International Journal of Industrial Ergonomics 40 (2010) 8–18

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Designing chairs with mounted desktop for university students: Ergonomics and comfort

M.G. Mohamed Thariq [a,*], H.P. Munasinghe [b], J.D. Abeysekara [c]

[a] *State Timber Corporation, No. 82, Rajamalwatta Road, Battaramulla, Sri Lanka*
[b] *Department of Architecture, Faculty of Architecture, University of Moratuwa, Sri Lanka*
[c] *Work Science Academy, Fårhjordvägen 60, 586 66 Linköping, Sweden*

ARTICLE INFO

Article history:
Received 19 November 2007
Received in revised form
4 October 2009
Accepted 16 October 2009
Available online 14 November 2009

Keywords:
Body dimensions
Mounted desktop
Design
Posture
Comfort

ABSTRACT

The chairs with mounted desktop are widely used in the lecture halls of Sri Lankan universities. An anthropometric survey was carried out among the university students in Sri Lanka to design fixed-type and side-mounted desktop chair and to assess the comfort levels of it based on the design dimensions. The first part of the study focused on design dimensions of the mounted desktop and recommended the dimensions for it. The side-mounted desktop chair needs to be tested for its effect on posture and comfort with proposed dimensions on user population.

Relevancy to industry: The existing design of side-mounted desktop chair is unlikely to satisfy the postural and comfort requirements of university students in their learning environment. The chair that supports the development of healthy and comfortable posture is considered important for students to produce healthy workforce to the industries.

1. Introduction

Chairs have become an important physical element of the learning environment. Chairs with side-mounted desktops are widely used in the lecture halls of Sri Lankan universities. The desktops are usually mounted on the right side of the chairs, where the armrests are fitted. The side-mounted desktops are used for writing purposes, instead of placing tables in front of the sitters. Two main advantages are associated with this type of lecture hall chair: saving the space occupied by tables and reducing the cost incurred in purchasing tables. When making furniture procurement decisions, university authorities are influenced by these advantages. Fixed-type chairs are generally used in the Sri Lankan universities; in general, junior schools, high schools and universities opt for fixed-type chairs and tables because of the funding and maintenance issues involved with adjustable chairs (Straker et al., 2006).

Educational furniture is expected to facilitate learning by providing a comfortable and stress-free workstation. The general impression among researchers is that sitting in fixed-type tables and chairs lead to the development of constrained postures. Several studies have investigated the postural problems associated with school furniture and its design (Parcells et al., 1999; Milanese and Grimmer, 2004; Murphy et al., 2004; Gouvali and Boudolos, 2006). Traditional chairs and tables forced the students to sit in cumbersome positions (Hänninen and Koskelo, 2003). Troussier et al. (1999) found that 23% of children experienced back pain in the sitting position, and the frequency of back pain increased with the duration of sitting at school. According to Parcells et al. (1999), school children are at special risk for negative effects from badly designed and ill-fitting furniture, due to prolonged periods of sitting during school. According to Genaidy and Karwowski (1993), the combination of bad posture and poor seating coupled with long periods of immobility can lead to the development of lower back pain. Grimes and Legg (2004) stated that with expectations and emphasis (in some sectors) on greater educational achievements, the duration of sitting is likely to increase. Along with the health-related consequences, an uncomfortable sitting posture can destroy a student's learning interest, even during the most stimulating and interesting lessons (Hira, 1980).

Workstations with adjustable seats are favored, since people differ in size and postural preference. Adjustable chairs are preferred for school students or adults, to promote health and comfort in sitting (Straker et al., 2006). Lueder (1994) stated that seat height adjustability is the most important element of a workstation and is used the most often. Seat height adjustability appears

* Corresponding author. Tel.: +94 112866612, +94 772640558 (mobile); fax: +94 112885850.
E-mail address: thariq026@yahoo.com (M.G. Mohamed Thariq).

0169-8141/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.ergon.2009.10.003

to be necessary (Helander et al., 1987). Hänninen and Koskelo (2003) found that the tension in the lumbar and trapezius muscles was significantly reduced among high school students who used adjustable tables and chairs. Toomingas and Gavhed (2008) conducted a study of call center operators, and concluded that optimal adjustment of the chair may contribute to less frequent neck/scapulae and back pain. A variety of designs of school furniture are being promoted for the improvement of posture and/or motility/mobility (Molenbroek et al., 2003). Jung (2005) developed and evaluated adjustable prototype tables and chairs for students. Adjustability of school furniture is an important feature in ensuring equal educational opportunities, increased comfort, and decreased incidence of musculoskeletal symptoms (Grimes and Legg, 2004). Hira (1980), after investigating fixed-type university chairs, suggested that the seats should be adjustable. Khanam et al. (2006) evaluated fixed-type university furniture, including a mounted desktop chair, and concluded that students preferred the furniture height to be adjustable. A workstation, including office equipment and furniture, designed to accommodate a wide range of postures is beneficial (Toomingas and Gavhed, 2008). Robinette (2006) urged that a product's ultimate success depends on how the variations in shape and size of the user population will be accommodated. Our literature review indicates that providing an optimal design solution with sufficient comfort is an extremely difficult task when a fixed-type chair is used.

According to Evans et al. (1992), it has not been shown that whether school furniture is responsible for students' discomfort, and whether discomfort can be related to a mismatch between an individual's anthropometry and the dimensions of that individual's school chair and desk. Despite this, Grimes and Legg (2004) stated that a mismatch between thigh length and seat depth is significantly related to general sitting discomfort, and a mismatch in seated elbow height and desk height is significantly related to reported neck and shoulder pain. The bodily dimensions of the user population are of primary importance in the design of workstations (Helander et al., 1987) to accommodate healthy and comfortable posture. Nissinen et al. (1994) stated that anthropometric measurements have also been taken to be a predictor of low back pain, although their role seems modest. According to Balague et al. (1993), the anthropometric parameters are one of the factors associated with lower back pain. Even though the design requirements for seating are different for students and adults (Straker et al., 2006), the reviewed literature indicates that anthropometric parameters are one of the important factors in deriving chair dimensions and in designing comfortable furniture for both students and adults.

Little attention has been paid to designing ergonomically correct side-mounted desktop chairs for university students. Thariq and Munasinghe (2005) found that the present day Sri Lankan university lecture room chairs do not fit the bodily dimensions of the students. On the other hand, the availability of data about the anthropometric characteristics of Sri Lankans related to chair design is very limited. A national anthropometric survey of the working population was carried out by Abeysekara (1985). He recommended a set of dimensions for seating at work. However, furniture designers or manufacturers have not used these dimensions, as they are not aware of the availability of this data. Also, the recommendations made by Abeysekara (1985) for work seat design are based on anthropometric data from a specific working population, and may not fit the present university student population of Sri Lanka.

The design dimensions presently used to construct lecture room chairs are a copied and modified version of British Standards (Thariq and Munasinghe, 2005). The study conducted by Thariq and Munasinghe (2005) further recommended that an anthropometric survey is needed to determine the design dimensions of educational furniture for university students. Hence, the intention of the study is to develop design dimensions for fixed-type side-mounted desktop chairs for university students in Sri Lanka. The present study is mainly focused on a design featuring a mounted desktop.

2. Method of study

Anthropometric measurements were taken from normal, healthy undergraduate students of two Sri Lankan Universities; the University of Peradeniya and the University of Moratuwa. The measurements were taken during the last quarter of 2005 and the first quarter of 2006. Students in their first year to their final year were selected for measurement. The sample consisted of 385 subjects: 221 males and 164 females. Their ages ranged from 20 to 28, with a mean age of 22.4 and a standard deviation of 1.6.

The anthropometric measurements taken were stature, eye height (sitting), sitting height, shoulder height (sitting), elbow height (sitting), lowest rib bone height (sitting), upper hip bone height (sitting), thigh clearance (sitting), seat surface height, hip breadth, forward arm reach, forearm–finger tip length, buttock-popliteal length, buttock-knee length, and weight (Fig. 1) and (Annex 1). Two anthropometers were used. Both anthropometers were tested against each other for consistency in measurements, and were found to be consistent. An adjustable stool and a bathroom scale were also used. The measurements were taken according to the procedure described by Weiner and Lourie (1969), Pheasant (1986) and Abeysekara (1985).

Subjects wore light normal dress, with empty pockets and no shoes. All sitting measurements were taken with subjects sitting in a fully erect posture, so that the knees and ankles formed right angles. The data was cross-checked for consistency, and inconsistent data was deleted. The data was analyzed using the MINITAB and SPSS statistical software packages.

3. Results and discussions

3.1. Seat height – seated elbow height bivariate cases for female sample

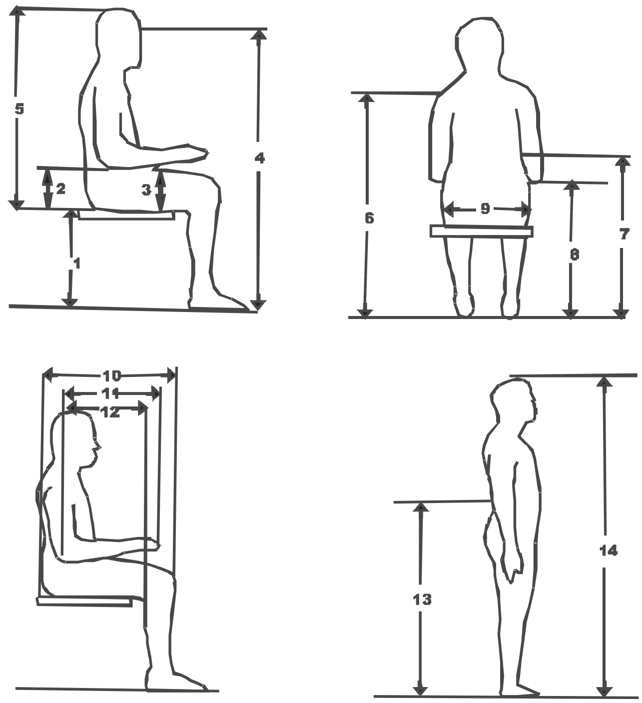
Determination of the seat height and seated elbow height is considered to be a bivariate anthropometric design problem. A scatter plot of the seat height and seated elbow height for the female sample is shown in Fig. 2. An ellipse enclosing 90% of the sample was imposed on the scatter plot. It was assumed (Robinette, 2006) that if the boundary cases selected in the ellipse (Case 1, Case 2, Case 3 and Case 4) are accommodated in the design, then all of the cases inside the ellipse would be accommodated.

To determine the seat height and the seated elbow height dimensions (Table 1), certain cases were examined more deeply. Since the dimensions for our chair are fixed, only a single dimension has to be taken for each chair feature under consideration. Therefore, we examine the mismatches among the four cases for a single dimension at a time. This process helped to identify how well the seat height fit across the different cases and the acceptability of the seated elbow height of the population under investigation. The method developed by Parcells et al. (1999) and later used by Panagiotopoulou et al. (2004) was employed to investigate the mismatch.

3.1.1. Elbow and shoulder height and desk height mismatch

The acceptable desk height is determined by the following equation:

$$hE = hEv + U[(1-\cos\theta) + \cos\theta(1-\cos\beta)],$$



1. Seat surface height
2. Elbow height, sitting
3. Thigh clearance
4. Eye height, sitting
5. Sitting height
6. Shoulder height, sitting
7. Lowest rib bone height, sitting
8. Upper hip bone height, sitting
9. Hip breadth
10. Buttock knee length
11. Forearm finger tip length
12. Buttock popliteal length
13. Elbow height, standing
14. Stature

Fig. 1. Anthropometric measurements.

where *hE* is the vertical distance from the top of the desk to the student's sitting surface, *hS* is the shoulder height, *hEv* is the elbow height, $U = hS - hEv$ is the upper arm length, (θ) is the shoulder flexion and (β) is the shoulder abduction.

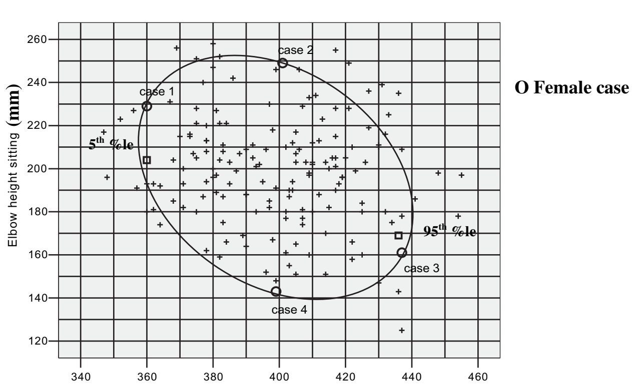


Fig. 2. Bivariate frequency distribution of seated elbow height and seat height of females, with 90% probability ellipse.

According to Chaffin and Anderson (1991), the minimum and maximum acceptable angles of the shoulder during writing are 0–25° of shoulder flexion and 0–20° of shoulder abduction. For the flexion angles, the corresponding cosines are 1 (0°) and 0.9063 (25°), and for the abduction angles, the corresponding cosines are 1 (0°) and 0.9397 (20°). By substituting these values in the previous equation, the desk height is determined by the following equations:

$$\text{Minimum desk height} = \text{seat height} + hE$$

where $hE = hEv + U[(1-1)+(1-1)] = hEv$.

The minimum desk height is determined by the vertical elbow height alone.

Table 1
Seat height and elbow height (sitting) dimensions (mm) for boundary cases.

Females	Case 1	Case 2	Case 3	Case 4	5th %le	95th %le
Seat height	360	401	437	399	360	436
Elbow height (sitting)	229	249	161	143	151	246
Males	Case 5	Case 6	Case 7	Case 8	5th %le	95th %le
Seat height	373	420	482	444	385	473
Elbow height (sitting)	221	259	185	157	164	254

The maximum desk height is determined by:

$$\begin{aligned} hE &= hEv + U[(1-\cos\theta) + \cos\theta(1-\cos\beta)] \\ &= hEv + U[(1-0.9063) + 0.9063(1-0.9397)] \\ &= 0.8517hEv + 0.1483Hs, \text{ since } U = hS - hEv. \end{aligned}$$

Thus, the elbow–shoulder height and the desk height were defined to be mismatched when the desk was either shorter than the minimum desk height or taller than the maximum desk height.

3.1.2. Popliteal and seat height mismatch

A mismatch was defined to be a seat height of either >95% or <88% of the popliteal height.

Mismatches in the seated elbow heights and the seat heights were examined for the different cases in the female sample. Tables 2 and 3 show the results of the examination.

Table 2 showed that the Case 1 seated elbow height (229 mm) was acceptable to Case 1 and Case 2, while Case 2 (249 mm) was acceptable only to Case 2. The Case 3 seated elbow height (161 mm) was acceptable only to Case 3, while Case 4 (143 mm) was acceptable to Case 3 and Case 4.

In this study, we measured the seat surface height instead of the popliteal height. In examining the mismatches, the seat surface height was considered to be the popliteal height. When the same cases were examined for mismatches (for example Case 1 – Case 1), they were considered to fit, since the measurements taken were of the seat height. Examination of mismatches between seat height dimensions (Table 3) showed that the Case 1 seat height dimension (360 mm) fits with Case 1, Case 2, and Case 4, while it was too low for Case 3. The Case 2 dimension (401 mm) fits with Case 2, Case 3, and Case 4, whereas it was too high for Case 1. The Case 3 dimension (437 mm) fits only with Case 3, as it was too high for Case 1, Case 2, and Case 4. The Case 4 dimension (399 mm) fits with Case 2, Case 3, and Case 4 but was too high for Case 1. The Case 2 and Case 4 seat height dimensions and their fits were found to be similar.

3.2. Seat height – seated elbow height bivariate cases for male sample

A scatter plot (Fig. 2) for the male sample was drawn. The variables were seat height and seated elbow height. An ellipse enclosing 90% of the sample was imposed on the scatter plot. The previously mentioned assumption was made, and the boundary cases selected were denoted in Case 5, Case 6, Case 7 and Case 8 (Table 4).

The Case 5 seated elbow height dimension (221 mm) was acceptable to Case 5 and Case 6 (Table 4), but was unacceptable to Case 7 and Case 8. The Case 6 seated elbow height dimension (259 mm) was acceptable only to Case 6. The dimension for Case 7 (185 mm) was acceptable to Case 5 and Case 7 but was unacceptable to Case 6 and Case 8. Case 8 (157 mm) was acceptable to Case 7 and Case 8 and unacceptable to Case 5 and Case 6.

The Case 5 seat height dimension (373 mm) (Table 5) fit only to Case 5, being too low for Case 6, Case 7 and Case 8. The Case 6 dimension (420 mm) was acceptable to Case 6 and Case 8, while it was too low for Case 7 and too high for Case 5. The Case 7 seat height dimension (482 mm) fits only to case 7, as it was too high for Case 5, Case 6 and Case 8. The Case 8 seat height dimension (444 mm) fits to Case 7 and Case 8, while it was too high for Case 5 and Case 6.

Table 3
Seat height fit between cases for female sample.

Cases for seat height	Case 1	Case 2	Case 3	Case 4
Case 1 (360 mm)	Fits	Fits	Too low	Fits
Case 2 (401 mm)	Too high	Fits	Fits	Fits
Case 3 (437 mm)	Too high	Too high	Fits	Too high
Case 4 (399 mm)	Too high	Fits	Fits	Fits

3.3. Seat height – seated elbow height bivariate cases for combined male and female sample

A scatter plot of the seat height and seated elbow height (Fig. 4) was drawn for the combined male and female sample. An ellipse enclosing 90% of the sample was imposed. The previously mentioned assumption was again made. The selected boundary cases (Fig. 4 and Table 6) were Case 1, Case 6, Case 7 and Case 8. Case 4 was outside of the ellipse and Case 2, Case 3 and Case 5 were inside of the ellipse.

In this study, our purpose is to determine seat height and seated elbow height dimensions for a fixed-type chair. Therefore, the mismatches in seat height between the different cases and acceptability of the seated elbow height (Table 6) for different cases were further examined using the procedure described above.

The Case 1 seated elbow height (229 mm) was acceptable to Case 1 and Case 6 (Table 7). Case 6 (259 mm) was acceptable only to Case 6. The Case 7 seated elbow height (185 mm) was acceptable to Case 1 and Case 7. The Case 8 elbow height (sitting) dimension (157 mm) was acceptable to Case 7 and Case 8.

The Case 1 seat height dimension (360 mm) only fits with Case 1 and was too low for Case 6, Case 7, and Case 8 (Table 8). The Case 6 seat height dimension (420 mm) fits Case 6 and Case 8 but was too high for Case 1 and too low to Case 7. The Case 7 dimension (482 mm) only fits Case 7 being too high for Case 1, Case 6, and Case 8. The Case 8 seat height dimension (444 mm) fits with Case 7 and Case 8, while it was too high for Case 1 and Case 6.

3.4. Seat height – seated eye height bivariate cases for female sample

A scatter plot (Fig. 5) of the seat height and seated eye height was drawn for the female sample. An ellipse enclosing 90% of the sample was imposed on the scatter plot. The previously mentioned assumption was again made, and the selected boundary cases were Case 9, Case 10, Case 11, and Case 12 (Fig. 5 and Table 9).

We examined the seated eye height boundary cases (Fig. 5 and Table 9) to design a fixed-type side-mounted desktop chair. According to Grimes and Legg (2004), an adult's focal range is 500–700 mm (due to presbyopia), and a school child's focal range is approximately 300 mm. University students in our sample were

Table 2
Acceptability of elbow height (sitting) between cases for female sample.

Cases for elbow height (sitting)	Case 1	Case 2	Case 3	Case 4
Case 1 (229 mm)	Acceptable	Acceptable	Unacceptable	Unacceptable
Case 2 (249 mm)	Unacceptable	Acceptable	Unacceptable	Unacceptable
Case 3 (161 mm)	Unacceptable	Unacceptable	Acceptable	Unacceptable
Case 4 (143 mm)	Unacceptable	Unacceptable	Acceptable	Acceptable

Table 4
Acceptability of elbow height (sitting) between cases for male sample.

Cases for elbow height (sitting)	Case 5	Case 6	Case 7	Case 8
Case 5 (221 mm)	Acceptable	Acceptable	Unacceptable	Unacceptable
Case 6 (259 mm)	Unacceptable	Acceptable	Unacceptable	Unacceptable
Case 7 (185 mm)	Acceptable	Unacceptable	Acceptable	Unacceptable
Case 8 (157 mm)	Unacceptable	Unacceptable	Acceptable	Acceptable

Table 5
Seat height fit between cases for male sample.

Cases for seat height	Case 5	Case 6	Case 7	Case 8
Case 5 (373 mm)	Fits	Too low	Too low	Too low
Case 6 (420 mm)	Too high	Fits	Too low	Fits
Case 7 (482 mm)	Too high	Too high	Fits	Too high
Case 8 (444 mm)	Too high	Too high	Fits	Fits

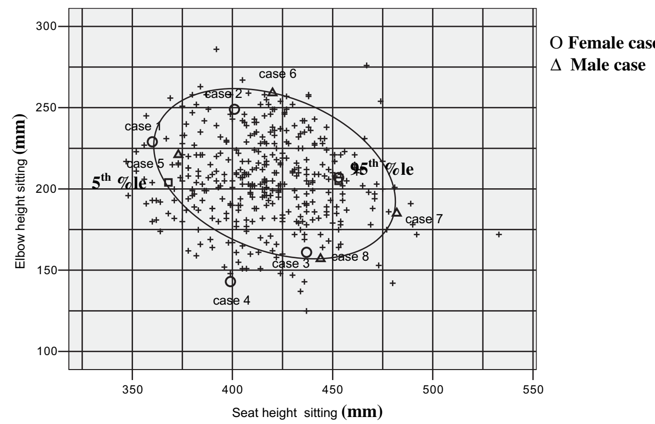


Fig. 4. Bivariate frequency distribution for seated elbow height and seat height of the combined male and female samples, with 90% probability ellipse.

young adults (mean age was 22.4, with a standard deviation of 1.6) and have just completed their growth stages. Therefore, the focal range of our student sample was taken from 300 mm to 700 mm, to include the focal range of both school children and adults. The viewing distances of the boundary cases within this focal range were considered acceptable viewing distances. To find the viewing distance for each case, the seated elbow height was subtracted from seated eye height. The seated elbow height for the female sample in this study was 229 mm (determination of this dimension was described in Section 4). To find the viewing distances for the female cases, the seated elbow height (229 mm) was subtracted from the seated eye height of each female case. This analysis showed that the viewing distances of all four female cases (Case 9, Case 10, Case 11, and Case 12) are within the acceptable focal range.

Comparing Tables 1 and 9 for the seat height dimensions in the female cases showed that Case 1, Case 2, Case 3, and Case 4 in Table 1 were found to be slightly different than Case 9, Case 10, Case 11, and Case 12 in Table 9, respectively. Likewise, for the male cases, the seat height dimensions of Case 5, Case 6, Case 7, and Case 8 in Table 1 were found to be slightly different than Case 13, Case 14, Case 15, and Case 16 in Table 9, respectively. Hence, the mismatches of seat height dimensions between the cases in Table 9 were not further examined.

3.5. Seat height – seated eye height bivariate cases for male sample

Scatter plot (Fig. 6) of the seat height and seated eye height was drawn for the male sample. An ellipse enclosing 9% of the sample was imposed on scatter plot. The previously mentioned assumption was again made, and the selected boundary cases were Case 13, Case 14, Case 15, and Case 16 (Fig. 6 and Table 9).

The same procedure used to determine the viewing distances for female cases (Section 3.4) was applied to the male cases in Table 9 and Fig. 6. The seated elbow height for the male sample was 221 mm (determination of this dimension described under Section 4). The viewing distances of all four male cases, i.e., Case 13, Case 14, Case 15, and Case 16 (Table 9), were found to lie within the acceptable focal range.

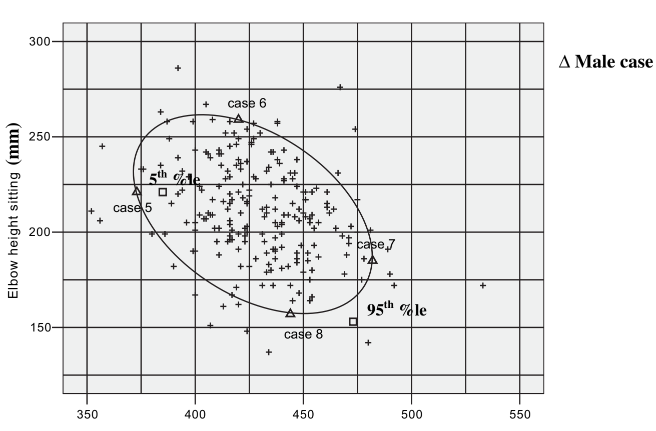


Fig. 3. Bivariate frequency distribution for seated elbow height and seat height of males, with 90% probability ellipse.

3.6. Seat height – seated eye height bivariate cases for combined female and male sample

Scatter plot (Fig. 7) of the seat height and seated eye height was drawn for the combined male sample. An ellipse enclosing 90% of the sample was imposed on scatter plot. The previously mentioned assumption was again made, and the selected boundary cases were Case 9, Case 13, Case 17, and Case 18 (Fig. 7 and Table 10).

Case 17 and Case 18 were newly selected from the extreme boundary of the ellipse. Case 12, Case 14 and Case 15 were found to be outside of the ellipse. Case 10, Case 11, and Case 16 were inside of the ellipse. The cases are shown below (Table 10). The seat heights of the new cases in this combined sample were examined for mismatches and the results are given in Table 11.

The same procedure for determining the viewing distances of the female cases (Section 3.4) was adopted for the combined sample cases in Table 10 and Fig. 7. The seated elbow height of the combined sample was 229 mm (determination of this dimension is described under Section 4). The viewing distances of all four boundary cases (Case 9, Case 13, Case 17, and Case 18) of the combined sample were found to be within the acceptable focal range.

The Case 9 seat height dimension (357 mm) (Table 11) fits with Case 9 and Case 13 while it was too low to Case 17 and Case 18. The Case 13 seat height dimension (375 mm) fits only with Case 13 and it was too high to Case 9 and too low to Case 17 and Case 18. The Case 17 seat height dimension (475 mm) fits only with Case 17 and too high to Case 9, Case 13 and Case 18. The Case 18 seat height dimension (446 mm) fits with Case 17 and Case 18 while it was too high to Case 9 and Case 13.

Table 6
Seat height and elbow height (sitting) dimensions (mm) for boundary cases for both female and male combined sample.

Females and Males Combined	Case 1	Case 6	Case 7	Case 8	5th %le	95th %le
Seat height	360	420	482	444	368	467
Elbow height (sitting)	229	259	185	157	160	252

Table 7
Acceptability of elbow height (sitting) between cases for combined sample.

Cases for elbow height (sitting)	Case 1	Case 6	Case 7	Case 8
Case 1 (229 mm)	Acceptable	Acceptable	Unacceptable	Unacceptable
Case 6 (259 mm)	Unacceptable	Acceptable	Unacceptable	Unacceptable
Case 7 (185 mm)	Acceptable	Unacceptable	Acceptable	Unacceptable
Case 8 (157 mm)	Unacceptable	Unacceptable	Acceptable	Acceptable

4. Discussion

The side-mounted desktop is the primary feature of this chair. The desktop is positioned where the armrest is fitted. Furniture manufacturers arbitrarily assemble 95% of the desktops on the right side and 5% on the left side of the chairs. This is done with the assumption that around 5% of the users are left-handed. Determining the correct position for the desktop is a critical aspect in the design process, which may affect the comfort and health of the students.

Almost all of the available research and recommendations are for a work surface positioned right in front of the occupant. Some researchers have recommended that the work surface height should be the same as the seated elbow height or slightly lower (e.g., Floyd and Robert, 1958; Oxford, 1969). Pheasant (1984) recommended different working heights for different tasks. For light tasks, such as writing, he suggested elbow level or above. Ayoub (c. Evans et al., 1988) proposed that the nature of the task should determine the table height. He suggests that, for coarse or medium manual work, the work surface should be equal to elbow height. He recommends progressively higher surfaces for writing, light assembly work, or precision work. Marmaras and Nathanael (2006) stated that a working surface should be at a height that permits a person to work with the shoulders in a relaxed posture. To increase comfort and to minimize occupational risks, the angle between the upper arm and elbow should be about 90° if no force is required. The sitting elbow height of the subject should approximate the vertical distance from the table surface to the seat surface (Milanese and Grimmer, 2004). The literature states that a working height equal to the seated elbow height or a little above is acceptable for writing.

Determining a fixed working height dimension for the side-mounted desktop chair is a critical task. The BSI standards (BS5873: Part 1, 1980) on school furniture recommended table heights slightly higher than the resting elbow height for most of the target population. In the Hong Kong standards, the 95th percentile resting elbow heights of the target groups have been added to the seat height (Evans et al., 1988). Molenbroek et al. (2003) used the 95th percentile of seated elbow height as the table height for school students. The 95th percentile of the seated elbow height was 252 mm for the combined female and male sample (Table 12). The 95th percentiles of seated elbow height for the female sample and the male sample were 246 mm and 254 mm, respectively (Table 1).

It is argued that using percentiles of anthropometric data is inappropriate to recommending design dimensions for certain chair features. Percentiles, minimums and maximums are one-dimensional points. It has become common for them to be used for multi-dimensional problems, but it is inappropriate and dangerous to do so (HFES 300 Committee, 2004; Robinette, 2006). The 95th percentile seated elbow height dimension, i.e., 252 mm, may not fit the targeted population percentage. This is because seated elbow height and seat height are bivariately distributed. Instead of using percentiles to determine seat height, seated elbow height, and seated eye height for a fixed-type seat, we used an alternative method (HFES 300 Committee, 2004; Robinette, 2006) and examined the boundary cases.

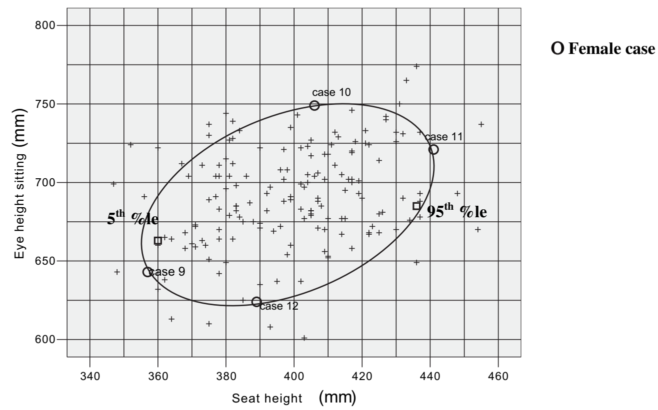


Fig. 5. Bivariate frequency distribution for seated eye height and seat height of females, with 90% probability ellipse.

For the female sample (Table 2), it was found that none of the boundary cases' dimensions (seated elbow height) were acceptable for all four cases. This makes the task of determining a single seated elbow height dimension for a fixed-type chair extremely difficult. The Case 2 (249 mm) and the Case 3 (161 mm) seated elbow height dimensions were acceptable only to themselves; hence, Case 2 and Case 3 were not selected for determining a single dimension of this chair. The Case 1 seated elbow height dimension (229 mm) was acceptable to Case 1 and Case 2, while it was unacceptable to Case 3 and Case 4. The Case 4 seated elbow height dimension (143 mm) was acceptable to Case 3 and Case 4, while it was unacceptable to Case 1 and Case 2. The Case 4 was the lower extreme dimension, and was dropped due to biomechanical consequences. According to Marmaras and Nathanael (2006), if the working surface is too low, a person will bend forward too far; if it is too high, he or she will be forced to raise the shoulders, provoking excessive muscle strain on the back and shoulders. Toomingas and Gavhed (2008) shared a similar conclusion from their findings. Therefore, from the four examined boundary cases, the Case 1 seated elbow height dimension (229 mm) for the mounted desktop was found to be more acceptable than the other cases' dimensions in the investigated female sample.

The seat height of Case 1 dimension was 360 mm (Tables 1 and 3), which is the extreme low value for the female sample, and it fits Case 1, Case 2, and Case 4. Both the Case 2 seat height dimension (401 mm) and the Case 4 seat height dimension (399 mm) fits Case 2, Case 3, and Case 4. Of the four boundary cases examined, Case 1, Case 2, and Case 4 were found with more fit for seat height. If the

Table 8
Seat height fit between cases for combined sample.

Cases for seat height	Case 1	Case 6	Case 7	Case 8
Case 1 (360 mm)	Fits	Too low	Too low	Too low
Case 6 (420 mm)	Too high	Fits	Too low	Fits
Case 7 (482 mm)	Too high	Too high	Fits	Too high
Case 8 (444 mm)	Too high	Too high	Fits	Fits

Table 9
Seat height and eye height (sitting) dimensions (mm) for boundary cases.

Females	Case 9	Case 10	Case 11	Case 12	5th %le	95th %le
Seat height	357	406	441	389	360	436
Eye height (sitting)	643	749	721	624	632	737
Males	Case 13	Case 14	Case 15	Case 16	5th %le	95th %le
Seat height	375	426	489	424	385	473
Eye height (sitting)	751	828	752	696	701	817

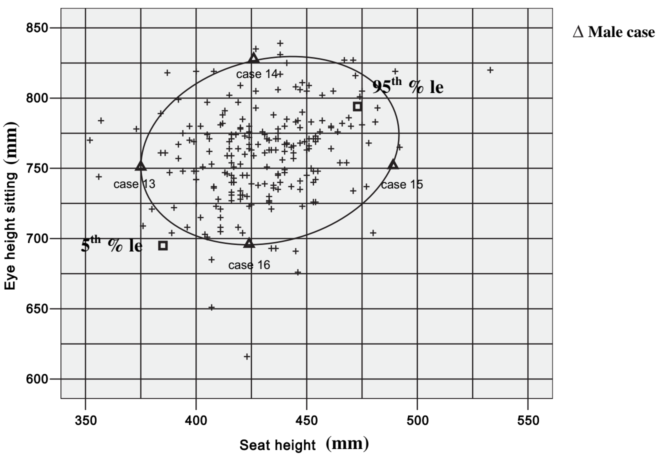


Fig. 6. Bivariate frequency distribution for seated eye height and seat height of males, with 90% probability ellipse.

seat height is too low, there is a marked tendency for the student to slouch, push their feet forward and become a nuisance to others, whereas a seat is uncomfortable if it is too high (Hira, 1980). The Case 2 (401 mm) was found to be the most reasonable seat height for the investigated female sample. The Case 1 seated elbow height dimension (229 mm) and the Case 2 seat height dimension (401 mm) were found to be less harmful in the side-mounted desktop chair. According to Robinette (2006), the dimensions for each case must be applied to the design as a set. It seems that Robinette's (2006) recommendation is applicable to adjustable chairs. Applying the case dimensions as a set to design a fixed-type chair seems difficult.

Determining the seated elbow height dimension from the male cases showed that a single case's dimension for a fixed seat might not be optimal (Table 4), because the seated elbow height dimensions of Case 5, Case 7 and Case 8 were each acceptable to two cases and unacceptable to two cases. The Case 6 dimension (259 mm) was acceptable only to itself (Table 4). The Case 8 dimension (157 mm) was the lower extreme for seated elbow height, and was not selected due to biomechanical consequences. The Case 5 (221 mm) and Case 7 (185 mm) seated elbow height dimensions were more acceptable.

Table 10
Boundary case dimensions (mm) for seat height and eye height (sitting) for both female and male combined sample.

Females and males combined	Case 9	Case 13	Case 17	Case 18	5th %le	95th %le
Seat height	357	375	475	446	368	467
Eye height (sitting)	643	751	808	676	651	806

Examination of the seat heights of the male cases showed that the seat height of Case 5 (373 mm) was the lower extreme for the male sample (Fig. 3 and Table 5). The seat height of Case 5 fits only to itself, while it was too low for Case 6, Case 7, and Case 8. As we stated before, a chair that is too low is not favorable to the classroom environment (Hira, 1980). The Case 7 seat height dimension (482 mm) is the upper extreme for male sample, and also fit only to itself. The seat heights of Case 5 and Case 7, two opposite extremes, were not selected. The seat height dimension of Case 8 (444 mm) fits only to cases with longer lower legs, i.e., Case 7 and Case 8. It was too large for cases with shorter lower leg lengths. The Case 6 seat height dimension (420 mm) fits Case 6 and Case 8, while it was too high for Case 5 and too low for Case 7. The Case 6 seat height dimension was found to better fit the male sample under investigation. The Case 5 seated elbow height dimension (221 mm) and the Case 6 seat height dimension (420 mm) were found to be less harmful dimensions for a fixed-type chair designed for the investigated male sample. We selected different cases' dimensions for seated elbow height and seat height. This indicates that the recommendation of Robinette (2006), i.e., that the dimensions for each case must be applied to the design as a set, was inapplicable to the male sample as well as the female sample. It seems that the recommendation of Robinette (2006) is not applicable to fixed-type chairs.

In the combined female and male sample, three male cases (Case 6, Case 7, and Case 8) and one female case (Case 1) happened to be selected from the boundary of the ellipse (Fig. 4 and Table 6). The Case 1 (female) seated elbow height dimension (229 mm) was similar to the Case 5 (male) seated elbow height dimension (221 mm). Similar results were obtained for the seat height dimension of the combined sample (Tables 7 and 8). The Case 1's (female) seated elbow height dimension (229 mm) and Case 6's (male) seat height dimension (420 mm) were found to be a reasonable compromise for the fixed-type side-mounted desktop

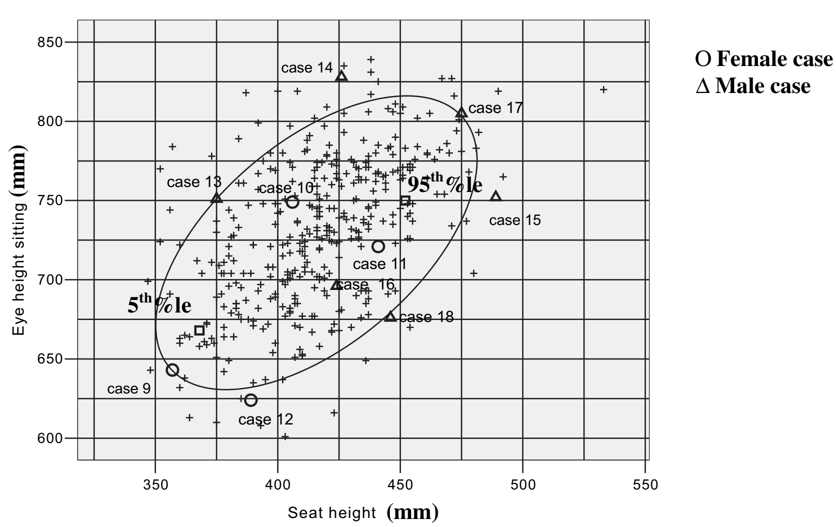


Fig. 7. Bivariate frequency distribution for seated eye height and seat height of the combined male and female samples, with 90% probability ellipse.

Table 11
Fit for seat height between cases for combined sample.

Cases for seat height	Case 9	Case 13	Case 17	Case 18
Case 9 (357 mm)	Fits	Fits	Too low	Too low
Case 13 (375 mm)	Too high	Fits	Too low	Too low
Case 17 (475 mm	Too high	Too high	Fits	Too high
Case 18 (446 mm)	Too high	Too high	Fits	Fits

chair designed for the combined sample under investigation. A shoe allowance (Table 13) has to be added to the seat height dimension, since the measurements were taken barefoot.

Based on the univariate method, in which percentiles were used, the 95th percentile seated elbow height dimension was 252 mm and the 5th percentile seat height was 368 mm for the combined sample (Table 12). Marked differences were found between the dimensions obtained using the multi-dimensional (alternative) method or using the percentiles. The assumption in the alternative method is that if the boundary cases selected on the ellipse are accommodated in the design, all of the cases inside of the ellipse (90% probability ellipse) will be accommodated. However, the accommodation of 90% of the cases for the side-mounted desktop chair designed with the proposed seated elbow height and seat height dimensions could not be ensured. The investigation indicated that designing a fixed-type mounted desktop chair with dimensions that accommodate 90% of the cases is a difficult task. The anthropometric fits a prototype mounted desktop chair with the proposed dimensions (Fig. 8) should be tested in the user population before making a final design recommendation.

The side-mounted desktop may promote different postures than a desk placed opposite to the users. A marked variation in arm posture is expected between a side-mounted desktop and a desk placed opposite to the users. According to Hira (1980), when the table is placed opposite to the users, the arms are supported on the desk (in the forward direction) for a large percentage of the time. A forward inclination, with both arms supported on the desk, was one of the three postures observed by Floyd and Ward (1969) during classroom activities. Toomingas and Gavhed (2008) observed that most of the time, the desk supports the forearms when a computer is being used. In contrast, in the side-mounted desktop chair, the writing arm will be supported by the side-mounted desktop. The writing arm can be kept closer to the body in a relaxed position. Shoulder flexion is therefore not expected in this chair. Chaffin (1973) has shown that even slight shoulder flexion can create fatigue in the shoulder musculature (Marras, 2006). Moving or placing the arms beyond shoulder width will increase the risk of awkward shoulder posture (Toomingas and Gavhed, 2008).

In the mounted desktop chair, an armrest on the side opposite the desktop is not recommended. Khanam et al. (2006) found that an armrest on the side-mounted desktop chair was uncomfortable for 70% of users; this could be because it interfered with the body while moving in and out of the chair. However, Lueder (2006) stated that armrests have been shown to improve posture and promote freedom of movement while stabilizing one's position, reduce the muscle load on the neck, shoulder and arms, reduce pressure on the spine, distribute pressures on the seat, support rising and sitting in the chair and support task-related movements. Nag et al. (2008) also found that the armrest component of the seat had a large contribution to reducing the weight on the seat pan and mitigating stress in the spine and other structures. However, Nag et al. (2008) stated that the height of the armrest needs to be optimized for it to be useful to the sitter. Thariq and Munasinghe (2005) found that in existing mounted desktop chairs, both the armrest and the desktop are fixed at the same level.

Table 12
Anthropometric measurements of university students in relation to chair design, mean values and percentile values (female and male combined sample).

Anthropometric measurement	Mean (SD)	5%le	50%le	90%le	95%le	99%le
Stature	1647(87)	1511	1648	1760	1779	1823
Seats surface height	416(30)	368	416	453	467	482
Hip breadth, sitting	346(28)	303	343	381	396	415
Buttock popliteal length	486(33)	434	485	528	543	579
Upper hip born height	194(20)	163	195	219	227	239
Lowest rib bond height	261(21)	226	259	287	296	311
Lumber height	66(20)	38	65	92	101	122
Sitting height	833(48)	753	833	891	906	942
Shoulder height, sitting	545(37)	485	547	590	604	630
Elbow height, sitting	206(27)	160	205	242	252	263
Thigh clearance	135(21)	104	133	163	171	194
Buttock-knee length	585(36)	523	584	631	648	668
Buttock heel length	1000(64)	896	1000	1086	1104	1140
Forearm–finger tip length	453(32)	405	453	492	504	542
Forward arm reach	825(52)	740	825	892	906	923
Elbow height, standing	1035(61)	938	1035	1113	1127	1168
Eye height, sitting	730(48)	651	733	786	806	827
Weight	56(12)	38	55	71	77	88

The side-mounted desktop chair is also expected to influence back posture. Postures adopted when the desks are placed in front of the users while sitting have been reported by many researchers. Grimes and Legg (2004) stated that a backward-leaning position, e.g., looking at the black board and watching the teacher, is one of the frequently adopted postures. Storr-Paulsen and Aagaard-Hensen (1994) found that approximately 43% of classroom time was spent in a backward-leaning position, whereas 57% was spent leaning forward, e.g., reading or writing. Chair backrests are not routinely used (Hira, 1980). Floyd and Ward (1969) reported that writing, reading and listening tasks take up to 30%, 10–15% and

Table 13
Recommended chair feature dimensions for fixed-type side-mounted desktop chair for both male and female university students.

Chair features	Anthropometric measurements	Design dimensions (mm)	Determinants
Seat surface height	Seat surface height	445	Seat height boundary case + 25 mm allowance
Seat depth	Buttock popliteal length	434	5%le of Buttock popliteal length
Seat width	Hip breadth, sitting	436	95%le Hip breadth, sitting + 40 mm allowance
Bottom of backrest height	Upper hip bone height	163	5%le upper hip bone height
Top of backrest height	Lowest rib bone height	296	95%le lowest rib bone height
Backrest width	Hip breadth, sitting	436	Same as seat width
Lumber support height	Distance between Case 4 & Case 5	133	Distance between Case 4 & Case 5
Desktop height	Elbow height, sitting	229	Elbow height, sitting boundary case
Desktop length	Forearm–finger tip length	453	50%le Forearm –finger tip length
Desktop width		198	As per existing desktop width
Desktop angle (to horizontal)		0°	
Seat angle (to horizontal)		0°	
Backrest angle (to horizontal)		96°	

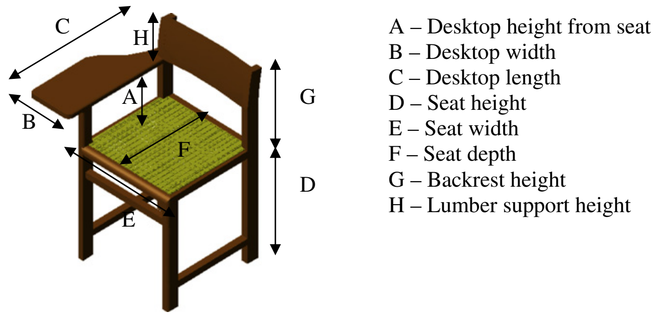


Fig. 8. Proposed side-mounted desktop chair.

Fig. 9. Use of existing mounted desktop chair in the lecture hall.

35–40% of classroom time, respectively. Up to 80% of the pupils' time was, therefore, spent slumped over the desktop.

In contrast, in the mounted desktop chair, there is no need for the students to lean forward. We believe that a table placed in front of students is one of the causes of forward leaning. We observed the postures of the students in the side-mounted desktop chair during lecture sessions on English and mathematics. They used the side-mounted desktop for writing during the lecture. No tables in front of the students were used. While performing their task, the students used the backrest (Fig. 8) for a fairly large amount of time (80%). The task did not require the students to lean forward, due to the absence of a table in front and the presence of a side-mounted desktop. Use of the side-mounted desktop keeps the seated subjects leaning back onto the backrest, since there is no need to lean forward towards the desk, thus promoting a straight back. According to Rasmussen et al. (2009), the friction with the backrest contributes to carrying the weight of the body, and the lumbar disk pressure is lower if the lordosis is maintained passively by lumbar support rather than muscular activity. Hence, it is expected that the mounted desktop chair may increase back comfort. This can be considered to be an advantage associated with this chair (Fig. 9).

While developing comfortable posture, educational chairs should also support the learning activities of the students. Knight and Noyes (1999) urged that school furniture should be able to facilitate learning by providing a comfortable and stress-free workstation. A student performs a large number of activities during a lecture session, such as writing, reading, listening, standing, speaking, using a calculator/slide rule, collecting books and other materials, etc. The most prominent of these are writing and listening (Hira, 1980). Similar activities in the classroom were identified by Floyd and Ward (1969). Murphy et al. (2004) stated that students' typical tasks are reading, writing, listening, and computer use, which are all performed while sitting. The side-mounted desktop chair is compact in design. It supports the main lecture room activities such as writing, listening and reading. It may also support standing up, sitting down and temporary absence from the classroom. It may not support preparation for lessons (assembling books, etc.) or reaching for the contents of a backpack. Also, it may not support modern classroom requirements, such as computer use. We observed the use of existing mounted desktop chairs in lecture halls during learning sessions. Students keep their bags under the chairs or on the ground between their legs most of the time. Ready access to their bags is not easy. They have to bend forward to reach their bags, which is an uncomfortable posture. This can be considered to be a significant disadvantage associated with these chairs. The postural behavior and postural comfort of the side-mounted desktop chair need to be tested.

Viewing distance is also an important factor in determining desktop height. We examined the seated eye height boundary cases, in relation to the focal range recommended in the literature. We found that the viewing distances of all four selected boundary cases, for the female, male, and the combined samples, were found to be within the acceptable focal range. The results indicated that 90% of students in our sample were accommodated within the acceptable focal range. Thus, it is expected that 90% of the university student population under investigation would have a comfortable viewing distance while using the proposed mounted desktop chair. Examination of seat heights in both bivariate distributions (seated eye height – seat height) as well as (seated elbow height – seat height) for both the female and male samples showed that seat heights were similar for the corresponding cases (Figs. 5–7 and Tables 9 and 10). Hence, the determination of seat height based on the seated eye height – seat height bivariate distribution was not investigated further. For the combined sample (seated eye height – seat height bivariate distribution), we examined the seat height fit between cases (Fig. 7 and Table 10 and 11). We found that the seat height determined based on the seated elbow height–seat height bivariate distribution was a better choice and a less harmful compromise.

Desktop inclination is considered to be an important factor in comfortable neck posture and viewing distance. The objective of desk inclination is to lower the tension in the neck and back by maintaining a comfortable focal range when the neck and trunk are drawn towards papers while writing and reading. According to Marras (2006), when the head moves forward (30° or more from the vertical position), increased activation of the neck musculature takes place, which increases the probability of fatigue, since a static posture is maintained by the neck muscles. According to De Wall et al. (1991), the degree of forward head and neck flexion, combined with the static nature of desk tasks, appears to be related to the incidence of neck and/or shoulder complains. With regard to computer use at a desk, it was stated (Straker et al., 2006) that 10–12 year olds respond in a fashion very similar to young adults, in terms of posture and superficial neck/shoulder muscle activity. Ankrum (1997) stated that the neck is more comfortable in flexion than in extension. According to Straker et al. (2006), the optimal viewing zone is between 15° and 45° from horizontal. This agrees with Ankrum (1997), who states that the visual system prefers downward gaze angles for close work. Considering the issues related to neck posture and comfortable viewing distance, some inclination in the desktop for writing and reading are recommended. Hira (1980) found that a desktop angle of 10–15° was preferred by most university and college students. De Wall et al. (1991) concluded that a desk with 10° inclination appears to have a positive effect on posture.

We recommend a horizontal and flat surface desktop for our proposed chair. Forward leaning of the trunk is discouraged in this chair, due to the use of a side-mounted desktop, which keeps the seated subjects leaning back onto the backrest, and also because 90% of the investigated students are given an acceptable range of viewing distances. However, neck flexion is unavoidable in this chair. As we already cited (Storr-Paulsen and Aagaard-Hensen, 1994), approximately 43% of classroom time was spent in a backward-leaning position, whereas 57% was spent in leaning forward, e.g., reading or writing. Based on this finding, changes in neck posture between leaning backward and leaning forward are expected during classroom activities. Thus, static neck flexion for a long period of time may be avoided, ultimately reducing discomfort in the neck. However, we suggest that the effect of the prototype side-mounted desktop chair on neck posture be tested.

5. Conclusions and recommendations

We recommend a side-mounted desktop height for fixed-type lecture hall chairs for university students of 229 mm from the seat surface. Designing a fixed-type mounted desktop chair with dimensions that can accommodate 90% of the target population is an extremely difficult task. The effects of a side-mounted desktop chair on posture and facilitation of learning activities need to be investigated. We also recommend that the anthropometric fit of a prototype mounted desktop chair with the proposed dimensions undergo short-term and long-term tests within the user population before it can be recommended for manufacture.

Acknowledgments

We would acknowledge the assistance of A.M.S. Attanayake in carrying out this research. Joint funding for this research by the Senate Research Committee of University of Moratuwa and National Science Foundation of Sri Lanka is acknowledged.

Annex 1: Anthropometric measurements

1. Seat surface height:

Description: The vertical distance from the foot-rest surface to the sitting surface.
Method: Subject holds thigh and lower leg at right angles during measurement. Subject may sit, or stand with the foot placed on a raised platform. The movable arm of the measuring instrument is moved to the seat surface.

2. Elbow height, sitting:

Description: Vertical distance from a horizontal sitting surface to the lowest bony point of the elbow, which is bent at a right angle with the forearm horizontal.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely. Upper arms hang freely downwards and forearms are horizontal.

3. Eye height, sitting:

Description: Vertical distance from a horizontal sitting surface to the outer corner of the eye.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely. Head is orientated in the Frankfurt plane.

4. Thigh clearance:

Description: Vertical distance from the sitting surface to the highest point on the thigh.
Method: Subject sits erect with knees bent at right angles, supporting the feet flat on the floor.

5. Sitting height (erect):

Description: Vertical distance from a horizontal sitting surface to the highest point of the head (vertex).
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely. Head is orientated in the Frankfurt plane.

6. Shoulder height, sitting:

Description: Vertical distance from a horizontal sitting surface to the acromion.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely. Shoulders are relaxed, with upper arms hanging freely.

7. Lowest rib height, sitting:

Description: Vertical distance from a horizontal sitting surface to the lowest rib bone.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely.

8. Upper hip bone height, sitting:

Description: Vertical distance from a horizontal sitting surface to the upper hip bone.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely.

9. Hip breadth, sitting:

Description: Breadth of the body measured across the widest portion of the hips.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely, knees together. Measurements are taken without pressing into the flesh of the hips.

10. Buttock – knee length:

Description: Horizontal distance from the foremost point of the knee-cap to the rearmost point of the buttock.
Method: Subject sits fully erect with thighs fully supported and lower legs hanging freely. The position of the rearmost point of the buttock is vertically projected onto the sitting surface by means of a measuring block, which touches the buttocks. Distance is measured from the measuring block to the foremost point of the knee-cap.

11. Forearm–finger tip length:

Description: Horizontal distance from the back of the upper arm (at the elbow) to the fingertips, with the elbow bent at a right angle.
Method: Subject sits erect with upper arm hanging downwards, forearm horizontal and hand extended.

12. Buttock – popliteal length (seat depth):

Description: Horizontal distance from the hollow of the knee to the rearmost point of the buttock.
Method: Subject sits fully erect with thighs fully supported and sitting surface extending as far as possible into the hollow of the knee, lower legs hanging freely. The position of the rearmost point of the buttock is vertically projected onto the sitting surface by means of

a measuring block, which touches the buttocks. Distance is measured from the measuring block to the forward edge of the sitting surface.

13. Stature:

Description: Vertical distance from the floor to the highest point of the head (vertex).

Method: Subjects stands fully erect with feet together. Head is orientated in the Frankfurt plane.

References

Abeysekara, J.D.A., 1985. Design requirements and dimensions for a comfortable work seat for Sri Lankans. Journal of National Science Council of Sri Lanka 13 (1), 77–88.

Ankrum, D.R., 1997. A challenge to eye level, perpendicular-to-gaze, monitor placement. In: Proceedings of the 13th Triennial Congress of the International Ergonomics Association, vol. 5. Finish Institute of Occupational Health, Helsinki, pp. 35–38.

Balague, F., Daminot, P., Nordin, M., 1993. Cross-sectional study of the isokinetic muscle trunk strength among school-children. Spine 18, 1199–1205.

British Standard Institution, 1980. BS5873: Part1: 1980. Educational Furniture: Specification for Functional Dimensions, Identification and Finish of Chairs and Tables for Educational Institutions. BSI, London.

Chaffin, D.B., 1973. Localized muscle fatigue: definition and measurement. Journal of Occupational Medicine 15, 346–354.

Chaffin, D., Anderson, G., 1991. Occupational biomechanics. Wiley, New York.

De Wall, M., Van Riel, M.J.P.M., Snijders, J.C., 1991. The effect on sitting posture of a desk with a 10° inclination for reading and writing. Ergonomics 34 (5), 575–584.

Evans, W.A., Courtney, A.J., Fok, K.F., 1988. The design of school furniture for Hong Kong school children. Applied Ergonomics 19 (2), 122–134.

Evans, O., Collins, B., Stewart, A., 1992. Unlocking potential for the future productivity and quality of life. In: Hoffman, E., Evans, O. (Eds.), Proceedings of the Annual Conference of the Ergonomics Society of Australia, Melbourne, pp. 31–37.

Floyd, W.F., Robert, D.F., 1958. Anatomical and physiological principles in chair and tables design. Ergonomics 2 (1), 1–16.

Floyd, W.F., Ward, J.S., 1969. Anthropometric and physiological considerations in school, office and factory seating. Ergonomics 12, 132–139.

Genaidy, A.M., Karwowski, W., 1993. The effects of neutral posture deviation on perceived joint discomfort ratings in sitting and standing postures. Ergonomics 36, 785–792.

Gouvali, K.M., Boudolos, K., 2006. Match between school furniture dimensions and children' anthropometry. Applied Ergonomics 37, 765–773.

Grimes, P., Legg, S., 2004. Musculoskeletal disorders (MSD) in students as a risk factor for adult MSD: a review of the multiple factors affecting posture, comfort and health in classroom environments. Journal of the Human Environmental System 7 (1), 1–9.

HFES 300 Committee, 2004. Guidelines for Using Anthropometric Data in Product Design. Human Factors and Ergonomics Society, Santa Monica, pp. 1–65.

Hira, D.S., 1980. An ergonomic appraisal of educational desks. Ergonomics 23 (3), 213–221.

Hänninen, O., Koskelo, R., 2003. Adjustable table and chairs correct posture lower muscle tension and pain in high school students. In: Proceedings of the XVth Triennial Congress of the International Ergonomics Association, Seoul, Korea.

Helander, M.G., Czaja, S.J., Drury, C.G., Cary, J.M., 1987. An ergonomic evaluation of office chairs. Office: Technology and People 3, 247–262.

Jung, S.H., 2005. A prototype of an adjustable table and an adjustable chair for schools. International Journal of Industrial Ergonomics 35, 955–969.

Khanam, N.C., Reddy, V.M., Mrunalini, A., 2006. Opinion of students on seating furniture used in classroom. Journal Human Ecology 20 (1), 15–20.

Knight, G., Noyes, J., 1999. Children's behavior and the design of school furniture. Ergonomics 42 (5), 747–760.

Lueder, R., 2006. Review: Armrest Design and Use. Humanics Ergo Systems, Inc. www.humanics-es.com.

Lueder, R., 1994. Adjustability in context. In: Lueder, Noro (Ed.), Hard Facts About Soft Machine. Taylor & Francis, UK, pp. 25–36.

Marmaras, N., Nathanael, D., 2006. Workplace design. In: Salvendy, G. (Ed.), Hand Book of Human Factors and Ergonomics. Wiley, pp. 575–589.

Marras, S.W., 2006. Basic biomechanics and workstation design. In: Salvendy, G. (Ed.), Hand Book of Human Factors and Ergonomics. Wiley, pp. 341–370.

Milanese, S., Grimmer, K., 2004. School furniture and the user population: an anthropometric perspective. Ergonomics 47 (4), 416–426.

Molenbroek, J.F.M., Kroon-Ramaekers, Y.M.T., Snijders, C.J., 2003. Revision of the design of a standard for the dimensions of school furniture. Ergonomics 46 (7), 681–694.

Murphy, S., Buckle, P., Stubbs, D., 2004. Classroom posture and self-reported back and neck pain in schoolchildren. Applied Ergonomics 35, 113–120.

Nag, P.K., Pal, S., Kotadiya, S.M., Nag, A., Gosai, K., 2008. Human–seat interface analysis of upper and lower body weight distribution. International Journal of Industrial Ergonomics 38 (5), 539–545.

Nissinen, M., Heliovaara, M., Seitsamo, J., Alaranta, H., Poussa, M., 1994. Anthropometric measurements and the incidence of low back pain in a cohort of pubertal children. Spine 19 (12), 1367–1370.

Oxford, H.W., 1969. Anthropometric data for educational chairs. Ergonomics 12, 140–160.

Panagiotopoulou, G., Christoulas, K., Papanckolaou, A., Mandroukas, K., 2004. Classroom furniture dimensions and anthropometric measures in primary school. Applied Ergonomics 35, 121–128.

Parcells, C., Stommel, M., Hubbard, R.P., 1999. Mismatch of classroom furniture and student body dimensions. Journal of Adolescent Health 24, 265–273.

Pheasant, S.T., 1986. Body Space: Anthropometry, Ergonomics and Design. Taylor and Francis, London.

Pheasant, S.T., 1984. Anthropometrics: An Introduction for Schools and Colleges (PP7310). British Standards Institution, London.

Rasmussen, J., Torholm, S., de Zee, M., 2009. Computational analysis of the influence of seat pan inclination and friction on muscle activity and spinal joint forces. International Journal of Industrial Ergonomics 39 (1), 52–57.

Robinette, M.K., 2006. Anthropometry. In: Salvendy, G. (Ed.), Hand Book of Human Factors and Ergonomics. Wiley, pp. 323–339.

Storr-Paulsen, A., Aagaard-Hensen, J., 1994. The working positions of schoolchildren. Applied Ergonomics 25 (1), 54–63.

Straker, L., Pollock, C., Burgess-Limerick, R., 2006. Excerpts from CybErg 2005 discussion on preliminary guidelines for wise use of computers by children. International Journal of Industrial Ergonomics 36 (12), 1089–1095.

Thariq, M.G., Munasinghe, H.P., 2005. Comparative study of existing institutional chairs used in Sri Lanka with special reference to design dimensions. Built Environment – Sri Lanka 6 (1).

Toomingas, A., Gavhed, D., 2008. Workstation layout and work postures at call centres in Sweden in relation to national law, EU-directives and ISO-standards, and to operators' comfort and symptoms. International Journal of Industrial Ergonomics 38 (11), 1051–1061.

Troussier, B., Tesniere, C., Fauconnier, J., Grison, J., Juvin, R., Phelip, X., 1999. Comparative study of two different kinds of school furniture among children. Ergonomics 42, 516–526.

Weiner, J.S., Lourie, J.A., 1969. Human Biology: a Guide to Field Methods. P.A. David, Philadelphia.