inexpensive [9].

Several studies report that fatigue, induced by sleep deprivation, extended wakefulness [10–12], or muscle exertion [13–15], degrades postural stability. It therefore would not be surprising if fatigue induced by a full day's work had a similar effect on posture. However, available data regarding this issue are inconsistent. Some studies evaluating the circadian rhythm of postural stability have found an increase of body sway from morning to afternoon [16–18], whereas others found no change [19] or even a decrease of body sway [20,21]. We attribute these discrepancies to the fact that most circadian studies did not control their participants' activities throughout the day; thus, some individuals might have arrived for afternoon testing fatigued, others with an intermediate vigilance level, and yet others even animated. To avoid the confounding effect of different activities during the day, we decided to limit our study to clerical workers of a single facility, who were engaged in

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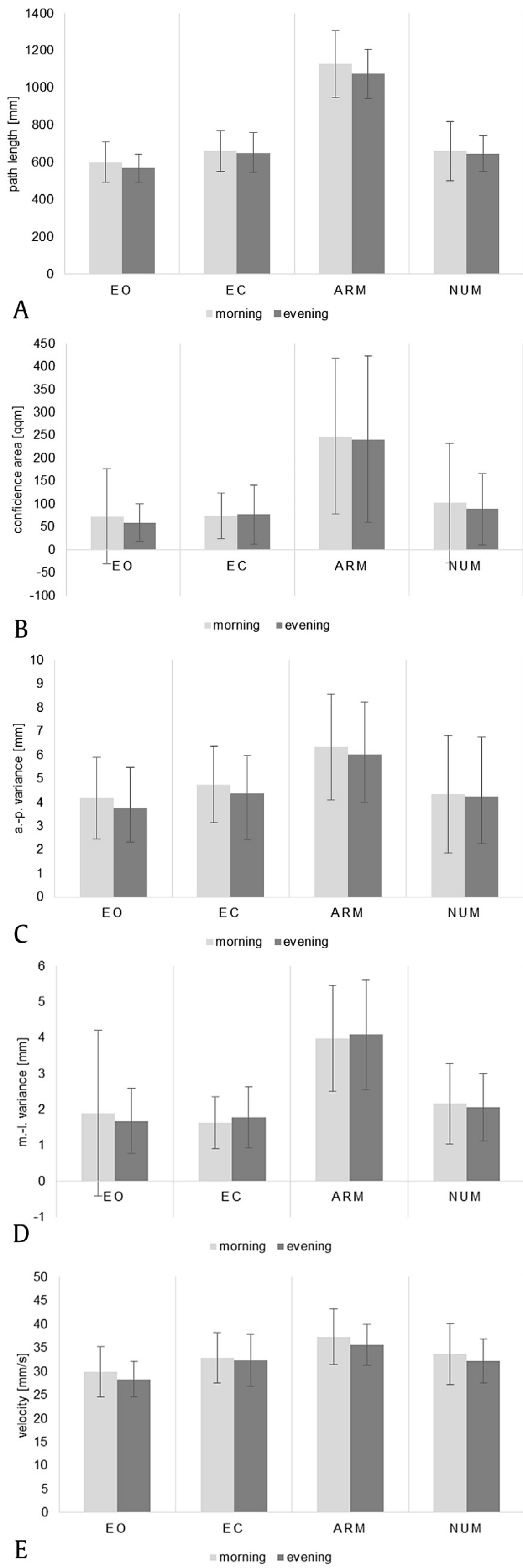

Fig. 1. Across-subject means and standard deviations for the five COP parameters: (A) path length, (B) confidence area, (C) anterior–posterior variance, (D) mediolateral variance, and (E) COP velocity. The data are plotted separately for the four tasks (EO, EC, ARM, and NUM) and for the two times of day. a.–p. var., anterior–posterior variance; ARM, arm swinging; COP, center of pressure; EC, eyes closed; EO, eyes open; m.–l. var., mediolateral variance; NUM, number count.

broadly similar tasks during their working hours. To prevent the influence of extraneous circumstances, we tested our participants twice at their site of employment, once on arrival in the morning and once on departure in the afternoon.

Postural balance has been quantified in the past by various parameters. Most of them use center of pressure (COP) trajectories to derive metrics that range from fairly straightforward (e.g., COP path length) to advanced (e.g., COP fractal dimension). According to Winter [22], COP is the location of the vertical ground reaction vector on the force platform. The measurement of COP parameters using a force platform is presented as gold standard in the literature [9,23]. The advantages and disadvantages of the various parameters are still unclear [24]. We decided on a set of five parameters that are frequently reported in the literature [10,14,17]. The aim of our study was to identify a posturography parameter that is sensitive to changes of postural balance over the workday of clerical workers, and thus could be a useful marker of work-induced fatigue.

2. Materials and methods

2.1. Participants

Thirty-six employees (18 women and 18 men) of the Leibniz Research Centre for Working Environment and Human Factors, Dortmund, Germany were recruited in the study. Their daily work consists mainly of computer data entry, reading, and writing, and thus is characteristic of clerical, as opposed to manual, workers. The participants' mean age was 34.8 ± 12.5 years (range: 15–64 years). At the time of testing, no participant reported any orthopedic, mental, or chronic disease, and had 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, Cologne, Germany.

2.2. Task design and materials

Each participant was tested once at the beginning (morning: 8:30–9:00 AM) and again at the end of the same working day (afternoon: 3:30–4:00 PM). Each testing session took approximately 30 minutes and consisted of, besides posturography, several other assessments that will be reported elsewhere. Between the two sessions, participants completed their usual work assignments.

Body posture was measured by a Nintendo Wii Balance Board (Nintendo, Kyoto, Japan), linked to a laptop PC via Bluetooth in conjunction with commercially available software (STAnding BaLance Evaluation—STABLE by pro-WISS, Bochum, Germany). The software samples raw data from four pressure sensors at a rate of 50 Hz and transforms them into x–y-coordinates representing the COP [24]. This method to measure postural balance has been validated by several studies [9,25].

Posturography consisted of four tasks, administered in balanced order. In task eyes open (EO), participants stood still with open eyes for 20 seconds, with their feet at hip distance and their arms hanging loosely at the sides of their body. Task eyes closed (EC) differed only in that participants had their eyes closed. In task arm swinging (ARM), participants stood still with eyes open for 5 seconds, then swung their arms forward and backward up to an angle of 90°, seven times within 7 seconds (the left arm moving mirror symmetrically to the right), and finally stood still again for further 18 seconds. Task number count (NUM) differed from EO in that participants counted backward in threes, starting with a different number in the morning and in the afternoon. As the ARM task is somewhat more complex, it was practiced twice before testing. For all tasks, the dependent measure was the confidence area.

2.3. Data analysis

The following parameters were calculated from the registered COP time series of each task: path length (mm), confidence area (mm^2), velocity (mm/s), anterior–posterior variance (mm), and mediolateral variance (mm). To explore the relationships between these parameters, Pearson correlations for each task (EO, EC, ARM, and NUM) and time of day (morning/afternoon) were conducted. To assess possible time-of-day differences of these parameters, we adopted a two-step approach. We first reduced the number of dependent variables from five posturography parameters to two underlying orthogonal factors, using factor analysis with varimax rotation; this minimized problems associated with multiple testing, and reduced data variability as each factor relied on more than one parameter. As a second step, we submitted the factor values to a 2×4 analysis of variance (ANOVA) with repeated measures on the following factors: time of day and task.

3. Results

The across-subject mean of each COP parameter, separately for each task and time of day, is illustrated in Fig. 1. The graphs show that all parameters consistently differed between tasks, but differences between times of day are less obvious.

The Pearson correlations between COP parameters are listed in Table 1, which shows that for each task and time of day, there was a strong correlation between COP path length and COP velocity; a strong correlation between COP confidence area, anterior–posterior sway, and mediolateral sway; but a poor correlation between the former two and the latter three parameters. Accordingly, factor analyses of each task and time of day reduced the five parameters to the same two factors, one representing path length and speed, and the other representing variability and confidence area (see Table 2). Although each factor analysis relies on only a small number of participants, all 10 analyses yielded comparable outcomes and were in line with the 10 correlation matrices of Table 1, which supports their validity. From this we concluded that the same factorial structure applies to all tasks and times of day, thus allowing comparisons based on factor values rather than parameter scores. Fig. 2 illustrates that the values of $F1$, but not those of $F2$, differed consistently between times of day in all tasks. ANOVA of $F1$ yielded significance for time of day [$F(1,34) = 10.70$; $p < 0.01$] and task [Greenhouse–Geisser-corrected $F(3,102) = 86.23$; $p < 0.001$], but not for the interaction. ANOVA of $F2$ revealed significance only for task [$F(3,102) = 35.77$; $p < 0.001$].

The relationship between participants' age and COP path length is presented in Fig. 3, averaged across tasks. Simple linear regression analysis yielded a significant effect of age for path length in the morning [$F(1,34) = 4.816$; $p < 0.05$] but not in the afternoon [$F(1,34) = 1.944$; $p > 0.05$]. Results were comparable for the relationship between age and COP velocity in the morning [$F(1,34) = 4.642$; $p < 0.05$] and in the afternoon [$F(1,34) = 1.234$; $p > 0.05$]. There was no significant relationship between the participants' gender and COP path length in the morning [$t(17) = -1.283$, $p > 0.05$] and in the afternoon [$t(17) = -1.706$, $p > 0.05$], nor between gender and COP velocity in the morning [$t(17) = -1.361$, $p > 0.05$) and in the afternoon [$t(17) = -1.673$, $p > 0.05$].

4. Discussion

Our study compared body sway of clerical workers at the beginning and at the end of a workday, using five common posturographic parameters. Only two of those parameters differed significantly between morning and afternoon; both probably reflect the same postural process, since they could be reduced to a single factor ($F1$). The three remaining parameters probably reflect

Table 1
Outcomes of Pearson correlations between five COP parameters (path length, confidence area, ant.–post. variance, med.–lat. variance, and velocity) for EO morning/afternoon; EC morning/afternoon, ARM morning/afternoon, and NUM morning/afternoon

	Velocity	Med.–lat. var.	Ant.–post var.	Confidence area	Path length	
EO morning						
Path length	0.999	0.428	−0.004	0.365		Path length
Confidence area	0.365	0.978	0.618		−0.171	Confidence area
Ant.–post var.	−0.004	0.468		0.751	−0.047	Ant.–post var.
Med.–lat.var.	0.462		0.400	0.850	−0.252	Med.–lat. var.
Velocity		−0.261	−0.049	−0.177	0.999	Velocity
						EO afternoon
EC morning						
Path length	0.998	0.355	0.227	0.389		Path length
Confidence area	0.394	0.887	0.851		0.363	Confidence area
Ant.–post var.	0.240	0.576		0.876	0.279	Ant.–post var.
Med.–lat var.	0.352		0.554	0.834	0.290	Med.–lat. var.
Velocity		0.290	0.287	0.368	0.999	Velocity
						EC afternoon
ARM morning						
Path length	0.999	0.135	0.093	−0.071		Path length
Confidence area	−0.067	0.922	0.878		−0.098	Confidence area
Ant.–post var.	0.091	0.674*		0.855	−0.037	Ant.–post var.
ed.–lat. var.	−0.128		0.679	0.917	−0.086	Med.–lat var.
Velocity		-0.800	−0.036	−0.091	0.998	Velocity
						ARM afternoon
NUM morning						
Path length	0.786	0.450	0.464	0.474		Path length
Confidence area	0.509	0.853	0.951		0.283	Confidence area
Ant.–post var.	0.483	0.833		0.897	0.103	Ant.–post var.
Med.–lat. var.	0.426		0.617	0.858	0.354	Med.–lat. var.
Velocity		0.364*	0.118	0.297	0.999	Velocity
						NUM afternoon

*Data are presented as correlation coefficients (r).
Ant.–post var., anterior–posterior variance; ARM, arm swinging; COP, center of pressure; EC, eyes closed; EO, eyes open; Med.–lat. var., mediolateral variance; NUM, number count.

Table 2
Outcome of factor analyses*

	EO				EC			
	Morning		Afternoon		Morning		Afternoon	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Path length		0.983		0.993		0.984		0.985
Confidence area	0.935		0.980		0.966		0.969	
Ant.-post. var.	0.828		0.822		0.887		0.879	
Med.-lat. var.	0.861		0.831		0.860		0.854	
Velocity		0.983		0.993		0.982		0.984
% Variance explained	0.466	0.438	0.468	0.408	0.504	0.408	0.500	0.404
	ARM				NUM			
	Morning		Afternoon		Morning		Afternoon	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Path length		0.999		0.999		0.912		0.990
Confidence area	0.992		-0.985		0.934		0.977	
Ant.-post. var.	0.907		-0.900		0.932		0.926	
Med.-lat. var.	0.919		-0.924		0.905		0.847	
Velocity		0.998		0.999		0.909		0.988
% Variance explained	0.530	0.406	0.527	0.400	0.438	0.372	0.513	0.413

Ant.—post var., anterior—posterior variance; ARM, arm swinging; EC, eyes closed; EO, eyes open; Med.—lat. var., mediolateral variance; NUM, number count.
* Separate analysis for each task and daytime. Scores are factor loadings, with blank cell representing loadings <0.7.

another postural process, since they could be reduced to another single factor, orthogonal to the first (*F*2).

It should be noted that the parameters loading on *F*2 quantify COP excursions about the mean COP position; since larger excursions will shift COP closer to the point of losing balance, *F*2 is a direct measure of postural stability. By contrast, the parameters loading on *F*1 quantify COP movement irrespective of excursions about the mean COP position; *F*1 is therefore not a direct measure of postural stability. In light of these considerations, we conclude that our participants used similar safety margins for posture in the morning and in the afternoon, but moved their COP inside those margins more in the morning than in the afternoon.

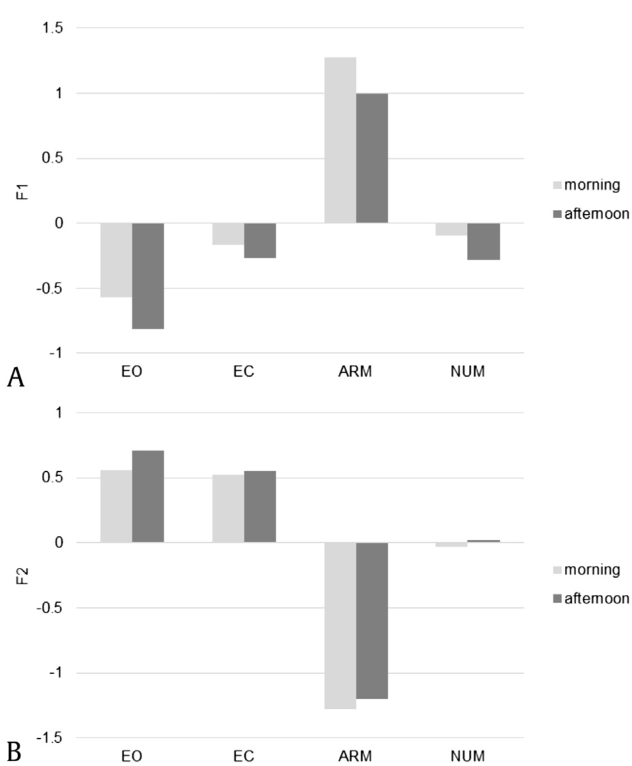

Fig. 2. Plots of factors *F*1 and *F*2. (A) *F*1 is plotted for the four tasks and for the two times of day. (B) (A) *F*2 is plotted for the four tasks and for the two times of day. *F*1 represents COP path length and speed, while *F*2 represents COP variability. ARM, arm swinging; COP, center of pressure; EC, eyes closed; EO, eyes open; NUM, number count.

One possible interpretation of this finding is that postural control was less effective in the morning, since the participants expended more energy to attain the same stability criterion. However, we favor an alternative interpretation. Dynamic systems theory posits that self-organizing motor systems benefit from movements through state space, which allow them to explore alternative performance solutions [25–28]; if postural mechanisms controlling the head, limbs, and trunk are considered as components of such a self-organizing coordinative system, then greater COP movement in the morning could indicate more exploration of the state space, and thus a better starting point for postural responses to unexpected perturbations. Accordingly, less COP movement in the afternoon would be indicative of a less agile system, reduced to postural maintenance without postural exploration. This interpretation is supported by our finding that older participants tended to produce less COP movement than younger ones, i.e., less COP movement might be a sign of age-related decay. Further support comes from the fact that COP movement was negatively associated with self-rated fatigue[1] ($r = -0.170$; $p < 0.05$), i.e., less COP movement was associated with higher rather than lower levels of fatigue.

In conclusion, our data suggest no change of postural stability over the workday of clerical workers, but a decrease of COP movement, possibly due to a fatigue-induced reduction of exploratory postural activity. One limitation of our study is that the effects of fatigue modifiers such as caffeine, nicotine, drugs, accomplishments and frustrations at work, as well as weather conditions were not

[1] We will report in a separate communication that our participants completed a 0–10 rating scale of momentary fatigue before posturography, both in the morning and in the afternoon.

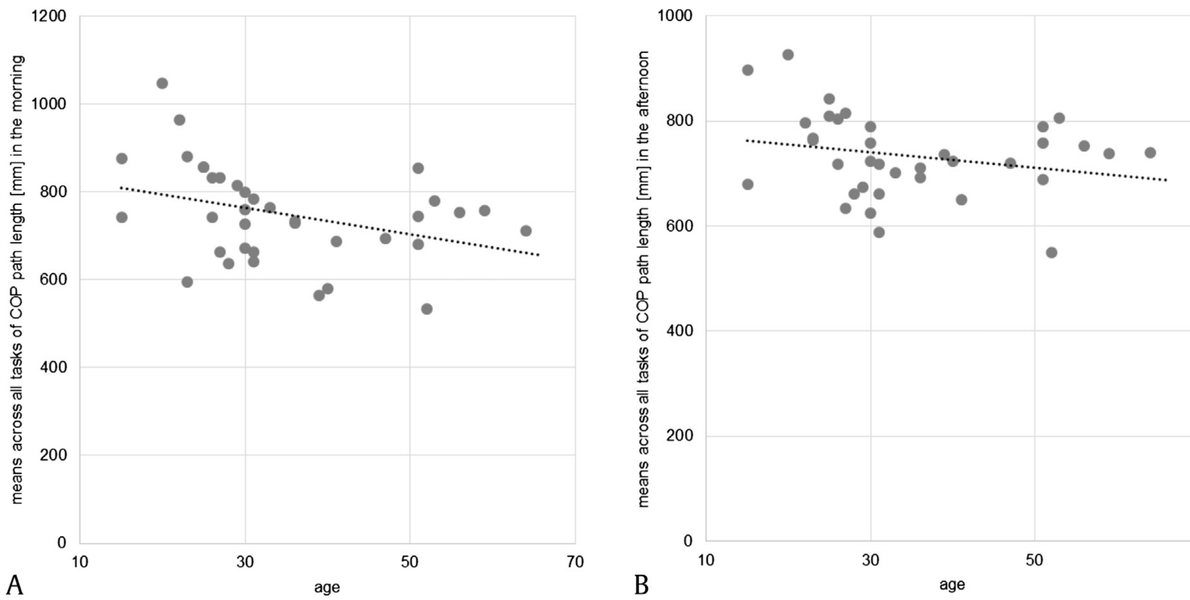

Fig. 3. Relationship between age and COP path length: (A) COP path length (means across tasks) in the morning and (B) COP path length (means across tasks) in the afternoon. COP, center of pressure.

controlled for. Our study, therefore, reflects the natural combination of those factors in a larger sample. Furthermore, we, similar to other authors, were unable to clearly disambiguate work-related fatigue from fatigue due to the circadian rhythm.

Conflicts of interest

There is no financial or other relationship that might be perceived as leading to a conflict of interest (i.e., affecting the author objectivity).

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