The Impact of T1-L5 Free Shoulders™ Back Rest Design on Prolonged Seated Office Work

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Table of Contents

Executive Summary

The subsequent report presents data collected from 20 subjects (10 males, 10 females) and compares the physiological responses to two different office chairs during two hours of simulated office work. Four different office tasks were examined (mousing, typing, a combination of the two and reading). The primary focus of the study was to assess back rest design influence on shoulder postural responses. Secondary purposes were to examine chair, task and gender effects on spinal posture, pressure distribution and muscular activation. All data were monitored for the entire two hour test session.

The KEILHAUER T1-L5 Free Shoulders™ back rest design with thoracic and lumbar support did not introduce any negative changes to a user's postural response. There was a non-statistically significant response that revealed there was a trend toward increased shoulder retraction in the T1-L5 Free Shoulders™ chair compared to the control chair. The spinal posture of the user was not significantly affected by the chair used, although the Keilhauer T1-L5 Free Shoulders™ did introduce a slight benefit of a less extended trunk angle, less flexed thoracic spine angle, and less posterior pelvic rotation. Similarly there was a positive impact on the lumbar posture of males when using the T1-L5 Free Shoulders™ for typing related tasks of less flexed lumbar spine postures. There was no difference is female lumbar postures between the two chairs.

The data illustrates *significant* differences between the KEILHAUER T1-L5 Free Shoulders™ and the control office chair in pressure distribution on the back rest. The lumbar region centre of pressure was at a lower height on the back rest, which may be beneficial in preventing posterior pelvic rotation. There is also *significantly* less total lumbar region pressure and *significantly* less contact area between the user and the lumbar region of the back rest. Conversely, the control chair resulted in a higher centre of pressure, greater total pressure and greater contact area between the user and the lumbar region of the back rest. The change in contact area and pressure on the KEILHAUER T1-L5 Free Shoulders™ chair did not significantly alter the stress (average pressure over the area between the chair and the user) on the back rest yet maintained the same or more optimal lumbar spine postures. The resulting stress values were below magnitudes of pressure that have been shown to be associated with chairs that result in more favorable comfort ratings.

The location of the seat pan Centre of Pressure (CoP) in reference to the front edge of the chair *significantly* varied by gender across the two chairs. Females sat with their CoP closer to the front edge on the KEILHAUER chair. Males sat with their CoP in the same location on both chairs. When body position relative to the pressure profile on the seat was examined there were *significant* gender differences for each chair and task. Females sat consistently different in the KEILHAUER chair compared to the control chair across all tasks whereas the male response varied differently across tasks in the two chairs. Females and males responded similarly in positioning their seat pan CoP further in front of their Centre of Mass (CoM) for the mousing and reading tasks in the KEILHAUER chair. For the combination and typing tasks, the genders responded oppositely, where females continued to position their seat pan CoP further in front of their CoM in the KEILHAUER chair, but males positioned their CoP further in front in the control chair. This reveals that typing is leading to a change in body positioning effected by the chair used; specifically the KEILHAUER chair is altering the way females interface with the chairs seat pan without altering the spine, pelvis, or upper extremity angles, and influencing males to sit in a better body position most notably with less lumbar flexion.

The right trapezius muscle activation exhibited *significant* gender by chair by task interactions. Females had less right trapezius activation in the KEILHAUER T1-L5 Free Shoulders™ for all tasks, whereas males had greater activation in the KEILHAUER T1-L5 Free Shoulders™ for all tasks except the reading task.

Overall, the results show that the alternative back rest design of the KEILHAUER T1-L5 Free Shoulders™ did not introduce any negative changes for seated office work and that the KEILHAUER T1-L5 Free Shoulders™ had the following beneficial impacts:

- less protracted shoulder posture
- lower centre of pressure location in the lumbar region*
- reduced pelvic posterior rotation for both genders
- decreased lumbar total pressure and contact area while maintaining the same or better lumbar postures*
- delayed onset of discomfort within the 1 hour seated period
- lower discomfort ratings at the end of the 1 hour seated work

*** Indicates findings that were statistically significant**

Introduction

Seated office work has become a major part of many occupations. This has lead to a field of research that focuses on reducing the risk of low back pain from exposure to prolonged sitting. Chair design has primarily placed attention on lumbar support and seat pan influences on spine posture with a large body or research published on lumbar supports in particular. However little attention has been placed on thoracic support and the influence this may have on upper body posture and the impact on task performance and discomfort.

The KEILHAUER T1-L5 Free Shoulders™ introduces a new design featuring thoracic support as well as shoulder cutouts. There have been no studies to our knowledge assessing the contour shape and/or width of the seat back and the influence of these factors on comfort, impact of physiological response, or task performance. There is evidence that thoracic support location (vertical alignment with the lumbar support) can influence lumbar support usage but no reporting of this factor on thoracic or upper extremity response. Makhsous et al (2003) concluded that sitting with a fitted back rest to the lower spine changes the contact area, reduces muscular activation and rotates the sacrum forward. Goossens et al (2003) found that muscular activation reduced with an increase in posterior seat pan tilt and that a larger part of the total backrest force was supported by the lumbar support.

In conjunction with KEILHAUER we have performed a prior study investigating the gender responses to seated exposures. Dunk et al. (2005) found that women adopt a different postural alignment than men when performing seated office work. Basically, the findings revealed that men tended to slouch against the back rest while females perched closer to the front of the seat pan. Females tended to preserve a more neutral lumbar spine and pelvis posture compared with males and had a more vertical alignment of the upper body centre of mass (CoM) over the seat pan centre of pressure (CoP). The influence of gender will be carried forward in the current study presented in this report.

The primary purpose of this study was to examine the benefits of a contour back design (T1-L5 Free Shoulders™ shape) with lumbar and thoracic support, specifically its influence on task performance and discomfort. Sub issues to be examined included the gender response, influence of postural response, change in contact area and corresponding pressure magnitudes on the seat pan and back rest, and muscular activation level differences. Particular focus was placed on the location of the centre of mass on the seat pan, the pelvic position, thoracic postural changes and muscle patterns. Only findings that were influenced by the chair factor differences are included in this report. In other words, while there are expected and well documented differences in physiological responses that were confirmed by this study between different work tasks, these are only included if they were impacted differently by the two chairs.

Definitions (From Winter, 1995)

Centre of Mass (CoM): a point equivalent to the total body mass and is the weighted average of the centre of mass of each body segment.

Centre of Pressure (CoP): a point on the support surface (seat pan) that represents a weighted average of all the pressures over the surface of the area in contact with the seat pan.

Methods

A total of twenty participants, 10 males (mean age = 23.7 ± 2.3 years; mean height = 1.81 ± 0.05 m; mean mass = 80.0 ± 9.3 kg) and 10 females (mean age = 22.2 ± 4.3 years; mean height = 1.64 ± 0.06 m; mean mass = 56.9 ± 5.1 kg), were recruited from the university population. This population was of particular interest as university students spend a major part of their day performing seated work such as reading and regularly perform computer based tasks such as word processing. 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 sit for 1 hour in each of two seated conditions including, 1) the KEILHAUER Junior and 2) a control seat (Borgo Jendra, www.borgo.com/i_jend.html) presented in a randomized order (Appendix, Figure A1). The two office chairs were standardized by setting the seat pan to back rest angle at 110° so that a similar exposure in the two chairs could be assessed. The seat pan height and desk height were matched for each participant to a knee angle of 90° and an elbow angle of 90° in the two chairs at the start of each 1 hour block. The back rest height was positioned so that the lumbar contour was in contact with the lumbar spine in the first chair, and set to the same height in the second chair. During the testing session, participants performed controlled activities to insure that any observed response was attributable to chair design differences and not individual behaviour in performing different tasks. Each participant performed four 15 minute trials of simulated office work in each hour block, consisting of a: typing, computer-aided design, typing/mousing combined work, and reading tasks. Prior to the two hour sitting trial, an upright standing trial was collected for baseline measurements. Three forward flexion trials were also collected and averaged to normalize spinal angles to maximum voluntary flexion.

Seat pan and back rest interface pressures were measured using a pressure mapping device (X2 Seating System, XSensor Technology Corporation, Calgary, AB) and continuously sampled at 4Hz throughout each 15 minute trial. The seat pressure profile was used to calculate the location of the centre of pressure (CoP) with respect to the front edge of the seat. While the back pressure profile was used to obtain the location of the centre of pressure (CoP) with respect to the base of the back rest and also subdivided within each of the lumbar and thoracic regions, as well as to assess the contact with and usage of the seat back.

Upper body centre of mass (CoM) location was calculated using an optoelectronic motion analysis system (Optotrak Certus, Northern Digital Inc., Waterloo, ON) at a sampling frequency of 32 Hz. Markers were placed on the right side of each participant's body at the following locations to make this calculation: hand, wrist, elbow, shoulder, ear canal, greater trochanter (hip), knee, and ankle. Additionally markers were placed on the left side at the hand, wrist, elbow and shoulder to compare bilateral upper extremity joint angles (elbow and shoulder flexion/extension) and trunk angle. By including markers on the T2 spinous process and the left and right acromioclavicular joints a 5 point (including shoulders) 3-dimensional shoulder and upper extremity posture tracking configuration was created (Appendix, Figure A4). This allowed for determining if the cutouts in the KEILHAUER T1-L5 Free Shoulders™ back shape altered overall upper body task related behaviour.

A calibration procedure was performed in order to locate the pressure mat on the chair in the global co-ordinate system. Briefly, points located on the pressure mats at the top of the back rest, side of the back rest and the front edge of the seat pan were digitized (i.e. global X, Y and Z co-ordinates were determined) and these points were located with respect to tracking markers fixed on the back rest and seat pan. Since the distance between these points remained fixed, the top of the back rest, side of the back rest and front edge of the chair (FEC) 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 these points.

Muscle activation of the trunk extensors and neck stabilizers were monitored throughout the 2 hours of seated work. Six pairs of disposable electromyographic (EMG) electrodes (Ag-AgCl) were affixed to the skin over the muscle belly of the left and right thoracic erector spinae (ES) approximately 5 cm bilateral to T9, left and right lumbar ES approximately 3 cm bilateral to L3, and the left and right upper trapezius approximately 4 cm from muscle edge at approximately a 55° oblique angle (Appendix, Figure A2). Maximal voluntary exertions for each of the muscle groups were performed so that all data could be expressed relative to 100% exertion and a resting trial was collected so that the muscle activation levels above a prone resting level could be assessed.

Participants completed ratings of perceived discomfort (RPD) at the beginning of each hour block (providing a baseline measure) and at 7.5 minute intervals, yielding 9 measures per chair. The approach utilizes a 100 mm visual analogue scale with endpoints tagged No Discomfort and Worst Discomfort Imaginable (Appendix, Figure A3). This method yields a quantitative measure of discomfort on a 100 point scale and will track the changes of relative subjective comfort between the two seats.

Three-way (gender*chair*task) repeated measures analyses of variance (ANOVA) with two repeated factors (chair and task) nested within gender were performed on all variables to determine if there were any significant differences. Effects due to gender or task factors were only considered if they influenced the two chairs differently.

Discussion of Results

POSTURAL RESPONSE

Shoulder and Scapular Posture

The back rest design of the KEILHAUER T1-L5 Free Shoulders™ did not generate any negative effect on the shoulder postures adopted by the participants. Analysis did reveal a non-statistically significant trend toward the KEILHAUER T1-L5 Free Shoulders™ resulting in smaller shoulder 4 segment length calculations (Figure 1 and Appendix Figure A4 for calculation). A smaller segment length means that the shoulders were less protracted or in a more neutral posture in the KEILHAUER T1-L5 Free Shoulders™ (Appendix, Figure A5). This is also supported by slightly smaller radius and arc length measurements.

Spinal Alignment

The trunk angle and the rotation of the pelvis the participant chose to adopt tended (not statistically different) to be dependant on the office chair they were sitting in. The KEILHAUER T1-L5 Free Shoulders™ chair resulted in less trunk extension (or a less reclined position) and less posterior tilt of the pelvis than the control chair, in other words a more upright alignment (Figure 2). Lumbar angle (percent of maximum flexion) was not influenced by the office chair used; this means that the change in trunk extension was accommodated by a beneficial response of less thoracic flexion (less rounding of the upper back).

PRESSURE MEASUREMENTS

Back Rest

The back rest pressure measurements revealed that back rest total pressure and total area are dependant on the task being performed; however there was no chair effect on these measures. Mousing and reading tasks result in greater back rest total pressure and total area, revealing that during these tasks participants used the back rest to a greater degree.

To further understand how participants were using the back rests, the back rest area was separated into two regions: lumbar and thoracic. A *significant* difference was found in the lumbar region centre of pressure (CoP) location between the two chairs. The KEILHAUER T1-L5 Free Shoulders™ resulted in a CoP lower on the back rest than the control chair (Figure 3). This supports the above findings of less posterior pelvic tilt as it is likely that the lower lumbar centre of pressure is maintaining the more upright pelvic rotation. There was no difference found between chairs in the location of CoP for the thoracic region.

The design of the KEILHAUER T1-L5 Free Shoulders™ introduced a *significant* difference in lumbar region total pressure, where the T1-L5 Free Shoulders™ had less total pressure than the control chair (Figure 4). There was a non-significant trend toward the KEILHAUER T1-L5 Free Shoulders™ introducing greater thoracic region total pressure.

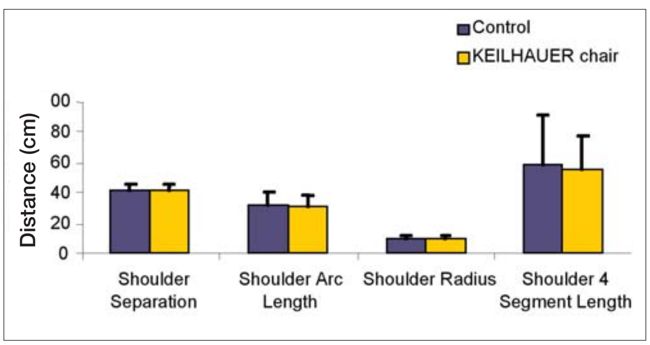

Figure 1. Distances calculated to reveal shoulder postural response between the KEILHAUER T1-L5 Free Shoulders™ and the control office chair.

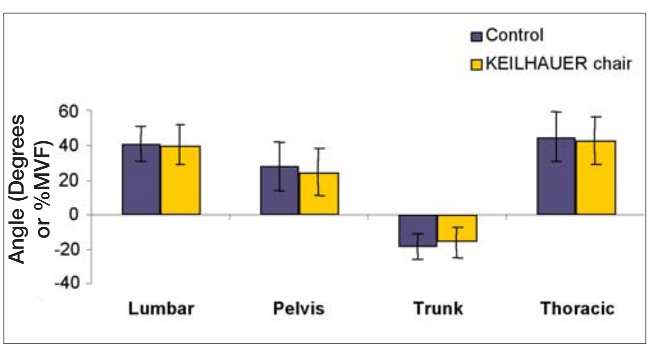

Figure 2. Chair differences seen in the lumbar, pelvis, trunk and thoracic angles. Lumbar angles are shown as a percentage of maximum standing flexion (positive values represent flexion). Pelvis, trunk and thoracic angles are shown as the number of degrees of deviation from vertical (positive values represent posterior tilt/flexion, negative values represent extension).

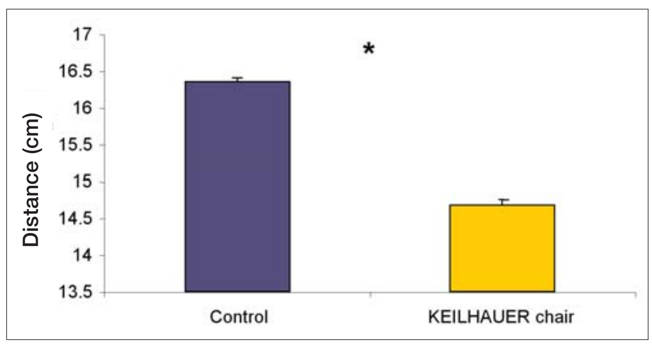

Figure 3. Differences in location of lumbar region CoP on the back rests described as the distance above the seat pan.

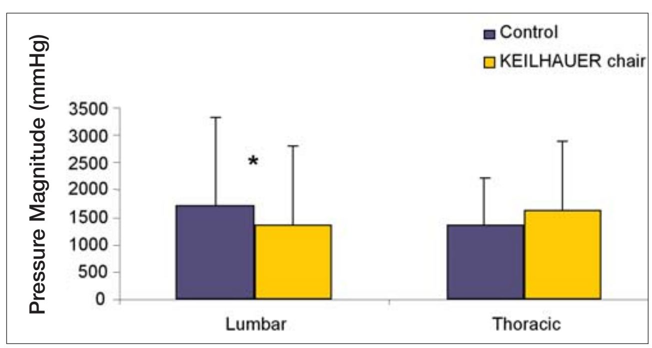

Figure 4. The differences in lumbar and thoracic regions total pressure magnitudes between the two office chairs.

The decrease in lumbar total pressure was followed by a gender by chair *significant* interaction for lumbar region total contact area in each chair. Both genders experienced less lumbar region contact area in the KEILHAUER T1-L5 Free Shoulders™ compared to the control chair (Figure 5) with males having a more marked difference than females. There was no difference in thoracic region contact area.

The KEILHAUER T1-L5 Free Shoulders™ may be beneficial in that although there is a smaller contact area, this does not induce a higher average pressure magnitude, but rather maintains the same or lower level of stress over the contact area for females in both the lumbar and thoracic regions and for males in the thoracic region. There is a *significant* difference between office chairs for male lumbar region stress (Figure 6). The KEILHAUER T1-L5 Free Shoulders™ does introduce more stress for males in the lumbar region, particularly for the mousing and reading tasks. However this does not affect the lumbar flexion angle adopted by the user, which is favorable and the magnitudes are well below pressures linked to discomfort.

BODY POSITION ON CHAIR

The KEILHAUER chair and the control chair *significantly* interacted with gender when analyzing seat CoP distance from the front edge of the chair. Females sat with their CoP closer to the front edge of the seat pan on the KEILHAUER chair compared to the control chair. Males sat with their CoP in the same location on both chairs.

Females and males responded *significantly* different in the positioning of their seat CoP in relation to their HAT (head, arm and trunk) CoM for each chair and task. Both genders responded similarly for the mousing and reading tasks, by positioning their CoP further in front of their CoM in the KEILHAUER chair (Figure 7a and 7b). It follows that during the mousing and reading tasks both genders had higher contact pressures and areas on the back rest. This reveals that during these tasks both genders are using the back rest to a greater degree, however the KEILHAUER T1-L5 Free Shoulders™ maintains their lumbar angle similar to the control chair, not allowing them to slouch into the chair (Figure 8). However for the combination and typing tasks, females exhibited a response that positioned their CoP further in front of their CoM in the KEILHAUER chair (Figure 7a), while males positioned their CoP further in front of their CoM in the control chair for these tasks (Figure 7b) this gender based difference is the primary result that influenced the Gender by Chair interaction.

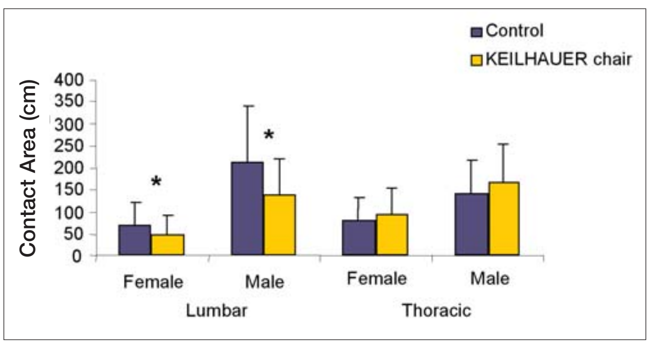

Figure 5. Gender differences in back rest lumbar and thoracic region contact area.

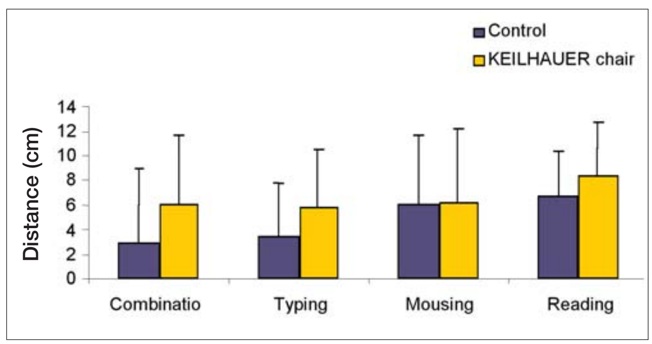

Figure 7a. Female interactions between chair and task performance for seat pan CoP versus HAT CoM. Positive values indicate the CoP is in front of the CoM.

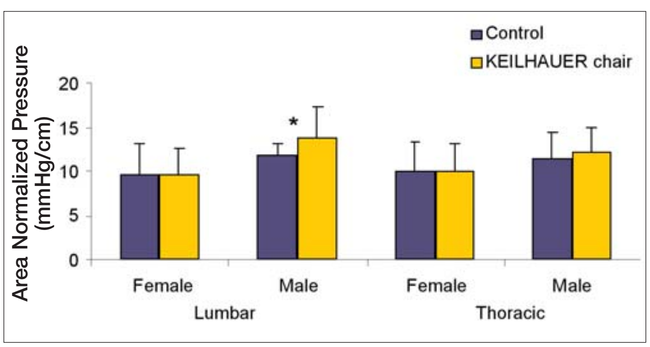

Figure 6. Back rest gender responses to lumbar and thoracic region stress (pressure/area) in each office chair.

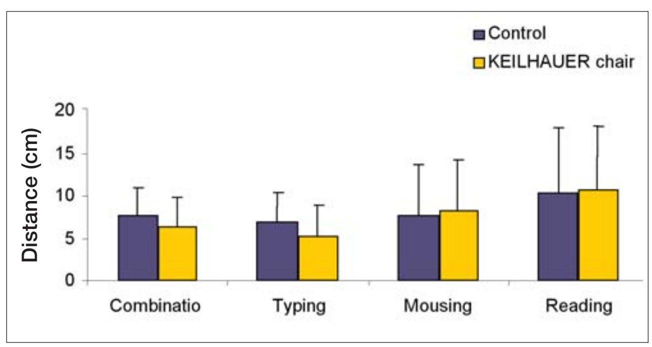

Figure 7b. Male interactions between chair and task performance for seat pan CoP versus HAT CoM. Positive values indicate the CoP is in front of the CoM.

Significant differences were observed between chairs for the location of the hip joint and the seat pan CoP. The CoP was located further in front of the hip joint location in the KEILHAUER chair; although the hip joint location itself was located the same distance from the front edge of the chair in both office chairs (Figure 9).

MUSCULAR ACTIVATION

Trapezius Muscle

A *significant* interaction between gender*chair* task was found for the muscular activation level of the right trapezius muscle. In other words, the two genders responded differently to the tasks depending on which chair they were using. Females tended to have lower muscular activation levels in the KEILHAUER T1-L5 Free Shoulders™ chair than the control chair in all tasks performed (Figure 10a). Males tended to have higher muscular activation levels in the KEILHAUER T1-L5 Free Shoulders™ for all tasks except the reading task (Figure 10b). Although males tended to have higher activation in the KEILHAUER T1-L5 Free Shoulders™, both genders had average static exposure values below the Jonsson standard (Jonsson, 1978 & 1988) that proposes at least 10% of working time (p = 0.1) needs to have muscle activation levels below 2 to 5 % maximal voluntary contraction to prevent muscular disorders. All six EMG channels were assessed using the Amplitude Probability Distribution Function (APDF) approach. The muscle activation levels for both genders for the p = 0.1 level were below 2 % MVC or more simply, well below the lower margin of the proposed standard to prevent muscular discomfort.

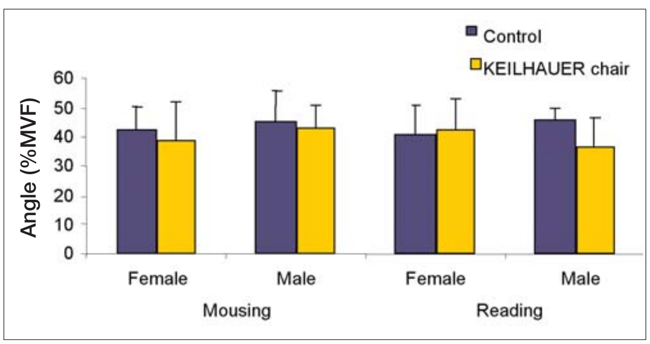

Figure 8. Lumbar angle response to mousing and reading tasks for each gender in both office chairs (larger magnitude numbers represent greater lumbar flexion).

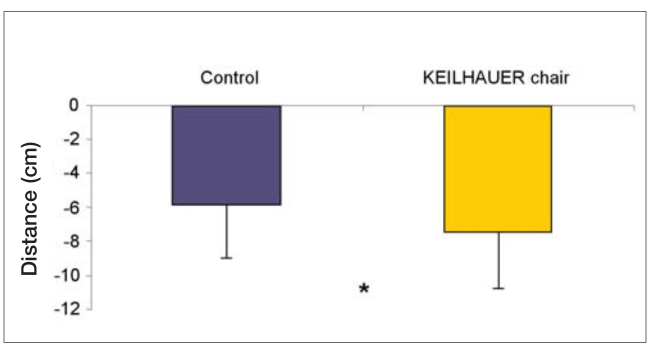

Figure 9. Chair comparisons between location of the hip joint and the seat pan CoP. (Negative values indicate that the hip joint was behind the seat pan CoP).

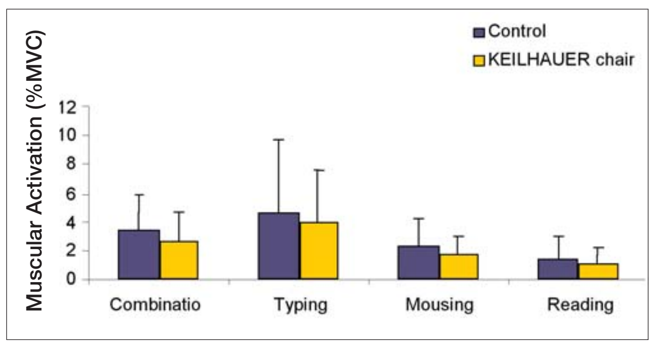

Figure 10a. Females right trapezius muscle response to chair and task.

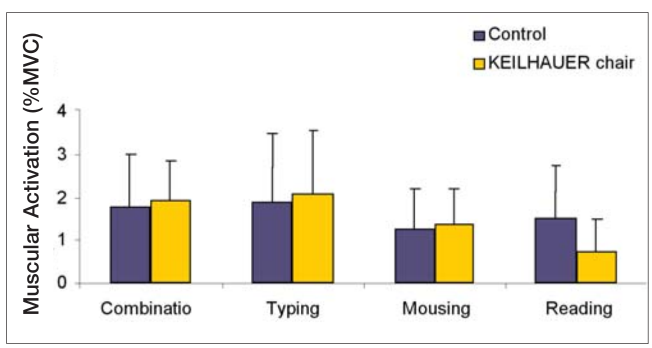

Figure 10b. Males right trapezius muscle response to chair and task.

COMFORT RATING (RATING OF PERCEIVED DISCOMFORT)

Overall the back rest design of the KEILHAUER T1-L5 Free Shoulders™ did not introduce any additional negative discomfort to the user; in fact it appeared to have a beneficial impact on subjective discomfort. The KEILHAUER T1-L5 Free Shoulders™ back rest design tended to lower the overall discomfort developed in the right shoulder in comparison to the control chair. This is a strong finding as the participants were all right side dominant for mousing and any primary movement tasks. The data revealed a non-significant trend toward the initiation of discomfort having a delayed onset in the KEILHAUER T1-L5 Free Shoulders™ chair in comparison to the control chair for various body regions (Figure 11). The KEILHAUER chair also resulted in a lower discomfort rating for all body regions at the end of the hour testing session (Figure 12).

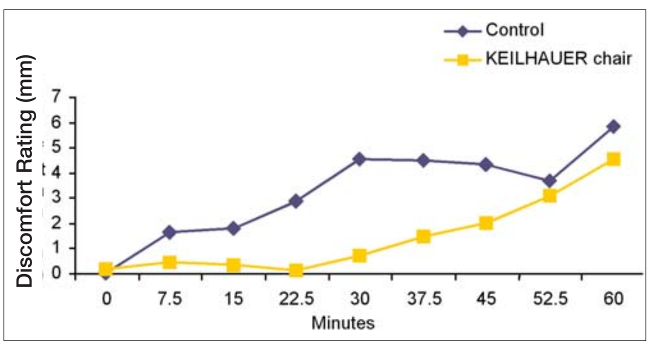

Figure 11. An example of discomfort rating delayed onset (Centre of back).

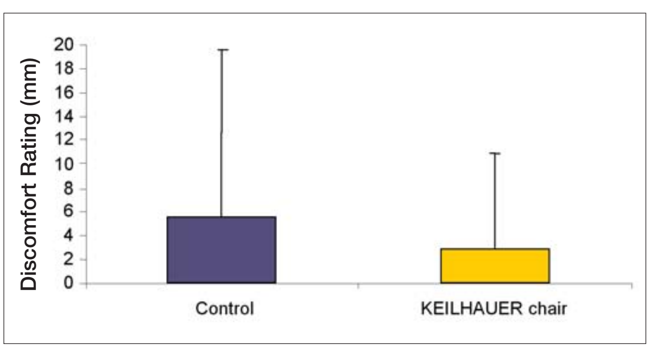

Figure 12. Average ratings of discomfort across all body areas at test conclusion for the two chairs (60 minutes).

Conclusions

Overall, the results show that the alternative back rest design of the KEILHAUER T1-L5 Free Shoulders™ did not introduce any negative changes for seated office work when compared to a more traditional chair back shape. The KEILHAUER T1-L5 Free Shoulders™ had the following beneficial impacts:

Statistically Significant

- a lowered centre of pressure in the lumbar region which is thought to help maintain a more anterior pelvic rotation more similar to the standing pelvic alignment
- decreased lumbar total pressure and contact area while still maintaining the same or more optimal lumbar postures

Statistically Non-Significant Trends

- a less protracted shoulder posture
- a reduction in pelvic posterior rotation helping to maintain a more neutral spine alignment
- delaying of the onset of discomfort
- a lower discomfort rating across all body regions after prolonged seated work

A less protracted shoulder posture is deemed beneficial as it may have an influence on decreasing the risk of developing such disorders as Tension Neck Syndrome and Carpal Tunnel Syndrome (Mekhora, 2000, Roquelaure, 2002).

The KEILHAUER T1-L5 Free Shoulders™ alternative back rest design lowers the centre of pressure location in the lumbar region of the back rest. This may be beneficial as it could help maintain a more anterior pelvic rotation by placing the lumbar support pressure lower on the sacrum, rather than on the lumbar spine itself. This pressure will prevent the backwards rotation of the pelvis and will more effectively force the lumbar spine into a less flexed posture than forces applied to the lumbar spine itself. Maintaining spine postures near neutral alignment is an important factor in maintaining back health and preventing back pain.

The change in contact area and pressure on the KEILHAUER T1-L5 Free Shoulders™ chair did not significantly alter the overall stress over the contact area on the back rest; however it did introduce more stress for males in the lumbar region, particularly for the mousing and reading task. Kamijo et al (1982) describe a "comfortable" seat pan as one with a mean pressure level of 2.9 kPa or less. The resulting mean pressure value on the lumbar region of the back rest is 1.7 kPa, revealing that this level of stress is still within a "comfortable" range and should not produce any discomfort for the male users.

The seat pan centre of pressure was located further in front of the hip joint in the KEILHAUER chair. As well, females tended to position their seat pan CoP further in front of their HAT CoM for tasks which included typing. There are no differences in any biomechanical (pelvic rotation, trunk, lumbar, thoracic, or upper extremity angles) or physiological variables that could have lead to this CoP difference. Furthermore, the ischial tuberosity average pressures are further back from the CoP for these tasks. This has led us to believe that there must be something within the contour shape of the KEILHAUER T1-L5 Free Shoulders™ that is causing this difference. As seen in Figure 13B, the KEILHAUER T1-L5 Free Shoulders™ chair introduces pressure in different locations and with a different contact shape over the entire seat pan in comparison to the control chair (Figure 13A), specifically near the front edge of the chair. This difference in pressure profile is what we believe results in the CoP being shifted towards the front edge of the chair in the KEILHAUER chair. The cause of the different pressure profiles seen in the two chairs appears to be related to the seat pan manufacturing differences. The control chair set pan is based on a flat platform with contours mainly provided by foam shape. The KEILHAUER chair appears to have a contoured seat base underlying the foam covering which provides greater support for the user and results in the more uniform pressure distribution under soft tissues. There were no negative impacts of these pressure differences of the discomfort scores. In fact the discomfort scores for the buttock regions (10 and 11 on the RPD - Appendix, Figure A3) generally followed the same positive discomfort trends previously reported for the KEILHAUER chair compared to the control chair.

Males tended to be positively effected by use of the KEILHAUER T1-L5 Free Shoulders™ office chair for typing tasks. The T1-L5 Free Shoulders™ chair influenced males to sit with less thoracic flexion, less lumbar flexion, and less pelvic posterior rotation when performing typing tasks in comparison to the control chair which resulted in males having greater thoracic flexion, greater lumbar flexion and greater posterior pelvic rotation.

Delayed onset of discomfort and lower discomfort ratings after prolonged seated work are both favorable outcomes in chair design. A chair that has lower developed discomfort at the end of a working block of time (i.e. from start of day until morning break) will likely allow for a faster recovery or quicker relief of that discomfort prior to reinitiating the next block of seated work. Delayed onset of discomfort from the initiation of a seated exposure period will allow a worker to have fewer distractions due to postural shifts and discomfort avoiding strategies over the same period of working.

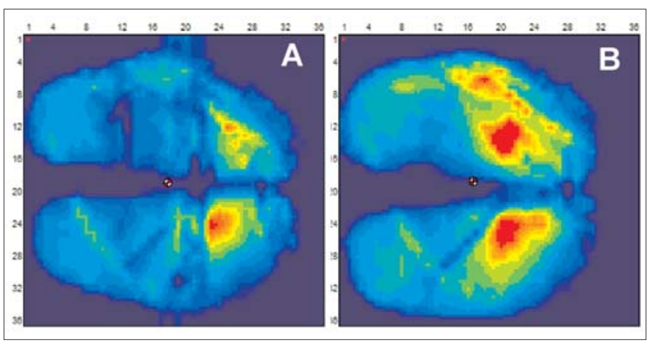

Figure 13. Different locations of contact pressure and contact shape over the entire seat pan for A) control chair and B) KEILHAUER chair. The figures are for the same subject performing the same task on the two different chairs.

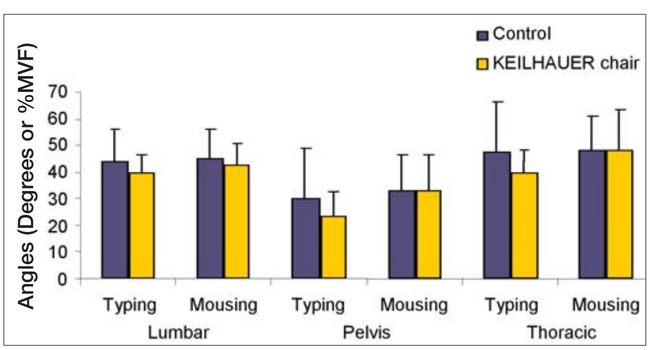

Figure 14. Male lumbar, pelvis and thoracic angles response to typing and mousing tasks in each office chair.

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Appendix A: Supplementary Information

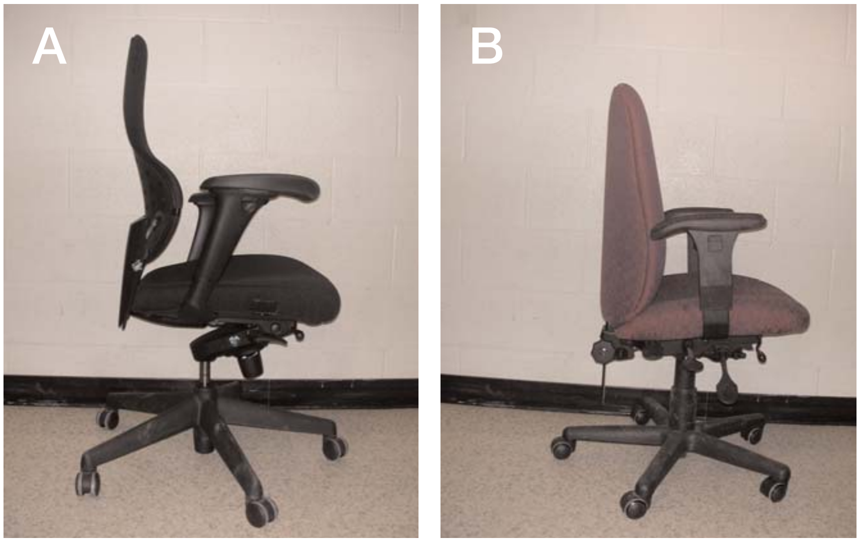


Figure A1: The two chairs used in the study. A) KEILHAUER chair; B) control chair

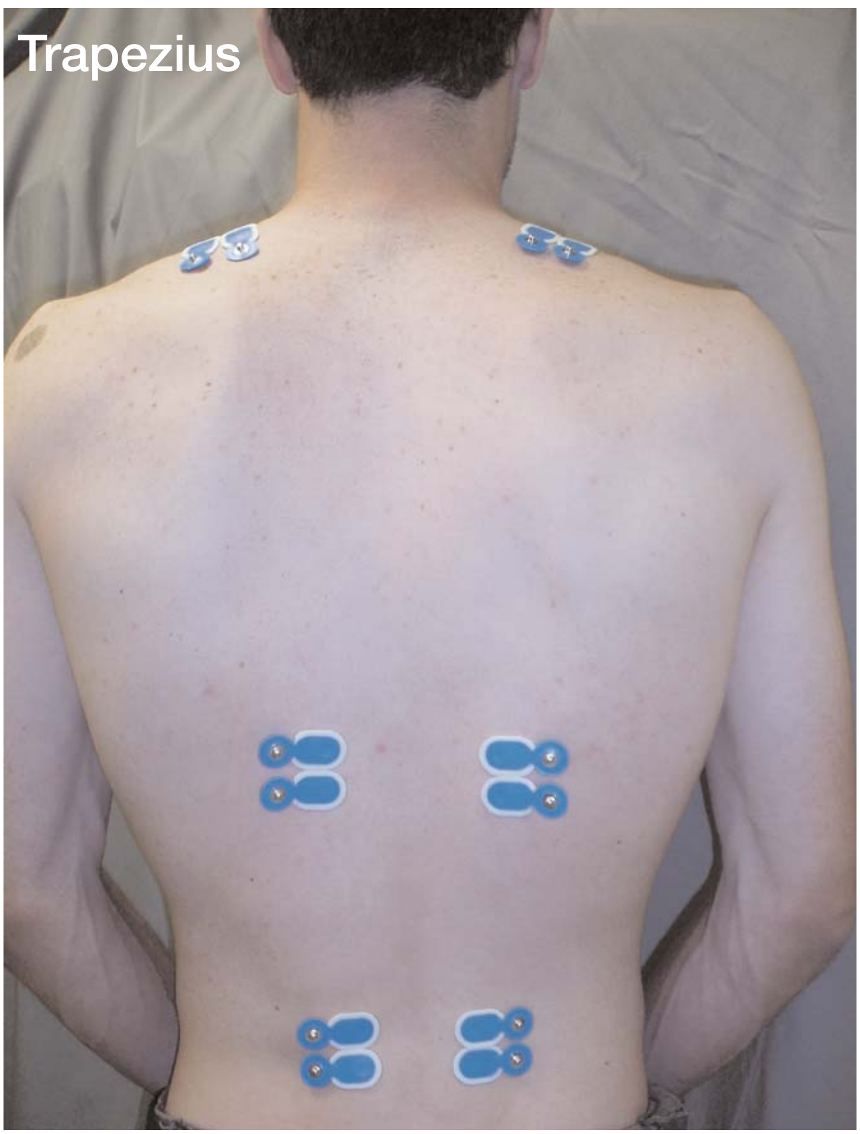
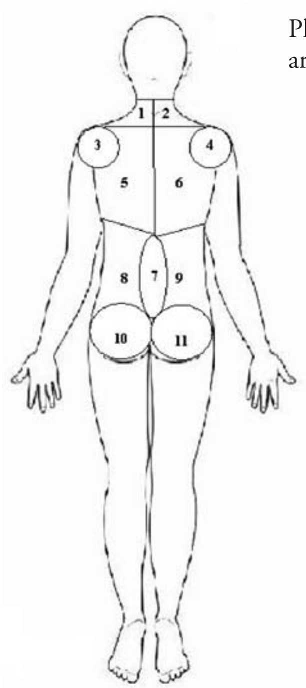


Figure A2: Figure illustrating the placement of the electromyographic electrodes used to record muscle activity levels

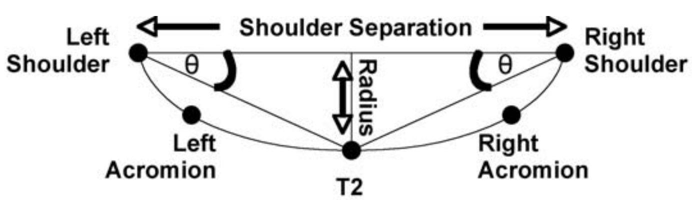
Rating of Perceived Discomfort Scale



Please make a mark on each line corresponding to the areas in which you are currently feeling discomfort

No Discomfort	Worst Discomfort Imaginable
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

Figure A3: Sample of the rating of perceived discomfort scale used to rank the subjective discomfort of 11 anatomical regions of the body. Subjects place a mark on the 100mm line which is then measured to provide a quantitative representation of the discomfort over time, and for the different chairs.



Shoulder 4 Segment Length = Distance from Left Shoulder to Left Acromion
+ Distance from Left Acromion to T2
+ Distance from T2 to Right Acromion
+ Distance from Right Acromion to Right Shoulder

Figure A4: Schematic of the measures and calculations made to measure shoulder and scapular posture protraction/retraction. The schematic is presented from a top down view with T2 representing the second thoracic vertebrae on the posterior aspect of the base of the neck

Figure A5: Figure illustrating shoulder and scapular A) protraction and B) retraction.

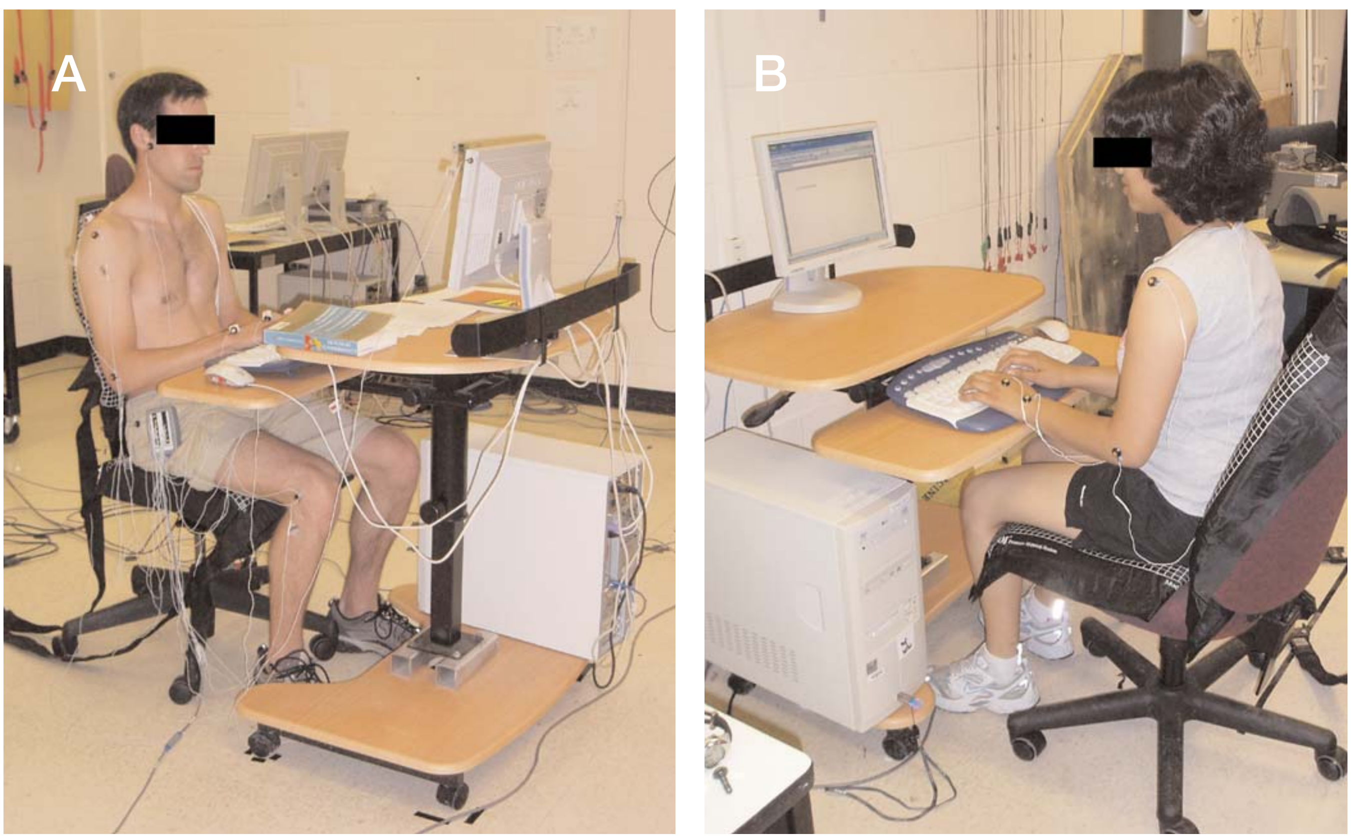


Figure A6: Sample Photos illustrating computer, instrumentation setup, and marker configuration; A) KEILHAUER chair, B) Control chair

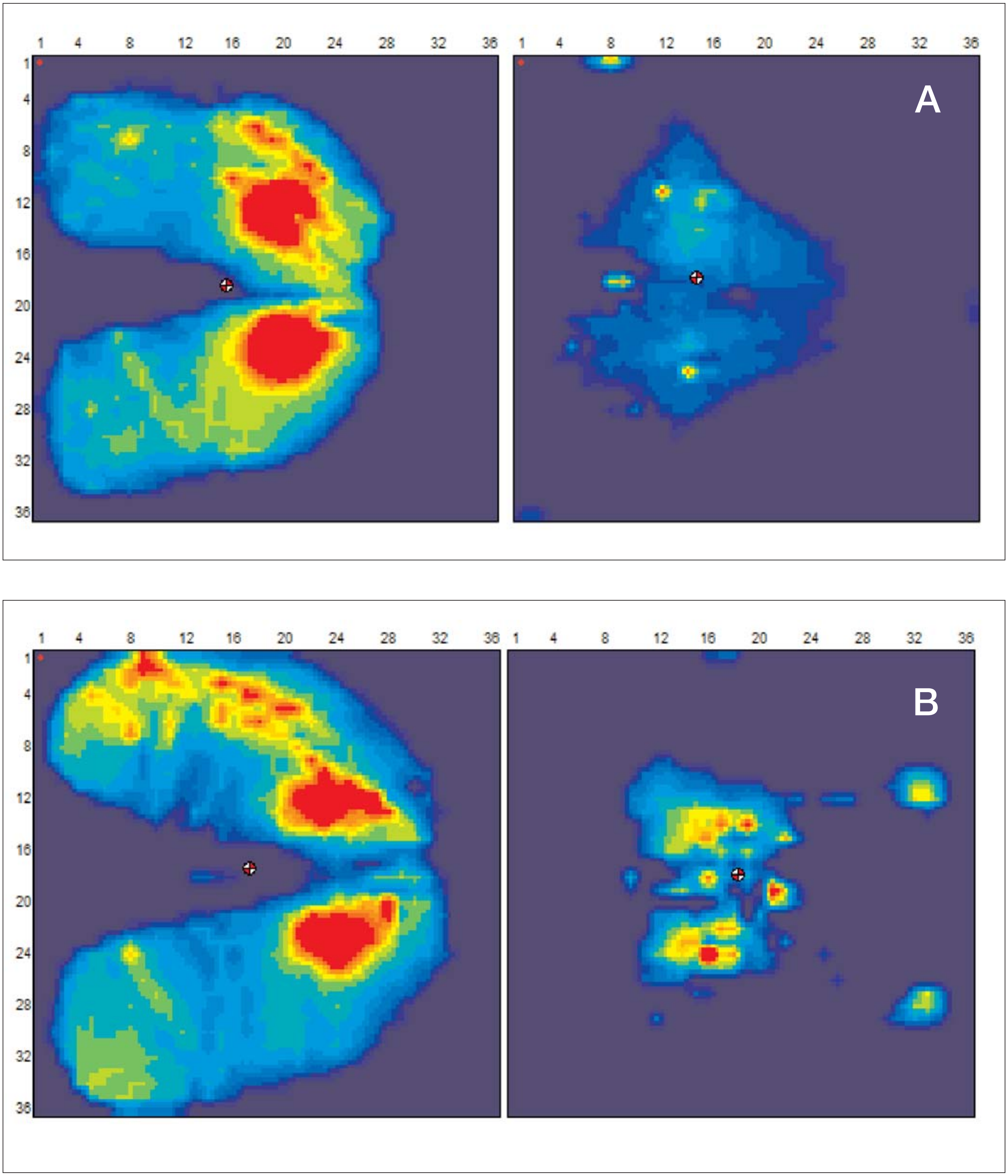


Figure A7: Sample figures illustrating pressure distributions on the seat pan and back rest on the two office chairs for the same subject performing the same task. A) KEILHAUER chair, B) control chair.