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An empirical study of preferred settings for lumbar support on adjustable office chairs

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Keywords: Lumbar support; Postural comfort; Office chairs.

The preferred settings for lumbar support height and depth of 43 male and 80 female office workers were investigated. All subjects were equipped with identical modern office chairs with foam-padded backrests adjustable in both height and depth. Measurements of lumbar support settings were recorded in the workplace, outside of working hours, on four different occasions, over a 5 week period. Preferred lumbar support height and depth settings extended to both extremes of the adjustment range. The mean preferred height setting was 190 mm above the compressed seat surface. The mean depth setting (horizontal distance from front of seat to lumbar support point) was 387 mm. A regression model examining the effects of standing height, Body Mass Index (BMI) and gender on mean preferred lumbar support height showed a significant relationship between preferred height and BMI. Higher lumbar supports were chosen by subjects with greater BMIs. Gender and standing height were not associated with preferred lumbar support height settings. Preferred lumbar support depth was not significantly associated with standing height, gender or BMI. Older subjects were more likely to readjust their lumbar support from a disrupted position than younger subjects, indicating that older users are more sensitive to the position of their lumbar support. Subjects who reported recent back pain or discomfort that they believed to be associated with their chair or office work were found to set their lumbar support significantly closer to the front of the seat, probably to ensure greater support for their back. Based on the evidence that a high proportion of users do make adjustments to the height and depth of their lumbar support, and the finding that different groups of users, with different physical characteristics, adjust the position of their lumbar support in distinct and predictable ways, the researchers conclude that office chairs with traditional padded fixed-height lumbar supports are unlikely to provide a comfortable or appropriate seat for the wide range of potential users.

1. Introduction

While there is wide agreement among experts that proper lumbar support is one of the fundamental requirements of an office chair, the most appropriate location for a lumbar support has not been established (Andersson *et al*. 1979, Stevenson 1991, McDowell and Straker 1993) and the ergonomics literature and standards are a maze of conflicting recommendations and requirements (Pheasant 1990). Some researchers (Keegan and Nebraska 1953, Keegan 1962, Branton 1966) recommend placement of the support over the lower lumbar region, other research indicates that a higher support is preferable (Sauter and Arndt 1984, Eklund and Corlett 1987). Floyd and

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Roberts (1958) suggest that a lumbar support is probably best positioned within the limits of the second to the fifth lumbar vertebrae (L2 to L5). Unfortunately, the anthropometric data for these landmarks are inadequate (Pheasant 1990) and very few studies provide designers of office chairs with useful and reliable dimensions for how high a lumbar support should be above the seat. The height above the seat of the foremost point of the lumbar support area, and whether it needs to be adjustable, is a matter of contention among chair designers (Stevenson 1991).

The uncertainty about the optimum position, the lack of anthropometric data for the relevant landmarks (Pheasant 1990), variation in sedentary work tasks (Corlett 1989), and the observation that different people will select different heights when adjustment is available and they have been trained to use it (Stevenson 1991), have led to ergonomists generally favouring adjustable lumbar supports (Burandt and Grandjean 1963, Branton 1984, Zacharkow 1988, Pheasant 1990, Andersson *et al.* 1991, Chaffin *et al.* 1991, Stevenson 1991). However, the uncertainty about the optimum position and the lack of direct research addressing lumbar support height adjustability have provided standards setting organizations around the world with no clear justification to exclude office chairs with fixed height lumbar supports. Consequently, the draft CEN Standard (CEN 1994, pr EN 1335) and the Australian Standard for the design of height adjustable swivel chairs (Standards Australia 1997) continue to provide for office chairs with either fixed or adjustable height lumbar supports.

The present study investigates user preferences for lumbar support and addresses some of the issues associated with lumbar support height, adjustability and user comfort.

The specific aims of this study were:

(1) to investigate the relationships between preferred position of lumbar support and stature, gender, body mass index, training in office ergonomics and back pain prevalence;
(2) to investigate whether office workers make use of lumbar support adjustment facilities; and
(3) to determine preferred settings for the height and depth of lumbar support on which to base recommendations for furniture manufacturers and the Standards Association of Australia.

2. Methods

2.1. *Subjects*

The subjects in the study were 123 government office workers employed by the Australian National Occupational Health and Safety Commission (NOHSC). Of the 123 subjects, 80 were female and 43 were male. Subjects ranged from senior executives to junior administrative staff. The physical characteristics of subjects were similar to what would be expected of the Australian white collar workforce (table 1).

2.2. *Chairs and tasks*

All subjects were equipped with identical office chairs. The chairs had an appropriate design and shape of lumbar support and the full range of seat and backrest adjustability recommended by Worksafe Australia (1991). All subjects had their own PC and during their working day mixed screen-based tasks with more traditional office work.

Table 1. Subject characteristics.

	Males (n = 43)	Females (n = 80)	All subjects (n = 123)
Age	Mean = 36·8 years Range: 19 – 64 years	Mean = 36·6 years Range: 20 – 60 years	Mean = 36·7 years Range: 19 – 64 years
Height	Mean = 1760 mm σ = 58 mm	Mean = 1640 mm σ = 73 mm	Mean = 1682 mm σ = 91 mm
Weight	Mean = 80·7 kg σ = 14·2 kg	Mean = 67·3 kg σ = 14·4 kg	Mean = 72·0 kg σ = 15·7 kg
BMI	Mean = 25·89 σ = 3·99	Mean = 25·16 σ = 5·34	Mean = 25·42 σ = 4·91

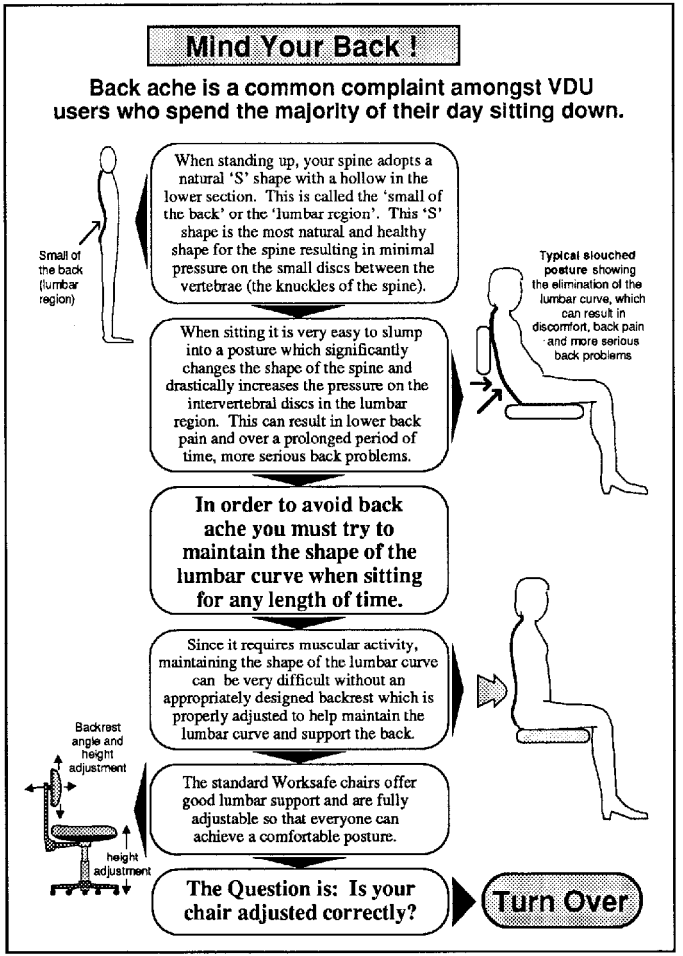
2.3. *Experimental design*

The first stage of the study involved systematic measurement of the current settings for lumbar support height and depth on all standard chairs. This measurement set is referred to as T1 (for 'Test 1'). Measurements were recorded outside working hours without prior explanation given to staff. Chairs were coded and labelled appropriately and chair locations were marked on floorplans.

Immediately following the first set of measurements, all staff received a letter (placed on their chair) inviting them to take part in the study by making appropriate adjustments to their backrests. The letter asked staff to read the two pages shown in figure 1 and ensure that their lumbar support was set to a *comfortable* position. Some general information on VDU workstation set-up was also provided. The letter informed staff how to make the adjustments and explained why, in the interests of their heath, they should do so. They were asked to tick a box on a label stuck to the back of their chair once they were satisfied that the position of their lumbar support was appropriate. They were also asked to tick a box indicating whether they were the sole user of the chair. This, in addition to the floorplans, enabled the identification of those chairs that were used primarily by one person.

Three days after receiving the letter and after receiving a reminder on the third day, measurements of lumbar support height and depth were repeated on all chairs to determine the changes that had been made (T2). This provided the first set of preferred settings for lumbar support height and depth. Having made the measurements the lumbar support of each chair was adjusted to its lowest and most forward position (the 'disrupted' position), which was considered to be an awkward setting for the majority of users and therefore encouraging readjustment. In a few cases, subjects had chosen the lowest most forward position of the backrest as their preferred setting. In these cases, the backrest was set to the highest most forward position. A note was fixed to the chairs thanking staff for their co-operation and advising them that they might need to readjust their lumbar support following the measurements made by the researchers. Four or five days later the measurements were repeated a third time (T3), providing a second set of data for preferred settings.

Subjects' height and body mass were measured at their workstations using portable scales and a stadiometer. Their age and gender were recorded and their body mass index was calculated. Subjects were also asked a few short questions regarding their history of back pain and any current symptoms, their knowledge and use of chair adjustment features, and whether they had had training in office ergonomics.



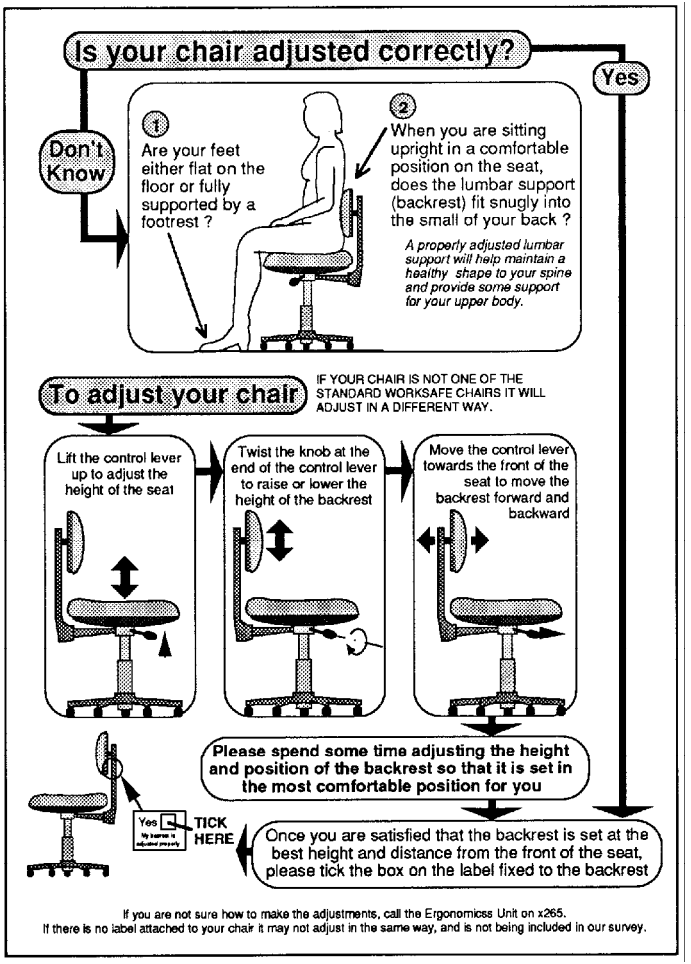


Figure 1. Photo-reduced pages of adjustment information supplied to subjects as part of the initial letter.

A fourth set of measurements (T4) was obtained for all chairs 4 weeks later providing a third set of data for preferred settings. Data were analysed using the SAS computer programme (SAS Institute 1987).

2.4. *Measurement techniques*

Figure 2 shows an approximate profile of the chairs used in the study. The backrests were small and designed only to provide lumbar support. The lumbar support point was taken to be in line with the pivotal centre of the backrest. This corresponded (appropriately) with the most prominent point of the lumbar support area. Lumbar support height and lumbar support depth were measured with the device shown on the chair (illustrated more clearly in figure 3). Lumbar support height was taken as the vertical distance from the seat surface (underside of the wooden base) to the lumbar support point. Lumbar support depth was defined as the horizontal distance, on the centreline of the seat's width, from the front of the seat to the lumbar support

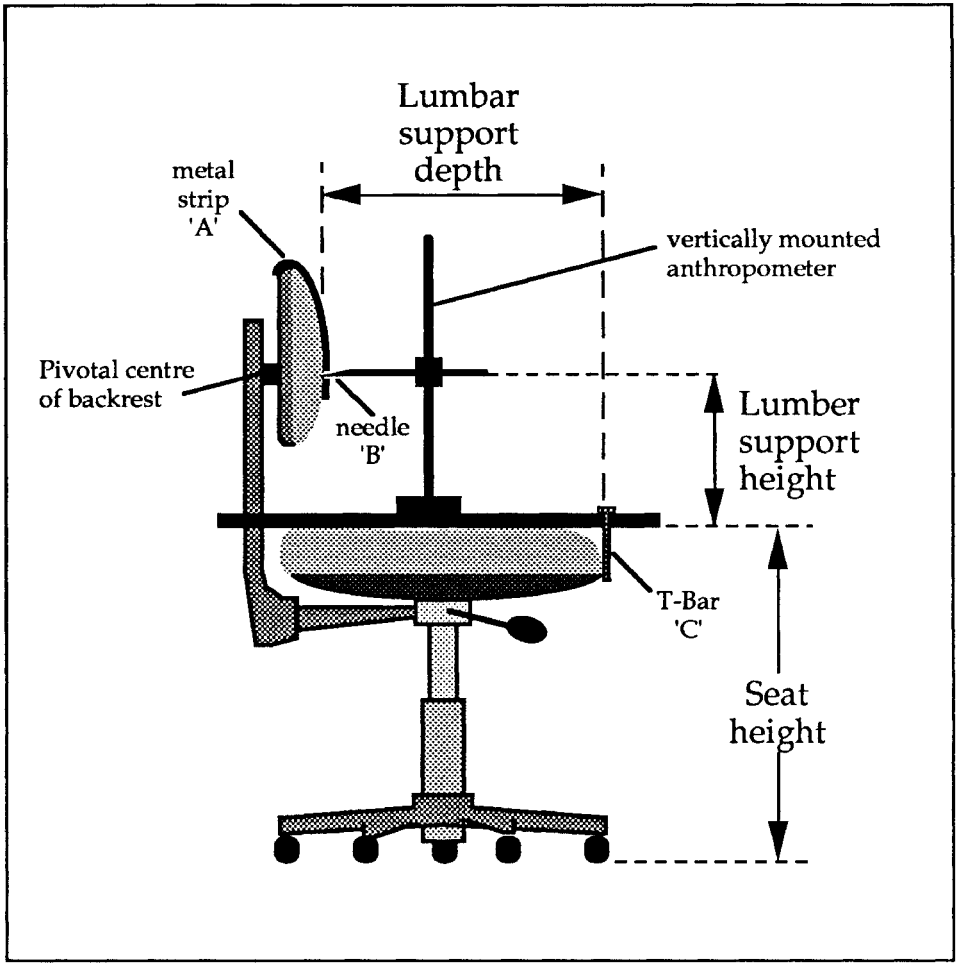


Figure 2. Approximate profile of chairs used in the study. The purpose-built measuring device is shown in place on the chair.

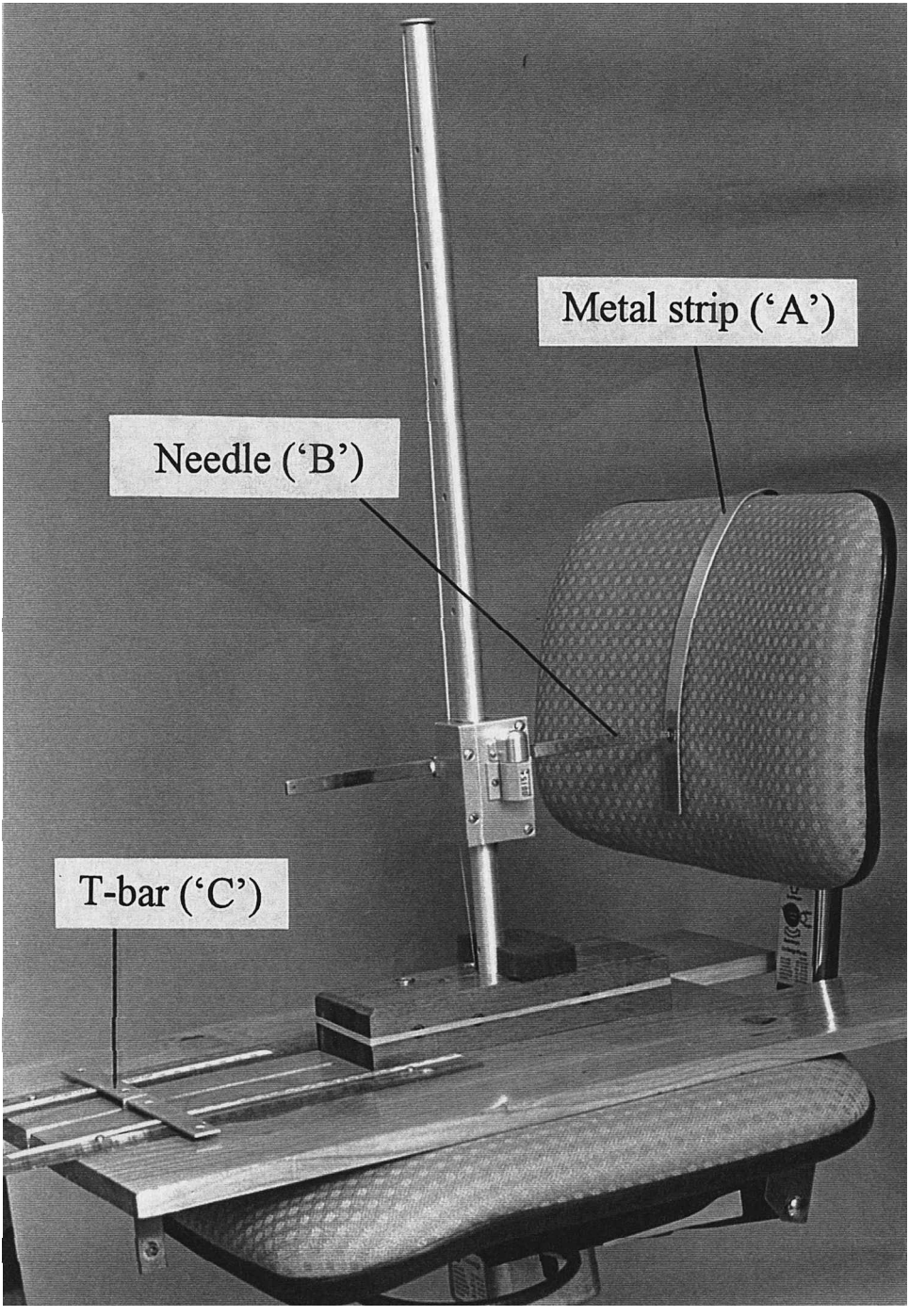


Figure 3. Photograph of chair and standard measuring equipment.

point. For speed, standardization, and ease of measurement, the lumbar support point on each chair was located by hooking a metal strip ('A') over the backrest of the chair. The strip was shaped to follow the lumbar curve of the chairs and had a small hole drilled at the lumbar support point. The needle ('B') of the vertically mounted anthropometer was raised to the height of the hole and the whole device was slid over the seat surface until the point of the needle just touched the fabric of the backrest through the hole in the metal strip. The lumbar support height was read off the counter on the anthropometer. With the needle of the anthropometer still in place, the T-bar ('C') was moved along a groove in the wooden base until it came in contact with the front of the seat. The position of the T-bar on a ruler fixed to the upper surface of the wooden base indicated the lumbar support depth. Test measurements showed that lumbar support height, lumbar support depth and seat height were repeatable ± 5mm.

Lumbar support heights were measured without allowing for cushion compression. Ten chairs were randomly chosen from the test sample and lumbar support height was measured under compression using the standard set of dummy buttocks described in BS5940: part 1 (British Standards Institution 1980). Mean cushion compression values were determined for use when interpreting results.

The chairs used in the study had some deflexion in the backrest column so that when users pushed back against the backrest the effective lumbar support depth increased. This movement varied depending on such factors as the age and condition of the chair; the upper body weight of the user, the user's sitting posture, and the angular position of the backrest. Standard measurement techniques are not available for the measurement of increased backrest rake under compression. For the purposes of this study, however, observations of sitting behaviours and backrest movements for ten subjects on ten different chairs were used to determine an approximate range for increased lumbar support depth under compression.

3. Results

Of approximately 250 employees at NOHSC, 203 were equipped with the standard study chair. All 203 chairs were originally measured and labelled (T1). After 3–4 working days (T2), 123 employees had chosen to participate in the study and had ticked the box to indicate that their backrest was set to a comfortable position.

Table 2. Measured lumbar support height and depth settings. Values in bold type provide a better idea of the settings actually used by subjects.

	T1 (mm)	T2 (mm)	T3 (mm)	T4 (mm)
Mean height	160·38	161·77	149·61	150·50
Minimum setting	110	110	112	112
Maximum setting	231	225	**221**	231
Mean height (allowing for cushion compression during use)	**194**	**196**	**184**	**185**
Mean depth	360·72	360·14	350·06	353·24
Minimum setting	312	313	302	314
Maximum setting	487	479	459	458
Mean depth (allowing for increased backrest rake and cushion compression during use)	**391**	**390**	**380**	**383**

Measurement set T3 showed that 1 week after the lumbar supports were set to the most forward and lowest or highest position, both the depth and height of the lumbar support had been readjusted on only 43% of the chairs, the depth alone had been readjusted on 15% of the chairs, and the height alone had been readjusted on 7% of the chairs. A total of 35% of lumbar supports had not been adjusted and remained in the disrupted position. Four weeks later, measurement set T4 showed that 23% of the chairs still remained unadjusted. Of the 65% of chairs that had been readjusted by T3, 53% had been subject to further readjustment.

Table 2 shows the measured lumbar support height and depth settings for each measurement set. The bold values for lumbar support height include an additional 34 mm for cushion compression. The mean value of 34 mm was partly due to compression of the seat cushion, and partly due to the wooden base of the measuring device spanning dips in the seat pan where the buttocks would normally sit. The bold values for lumbar support depth include an additional 30 mm for increased backrest rake and cushion compression during use. This provides a better idea of the mean depth actually used by subjects. Measurements showed that, when in use, the backrest column

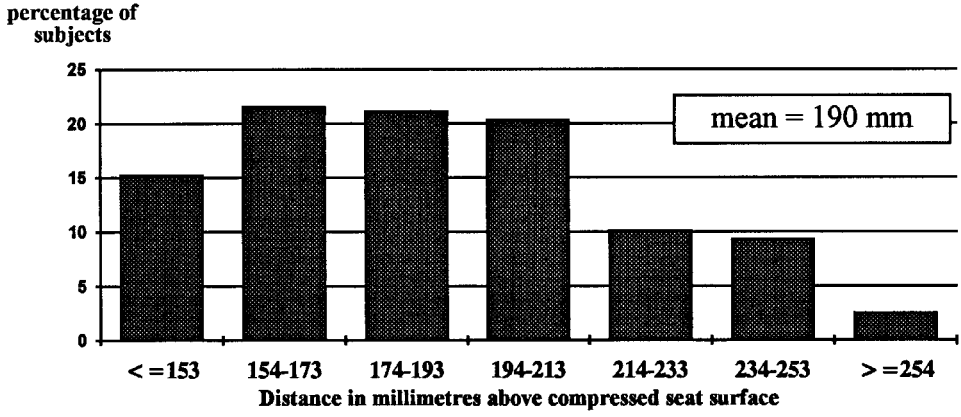


Figure 4. Distribution of preferred lumbar support height settings.

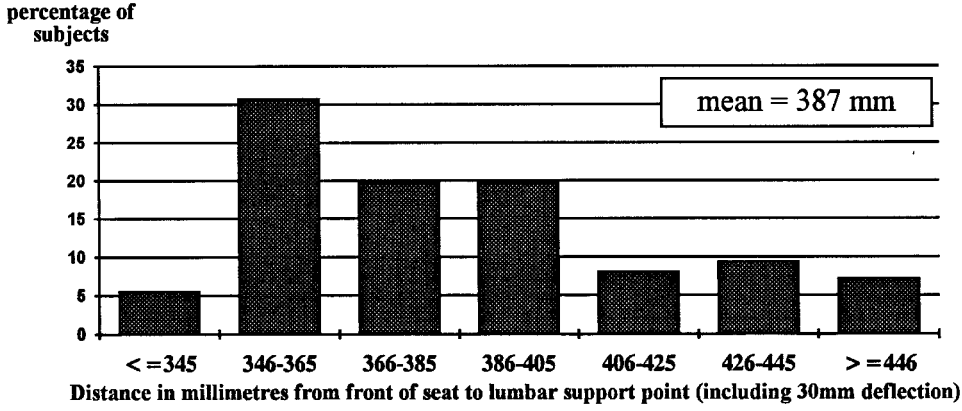


Figure 5. Distribution of preferred lumbar support depth settings.

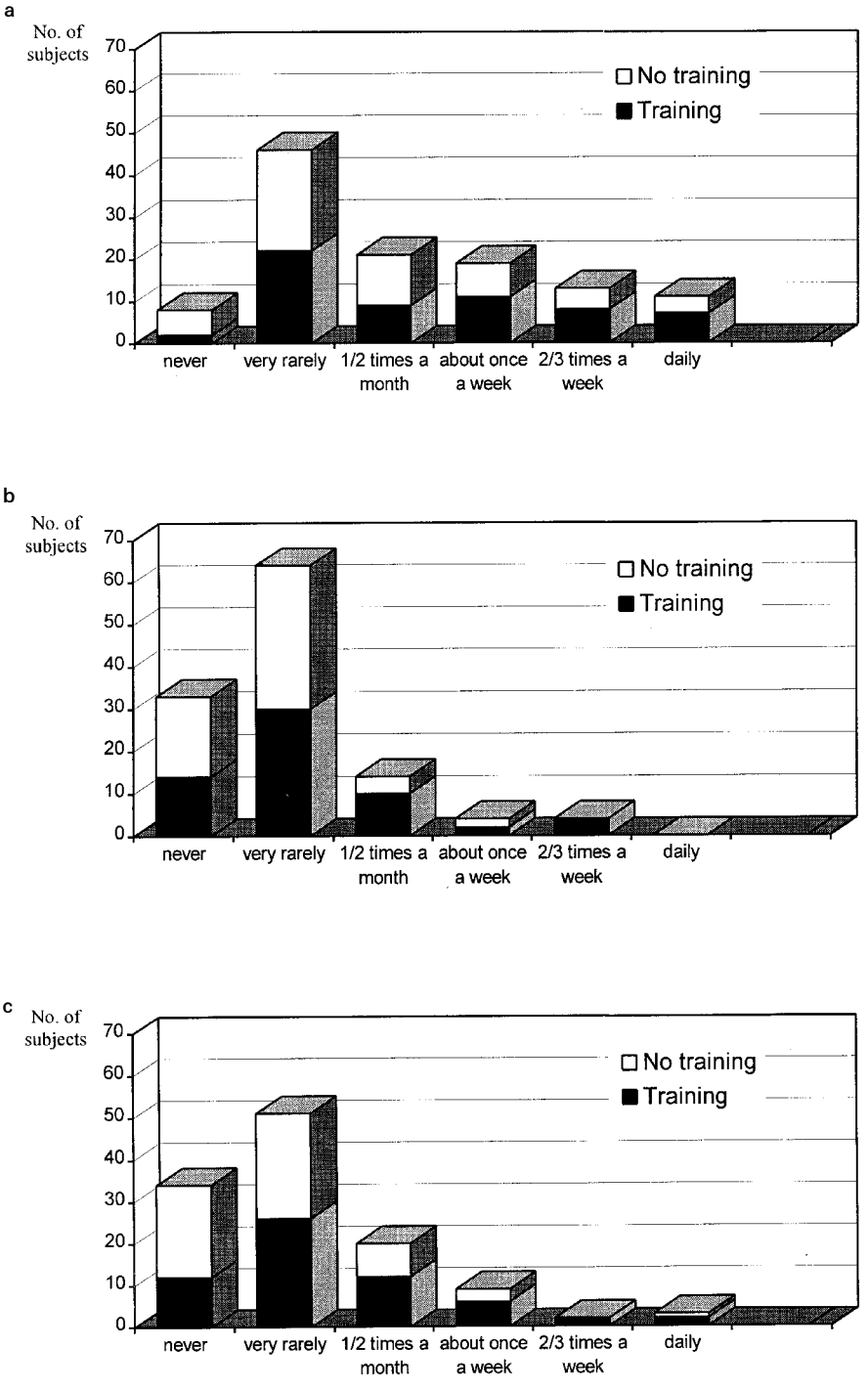


Figure 6. Reported frequency of: (a) seat height adjustments; (b) backrest height adjustments; (c) backrest depth adjustments.

reclined an average of 23 mm (values ranged from 15 to 42 mm). An extra 7 mm has been added to the 23 mm to allow for compression of the lumbar support cushioning.

3.1. *Mean settings*

The measurement sets T2, T3 and T4 represent three separate measures of preferred settings for lumbar support. However, since T3 and T4 were not independent (no intervention between them) they cannot both be included in the calculation of mean preferred settings. A high proportion of subjects failed to readjust their backrest from the disrupted position by T3. This test was performed 4 – 5 working days after lumbar supports were moved to the disrupted position. Since they were not monitored, holidays, sick leave and external work activities might explain a significant proportion of those who failed to readjust. Measurements recorded during T2 provide data based on informed stated preferences, and measurements recorded during T4 provide empirical data on the lumbar support settings that subjects used for 4 weeks (or adjusted to in that time). Therefore, measurement sets T2 and T4 were taken as the most reliable estimates of mean preferred lumbar support settings.

Derived from data sets T2 and T4 $\left(\frac{\sum [(T2+T4)/2]}{n}\right)$ the mean preferred lumbar support height setting of the experimental population was calculated to be 190 mm above the *compressed* seat surface. The mean preferred lumbar support depth, including 30 mm for increased backrest rake and cushion compression during use, was calculated to be 387 mm. Figures 4 and 5 show distributions of the mean preferred lumbar support height and depth settings of subjects. For both lumbar support height and depth, the full range of available adjustment was used.

3.2. *Anthropometric survey and questionnaire*

A total of 97% of subjects reported knowing how to adjust the height of their seat prior to receiving the original letter (shown in figure 1). Seventy-six per cent said that they knew how to adjust the height of their backrest and 76% said that they knew how to adjust the seat/backrest depth. Of the subjects who reported having had previous training in chair adjustment, 100% knew how to adjust their seat height, 85% knew how to adjust the height of their backrest and 85% knew how to adjust the backrest angle ('lumbar support depth') prior to receiving the letter.

Figures 6a – c show reported data on frequency of chair adjustment prior to the research. The charts distinguish between those subjects who said that they had been previously trained in how to set up their chair and those subjects who said that they had not. Seat height adjustment was used far more regularly than backrest height or depth adjustment. Whereas only 7% of subjects reported never using seat height adjustment, 28% reported never using backrest height adjustment and 29% reported never using backrest depth adjustment. The majority of subjects reported only 'very rarely' making adjustments to their chair, particularly backrest height. Many subjects qualified this response with statements such as 'Once I've set it so that its right for me I leave it there' or 'I only readjust it if someone else has been using my chair and changed it'.

Chi-square tests showed that subjects who reported having had training in how to set up their chair did not adjust it any more frequently than subjects who reported having had no training. Of the 123 subjects, 38·5% of subjects reported having back pain, aching or discomfort within the last 6 months which they attributed to their chair or office work. Of those subjects, 41% considered their back pain/discomfort severe enough to seek professional advice.

Table 3. Results of individual regression models examining the effects of standing height, BMI and gender on lumbar support heights (LSH) recorded at T2, T3 and T4.

	LSH at T2	LSH at T3	LSH at T4	Mean preferred LSH
BMI	n.s. ($p = 0{\cdot}10$)	$p < 0{\cdot}005$	$p < 0{\cdot}001$	$p < 0{\cdot}005$
Stature	n.s.	n.s.	n.s.	n.s.
Gender	n.s.	n.s.	n.s.	n.s.

3.3. *Analysis*

Each of the following statistical tests were preceded by standard diagnostics to ensure that there were no major violations of the underlying assumptions.

3.3.1. *Lumbar support height*: In order to investigate whether subjects had specific areas of preferred lumbar support within the available height a random effects model was used to estimate the components of variance at T2 and T4.

A relatively small variance within subjects compared to the variance between subjects would have indicated that the majority of participants had specific height preferences for lumbar support within the wider range of height adjustment available. This was shown not to be the case. A total of 65% of the variance was explained by within-subject differences. None the less, the analysis showed highly significant differences between subjects.

Spearman's correlation analysis showed that preferred lumbar support height settings at T2 and T4 were significantly related ($p < 0{\cdot}0001$), indicating that while some subjects consistently preferred a higher lumbar support, others consistently preferred a lower lumbar support.

A regression analysis was used to investigate whether the differences in preferred lumbar support height settings between subjects could be explained by differences in physical characteristics. A model, examining the effects of standing height, BMI and gender on mean preferred lumbar support heights, showed a significant positive relationship between mean preferred lumbar support height and BMI ($t_{3,113} = 3{\cdot}16$; $p < 0{\cdot}005$). The gender and standing height of subjects did not significantly influence mean preferred lumbar support height settings. Even though significant, variations in BMI explained only 8% of the variance in lumbar support height settings, indicating that other unknown factors influence preferred lumbar support height settings along with BMI.

Similar tests were carried out separately on the lumbar support height data from measurement sets T2, T3 and T4 (table 3). In each case, standing height and gender showed no association with lumbar support height settings. BMI showed a significant association with lumbar support height settings at T3 and T4, but was not significantly associated with settings at T2.

3.3.2. *Lumbar support depth*: A regression model examining the effects of standing height, BMI and gender on preferred lumbar support depths showed no significant relationships ($F_{(3,113)} = 2{\cdot}01$; $p = 0{\cdot}116$).

3.3.3. *Adjustment characteristics*: *t*-tests and Chi-square tests were used to investigate the characteristics of subjects displaying different adjustment strategies. The 28 subjects who did not readjust their backrest from the disrupted position by

T4 were significantly younger than subjects who did readjust ($p < 0{\cdot}05$). Of these 28 subjects, 26 had their backrests disrupted to the most forward and lowest position, and two had them disrupted to the most forward and highest position. The lumbar support height settings measured at T2 for the 26 subjects were significantly lower than those of other subjects ($p < 0{\cdot}05$). Readjustment from the disrupted position was not significantly associated with reported back pain history or reported prior training in office ergonomics.

Of the 80 subjects who readjusted their lumbar support by T3, 53% made further readjustments by T4. The subjects who made further readjustments did not report any more or less back pain than other subjects, were no older, and had had no more training in chair adjustment than the subjects who made a single readjustment from the disrupted position.

3.3.4. *Back pain*: A *t*-test was used to investigate the effects of recent back pain/discomfort on mean preferred lumbar support height settings. Subjects who answered 'yes' to the question. 'In the last 6 months, have you had any back pain, aching or discomfort which you think might be related to your chair or office work?' were found to set their lumbar support significantly lower and further forward than subjects who answered 'no'. Recent back pain was therefore built into the regression model with BMI, stature and gender to more accurately determine its affect on mean preferred lumbar support height and mean preferred lumbar support depth. This refined model showed that recent back pain/discomfort did not significantly affect lumbar support height settings after adjusting for the effects of BMI, stature and gender. However, recent back pain was shown to be significantly associated with depth settings ($p < 0{\cdot}05$) with sufferers preferring their lumbar support significantly closer to the front of the seat.

4. Discussion

4.1. *Preferred lumbar support height settings*

The present research provides some evidence to support the inclusion of adjustable lumbar support height in office chairs. The most important finding is that BMI was strongly associated with preferred lumbar support height settings whereas stature was not. In the study population, BMI is more likely to represent an index of obesity than muscular development. This indicates that more obese people, regardless of height, prefer sitting on an office chair with a higher lumbar support and that slimmer people prefer sitting on an office chair with a lower lumbar support. For several reasons, this is a very important finding.

The first is that given the variation in body sizes of the Australian multicultural white collar workforce, a single fixed height lumbar support is likely to result in increased discomfort, or reduced comfort, for a high proportion of users compared to a lumbar support that is appropriately adjusted for individual BMIs. The second reason is that this finding provides the first research-based justification for the inclusion of lumbar support height adjustment in office chairs. The third is that it is very often assumed that it is the very tall and very short people who may not be fully accommodated at a fixed height backrest (Lueder 1994, CEN 1994) rather than the plump or the slim.

The association of preferred lumbar support height with BMI has several possible explanations. For more obese people with more weight around the buttocks, it is likely that a higher lumbar support may be necessary to provide adequate

clearance for the extra padding around the buttocks. It is also possible that the extra fat tissue under the buttocks may raise the sitter so that their lumbar spine is effectively higher above the compressed seat – requiring a higher lumbar support height. A lot of fat around the buttocks and the lower back may also reduce the sitter's sensitivity to the position of their lumbar support. The extra padding could prevent the lumbar support from fitting snugly into the small of the back, therefore reducing its effectiveness. This may lead to larger users not fully appreciating the benefits of lumbar support and preferring to set it higher for use as a general backrest. Finally, it is possible that bulkier people do not require the same degree or type of support when sitting as do slimmer people. The extra body tissue may help to support the sitting posture.

Several studies (Grandjean *et al.* 1969, Fernand and Fox 1985, Bodguk and Twomey 1987) have highlighted anatomical and physiological differences between males and females, which could result in significant differences in preferred lumbar support heights. No differences were observed in the preferred lumbar support heights of males and females in this study.

In discussing the issue of fixed versus adjustable height lumbar supports it would be inappropriate not to mention the research by Andersson *et al.* (1979), which has provided the basis for many arguments in favour of the fixed height option. Their radiological study revealed that the shape of the lumbar curves in 10 young healthy males were not significantly affected by variations in the height of lumbar support from L1 to L5. This finding could be interpreted as meaning that the height of a lumbar support need not be exact and can be positioned anywhere within the L1 to L5 range. However, like many clinical studies, one of the major limitations of this research is that it focuses entirely on one function of lumbar support (maintaining lumbar lordosis) and ignores the others (stabilizing the pelvis, minimizing the muscular effort required to support the trunk and relieving the lower spine of some of the upper body weight). This limitation was recognized by Andersson who continued to recommend adjustable height lumbar supports (Andersson *et al.* 1991). Sitting comfort and user preference is commonly used and widely regarded as one of the best overall indicators of good seats and healthy sitting postures (Burandt and Grandjean 1963, Branton 1969, Kroemer and Robinette 1969, Shackel *et al.* 1969, Kroemer 1971, 1994). Accordingly, the present study investigated the preferred settings and adjustment behaviours of office workers trying to achieve the most comfortable lumbar support in their usual office environment.

4.2. *Do people use adjustments?*

The establishment of a relationship between preferred lumbar support height settings and the physical characteristics of individuals does not necessarily imply that height-adjustable lumbar supports are necessary. Research indicates that many users, particularly those who have not had specific training, fail to make use of the chair adjustments provided (Webb *et al.* 1984, Shute and Starr 1984, Lueder 1994). On this premise, there remains a strong argument for a well-positioned fixed height lumbar support that provides the best compromise for the full range of potential users. However, from a review of the literature, Lueder (1994) concludes that people consider adjustability important and will use controls frequently if they are easy to use and circumstances are good.

The majority of subjects in this study did not make adjustments to the height and depth of their lumbar support. Prior to receiving the information on how and why to

make adjustments, only 29% of subjects reported never using backrest height adjustment and 28% reported never using backrest angle for depth adjustment. While some subjects appeared to prefer a set position for lumbar support, others preferred to make more regular adjustments to its position.

A high proportion of subjects continued to adjust both the height and depth of their lumbar support after the time when they believed the research had ended and their settings were no longer being monitored. Of the subjects who readjusted their lumbar support to a more appropriate position by T3, 53% had readjusted it again by T4, 4 weeks later. Some 39% of the subjects readjusted the height of the lumbar support and 45% readjusted the depth. These subjects were either not happy with their initial choice of lumbar support height/depth, or they preferred to make more regular adjustments to its position because of task differences or the need to support different postures. For whatever reason, a fixed height lumbar support would clearly have interfered with the preferred adjustment behaviours of a considerable proportion of users.

In contrast, another distinct group of users appeared not to be concerned about the height of their lumbar support. By the measurement set T3 (4 – 5 days after all backrests had been set to the most forward and lowest position) 35% of subjects had failed to readjust their backrests. Since work activities and absenteeism were not monitored during this period, it is unclear if this is a true representation of the number of subjects who were not concerned about the position of their lumbar support. Even by T4, when all subjects should have had ample opportunity to readjust if desired, 23% of subjects still had not done so. This group was significantly younger than the rest of the subjects, suggesting that older users may be more sensitive to the position of their lumbar support. This supports the observations of Keegan and Nebraska (1953) and Branton (cited in Corlett 1989) that younger people are able to subject their lumbar spines to considerably more stress and strain than older people without experiencing discomfort, and it adds weight to the argument of Keegan and Nebraska (1953) who emphasize the importance of a well-positioned lumbar support to minimize sitting discomfort for users with degeneration of the intervertebral discs. Changes in mobility and degeneration of the lumbar vertebrae and intervertebral discs with age is well documented (Bodguk and Twomey 1987, Floyd and Roberts 1958, Keegan 1962, Kroemer and Robinette 1969, McCall 1992). The sensitivity of older people to the height of their lumbar support should not be disregarded given the ageing workforce.

4.3. *Comfort ranges*

Several findings of this research suggest that, rather than having specific lumbar support height preferences, people may have 'comfort ranges' for lumbar support height settings. It is possible that only when the lumbar support is positioned outside of this comfort range do people perceive a reduction in comfort (or the onset of discomfort) and decide to readjust. Three separate findings support this theory:

(1) The subjects who did not readjust when their lumbar support was moved to its lowest and most forward position were the people who selected lower lumbar supports as their preference for T2. It seems likely that in its lowest position the lumbar support was still within the comfort range of these subjects.
(2) The components of variance analysis indicate that people do not have small and specific regions of personal preference for lumbar support height.

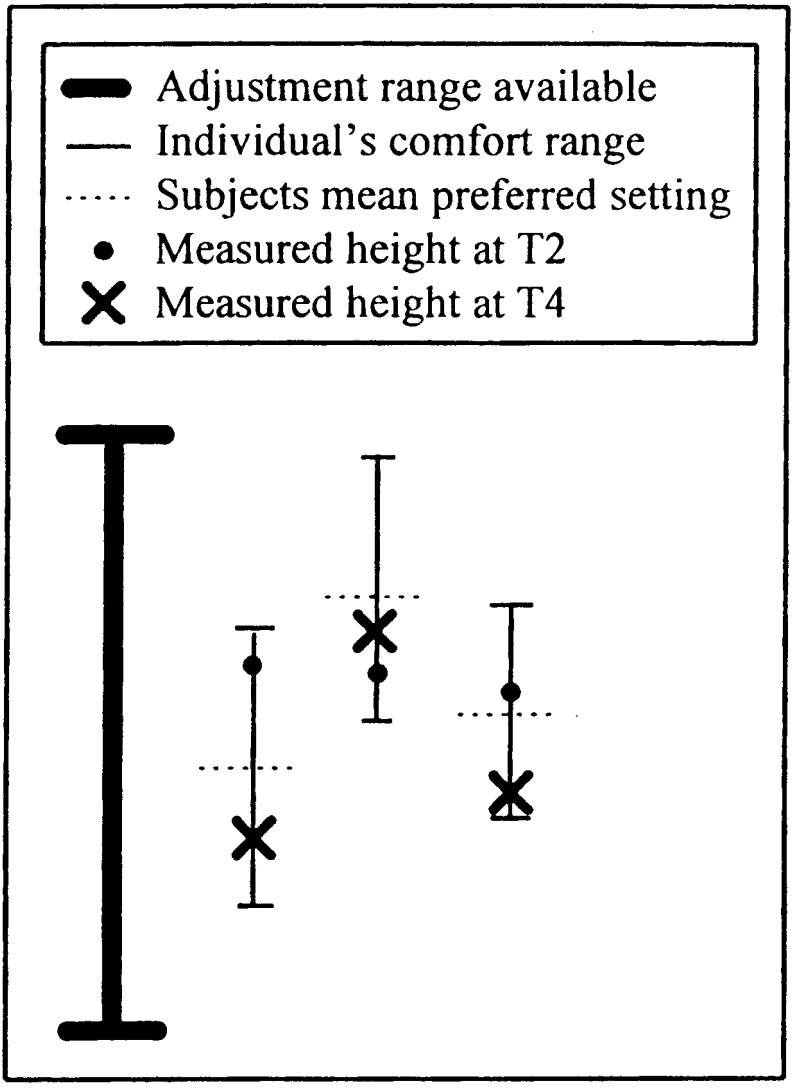


Figure 7. Representation of possible lumbar support height measurements for three hypothetical subjects at T2 and T4.

However, other testing clearly highlighted systematic differences between subjects.

(3) While BMI showed a highly significant association with lumbar support height settings at T4 ($p < 0{\cdot}001$), it was not significantly associated with settings at T2 ($p = 0{\cdot}10$). The concept of comfort ranges may go some way towards explaining this. Since backrest heights started off widely distributed across the available range, lumbar support height settings at T2 could have fallen anywhere within each individual's comfort range. The measured lumbar support height at T2 could therefore have been towards the top of an individual's comfort range, towards the bottom of their comfort range, or

somewhere in the middle. Possible measurements for three hypothetical subjects at T2 are represented by dots (•) in figure 7. The vast majority of backrests were set to the lowest position before subjects readjusted for T4. Presumably, since subjects had to adjust their lumbar support upwards, the majority of settings for T4 are towards the bottom end of most individuals' comfort ranges (see the hypothetical settings represented by crosses (×) in figure 7). The respective positions of these settings, while being lower, would provide a more comparative representation of each subject's mean preferred setting, of which the best estimate is associated with BMI ($p < 0{\cdot}005$). On average lumbar support heights measured at T4 were shown to be significantly lower than lumbar support heights measured at T2 by 12 mm.

If the concept of individual comfort ranges is pursued, this study indicates that the centrepoint of an individual's comfort range above the seat (or their 'mean preferred setting') is partly a function of the individual's body mass index. It could also be argued that the size of an individual's comfort range is to some extent determined by their age, with younger people generally being more tolerant of a wider range of lumbar support heights.

4.4. *Effects of back pain*

The adjustment patterns of subjects who had experienced long-term back pain did not differ from other subjects. However, subjects who experienced back pain, aching or discomfort in the last 6 months, which they thought might be related to their chair or office work, were found to set their lumbar support significantly closer to the front of the seat than subjects who had not. The most likely explanation for this is that people with back pain adjust their lumbar support further forward so as to ensure maximum support for the back.

4.5. *Lumbar support depth*

There were no other associations between subject characteristics and preferred lumbar support depth. Initially it appears surprising that the depths chosen by subjects were entirely independent of stature. However, various other studies report a similar lack of association between upper leg (buttock to popliteal) length and the preferred distance from the front of the seat to the backrest (Le Carpentier 1969, de Groot and Vellinga 1984). There are several possible explanations as to why taller users may not set their lumbar support further back from the front of the seat. First, while the seats of the standard chairs used in this study were essentially flat and not excessively dipped or shaped, the seat provided a definite target area for the buttocks. Placement of the buttocks further back on the seat would almost certainly result in a less even distribution of pressure over the buttocks and upper thighs. Second, sitters frequently like to change their posture (Branton 1969) and regular postural changes when sitting are often recommended (Winkel and Oxenburgh cited in Lueder *et al.* 1994). The more of the thighs that are supported by the seat, the more difficult it is to change posture. Consequently, many taller users may choose not to set their lumbar support further back in order to take advantage of the extra seat depth. Another explanation could be that subjects set their seats higher than is generally recommended as a result of the fixed height desks at which they worked. Higher seats encourage users to sit further forward.

The lumbar support depth measurements recorded in this study indicate that subjects most commonly prefer short lumbar support depths, preferring the backrest

closer to the front of the seat. It is possible that many subjects would have set their lumbar support even closer to the front of the seat if the option had been available to them.

4.6. *Design guidelines*

The following recommendations can be made concerning the design of chairs with lumbar supports adjustable in both height and depth.

(1) The findings of this study indicate that many current recommendations for lumbar support height adjustability may be too high (DIN 1987, Pheasant 1990, Worksafe Australia 1991). The present results suggest that, for the majority of users to be able to achieve their preferred lumbar support height settings, the lumbar support point should adjust from 150 mm to 250 mm above the compressed seat. Certainly the results indicate that, for a lumbar pad with similar shape and contouring to the test chairs, the centrepoint of the adjustment range should be no higher than 200 mm above the compressed seat surface.

(2) To encourage adjustment, controls must be easy to use. This study found that lumbar support depth was more frequently adjusted than lumbar support height. This may be at least partly due to the relative ease of use of the adjustment controls. Many other studies have linked the appropriate use of adjustments with their ease of operation (Hozeski 1986, Lueder 1994, Dainoff cited in Lueder 1994).

(3) Lumbar support height adjustment probably does not need to be continuous. Given that users have comfort ranges for lumbar support height, the provision of four or five discrete options spread across the total range is likely to be just as suitable as a continuous system.

4.7. *Limitations*

Design issues associated with the manufacture of ergonomic chairs for contemporary office tasks are very complex. Despite increased awareness of ergonomics and recommended sitting postures, people continue to spontaneously adopt postures that are considered undesirable. Many studies show that people do not necessarily prefer chairs that correspond to their anthropometric dimensions and frequently fail to adjust chairs accordingly (Burandt and Grandjean 1963, LeCarpentier 1969, Shackel *et al.* 1969, deGroot and Vellinga 1984, Lueder 1994). While this study has demonstrated that people do adjust their chairs, and that there is a strong association between preferred lumbar support height and body mass index, the fact that BMI still only explains 8% of the variance shows that there remains a number of other unexplained variables that affect how high a person likes their lumbar support. These may include variations in sedentary work tasks and temporal factors.

The results of this research can only be interpreted in terms of traditional padded office chairs. The indication that fixed height lumbar supports are unlikely to provide a comfortable or appropriate seat for the wide range of potential users may not apply to other designs that make use of different materials and mechanisms.

5. Conclusion

Based on the evidence that a high proportion of users do make adjustments to the height and depth of their lumbar support, and the finding that different groups of

users, with different physical characteristics, adjust the position of their lumbar support in distinct and predictable ways the researchers conclude that chairs with easy-to-use lumbar support height adjustment must be recommended for contemporary office work.

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