Gender-based differences in postural responses to seated exposures

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Abstract

Background. Individuals may respond differently to various chair designs and the factors that influence these sitting behaviours are not well understood. There is very little information in the scientific literature regarding the observation and documentation of gender differences in seated postures. In particular, anecdotal observations of potential gender-specific sitting behaviours led us to test the influence of gender on the postural responses to different seated conditions.

Methods. Sixteen healthy university students (8 males and 8 females) were tested on four different chair configurations. Upper body kinematics (spine angles and centre of mass) and seat pressure profiles (centre of pressure, peak pressure) were obtained during each testing session.

Findings. Regardless of the chair used or the task performed, average lumbar and trunk angles were significantly more flexed for males than for females (P = 0.047 and P = 0.0026, respectively). Males exhibited average lumbar spine and trunk angles of 65.4° (SD 16.2°) and 29.8° (SD 28.3°), respectively, while female lumbar spine and trunk angles were 49.6° (SD 23.1°) and −3.3° (SD 9.3°) (P = 0.0008). Significant gender * chair interactions of the location of the individual on the chair seat were most marked for the pivoting chair with a back rest. Females positioned their centre of mass and hip joints anterior to the chair pivot point while males’ centre of mass (P = 0.0003) and hip joints (P = 0.0039) were located posterior to the pivot point. Females also sat with their centre of mass closer to the seat pan centre of pressure than males when a back rest was present (P = 0.0012).

Interpretation. Males and females may be exposed to different loading patterns during prolonged sitting and may experience different pain generating pathways. Therefore, gender-dependent treatment modalities and/or coaching should be implemented when considering methods of reducing the risk of injury or aggravation of an existing injury.

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1. Introduction

An extensive amount of research has attempted to determine the “optimal” seating position for the human spine that would reduce the risk of developing low back pain. Thus, different chair designs have emerged with the goal of allowing the individual to assume an optimal seated posture while maintaining comfort and functionality of the chair. However, individuals may respond differently to different chair designs and the factors that influence these sitting behaviours are not well understood. In particular, anecdotal observations of potential gender-specific sitting behaviours have driven us to examine if males and females exhibit different responses from exposure to various seated conditions.

The evidence in the scientific literature is controversial for the benefits of dynamic office chairs. Bendix
and colleagues have shown in a series of experiments that pivoting chairs do not significantly change trunk kinematics (Bendix, 1984; Jensen and Bendix, 1992), however neither study examined any potential gender differences in the response to the various chairs tested. When examining three chairs, one with a fixed seat and back rest and two dynamic chairs, van Dieen et al. (2001) found that there was an increased gain in stature over the 3 h period for the two dynamic chairs when compared to the fixed chair. They attributed this stature gain to the recovery of disc height because of more effective support from a spring-loaded back rest of the dynamic chair which would subsequently reduce spinal compression. Data from males and females were not analyzed separately, nor was there any extensive reporting of other postural variables such as trunk or spinal angles. Investigating which factors determine lumbar spine posture in sitting, Bridger et al. (1992) noted that when moving from a standing to a sitting posture, males have a greater loss of lumbar lordosis than females. Although their study examined a substantial number of both male and female participants (n = 25 for each gender), they did not extensively compare nor emphasize any gender differences observed in seated postures. In a study conducted in our own laboratory examining the difference between sitting on a stability ball and on an exercise chair, females exhibited a similar response to that reported by Bridger et al. (1992) with less lumbar flexion than males when sitting on both the chair and the ball (Gregory et al., in press). Females also tended to be more static sitters than males, maintaining a narrow range of lumbar spine postures for prolonged periods of time (Gregory et al., in press). Furthermore, the passive tissues of the trunk in males and females have been found to respond differently over time when exposed to 2 h of prolonged sitting (Beach et al., 2005). For males, the lumped passive structures in the spine (e.g., spinal ligaments, and intervertebral discs) became stiffer during the 2 h period. Females showed changes in passive stiffness; however these changes were not consistent across female participants. Nevertheless, there is evidence that males and females respond differently while sitting. To our knowledge, gender differences have not been taken into account when examining different configurations of office chairs, such as the presence of a pivoting seat pan and/or a backrest.

The primary purpose of this project was to test the influence of gender on the postural responses to different office chair configurations. Particular focus was placed on the relative location of a chair’s pivot point and an individual’s selected seating position with measurements of the participant’s centre of mass, spine postures and pelvic position. A secondary purpose included determining if and/or how males and females respond to different computer-based tasks while seated.

2. Methods

A total of 16 participants, 8 males (mean age = 24.8 years (SD 1.5); mean height = 1.81 m (SD 0.06); mean mass = 84.6 kg (SD 11.2)) and 8 females (mean age = 23.4 years (SD 2.1); mean height = 1.71 m (SD 0.08); mean mass = 66.5 kg (SD 12.9)), were recruited from a university population. This population was deemed to be relevant to this study as university students tend to spend a large amount of time performing seated work. All participants were free of low back pain for 12 months prior to the testing period. The study protocol received approval from the University Office of Research and subjects gave informed consent before testing began.

Participants were required to attend four testing sessions that occurred on different days, at the same time of day for each individual. Each testing session involved 45 min of seated computer work. Four different office chair configurations were randomly tested and included: (1) a fixed seat pan with no back rest, (2) a pivoting seat pan with no back rest, (3) a pivoting seat pan with a back rest and (4) a freely pivoting spring-post stool (seen in Fig. 2B). The chairs were adjusted at the start of the first session such that the initial seated position for each participant allowed the knees to be at 90° when the feet were in full contact with the floor. The desk was adjusted so that the elbows were at 90° with relaxed shoulders when the participant was typing on the keyboard. The heights of the chair and desk were measured and reproduced in each of the test sessions for the participant. Participants were tested at approximately the same time of day for each session they attended. They did not receive any specific instructions regarding their activities prior to arrival for testing. However, upon arrival each participant was subject to approximately 30 min of upright standing and moderate forward flexion during the set-up period. It is thought that this is sufficient time to equalize any effects of prior loading for relative comparisons within participants, as has been demonstrated in stadiometry studies (Althoff et al., 1992; Leivseth and Drerup, 1997).

During each testing session, participants performed three 15-min intervals of simulated office work consisting of a mousing task (various computer games that used the mouse to move objects around), a typing task (transcription of a type-written document) and task involving a combination of the two (a quiz requiring Internet searches) (Fig. 1). The tasks were standardized between participants and presented in a random order to ensure that any observed differences were not attributable to the order of task performed. Participants were asked to stand up and move around after each 15-min interval in order to assess the repeatability of repositioning the body on the chair. Prior to the 45-min sitting period, an upright standing trial was collected for baseline
measurements of spine and pelvis postures. Three maximum forward flexion trials were collected before the 45-min sitting period and the resulting maximum angles were averaged and used to normalize spinal angles. Three maximum forward flexion trials were collected after the 45-min sitting period to compare with the pre-sitting trials.

Ratings of perceived discomfort (RPD), using a 10 cm visual analogue scale, were taken during each session in order to obtain a relative measure of subjective discomfort for the four seating configurations. Measures were taken at the beginning, middle and end of each of the three tasks performed, yielding a total of nine RPDs per session (Fig. 1).

Kinematics were recorded using an optoelectronic motion analysis system (Optotrak Certus, Northern Digital Inc., Waterloo, Ontario, Canada) at a frame frequency of 30 Hz. Markers were placed on the chair being tested and over the following anatomical landmarks on the right side of the participant’s body: hand, wrist, elbow, shoulder, ear canal, C7/T1, T12/L1, sacrum, greater trochanter, knee and ankle. The markers at C7/T1, T12/L1 and sacrum consisted of fins affixed with two markers located 6 cm apart. These markers were used to calculate the equation of a line that was then extrapolated to the joint center for each of C7/T1 and L4/L5 using the location of the skin surface determined from the fin markers as well as trunk depth measurements obtained for each individual at the corresponding spinal levels. The neck measurement was extrapolated to 50% of depth while the trunk measurement was extrapolated in 43% from the posterior surface (McGill et al., 1988). Thoracic and lumbar spine angles were calculated as the angle between adjacent fin markers (Fig. 2A). The pelvic tilt was calculated as the algebraic dot product between the fin marker and the horizontal, and assuming a rigid attachment of the fin marker to the sacrum, the resulting angle was reported as the deviation of the sacrum from vertical. Upper body (head, arms and trunk) centre of mass (CoM) was calculated using anthropometric properties summarized by Winter (1990) with modifications for the trunk (Pearsall et al., 1996).

Seat pan interface pressure was measured using a pressure mapping device (X2 Seating System, XSensor Technology Corporation, Calgary, AB, Canada) and continuously sampled at 5 Hz throughout each 15-min interval. The seat pressure profile was used to obtain the location of the centre of pressure (CoP) and peak pressure over time as well as the average peak pressure for each 15-min interval. For each sample within the 15-min interval, the area of peak pressure under the ischial tuberosities (IT) was calculated by locating the cells containing the peak pressure to the left and right side of the midpoint of the pressure area on the mat; any adjacent cells whose pressure was within 10% of the maximum value were included in the peak pressure area. Left and right peak pressure areas (PP area) were expressed as a percentage of the total seat pressure area and averaged to obtain an overall mean value for each trial within each subject. The mean pressure of this peak pressure area (called peak pressure magnitude or PP mag) was calculated by averaging the pressure values of the cells included in the peak pressure area yielding an overall mean value for each trial within each subject.

A calibration procedure was performed in order to locate the pressure mat on the chair in the global coordinate system of the motion analysis system. Briefly, a point located on the pressure mat at the front edge of the chair was digitized with a four-marker rigid body digitizing probe (i.e., global x and y co-ordinates were determined) and this point was located with respect to a marker fixed on the seat pan. Since the distance between these two points remained fixed, the point at the front edge of the chair could be tracked regardless of the movement of the chair in space. Using the dimensions of the pressure mat cells, the location of the CoP could also be determined with respect to the point at the front edge of the chair, thereby allowing the pressure system measures to be related to the anatomical kinematic data and located on the chair. Finally, participants were asked to pivot the chair as far forwards and backwards as possible. Two markers were fixed to the underside of the seat pan and the maximum displacements were used to calculate the pivot point of the chair using the Reuleaux method (Zatsiorsky, 1998).
Dependent variables were calculated for each 15-min interval. Centre of pressure and peak pressure were expressed with respect to each other as well as the front edge of the chair, the pivot point/base of the chair and the upper body CoM. In order to analyze where the individual was sitting on the chair, the hip joint was expressed with respect to the front edge of the chair, the pivot point/base and CoP. All variables, including spine angles, were averaged over the 15-min intervals and these values were used in the analyses since the time series were stable and the coefficients of variation were generally below 20% which is within the acceptable range for human variability in gait studies (Winter, 1984).

Three-way (gender * chair * task) repeated measures analyses of variance (ANOVA) with two repeated factors (chair and task) were performed on all variables to determine if there were any significant differences between gender or effects due to the chair or task performed. Tukey’s post-hoc multiple comparisons were used to examine significant chair or task effects and interactions.

3. Results

The average lumbar spine, pelvis and trunk angles were significantly different between genders regardless of the chair used or the task performed (Table 1). For the pivoting chair with a back rest, the female participants tended to sit with their trunks more upright or slightly leaned forward (0.5° (SD 4.8°) from the vertical) when compared to the male participants (−2.8° (SD 9.0°) from vertical), although this difference was not significant (P = 0.166). The movement of the pelvis from its position in upright standing to sitting showed a trend (P = 0.0556) indicating that males tended to have a greater amount of pelvic posterior tilt (17.5° (SD 8.3°)) when moving from standing to sitting than females (11.5° (SD 8.5°)). The task performed had an effect on the average lumbar angle of all subjects (P = 0.0029); the lumbar spine was the least flexed during the typing task (52.5% (SD 20.8) of max flexion), followed by the combination task (57.9% (SD 22.1) of max flexion) and the mousing task (62.1% (SD 20.7) of max flexion). There were no significant differences in spine and pelvis angles measured at the beginning and at the end of each session, nor were there any detected differences between males and females.

The location of the individual on the chair seat pan exhibited significant gender * chair interactions in several of the body position (i.e., CoM) and seat pressure measurements. These gender based differences were most marked for the pivoting office chair with a back rest. Changing the characteristics of the chair (pivoting seat pan, backrest, etc.) had a greater effect on the way male participants positioned their body on the chair, whereas there was little effect on the postural response of the female participants. Analysis of the average location of the upper body CoM relative to the base of the chair revealed that males’ CoM was located 1.1 cm (SD 2.0) posterior and females’ CoM was 4.6 cm (SD 1.5) anterior to the pivot point of the chair when a back rest was present.
rest was present (Fig. 3A). This response was reversed in the fixed chair with no back rest where males positioned their CoM more anterior to the base of the chair than females (Fig. 3A). Additionally, when a back rest was present the average hip joint location was 2.4 cm (SD 1.4) posterior for male participants and 2.4 cm (SD 1.5) anterior for female participants (Fig. 3B).

The seat pan pressure measurements also revealed that males and females responded differently to the pivoting office chair with a back rest. The upper body CoM for males was located more posterior relative to the seat pan centre of pressure (CoP) than females (Fig. 3C). In other words, females sat with their CoM more vertically aligned over the seat pan CoP (1.2 cm (SD 1.0)) than males (5.4 cm (SD 2.1)) when a back rest was present. The peak pressure was located 0.3 cm (SD 1.8) in front of the upper body CoM for males and 3.2 cm (SD 1.1) behind the upper body CoM for females (Fig. 3D). The seat pan pressure profiles of a typical female and

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Table 1
Thoracic, lumbar and pelvis angles (standard deviations in parentheses) averaged over chair and task

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Male</th>
<th>Female</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>% max flexion</td>
<td>Thoracic 8.6 (12.0)</td>
<td>3.1 (8.1)</td>
<td>P = 0.201</td>
</tr>
<tr>
<td></td>
<td>Lumbar 65.4 (16.2)</td>
<td>49.6 (23.1)</td>
<td>P = 0.047</td>
</tr>
<tr>
<td></td>
<td>Trunk 29.8 (28.3)</td>
<td>-3.3 (20.4)</td>
<td>P = 0.0026</td>
</tr>
<tr>
<td>Deviation from vertical (degrees)</td>
<td>Pelvis 7.6 (8.2)</td>
<td>-5.5 (9.3)</td>
<td>P = 0.0008</td>
</tr>
</tbody>
</table>

Ranges are the minimum and maximum values over all chairs and tasks. Lumbar and trunk angles are shown as percentages of maximum standing flexion (positive values represent flexion). Pelvis angle is shown as the number of degrees of deviations from vertical (positive values represent posterior tilt).

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Fig. 3. Significant gender*chair interactions were found for the following variables: the upper body (HAT = head, arms, trunk) CoM relative to base of chair (A), hip joint relative to base of chair (B), centre of pressure (CoP) relative to the upper body CoM (C), and peak pressure relative to the upper body CoM (D). All values indicated on the graphs are averaged across the three tasks performed and all subjects of the particular gender. A star (*) indicates a significant difference (P < 0.05). (■—male subjects; □—female subjects).
a typical male demonstrate that females exhibit a more focal area of peak pressure versus the more diffuse pressure seen in the male profile (Fig. 4). The mean area under a single ischial tuberosity was significantly larger for males (PP area = 2.51% (SD 2.85) of total pressure area) than females (PP area = 1.51% (SD 1.72) of total pressure area) ($P = 0.0014$) over all chairs and tasks performed (Table 2). Furthermore, males tended to have higher mean peak pressure magnitudes (PP mag = 152.1 mm Hg (SD 38.6)) than females (PP mag = 134.6 mm Hg (SD 38.0)) ($P = 0.058$; Table 2).

In an attempt to normalize the pressure values to account for the different areas of peak pressure, the PP mag values were divided by the absolute area values to obtain a measure with units of mm Hg/cm$^2$ (called PP per cm$^2$). It was observed that females had significantly higher peak pressures per unit area (PP per cm$^2 = 11.7$ mm Hg/cm$^2$ (SD 4.5)) than males (PP per cm$^2 = 9.1$ mm Hg/cm$^2$ (SD 4.3)) ($P = 0.034$; Table 2). In addition, all participants, while sitting on the spring stool, demonstrated significantly larger PP areas, higher PP mag, and lower PP per cm$^2$ ($P < 0.0001$ for all three variables) than the three other chairs tested (Table 2). The pivoting chair with a back rest showed significantly lower PP mag values than the other three chairs ($P > 0.01$; Table 2).

Average ratings of perceived discomfort for each chair were analysed, revealing a significant chair effect for the upper back and overall discomfort. Overall, discomfort levels were fairly low, and quite variable; however, some participants reported discomfort levels approaching 30 mm on a 100 mm scale. Both male and female participants had significantly less upper back discomfort ($P = 0.018$) and overall discomfort ($P = 0.012$) using the pivoting chair with a back rest when compared to the spring stool (Table 3). The perceived discomfort scores documented from all participants for the two other chairs (fixed chair, no back and pivoting chair, no back) were not significantly different from either the pivoting chair with a back rest or the spring stool (Table 3).

### Table 2
Mean seat pan pressure variables (and standard deviations) averaged over tasks and subjects

<table>
<thead>
<tr>
<th>Pressure variables</th>
<th>Fixed chair, no back</th>
<th>Pivoting chair, no back</th>
<th>Pivoting chair, with back</th>
<th>Spring stool</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PP area (% total area)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.7 (0.2)</td>
<td>0.7 (0.2)</td>
<td>0.7 (0.3)</td>
<td>3.9 (2.1)</td>
<td>1.5 (1.7)*</td>
</tr>
<tr>
<td>Male</td>
<td>0.9 (0.3)</td>
<td>1.1 (0.5)</td>
<td>0.9 (0.2)</td>
<td>7.1 (1.9)</td>
<td>2.5 (2.9)*</td>
</tr>
<tr>
<td>Mean</td>
<td>0.8 (0.3)</td>
<td>0.9 (0.4)</td>
<td>0.8 (0.3)</td>
<td>5.5 (2.6)#</td>
<td></td>
</tr>
<tr>
<td><strong>PP mag (mmHg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>126 (26)</td>
<td>119 (18)</td>
<td>109 (31)</td>
<td>184 (20)</td>
<td>135 (38)</td>
</tr>
<tr>
<td>Male</td>
<td>136 (25)</td>
<td>147 (31)</td>
<td>124 (30)</td>
<td>201 (3)</td>
<td>152 (39)</td>
</tr>
<tr>
<td>Mean</td>
<td>131 (26)</td>
<td>133 (28)</td>
<td>117 (31)§</td>
<td>193 (17)#</td>
<td></td>
</tr>
<tr>
<td><strong>PP per cm$^2$ (mm Hg/cm$^2$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>13.4 (3.4)</td>
<td>13.6 (4.2)</td>
<td>12.6 (4.2)</td>
<td>7.3 (3.4)</td>
<td>11.7 (4.5)*</td>
</tr>
<tr>
<td>Male</td>
<td>11.9 (2.8)</td>
<td>10.0 (2.7)</td>
<td>10.6 (3.5)</td>
<td>3.6 (1.3)</td>
<td>9.1 (4.3)*</td>
</tr>
<tr>
<td>Mean</td>
<td>12.7 (3.5)</td>
<td>11.8 (3.9)</td>
<td>11.6 (4.0)</td>
<td>5.5 (3.2)#</td>
<td></td>
</tr>
</tbody>
</table>

Peak pressure area (PP area) is expressed as a percentage of the total area. Peak pressure magnitude (PP mag) is the mean magnitude of the PP area. Peak pressure per unit area (PP per cm$^2$) was calculated by dividing the PP mag by the absolute area values (*—indicates a significant gender effect ($P < 0.05$); #, §—indicate a significant chair effect ($P < 0.01$), where the indicated value is significantly different from all other values).
4. Discussion

Overall, men and women adopted different postural alignments, specifically when examining spine and pelvis postures, during seated office work. In general, female participants sat with more anterior rotation of the pelvis, less lumbar flexion and very little trunk flexion when compared to the male participants. The characteristic of an office chair that causes the most noticeable gender differences in body position is the presence of a back rest; men tended to lean against the back rest while females perched closer to the front of the seat pan. Men and women responded similarly to the different tasks examined; all participants sat with the least lumbar flexion during the typing task and the most flexion during the mousing task, regardless of the chair used.

In the current study, we were unable to measure spinal angles while participants sat in the chair with a back rest because of the fin methods used. The gender differences in spinal alignment were only noted using the chairs without back rests. However, visual observations made during data collection as well as the significant gender differences noted in body position (CoM) and pressure measurements indicate that spinal alignment likely differed between males and females when sitting on a chair with a back rest to accommodate the significantly different adopted body positions. Furthermore, another study that used an electromagnetic device (ISOTRAK 3Space) to measure lumbar spine angles while sitting in a chair with a back rest documented average lumbar spine angles of 29.1% of maximum flexion for females and 57.3% of maximum flexion for males (Gregory et al., in press). It follows that males and females may be exposed to different loading patterns and may experience different injury pathways. Maintaining spine postures near neutral alignment, avoiding excessive spine flexion, and minimizing joint loading by adopting an upright posture are important factors in maintaining back health and preventing low back pain. The association between low back pain and sitting has been attributed to the required flexed curvature of the lumbar spine (Wilder and Pope, 1996) which would place males at a greater risk of developing disc herniations as a consequence of the observed seated spine postures (Wilder et al., 1988). Furthermore, the flexion relaxation phenomenon, where the muscles of the back shut off during spine flexion and do not actively help to support the moment, has been found to occur in seated flexion at lumbar flexion angles ranging from 40% to 80% of maximum flexion (Callaghan and Dunk, 2002). In the current study, males adopted lumbar spine angles that were well within the range for flexion relaxation whereas female spine angles were at the lower margin of this range. Flexion relaxation has been proposed as a mechanism for low back pain during sitting through potential stretching of the passive tissues responsible for bearing the load moment after the muscles shut off, further emphasizing the importance of maintaining near neutral postures. The typical female sitting posture documented in the current study demonstrates that females tend to avoid excessive spine flexion and maintain a more upright posture. Although muscle activity was not monitored in this study, it is well documented that upright sitting postures require a higher level of muscle activation than slumped sitting and even upright standing (Andersson et al., 1974; Andersson and Orten gren, 1974; Callaghan and Dunk, 2002). Prolonged low level muscle activation has been associated with the reporting of muscle pain (Veiersted et al., 1990; Hagg and Aström, 1997); the low level contractions seen in upright sitting can impair oxygen transport in the muscles (McGill et al., 2000) which could be a source of pain and injury, especially for females exposed to prolonged seated work. However, there were no differences in the reporting of discomfort between the male and female participants in the current study. The lack of difference in discomfort could be attributed to gender-based perception differences in discomfort (which is an inherent issue with perceived discomfort measurements), or the relatively short period of 45 min used to assess the responses in each test session. Gyi and Porter (1999) reported that at least 2 h of testing was required to clearly assess comfort. Longer sitting times in the current study could have shown differences in discomfort of functional significance. Furthermore, participants were allowed to stand up and move around after each 15-min trial, which could have relieved any discomfort felt during the seated period. RPD scores could have been affected by the fact that participants were screened for recent occurrences of acute or chronic low back pain symptoms, as people without low back pain may not be expected to report significant changes in discomfort during 45 min of seated computer work.

Previous studies have shown that the type of computer workstation tasks performed has an effect on postural responses while sitting. Both van Dieen et al. (2001) have shown that...
and Gregory et al. (in press) demonstrated higher back muscle activation levels and the lower probability that the back muscles were at rest during typing tasks. Furthermore, Gregory et al. (in press) reported that typing resulted in the least amount of lumbar flexion and that males and females responded similarly to the task demands, which corresponded to the results in this study. Significant task effects seen in this study could possibly be attributed to the participants repositioning themselves between tasks. However, because average lumbar flexion was the only variable affected by task, it is thought that participants were repeatable in their repositioning and that the differences observed in the lumbar spine for both genders are due entirely to the nature of task that they performed, i.e., the mousing task may have required more “scrutiny” or the participants chose to lean forward on the desk while working.

It would appear as though males were more affected by changing the characteristics of the chair that they sat in. The presence of a pivoting seat pan caused a significant shift in the location of the centre of mass closer to the base of the chair (Fig. 3A) and a tendency to locate the hip joint directly over the base of the chair (Fig. 3B) for the male participants (see Fig. 3A). This shift in body position most likely occurred in order to improve balance of the upper body over the pivot point and control the seat pan rotations. For females, there was little change in the location of the CoM or hip joint between the fixed chair and the pivoting chair, which could be attributed to the fact that the female participants tended to be smaller and lighter and less capable of maneuvering the pivoting seat pan. The addition of a backrest had a large effect on the male sitting behaviour. Because a condition with a fixed seat pan with a backrest was not tested, it is difficult to ascertain which characteristic had the largest effect (pivot or backrest). However, some level of effect can be deduced from the data; based on the trends seen in Fig. 3, the changes seen in the pivoting chair with a backrest are due to a combination of the two factors and most likely in large part to the addition of a backrest.

Peak seat pressure values under the ischial tuberosities that have been associated with more comfortable chairs range from 43.5 mm Hg (Kamijo et al., 1982) to values greater than 116 mm Hg (Kolich and Taboun, 2004) to a range of 75–225 mm Hg (Kurtz et al., 1989). In this study, peak pressure values ranged from approximately 135 mm Hg for females to 152 mm Hg for males which correspond to values seen in other studies performed on office chairs (Makhsous et al., 2003) and car seats (Kolich et al., 2004). However, when the peak pressure magnitude was normalized to the area, this translated to a lower pressure per unit area for the male subjects; in other words, male participants in this study demonstrated a more diffuse pressure distribution. Discomfort specific to the buttocks was not directly measured in this study, so it is not possible to link buttocks pressure to local or general discomfort. Although no significant differences in discomfort were observed between genders in this study, the male participants tended to report higher overall RPD scores than the females across tasks and chairs. This “overall” discomfort score was highly non-specific and could be related to discomfort felt in the buttocks region. However, in a meta-analysis performed by de Looze et al. (2003), seat pressure distribution was suggested to be the objective measure with the most clear associations with discomfort. It is thought that a more uniform distribution of pressure under the buttock area may be a cause for discomfort or pain since a portion of the high peak stresses under the ischial tuberosities, which have a higher pressure threshold, are transferred to the soft tissue of the gluteal region (de Looze et al., 2003; Gregory et al., 2004). Although much of the research examining the development of sitting-induced pressure ulcers has indicated that lower peak pressures and pressure gradients (Brienza and Karg, 1998; Geyer et al., 2001) reduce the incidence of pressure ulcers, the populations under investigation include patients with spinal cord injuries and the elderly. These populations may have compromised tissue integrity and decreased blood flow which could exacerbate the detrimental effects of high buttocks–chair interface pressure. Still, the implementation of pressure-reducing contour cushions to distribute the load over an increased surface area (Sprigle and Press, 2003) has been shown to reduce the development of pressure ulcers under the ischial tuberosities (Geyer et al., 2001). The effects of higher pressures may not have the same detrimental effects in healthy participants as compared to patient populations. However, soft tissue deformation should be minimized (Brienza and Karg, 1998) and a more diffuse pressure that is not concentrated directly under the ischial tuberosities could potentially be a source of discomfort for healthy participants (de Looze et al., 2003). Participants in the current study also reported significantly higher overall RPD when sitting on the spring stool, the chair condition which demonstrated the highest peak pressure magnitudes and areas of the four chairs tested. This could be due to the design and material of the seat pan for this chair, as it had a slightly convex surface as opposed to the concave and contoured surface of the office chair which was used for the three other conditions.

The evidence in the literature is controversial for the benefits of dynamic office chairs. The general opinion is that pivoting or dynamic chairs do not significantly affect trunk kinematics (Bendix, 1984; Jensen and Bendix, 1992) or erector spinae EMG (van Dieen et al., 2001). Back rests have been shown to transmit some of the forces relieving the lower back of some load (Corlett and Eklund, 1984; Bendix et al., 1996), but could also potentially induce kyphosis because individuals push
their lumbar spine backwards against the back rest to create increased stability (Bendix et al., 1996). However, it is thought that spring loaded back rests may provide more effective support by tracking movements made by the seated individual, thereby reducing spinal compression (van Dieen et al., 2001). Very little information regarding gender differences in back rest use has been reported. According to the results of this study, males and females tended to assume different trunk postures when interacting with a back rest. Furthermore, the presence of a back rest significantly reduced the peak pressure magnitudes under the ITs for all participants. Information such as back rest pressure and contact time would give more insight into how individuals use a back rest and its impact on spine loading and posture.

5. Conclusions

The results of this study reveal there are fundamental biomechanical differences between male and female sitting behaviour. It follows that males and females may be exposed to different loading patterns and may experience different injury pathways. Therefore, gender-dependent treatment modalities and/or coaching should be implemented when considering methods of reducing the risk of injury or aggravation of an existing injury. For example, females could be encouraged to use the back rest more to reduce muscle activity, and males may need greater lumbar support to increase lordosis. Furthermore, when incorporating sitting into an occupational setting, either as a job rotation option or treatment modality, gender should be considered as an important factor.

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