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The Potential for Actigraphy To Be Used as an Indicator of Sitting Discomfort

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Objective: A novel technique that uses actigraphy, the study of activity involving the use of body-mounted accelerometers, to detect the discomfort-related movements of a sitting individual has been proposed as a potential indicator of sitting discomfort, and the purpose of this study was to test its validity. **Background:** Objective measurement of sitting discomfort has always been challenging for researchers. Electromyographic measurements, pressure mapping, and a wide range of other techniques have all been investigated with limited success. **Method:** The activity monitor's ability to detect and measure seated movement was assessed, and 12 participants were tested on four different chairs (100-min sessions for each). **Results:** The activity monitor was able to detect participants' sitting movements (Pearson coefficients > 0.9). The chairs were shown to have significantly different subjective discomfort ratings, all of which increased over time. The movements detected by the activity monitor also increased significantly with time, and the amount measured was greater in the chairs rated as most uncomfortable. Regression analysis indicated that the actigraphy data were able to account for 29.6% of the variation in perceived discomfort ratings. **Conclusion:** Actigraphy can reliably detect sitting movements and may be of use in measuring sitting discomfort. **Application:** Potential applications of this technique exist for seating research in the automotive industry, health care, and office and leisure chairs.

INTRODUCTION

The minimization of discomfort is of paramount importance to an individual sitting in a seat. It is therefore an area of great interest to chair manufacturers and automotive industry professionals who wish to show customers that their products cause minimal discomfort (Andreoni, Santambrogio, Rabuffetti, & Pedotti, 2002) and to the health care industry, where discomfort caused by wheelchairs and beds can be important in terms of the overall quality of life of the individuals who depend on such devices for mobility and more. However, it is not always an easy task for researchers to relate comfort to specific biomechanical variables (de Looze, Kuijt-Evers, & van Dieen, 2003). Individuals without any neuromuscular problems will instinctively search for a sitting posture that allows task execution to be performed easily and efficiently as well as the posture that results in the lowest expenditure of energy, within biomechanical and physiological limits (Kolich, 2007). Thus, a sitting posture at any given time represents the outcome of often very dynamic internal and external constraints and of any task that is being carried out, making it a highly complex problem with a large number of variables.

Although research has been carried out in this area (for example, a standard set of biomedical causes of seating discomfort was developed for the automotive industry; Viano & Andrzejak, 1992; and a model for applying biomechanics to seat design has been produced; Mehta & Tewari, 2000), it remains to be seen whether such a distinctly subjective experience as sitting discomfort can fully be described with the use of biomechanical variables alone.

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The Balance Between Comfort and Discomfort

The true definitions of comfort and discomfort have been the subject of some debate in recent years. For a long time, researchers considered comfort states to be part of a continuous scale, with extreme discomfort at one end, a neutral state at the midpoint, and extreme comfort at the other end (Shackel, Chidsey, & Shipley, 1969). Recent work, however, has suggested that comfort states are primarily associated with aesthetics, whereas discomfort is more closely related to biomechanical and physiological factors (Zhang, Helander, & Drury, 1996). Obviously, comfort and discomfort are not completely unrelated, as even the most aesthetically pleasing chair, if it causes pain to the user, will not be considered comfortable. This line of reasoning led Zhang et al. (1996) to produce their hypothetical model of the relationship between comfort and discomfort in seating. In it, comfort is defined as related to a state of well-being and the plushness of the seat, and discomfort is defined as poor biomechanics, fatigue, and restlessness. The model suggests that comfort cannot be achieved through the absence of discomfort, but the presence of discomfort *can* reduce the overall level of comfort. This study attempted to focus on discomfort as influenced by biomechanical factors.

Measurement of Sitting Discomfort

Sitting discomfort is generally assessed with the use of subjective rating scales, of which there is a wide range (in terms of both approach and reliability) available. Finding a useful means of objectively measuring sitting discomfort is one of the greatest challenges facing seating researchers today (Andreoni et al., 2002). A number of techniques have been investigated with varying success, including the following

- electromyographic (EMG) activity of spinal muscles (Babski-Reeves, Stanfield, & Hughes, 2005; Bennett, Gillis, Portney, Romanow, & Sanchez, 1989; El Falou et al., 2003; Makhsous, Lin, Hendrix, Hepler, & Zhang, 2003),
- intramuscular pressure in paraspinal muscles of the lumbar region (Konno, Kikuchi, & Nagaosa, 1994; lower back pain has been related to poor lumbar spine posture when seated; Wilder & Pope, 1996; but it is difficult to make useful measures of spinal posture without altering the seat itself; Carcone & Keir, 2007),
- spinal shrinkage (Leivseth & Drerup, 1997; McGill, Van Wijk, Axler, & Gletsu, 1996; van Dieen & Toussaint, 1993; van Dieen, de Looze, & Hermans, 2001),
- postural angles (Dunk & Callaghan, 2005; Na, Lin, Choi, & Chung, 2005),
- pressure maps at the body-seat interface (involving both the measurement of peak pressures and the analysis of center-of-pressure [COP] behavior; Fenety, Putnam, & Walker, 2000; Gyi & Porter, 1999; Porter, Gyi, & Tait, 2003), and
- verification of the anthropometric sizing of the seat through the description of interfacing surfaces of seat and body (Kolich, 2003; Zhoa & Tang, 1994).

Dynamic Measurements and In-Chair Movement (ICM)

A recent study that examined dynamic body pressure distribution data managed to show a significant correlation between body pressure variables and subjective discomfort ratings (Na et al., 2005). This finding suggests that dynamic pressure distribution data may be a more useful tool for the assessment of seated discomfort than data obtained from static measurements.

The use of dynamic measurements relates back to a suggestion by Branton (1969) that sitting should be viewed as a behavior rather than as a posture and, as such, should be described on a continuous (dynamic) basis. This contention is supported by the assertion that any sitting posture, no matter how well positioned the spine or how equal the distribution of pressure, cannot be maintained for any significant period of time without becoming uncomfortable (Graf, Guggenbuhl, & Krueger, 1995).

Branton's (1969) original work involved studying the patterns of postural shifts of train passengers on long journeys, and this led to using ICM as a measure of discomfort after a study showing a link between increases in discomfort and increases in ICM and fidgeting was carried out (Fenety et al., 2000). Interest has also been shown in the use of nonverbal communication in the form of movement and postural shifts as an indicator of discomfort and boredom (Bull, 1987). The assumption on which these and other studies using ICM or similar postural variables are based is that individuals will increase the frequency and/or magnitude of their movements, at a conscious or unconscious level, as time passes in a manner that is influenced by their level of discomfort (Fenety et al., 2000).

Actigraphy

There has been a shift in recent years toward using low-powered and miniaturized sensors for certain areas of postural and clinical research (Wong, Wong, & Lo, 2007). These devices have the advantage of being lightweight and portable, and they often have built-in data loggers, resulting in potential for information relevant to outcome measures that previously only have been able to be assessed in the laboratory to be recorded in "real-life" situations.

The activity monitor is one such sensor. Developed initially as an instrument for measuring sleep activity (Brown et al., 1990), it uses body-mounted accelerometers to provide a continuous measure of movement. Outside of sleep research, activity monitors have been used to measure the agitation of patients in critical care units (Grap, Borchers, Munro, Elswick, & Sessler, 2005), for gait analysis (Veltink & Franken, 1996), and for measuring upper limb movement (Van Someren, 1996). Activity monitors can also be used, depending on the type of accelerometer employed, to measure posture as well as movement (Foerster & Fahrenberg, 2000; Prill & Fahrenberg, 2006).

The aim of this study was to investigate a novel approach to measuring sitting movements by the use of actigraphy. The hypotheses were that sitting movements could be identified from the actigraph data and that it would be possible to find some relationship between discomfort-related movements as measured by the actigraphy system and the subjective discomfort measurements given by participants.

METHOD

Participants

For this study, 12 participants (9 men and 3 women) volunteered. Demographic details are summarized in Table 1. Participants were recruited from the student and staff bodies at the Bioengineering Unit at the University of Strathclyde. All were reported to be in good health and to have no history of neuromuscular disorders or pain when sitting. All experimental work was approved prior to its commencement by the departmental ethics committee at the Bioengineering Unit (reference UECO708/09), and all participants gave their written informed consent.

TABLE 1: Summary of Demographic Details

Variable	Median (IQR)[a] or *M* (*SD*)[b]
Gender (male/female)	9/3
Height (mm)	1753 (84)[b]
Mass (kg)	73.03 (15.4)[b]
Age (years)	25.75 (25.43, 26.5)[a]

Note. Anderson-Darling test used to assess normality of data. IQR = interquartile range.

Actigraphy Materials

The device used to measure the participants' activity was the ActivPAL™ Trio (PAL Technologies, Glasgow, UK), a triaxial activity monitor that uses piezoelectric accelerometers. This device was chosen because of its compact size, light weight (20 g), and the fact that it had a built-in data logger of a capacity suitable for this study. The activity monitor was attached to the participants with the use of PALstickies™ (PAL Technologies, Glasgow, UK) hydrogel adhesive pads, which are designed to stick the device directly to the skin. The monitor was affixed to the participant at the top of the sternum. This location was chosen because it would allow the monitor to detect all major changes in posture of the upper body while being unobtrusive. It has been previously suggested that upper-body movement increases with perceived discomfort in driving tasks (Na et al., 2005). The location of the monitor also served to minimize the amount of flesh between skin and bone. For participants whose chest hair was an issue, sticky tape was used to reinforce the monitor's position.

Movements were recorded at 10 Hz (without compression), the standard sampling frequency

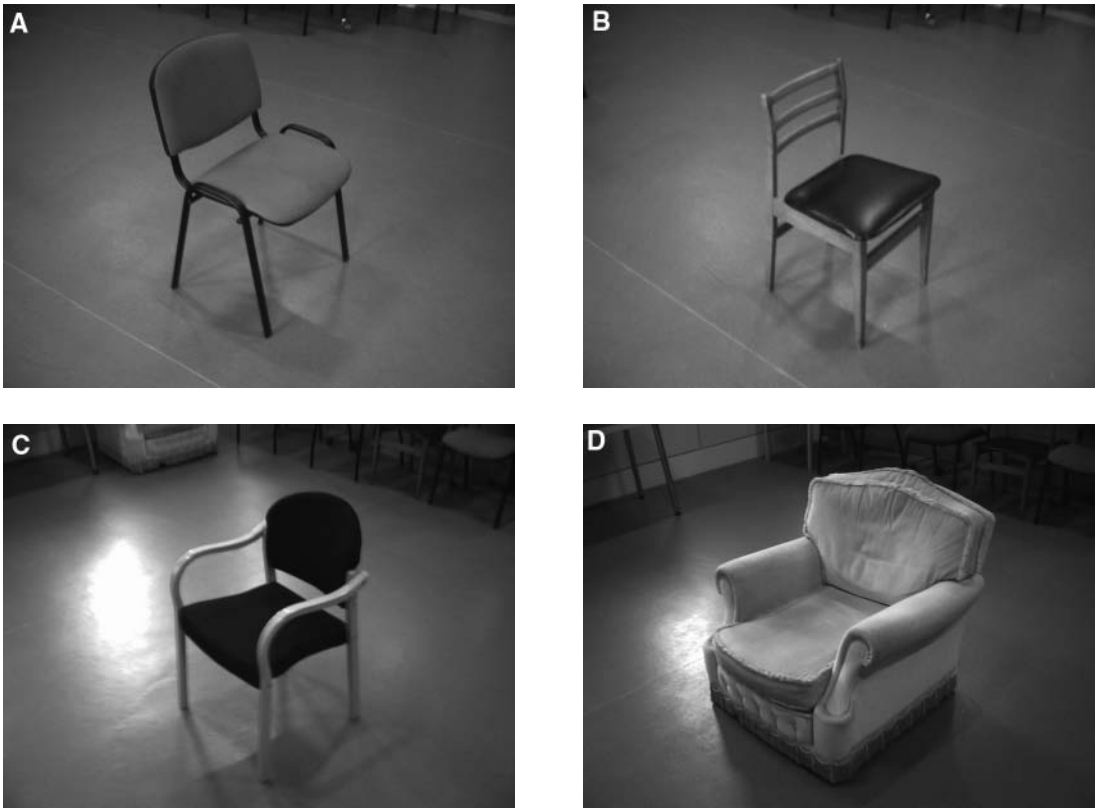

Figure 1. Chairs used in test. Chair A: a simple wooden framed chair with minimal cushioning on the seat base and an almost-vertical, uncushioned, midheight backrest; Chair B: cushioning on both the seat base and its midheight and a more reclined backrest than the previous chair; Chair C: more cushioning on both the seat base and the midheight backrest and armrests (uncushioned); Chair D: a standard, well-upholstered armchair with cushioned armrests and a relatively high backrest.

of the activity monitor, as previous work has shown that participants can move at frequencies approaching 0.5 Hz (Fenety, 1995). The monitor has a range of ±2 g and a sensitivity of ±0.5° and frequency response of 5Hz when used as an inclinometer. We downloaded the data from the monitor using ActivPAL Professional, Version 5.8.1.12 (PAL Technologies, Glasgow, UK).

Chairs

Four chairs (Figure 1) were selected that were believed to provide distinctly varying comfort levels across the different sitting sessions. The chairs also had to be nonswivel, as these types of movements may cloud the actigraph data. Chair A was a simple wooden framed chair with minimal cushioning (10 mm depth) on the seat base and an almost vertical, uncushioned, midheight backrest. Chair B had cushioning on both the seat base (20 mm depth), and its midheight backrest was at a more reclined angle than the previous chair. Chair C featured more cushioning on both the seat base (50 mm depth) and the midheight backrest, and it had armrests (uncushioned). Chair D was a standard, well-upholstered armchair (cushion depth 100 mm) with cushioned base and armrests and a relatively high backrest.

Perceived Discomfort

The Category Partitioning Scale (CP-50) was used to measure participants' perceived feelings of discomfort. Originally developed as a scale for measuring pain intensity, the

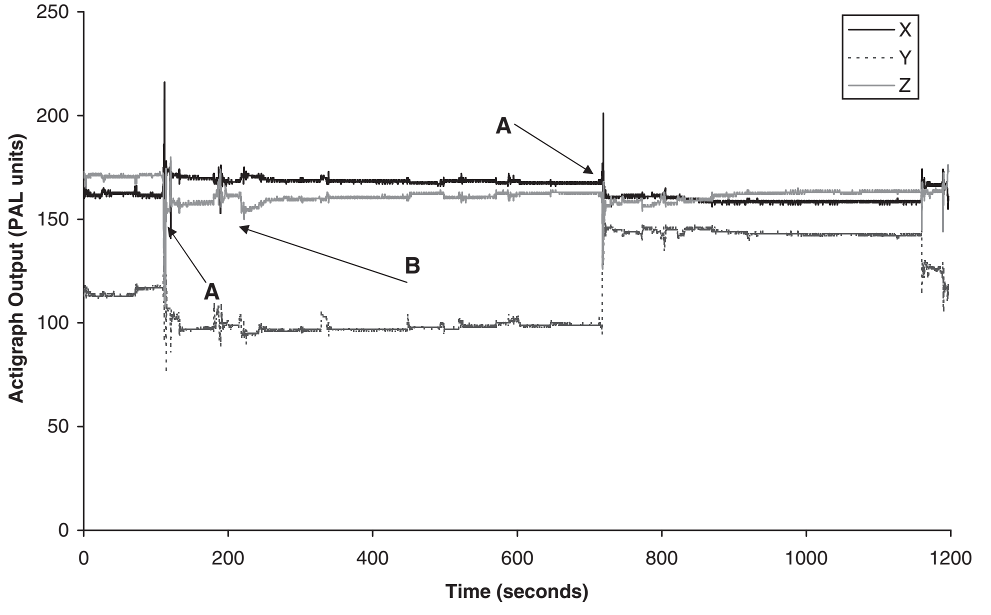

Figure 2. Example of data output from test session with distinct postural changes (marked A) and transient postural changes (marked B) indicated. *X* represents changes in the sagittal plane; *Y*, coronal; and *Z*, transverse. A change of 1 PAL unit is equivalent to a change in inclination of the activity monitor of 1° in the related axis.

CP-50 has been tested thoroughly for reliability and absoluteness in scaling (Gobel, Heller, Nowak, & Westphal, 1988). It is a vertical rating scale that requires the participant to first choose a category that describes his or her overall feeling of body discomfort (0 = *no discomfort*, 1 = *slight discomfort*, 2 = *low discomfort*, 3 = *medium discomfort*, 4 = *high discomfort*, and 5 = *severe discomfort*). Each of the categories is then further divided into 10 scale points with which the participants are asked to refine their answer. Therefore, the scale normally results in a number between 0 and 50 (points above 50 are provided to avoid the ceiling effect). The scale has previously been adapted and tested for measuring seated pressure discomfort and showed the highest reliability of all the tools measured (Shen & Parsons, 1997).

Experimental Design and Analysis

For this experiment, sitting movement has been defined as a shift in position in the seat, for any reason, that alters the signals from the activity monitor. We decided to analyze the results at this stage by defining two types of movement, which were identified in the pretesting data:

- Distinct postural change (DPC): A change in orientation of at least 10° (calibration of actigraph showed that a change of 1 PAL unit was equivalent to a change of 1° in the angular position of the activity monitor) across all channels that is maintained for more than 10 s (see points marked *A* in Figure 2). This definition was chosen after analysis of pretesting trials for postural movements that could be visually observed and time required to reestablish a static sitting posture after movement. Changes of position made over time, that is, if the participant was to gradually slump in the chair in a period of a few minutes, were also considered to be DPC if they produced a change of 10 PAL units or more for at least 10 s.
- Transient postural change (TPC): A perturbation in the signal greater than 10 PAL units across all channels that returns to baseline levels within 10 s (see Point B in Figure 2).

In the data generated by the actigraph, the *X* channel represents movement in the sagittal plane; the *Y*, movement in the coronal plane; and *Z*, movement in the transverse plane.

Task and Environment

Tests were carried out in a quiet room where interruptions could be prevented. No desk was used in this experiment. For each test session, participants were asked to bring enough reading material to last the full 100 min of each session. Participants were allowed to highlight parts of this material if they wished but were asked not to carry out any actual writing tasks. Each participant was tested during the same time slot for each test session to minimize the influence of factors such as general fatigue levels on the results. Time slots began at 9:00 a.m., 11:00 a.m., 1:00 p.m., or 3:00 p.m. and lasted for approximately 1 hr 50 min, including set-up time. Three participants were tested in each time slot, and the slots were randomly allocated. The maximum time for each individual between completing the first and last test sessions was 28 days, and the majority of sessions were completed in less than 3 weeks. Participants were also asked to wear the same trousers (or skirt) to each test session in case the material used for these may have had an effect on their comfort. The room was maintained at a steady temperature of 21 °C.

Test Procedures

To validate the assumption that changes in sitting posture would be shown on the data recorded by the activity monitor, it was necessary to carry out tests comparing the recognizable ICM with the output from the activity monitor. This was achieved by videotaping two 100-min trial sitting sessions and playing them back as we looked for DPCs or TPCs, noting the time that these occurred and comparing them with those independently identified from the activity monitor.

Prior to commencing the second part of the experiment, we randomized the order that the chairs would be tested for each participant. Participants were not informed of the purpose of the activity monitor, and the labeling on the device was obscured for the purposes of the trial (indeed, the gel-like nature of the sticky pad led several participants to speculate when asked after the completion of the trial that it was a device for monitoring heart rate or muscle activity). Before their first test session commenced, participants were instructed on how to use the discomfort scale and were reminded of this for each of their following sessions.

The timers in the activity monitor and the laptop used for data collection were synchronized at the start of each test session, and a timer function on the laptop was used to mark 20-min intervals. The monitor was then adhered to the participant and its orientation checked visually by the researcher. After sitting down, participants were given a few seconds to familiarize themselves with the chair that they had been allocated for the session; then the timer was started and the first discomfort scale handed out. Scales were then filled in at intervals of 20 min for the duration of the 100-min test, including at the end of the session.

Statistical Analysis

We performed statistical analyses using Minitab 14 statistical software (Minitab Inc., State College, PA, USA). We carried out the comparison of the observed and measured postural changes by finding the Pearson correlation coefficient. Descriptive and discomfort data are given as the mean (and standard deviation) or median (and interquartile range [IQR]), depending on their distribution based on the Anderson-Darling test. Because of the nonparametric nature of much data, the Friedman test was used to determine if there were any significant effects on CP-50 and activity data from chair used and time period. Because multiple comparisons were undertaken, Bonferonni correction was applied. Therefore, the level of significance was set at $p < .005$. Regression analysis was used to determine the extent to which participants' sitting movements, as measured by actigraphy, could be used to predict perceived discomfort.

RESULTS

Verification of Activity Monitor's Ability to Detect Sitting Movements

Correlation between the observed and detected movements were found to be high with Pearson coefficients of >0.95 ($p < .005$) for both DPCs and TPCs.

TABLE 2: Summary of Friedman Test Results for Category Partitioning Scale (CP-50) Versus Chair and Blocked by Participant, Distinct Postural Changes (DPC) Versus Chair and Blocked by Participant, and Transient Postural Changes (TPC) Versus Chair and Blocked by Participant

	CP-50		DPC		TPC	
Chair	Estimated Median	Sum of Ranks	Estimated Median	Sum of Ranks	Estimated Median	Sum of Ranks
A	15.750	44.0	16.0	43.5	31.375	41.0
B	11.125	32.0	11.5	30.0	25.250	35.0
C	9.375	28.5	9.5	27.0	17.500	21.5
D	1.750	15.5	6.5	19.5	17.875	22.5
p value (adjusted for ties)	<.001		.001		.002	

Analysis of Chair and Time Effects

Comparing different chairs for effects on both perceived discomfort (as measured by the CP-50 scale) and DPCs and TPCs, it was shown there were significant differences between the different chairs for each of the measures (Table 2). In terms of discomfort induced, Chair A was perceived as the most uncomfortable, followed by Chair B and Chair C; Chair D induced the least discomfort. DPCs and TPCs were detected in all chairs. A comparison of the effects attributable to the time the participant had been sitting showed similarly significant results for CP-50 in all chairs, DPC in all chairs except Chair D, and TPC in all chairs except Chair B. These results are summarized in Table 3. In general, perceived discomfort and the frequency of DPCs and TPCs tended to increase during the time course of each trial, as shown in Figures 3, 4, and 5, respectively.

Prediction of Discomfort

Table 4 summarizes the multiple regression model. As the primarily interest was the relationship between perceived discomfort and participants' sitting movement as measured by the actigraph, CP-50 was made the dependent variable. With DPC and TPC as predictors, it was possible to account for 29.7% of the variance in the subjective discomfort data. The model as a whole was significant ($p < .001$).

TABLE 3: Summary of Friedman Test for Category Partitioning Scale (CP-50), Distinct Postural Changes (DPC), and Transient Postural Changes (TPC) Versus Time and Blocked by Participant for Each Chair (*p* values adjusted for ties)

Variable	Chair A	Chair B	Chair C	Chair D
CP-50	<.001	<.001	<.001	.001
DPC	.001	<.001	<.001	.029
TPC	.001	<.001	<.001	.029

DISCUSSION

The aim of this study was to determine if actigraphy, the measurement of activity with the use of body-mounted accelerometers, has the potential to be used as (a) a technique for detecting the discomfort-related movement produced by a sitting individual and (b) an objective indicator of seating discomfort. To achieve this aim, an experiment was devised that measured the frequency and type of participants' movements and their own perception of their discomfort when sitting for a set period of time and in a range of different chairs. The rationale was based on the dynamic nature of sitting and the related theory that as an individual becomes more uncomfortable in a seat, for any reason, he or she will tend to move around and fidget more and that these movements may be able to be related, directly or indirectly, to sitting discomfort.

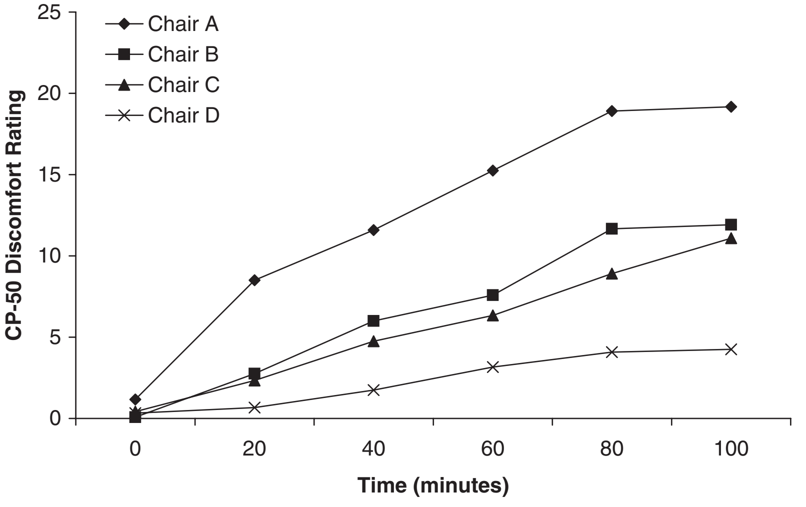

Figure 3. Perceived discomfort as measured by the Category Partitioning Scale (CP-50). Data shown are estimated medians for all participants.

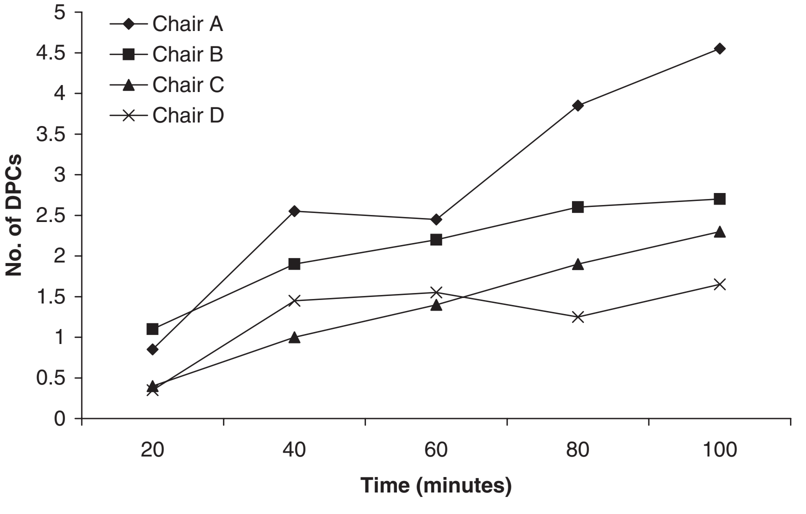

Figure 4. Distinct postural changes (DPCs) as detected by activity monitor. Data shown are estimated medians for all participants.

Results showed that changes in sitting posture could be reliably identified from the actigraph data. The chairs chosen for this study were shown to induce a wide range of perceived discomfort levels, and these levels increased significantly over time. This meant that the hypotheses could be tested across a wide range of discomfort states.

The sitting activities detected by the actigraph were split into DPCs and TPCs. The frequency of these measures' occurrence was shown to increase significantly over time, and in general, the more uncomfortable a chair had been perceived to be by the participants, the more DPCs and TPCs were presented in them. Regression analysis showed that there is a relationship between the sitting movements identified by the actigraphy and perceived discomfort, albeit a small one (this is likely to be attributable to the relatively small sample size with high variance used in this study, and future work should involve the investigation of a larger sample).

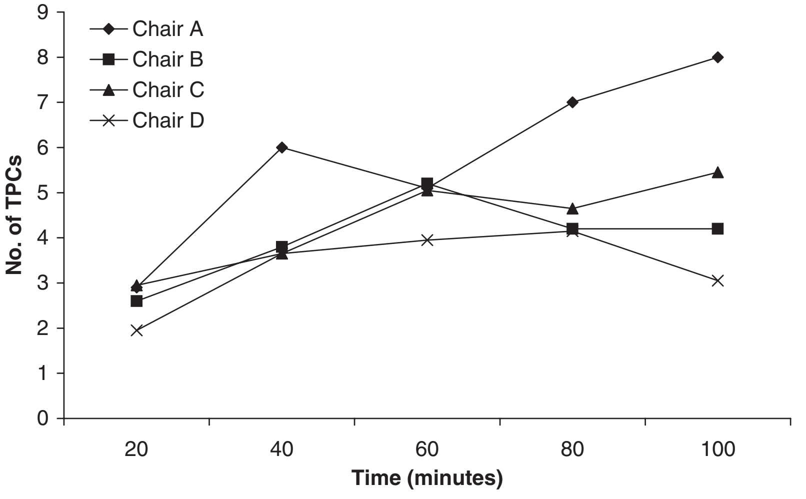

Figure 5. Transient postural changes (TPCs) as detected by activity monitor. Data shown are estimated medians for all participants.

TABLE 4: Summary of Discomfort Measure Variables and Regression Analysis

		Regression Analysis		
Measure	Median (IQR)	*B*	β	*p* Value
DPC	2 (0, 4)	.4852	.2423	.046
TPC	25.75 (25.43, 26.5)	.5848	.1801	.001

Note. Anderson-Darling test used to test normality of data. IQR = interquartile range; DPC = distinct postural changes; TPC = transient postural changes.

The suggestion that the major changes in posture in the form of DPCs and TPCs that are detected by the sternum-mounted activity monitor are related to sitting discomfort is reinforced by earlier studies finding that large changes in posture are good indicators of the presence of discomfort (Vergara & Page, 2000, 2002).

The advantage of actigraphy as a measurement technique lies in its portability and the ease of interpreting the data it generates. The software exists such that an individual's different activities (i.e., walking, lying, or sitting) can be indentified from the data from the monitor; therefore, sitting discomfort tests could feasibly be carried out without the need for supervision in the participant's own workplace or home for extended periods. This is important, as it is considered best practice to measure discomfort in the field. It is believed that despite the reduction in the accuracy of the precise amount of movement measured, for longer and larger studies especially, the advantages presented by using actigraphy are important to take into consideration. Future work should involve the comparison of actigraphy to gold-standard discomfort measurement techniques, such as dynamic pressure distribution.

There are a number of factors that can influence sitting discomfort and our reaction to it. These include fatigue, boredom, general well-being, and the task being performed. Researchers who used surface EMG signals to investigate the effects of fatigue during sitting did not find any significant effects on the signals from cervical erector spinae and external oblique muscles after a 150-min trial (El Falou et al., 2003), suggesting that fatigue may not have played a significant role in this 100-min study. This is reinforced by the findings that even in the chair considered the most uncomfortable, perceived comfort levels tended to peak below 20 on the 50-point CP-50 scale, with 20 considered to represent low discomfort.

Another influence on discomfort that is not dealt with directly in this experiment and must be noted is boredom. ICM has been used as a measure of boredom but it is believed, given the relatively short period of these trials and the fact that the participants had reading material, that its effects would be minimal. There are also flaws with using questionnaires at set intervals to determine discomfort levels, especially given the fact that continuously raising the issue of discomfort may make the participant more conscious of sensations that could be related to discomfort (Kolsch, Beall, & Turk, 2003). Differences in some aspects of sitting behavior between men and women have been noted (Dunk & Callaghan, 2005), and this is another area that, although beyond the scope of this general study, is worth investigation in the future.

It could be argued that some of the seats used and the fact that there was no desk to lean on in this experiment meant that reading was not an entirely suitable task. However, it was intended to test whether the technique would be robust enough to determine changes in discomfort levels while participants were carrying out a simple, everyday task, and it is believed that any specifically task-related discomfort felt by the participants would be registered on both the subjective rating scales and the activity-monitoring data. Previous research has suggested that participants carrying out reading tasks may present more upper-body movements (van Dieen et al., 2001) than those carrying out word processing or computer-aided design; however, there were no differences in the amount of these task-related movements in different chair types. The lack of a true office chair in the selection tested here is a limitation to the general applicability of this study and presents a further opportunity for future research.

There were some unforeseen events, including coughing and sneezing, that occurred during the test sessions that could be recognized in the results as TPCs. As these were involuntary actions not related to discomfort, it is possible that they could skew the results for the TPC data, as there were significant effects from the chair used and time period. Task-related movements, such as turning pages or opening and closing books, may also have shown up as TPCs and contaminated the results.

It is sensible, therefore, to note that these results should be interpreted with some level of caution. Predicting human sitting behavior is far from a precise science, and a number of other factors must be considered. Indeed, the lack of a clear and precise biomechanical definition of discomfort in itself presents a major problem for seating research. However, it is believed that the results presented here and the advantages inherent with the use of activity monitors of the type used in this study do suggest that actigraphy may be able to play a useful role in future sitting discomfort research and related fields.

CONCLUSION

The technique of actigraphy could potentially have a number of applications in seating research. In a variety of sitting conditions, it was possible to measure participants' reactions to a range of discomfort states. Further investigation using a larger sample and incorporating other current methods of objective sitting discomfort measurement is required to fully validate the technique.

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