In-chair movement: validity, reliability and implications for measuring sitting discomfort

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Abstract

Sitting discomfort is traditionally evaluated with subjective rating scales which are referenced to an objective correlate (e.g. sitting posture) measured on a static (i.e. non-continuous) basis. Since sitting discomfort is dynamic in nature, it requires continuous, objective measurement. We therefore adapted an interface pressure mat to continuously record in-chair movement (ICM) as an indirect measurement of sitting discomfort by tracking the center of pressure (COP) at the buttock–chair interface. Here we report on two phases in the development of the COP system: laboratory validity and field reliability. In the laboratory study we confirmed system validity by simultaneously tracking ICM with the mat and a force platform ($r^2 = 0.80$) and by comparing subjects’ COP movement with their gross trunk movements ($r^2 = 0.86$). In our field study we used the intraclass correlation coefficient to establish a data sampling (i.e. selection) protocol that was reliable. We collected ICM data on seated telecommunications Directory Assistance operators during 2 h field tests. Results showed that using a minimum sampling time of 5 min and then averaging a series of 5 min samples of ICM was more reliable than single discrete samples. Using the averaging protocol, we also showed that ICM increased significantly over 2 h and that ICM did not differ between trials. © 2000 Elsevier Science Ltd. All rights reserved.

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Measurement of sitting discomfort is one of the greatest challenges in seating research (Corlett, 1990). By tradition (Drury and Coury, 1982; Corlett, 1990), sitting discomfort (or comfort) is evaluated with subjective scales, such as the general comfort rating (Shackel et al., 1969), which then are referenced to some objective measure of the chair, the occupant, or the task. To date, most discomfort investigators have scored the objective measure discontinuously. That approach may be termed static. For example, such factors as spinal posture (Bishu et al., 1991) or seated pressure distribution (Gyi et al., 1998) have been sampled on an infrequent basis. While remaining with the conventional subjective/objective approach to measuring discomfort, we broke with tradition by using a continuous objective correlate of sitting discomfort, namely in-chair movement (ICM). By contrast, we consider our approach to be dynamic. This dynamic approach presented a unique problem — how to establish a data sampling (i.e. selection) protocol that was reliable and that would allow detection of temporal changes in ICM. In this paper we present a rationale for dynamic, objective measurement of discomfort, introduce a unique system to measure ICM, and report on the results of two studies: laboratory validity and field reliability of the ICM measurement system.

1. In-chair movement as a dynamic correlate of sitting discomfort

We took this dynamic approach primarily because sitting is a dynamic activity. That is, seated subjects reportedly move continuously (Branton, 1966) and often move in excess of task demands (Fleischer et al., 1987). We also took this approach because sitting discomfort is considered dynamic (i.e. time dependent) (Bhatnager et al., 1985). According to Helander and Zhang (1997) comfort and discomfort are not ends of a bipolar continuum and each therefore requires independent measurement.
Furthermore, using multidimensional scaling and cluster analysis, the same authors reported that subjects associated seated movements (i.e., ICMs) with sitting discomfort (Zhang and Helander, 1992). Consequently, we focus on the measurement of discomfort, operationally defined as the presence of a distracting bodily sensation (Corlett, 1990).

ICM is an outcome measure that has provided a dynamic, time-based measure of sitting discomfort in previous laboratory studies (Grandjean et al., 1960; Bhatnager et al., 1985; Bendix et al., 1985). The underlying assumption in these precedent studies was that subjects move little when first sitting, but as time passes, they increase their in-chair movements, possibly due to discomfort. The relationship between in-chair movement and discomfort is somewhat enigmatic since some movement is necessary to avoid undesirable static work postures (Winkel, 1986) and some movement is task related. The mathematical relationship between in-chair movement and discomfort is somewhat speculative at present. However, while no seating researchers have plotted movement versus discomfort, Bhatnager et al. (1985) clearly demonstrated that discomfort and seated movements both increased over time in a linear fashion, with similarly steep slopes.

2. Measuring in-chair movement in the laboratory: validity

Sitting discomfort is best evaluated in the field since it is dependent on the task and on a variety of workplace factors related to the job (e.g., overtime, peer interactions) and to the individual (e.g., job satisfaction) (Drury and Coury, 1982). In order to determine the temporal relationship between sitting discomfort and ICM in the workplace, a non-invasive, non-disruptive measure of seated movement was required. In collaboration with the manufacturers, we adapted the VERG interface pressure mat (Force Sensing Systems, Winnipeg, MN, Canada) to collect continuous ICM data in the field by tracking a subject’s center of pressure (COP) at the buttock—chair interface. The primary purpose of this laboratory part of our study was to determine the validity of the adapted VERG system in tracking the COP in a continuous, dynamic fashion. A second purpose was to establish the mathematical relationship between trunk movement and COP movement in seated subjects to improve the interpretation of future field studies.

3. Measuring in-chair movement in the field: reliability

In previous work we established the inter-trial reliability of the VERG ICM system in the laboratory for standardized movements of 15 s duration (Fenety et al., 1994). Laboratory reliability notwithstanding, conditions are more variable in the field for at least two reasons. First, ICM is composed of required task movements and extraneous movements (Corlett, 1990). Regardless of experimental controls, day-to-day variations in tasks and extraneous movements may be great in field trials (Jurgens, 1989). Second, many non-work issues (e.g., fatigue, family) and work factors (e.g., mental workload, employer–employee relations) contribute to variable field conditions. Given these sources of variance, the expectation of similar movements occurring at similar times from day-to-day may be unrealistic. Consequently, the issue of a reliable data sampling technique was central to the field component of our study.

Our goal for future intervention studies was to be able to compare ICM data over three test periods: at the start, the midpoint and the end of 2 h work periods. To accomplish that required that we address the issues of sampling and reliability. The first issue, sampling, was an issue about how to select representative data from the large volumes of data generated by the VERG computer system (0.30 MB/h). Therefore, our first need was to establish the duration of the sample periods that represented movement during the 3 test periods (i.e., start, middle and end), such that we could test for temporal trends in seated movement in future studies. While there were no clear guidelines in the literature, there were some precedents of 5 min (Jensen and Bendix, 1992), 15 min (Rieck, 1969), and 30 min (Grandjean et al., 1960) periods sampled over 2 or 3 h tests. Notably, temporal trends in seated movement were seen in the 15 and 30 min sample protocols, but not in the 5 min protocol (Jensen and Bendix, 1992). Reliability of these various sampling techniques has not been reported.

The second issue was to determine the most reliable means to analyze the sampled data. On the one hand, movement data could be analyzed as a long continuous block of time. For example, Bhatnager et al. (1985) used the total ICM in a 30 min block. Alternatively, sampling theory (Kroll, 1967) suggests that data could be averaged as a series of smaller time blocks (e.g., ICM as an average of six, 5 min blocks). Sanford et al. (1993) showed that for optimum reliability, the mean of these short blocks can be used — but only if there is no time trend among the blocks. In the literature, the minimum duration of recording seated movement is 5 min (Jensen and Bendix, 1992).

We resolved both the sampling and the reliability issues by using a reliability statistic — the intraclass correlation coefficient (ICC) (Shrout and Fleiss, 1979). Defined generally as (among groups variance)/(among groups variance + between groups variance), the ICC measures consistency between trials. The primary purpose of the field component of this study was therefore to compare the inter-trial (i.e., day-to-day) reliability of single 5 min blocks versus the means of three
A second purpose was to then use the most reliable sampling method to test for between-trials differences in ICM in workers performing a common seated task, VDU operations. Our final purpose was to confirm in the field, the laboratory reports that ICM increases over time (Grandjean et al., 1960; Rieck, 1969; Jurgens, 1989).

4. Materials and methods

4.1. Part 1: laboratory study

4.1.1. Materials

**VERG interface mat.** The VERG interface pressure mat is a 15 × 15 array of 2.54 cm² force sensing resistors (FSRs). Measuring 45 cm square, the mat was developed to measure pressure distribution at the buttock–chair interface. The 225 VERG FSRs are embedded in a 2 mm thick rubber mat, making the system adaptable to most chair seats. Each VERG FSR — sensitive to compression only — is calibrated by mapping its response characteristics (Knudson and White, 1989). During sampling, differences due to hysteresis (< 5%) are corrected for each VERG FSR using its own on-line calibration curve (Mokshagundam, 1987). For the VERG FSRs, creep has been shown to peak at 5.3% and cease after 12 min of loading (Fenety, 1995). Using regression analysis, the between-trials reliability of the VERG mat has been reported to be 0.9 ($p < 0.001$) for measuring peak interface pressures (Rosenthal et al., 1996).

The original VERG software sampled each FSR at 0.5 Hz via multiplexers and stored data on-line in an IBM compatible computer. Since previous work showed that seated subjects could move at frequencies approaching 0.5 Hz (Fenety, 1995), the mat developers reset the dynamic collection rate for the VERG COP system at 10 Hz and low-pass filtered the data at 3 Hz. In this mode, the interface mat measures in-chair movement in a quasi-continuous fashion by tracking a subject’s COP at the buttock–chair interface. The COP is calculated on-line from summing the pressure moments about a defined origin (0,0) at the left rear corner of the mat.

The COP is defined as the point of application of the resultant force between two contacting surfaces, such as a body and a floor surface. Moreover, when that surface is the only support for the body in static postures (e.g. feet in standing), the position of the COP actually reflects the position of the center of gravity (COG) within a plane parallel to the support surface (Winter, 1990). In the present study, **ICM is operationally defined as any movement of the chair occupant (task related or otherwise) that changes the position of the COP**.

Validity of the operational definition of ICM requires the following two underlying assumptions about the COP. The first assumption — that most of the body weight is supported by the seat — implies that the COP of the forces at the buttock–chair interface reflects the COG. Second, the dynamic component of sitting (i.e. acceleration) is assumed to be small compared to the static component, implying that seated positions can be assumed to be a series of static postures — in which case, once again, the COP reflects the COG.

If the first assumption was violated, such that there were substantial loads placed on the backrest and feet, the COP of the buttock–chair interface would not necessarily be vertically aligned with the COG. This would be true even under conditions of static equilibrium. In other words, a violation of the first assumption would mean that the body weight vector which passes through the COG would not necessarily be collinear with the reaction force passing through the COP of the buttock–chair interface, if there were substantial reaction forces at the feet and/or back. If the second assumption was violated, and the body experienced a significant angular acceleration during the course of its movement, the COG would not necessarily remain vertically aligned with the COP of the buttock–chair interface. This would be true even if all the body weight was supported by the seat. In other words, a violation of the second assumption would mean that the body weight and buttock–chair reaction force vectors would no longer have to be collinear to satisfy the conditions of static equilibrium.

**Kistler force platform.** COP data collected with a Kistler 9281B multicomponent force platform (Kistler Instrument, Eulachstrasse 22 AG CH-8408, Winterthur, Switzerland) were used as the validation standard in the present study. The force platform was sampled at 100 Hz with a Hewlett-Packard Multiprogrammer 6942A (Hewlett-Packard, Fort Collins, CA). The validity of the force platform in tracking the COP has been previously documented (Goldie et al., 1989).

4.1.2. Methods

**Dynamic validation.** In this experiment we examined differences between the VERG mat and the force platform in the determination of (i) the COP coordinates and (ii) tracking velocity (defined as the distance moved by the COP between samples, divided by the time between samples; or $d - d_i / t - t_i$ in cm/s). The VERG mat was placed on the force platform. A female subject (height 160 cm, weight 51 kg) then was positioned in long sitting (i.e. buttocks on force platform/hips flexed to 90°/knees extended) with her legs off the force platform below mid-thigh. COP coordinates were simultaneously tracked while the subject flexed, extended and alternately side flexed her trunk to her point of discomfort and returned upright.

**Trunk movement versus COP position.** To facilitate interpretation of the VERG data, changes in subjects’ trunk postures measured by motion marker analysis were compared to resulting COP changes measured by
Fig. 1. Trunk movement versus COP position: Subject positioning for the purpose of simultaneous recording of the center of pressure (measured with the VERG interface mat), trunk inclination (measured using white, joint center of rotation markers) and spinal movement (measured with striped motion markers).

the interface mat. Each of the two volunteers (female, age 27, height 165, weight 61 kg; male, age 21, height 186 cm, weight 84 kg) sat on the mat which was centered on the chair seat (Harter Furniture, Guelph, ON, Canada). The chair height was adjusted for each subject to support their feet on the floor and to facilitate an approximately 90° knee angle (see Fig. 1). Markers were placed on the centers of rotation (COR) of the hip and shoulder joints. Spinal motion markers (Fenety and Kumar, 1992) were fixed perpendicular to the spine (Fig. 1), level with the first thoracic (T₁) and first sacral (S₁) vertebrae.

With the subjects’ forearms resting on their thighs, VERG COP data and trunk movement were captured simultaneously during two tests: (i) to the limits of sagittal flexion and extension, and (ii) to the limits of bilateral side flexion. Trunk motion in the sagittal and frontal planes was filmed at 30 frames/s with two VHS video cameras and analyzed at 3 Hz using a video cassette player and frame grabber. The following angles were measured with a goniometer: (1) trunk inclination (i.e. flexion or extension), or the angle subtended by a plumb line and a line joining the shoulder and hip CORs and (2) lateral trunk flexion, or the angle subtended by a plumb line and a line joining the motion markers at T₁ and S₁. The spinal marker methodology has been shown to be valid (Bryant et al., 1989) and reliable (Fenety and Kumar, 1992).

4.1.3. Data analysis

The laboratory study involved method comparisons, that is: (i) COP calculations were compared between an interface pressure mat and a force platform, and (ii) COP movement was compared to a subjects’ trunk/spinal movement. Following Altman and Bland’s (1983) recommendation, regression analysis (SPSS, Chicago, IL 60611) was used to compare data.

4.2. Part 2: Field study

4.2.1. Subjects

The subjects were volunteers (1M, 7F) ranging in age from 23 to 45 years (median 39.5) whose term of employment as Directory Assistance (DA) operators ranged from 36 to 189.5 months (median 147.2 months). Their height ranged from 158.5 to 170 cm (median 165.5 cm) and their weight ranged from 59.3 to 85.5 kg (median 73.4 kg). Volunteers were required to meet musculoskeletal health (Nordic Questionnaires; Kuorinka et al., 1987) and vision standards (Akbari and Konz, 1991). Subjects were masked to the fact that movement would be derived from the VERG mat recordings. All subjects gave their signed, informed consent. Research was approved by a Human Ethics Review Committee of Dalhousie University.

4.2.2. Task and environment

The VDU task selected, DA operations at a local telephone company, was chosen because the areas of task, workload, environment, and furniture were standardized. The operators’ task — centered on a VDU and a headset — required no movements other than key-boarding, screen viewing and speaking to customers via a headset. The operators’ workload (i.e. calls/operator/hour) was maintained relatively constant because the telephone company continually adjusted the number of on-line operators in proportion to the total volume of incoming calls. During the study, subjects worked exclusively on day shifts in DA operations. The maximum continuous work period allowed under the terms of the collective agreement was 120 min, a period considered sufficient to detect changes in sitting discomfort (Bhatnager et al., 1985) and ICM (Jurgens, 1989).

In terms of the indoor climate, the DA room met ASHRAE (1985) standards for lighting, temperature, air flow rates and humidity. The operators’ equipment,
including VDUs, workstations and chairs (Concentrix, Steelcase, Grand Rapids MI), was standardized throughout the entire office. The keyboard and screen were not height adjustable. In view of the effect of operator/workstation fit on in-chair movement (Mark et al., 1985; Pustinger et al., 1985) subjects were screened on height. That is, subjects were excluded if they could not achieve a minimum of 90° angles at their elbows and knees while seated at their computer terminal.

4.2.3. Materials

We used the VERG interface pressure mat with customized software for continuous on-line (Packard Bell 486SX-20) collection of COP data in the form of 24, 5 min blocks over each 2 h test. Using post-collection software, the total COP track (i.e. COP distance) was calculated for each 5 min time block. Customized graphics software provided two-dimensional COP plots (Fig. 2), to assist with direct, visual interpretation of the COP data.

4.2.4. Test procedure

Tests were 2 h long and took place exclusively during weekday mornings at the start of the shift. Subjects began each test with the chair (height, backrest angle, seat tilt) and screen distance set at their pre-determined preferred position. Although DA operators were allowed to re-adjust any setting in the course of their work, none were observed to do so throughout the study. As subjects sat on the mat, COP data were collected continuously for 120 min. Tests were repeated 23–25 h later at the same workstation set at each subject’s preferred position.

4.2.5. Data analysis

Movement data were not analyzed during blocks 1 and 24 when subjects were signing on or off their computer. COP data were analyzed as the means of three (or six) 5 min blocks in the following test periods: the start of the test (5–20 or 5–35 min); at the end of hour 1 (50–65 or 35–65 min); and at the end of hour 2 (100–115 or 85–115 min). These three time periods (start, hour 1, and hour 2) were selected to study correlations between ICM and perceived discomfort in future studies.

4.2.6. Experimental design and analysis

Using a Subject x Block repeated measures ANOVA, we compared the reliability of a single (5 min block), versus the 15 and 30 min ICM protocols and evaluated time trends within these protocols. In terms of the ICC, multiple forms of the statistic are available (Shrout and Fleiss, 1979). We selected ICCs based on the error of interest; namely the error related to sampling. Consequently, ICCs were calculated for single blocks [ICC (2,1)] and for the mean of 3 [ICC (2,3)] or 6 [ICC (2,6)] 5 min blocks at each of 3 test periods (start, hour 1, and hour 2). Given the novelty of both the ICM system and the sampling protocol, we set a stringent ICC acceptance level at 0.90, in line with other ergonomic studies utilizing the ICC (Capodaglio et al., 1997).

The within-days and between-days effect of time on in-chair movement was tested with a Day (2) x Time (3) repeated measures ANOVA. The time conditions selected as independent variables were: within-days (3); at the start of the test, and the end of hours 1 and 2, and between-days (2); two consecutive weekdays. The outcome measure used to evaluate the experimental conditions was COP distance analyzed using the most reliable COP protocol identified in the Subject x Block tests. All analyses were conducted at the 0.05 alpha level using SPSS. Statistical power was calculated for single blocks and the means of three and six, 5 min blocks using a repeated measures ANOVA formula (Lipsey, 1990)

5. Results

5.1. Laboratory study

5.1.1. Dynamic validation

The fore-aft components of the COPs derived from the VERG and Kistler are plotted as a function of time in Fig. 3 for a single trial. Regression analysis showed that tracking velocities in the side-to-side (X-axis) and fore-aft (Y-axis) directions of the Kistler and VERG systems were highly correlated; X-axis ($r = 0.99; r^2 = 0.99$, $p < 0.001$) and Y-axis ($r = 0.89; r^2 = 0.80$, $p < 0.001$). Similarly, COP coordinates measured by the Kistler and VERG systems were highly correlated on the $X$ ($r = 0.99$;
Fig. 3. Validation plots of the fore-aft components of the COP versus time recorded simultaneously by a VERG mat and a Kistler force platform over 9 s for a seated subject moving in the sagittal plane. Note the ability of the VERG sensors to respond to directional changes in movement.

\[ r^2 = 0.99, \ p < 0.001 \] and \[ Y \ (r = 0.97; \ r^2 = 0.95, \ p < 0.001) \] axes.

5.1.2. Trunk movement versus COP position

Fig. 4 contains regression plots for trunk inclination (upper plot) and left lateral flexion (lower plot) versus COP position for one subject. For both subjects, trunk inclination was positively correlated with changes in the COP \( (r^2 > 0.97; \ p < 0.001) \), as was left and right lateral flexion \( (r^2 > 0.86; \ p = 0.001) \).

5.2. Field study

5.2.1. Protocol analysis: in-chair movement

In Table 1, results of protocol comparisons for COP distance show that regardless of time period, reliability coefficients (ICCs) for the means of 3 (and 6) trials were greater than those based on a single trial. The highest ICC values are for the 30 min means. Unfortunately, as seen in Table 1, the 6 trials exhibited significant time trends \( (p < 0.01) \) and were inappropriate for averaging according to sampling theory (Sanford et al., 1993) and ICC protocols (Shrout and Fleiss, 1979). Consequently, the 30 min protocol was dropped from the study. Since the 3 × 5 min (i.e. 15 min) protocol exhibited no time trend, it was evaluated in the Day × Time analysis.

5.2.2. Day × time results: in-chair movement

Fig. 5 illustrates the results of the Day (2) × Time (3) analysis for ICM (COP distance) measured in 15 min blocks: 5–20, 50–65, and 100–115. While ANOVA showed significant temporal increases in ICM on both days \( (p < 0.01) \), there was no difference between days \( (p = 0.15) \).

5.2.3. Power determinations. in-chair movement

Our probability of finding true differences where they existed (i.e. statistical power) ranged from 0.67 to 0.79 for the single blocks. By comparison, power exceeded 0.90 for each of our 3 × 5 min blocks. Given the results of the protocol analysis, power was not determined for the 30 min blocks.

6. Discussion

In our quest to examine the relationship between sitting discomfort and in-chair movement (ICM), we adapted the VERG pressure mat to measure ICM in field studies by tracking the center of pressure (COP). In the laboratory component of our study, we established the validity of the VERG COP system and demonstrated that the relationship between gross trunk movement and COP movement was linear. Field results showed that our ICM data sampling protocol was reliable and would allow detection of temporal changes in ICM.

6.1. Laboratory study

6.1.1. Dynamic validation

In spite of the difference in sample rates between the kistler \( (100 \text{ Hz}) \) and the verg \( (3 \text{ Hz}) \), there was minimal
Fig. 4. Regression plots of COP position (cm) versus trunk angle (degrees) in sitting, for trunk inclination (upper plot) and left lateral flexion (lower plot) for the female subject. These plots demonstrate linearity and a high proportion of explained variance in both cases. Note that the (0,0) COP position is the left rear corner of the mat.

Table 1

<table>
<thead>
<tr>
<th>Sample period (min)</th>
<th>15 min</th>
<th>30 min</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Single block ICC (2,1)</td>
<td>Mean 3 blocks ICC (2,3)</td>
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<tr>
<td>5–20</td>
<td>0.82</td>
<td>0.93</td>
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<td>Trend (P)</td>
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<td>(0.15)</td>
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<tr>
<td>50–65</td>
<td>0.89</td>
<td>0.96</td>
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<td>Trend (P)</td>
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<td>(0.28)</td>
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<tr>
<td>100–115</td>
<td>0.76</td>
<td>0.90</td>
</tr>
<tr>
<td>Trend (P)</td>
<td>—</td>
<td>(0.64)</td>
</tr>
</tbody>
</table>

6.1.2. Trunk movement versus COP position

The two trunk movement versus COP position curves provide graphic interpretation of the COP changes with
6.1.3. Limitations of the VERG system

The VERG COP system has limitations, but none is considered major. First, the FSRs are insensitive to shear loads, but this is a minor drawback since compression is the predominant form of loading at the buttock–chair interface (Bader, 1990). Second, by measuring at the buttock interface, only indirect information on leg movement is obtained. The mat, however, readily detects movement in the head, trunk and upper limbs—common sites of sitting discomfort (Sauter et al., 1991). The third limitation is that all interface pressure transducers interfere with (i.e. perturb) the interface they are mapping. Nevertheless, none of these three limitations restricts future applications of the VERG system, in which subjects serve as their own control in repeated measures designs. A fourth limitation—FSR creep—was minimized in the field study by loading the mat for 10 min prior to testing and by eliminating the subject’s first 5 min of data.

6.2. Field study

6.2.1. In-chair movement protocol analysis

Continuous data collection with the VERG COP system provided the opportunity to select time periods for statistical analysis. Given the uniqueness of the COP measures and the absence of any data analysis guidelines in the literature, a primary goal of this research was to determine the most reliable protocol for data analysis. Results clearly showed that, compared to the use of a single 5 min block, averaging consecutive 5 min blocks improved ICM reliability as measured with ICCs. The unfortunate limitation of averaging is that only stable trials can be used (Sanford et al., 1993). Therefore, in spite of having high reliability, all 30 min blocks (5-35, 35-65 and 85-115) had a significant within-blocks time trend and were inappropriate for the averaging protocol.

Our protocol analysis results support the treatment of 5 min blocks as discrete trials and the analysis of 3 × 5 min blocks (i.e. mean of 3, 5 min blocks) for the three test periods (5-20, 50-65 and 100-115 min). These protocol results are credible considering that behavior, in this case seated movement, can be expected to vary daily and larger blocks accommodate those fluctuations. Jensen and Bendix (1992) failed to detect a time trend in ‘spontaneous’ seated movements when they analyzed data every quarter hour as single, discrete 5 min blocks; a result that supports our use of larger, averaged blocks.

The power in excess of 0.90 that was demonstrated in the 3 × 5 blocks lends further support to the use of averaged, rather than single blocks. High statistical power is critical when comparing ICM between different ergonomic (e.g. workstation) designs—especially when the differences are subtle. Unfortunately, most researchers have compared ICM between highly dissimilar ergonomic conditions. Grandjean et al. (1960), for example, compared ICM over time for subjects reading in a wooden chair versus a padded recliner chair. Similarly, Mark et al. (1985) compared seated movement between two chair/workstation configurations—a “best case” (adjustable) and a “worst case” (non-adjustable). In both of the above studies, the researchers found statistical differences in subjects’ ICM between the two conditions. However, since differences in chair or workstation design are rarely so different in field research, statistical power is crucial. In our study, we demonstrated how power could be improved by applying Kroll’s (1967) sampling theory and testing inter-trial reliability.

6.2.2. In-chair movement time effect

This field study supports numerous laboratory studies which have shown that seated movement (i.e. ICM) increased with time whether subjects read (Grandjean et al., 1960), drove an automobile simulator (Rieck, 1969), piloted a boat simulator (Jurgens, 1989) or worked at VDU tasks (Michel and Helander, 1994). Temporal increases in seated motion have previously been shown in the field, but only Bendix et al. (1985) studied office tasks. Although many investigators have evaluated in-chair movement, this is the first report on inter-trial reliability of ICM.

Our results show that tracking the COP with an interface mat was non-disruptive and suitable for field use. Also, the hardware performed well in detecting time trends in ICM for seated VDU operators. The temporal increases in ICM demonstrated here were due, in part, to factor control (task, environment, time-of-day), subject screening (i.e. health and workstation fit) and a repeated measures design (control of inter-individual differences). Nevertheless, the increase in COP movement over time was significant ($p < 0.01$). We hypothesized and proved that ICM would increase over 2 h in seated tasks. An unexpected finding was, however, that movement

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1 Since the ICC may positively bias reliability when subjects are heterogeneous (Bland and Altman, 1990), reliability results were cross checked with an alternative reliability statistic — the standard error of measurement (Fenety, 1995).
patterns (i.e. ICM) were stable over 15 min, but changed significantly over 30 min. Those temporal changes have implications for ergonomists measuring any work posture. Thus, it may not be safe to assume that any posture measured at a single point in time is a fair representation of a subject’s posture, whether it is whole body posture or posture of a particular body part (e.g. wrist position).

To bring these ICM results into perspective, previous calibration work (Fenety, 1995) showed that seated subjects’ COP moved 4.6 (sd 1.5) cm when subjects turned from side to side, and moved 7.1 (sd 1.6) cm when subjects moved from sitting upright to slouching. Larger shifts in the COP (i.e. up to 20 cm) took place when subjects leaned to one side and returned upright (see Fig. 2). Considering these calibration results, only a few large movements would be required to produce an additional 50 cm of COP movement — the difference between COP motion over 15 min at the start and the end of hour 1. Our previous work in posture sampling provides some insight to that interpretation (Fenety, 1995). Using a modified posture targeting technique (Corlett, 1990), we took multiple random samples of the working postures of 22 DA operators over a one week period. Results showed that the operators’ working posture was primarily one of a relatively fixed upright trunk with occasional postural shifts (e.g. leaning on armrest, arms stretched overhead, etc.) (Fenety, 1995). That picture of DA operators seated behaviour is reinforced by the five minute COP traces as shown in Fig. 2. While we did not statistically analyze COP motion for size or frequency of the COP excursions, Fig. 2 illustrates that typical COP tracings were composed of two types of motion: excursions within a small radius that overwrote each other and large radius excursions that appear to be major changes in posture (i.e. postural shifts).

The smaller, more frequent movements resemble postural sway seen in standing subjects and appear to be related to the maintenance of the operators’ upright postures. The larger, less frequent movements may have been related to preventing sitting discomfort, though we cannot state that with any certainty. Unfortunately, due to the limitations of our data analysis, we are also uncertain whether the increases in COP movement were due to increases in the smaller movements, the larger movements, or both. There are, however, two things we can state with assurance. When our field results (COP distance per 5 min block) are compared to our calibration results (COP distance per specific movement), it is evident that DA operators move very little while performing VDU-based telecommunications tasks. Second, and most importantly, we have shown that these COP movements — minimal as they are — increase significantly over the 2 h work period.

Caution must be exercised in interpreting the temporal increases in in-chair movement reported here. First, in-chair movement also may be influenced by the effect of many job stressors not measured in this study, such as those related to electronic productivity monitoring, to the need for Directory Assistance operators to deal with the variable, often unrealistic expectations of the public (Armistead, 1987), and to the loss of control due to external work pacing (Carayon, 1993). As an example, during our posture sampling study (Fenety, 1995), we observed that some postural shifts (i.e. movements away from upright) occurred during the rare occasions when the external work pacing came to a halt (i.e. no incoming telephone calls).

The second reason for caution in the interpretation of ICM increases is more philosophical. Seated movement per 15 min block (i.e. 3 × 5 min) increased by up to 120 cm from the start to the end of the 2 h test. While the increase was significant, the relevance is not clear. In fact it may be premature to address the issue of why subjects moved more over 2 h, when so little is known about why seated subjects move at all. There is some corollary evidence to suggest that the need to move may be related to discomfort. Zhang and Helander (1992) asked 42 subjects to rate descriptors of comfort and discomfort with respect to their perceptions of the seated workplace. Cluster analysis showed that feelings of discomfort corresponded primarily to four factors: low energy levels, restlessness, feeling constrained (e.g. stiff, cramped), and a feeling of circulation being cut off to legs—all negative feelings that may stimulate movement in order to diminish those feelings. The preceding argument suggests that seated movements serve a useful purpose. Pustinger et al. (1985) and Swanson and Sauter (1993) suggest otherwise, citing negative correlations between movement and productivity.

6.3. Generalizability

Our ICM results should be generalized with the following precautions. First, the subjects are predominantly female and gender related differences in seated “restlessness” have been suggested, but not tested (Jurgens, 1989). Generalizability is also limited by the singularity of the subjects’ task, controls on the environment (time-of-day, workload) and screening standards (health and workstation fit). A major aspect of this study, our method of improving statistical power through sampling trials, is generalizable to researchers measuring temporal changes in work postures and movements.

7. Conclusion

Measurement of in-chair movement with the VERG system has the potential to overcome the two principle weaknesses of traditional objective measures of discomfort: the need for continuous, time-based discomfort measures and the need to reference discomfort to field
tasks. In our laboratory study, we have introduced the measurement of in-chair movement via the VERG interface pressure mat, demonstrated its validity, and calibrated COP movement with two common trunk movements. In our field study, we used an ordered approach to resolve a common research problem — how to sample data for analysis in computerized measurement systems that generate massive volumes of temporal data. We compared the use of a single, 5 min block of ICM data with that of the mean of three (or six) consecutive 5 min blocks. Using the ICC reliability statistic, we have clearly shown that ICM was most reliable when sampled and analyzed as three, 5 min blocks. This study also showed that — regardless of the day, ICM increased over time in the 2 h tests. Finally, the absence of day-to-day differences in ICM and the reliability of the ICM sampling protocol, establishes the suitability of the test conditions for our future field studies.

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References


