Final Submission to Close a SRC Funded Research Project

Project Title

Study of Ergonomic Needs in Designing and Manufacturing of Furniture for Sri Lanka; Case Study of Chairs Used in Tertiary Education Institutes

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25th February 2008
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Brief Report

Need for the study

Teachers, learners, and educational materials are considered basic ingredients of the teaching and learning process, but the physical environment in which learning occurs where furniture has become an important component of learning environment is often neglected. A study by Thariq et al (2004 under review) on chair dimensions showed that various government tertiary education institutes in Sri Lanka provide various design dimensions to manufacture lecture hall chair, for a same user population to perform a same particular task.

The same study concluded that the presently used lecture hall chairs would not match body dimensions of users therefore would be unhealthy and uncomfortable for the user population. From the findings of the study they recommended to measure the body dimensions of students of tertiary education institutes and thereby to develop dimensions to design healthy and comfortable institutional chairs. Abeysekara (1985), based on the anthropometric survey among workers population carried out in Sri Lanka recommended dimensions for work seat. Abeysekara's (1985) recommendations are based on the anthropometric measurements of Sri Lankan worker population, which may not match the recent student population of tertiary education institutes and needs are also different between workers and students. The design dimensions presently used in Sri Lanka to manufacture chairs are not based on the anthropometric characteristics of Sri Lankan user population instead it has been copied from British Standards and modified (Abeysekara, 2003). An ergonomic survey in Sri Lanka conducted by Abeysekara (1996), an ergonomic expert, shows that the common problem observed in the places (indoors) was the mismatch regarding the works and their operating level, whether standing or seated.

Many research works revealed the consequences of mismatch of furniture to the users. Evans et al (1988) concluded in a study, as bad posture associated with badly designed chairs and tables, unfitting to children, in schools are factors which may affect academic performance and physical development of school children. Though this study is relevant to schoolchildren the same is applicable for the students of the tertiary education institutes. A study by Balaque et al (1988) showed a surprisingly high proportion of school students reported suffering from musculoskeletal discomfort and low back pain. This is of great concern because the strongest predictor of having future back pain is often considered to be a previous history of such symptoms. A small body of research has implicated the mismatch between school furniture and body size as a causative factor for musculoskeletal discomfort and low back pain amongst school students (Floyd and Ward 1969, Mandal 1982, Parcells et al 1999). Colombini et al (1985) reported the increasing number of people spends their working days sitting down, many of them complain back and neck pain. Almost half of the population of the industrialized world is thought to be suffering from some form of back complaint, many of them are related to poor seat design (Mandel, 1985).

The chairs currently used in Sri Lankan tertiary education institutes do not follow ergonomic design criteria i.e. matching to the body sizes of the users and the material comfort characteristics of seat surface and backrest. In designing chairs, concern to the task to be performed, localizing ergonomic criteria i.e. matching the chairs to the users and integrating material characteristics of seat surface and backrest according to user comfort are necessary to develop good

posture that would ensure functional efficiency, ease of use, comfort, health and safety and quality of working life.

Therefore an understanding of the anthropometric characteristics of the user population and the user comfort to the material characteristics of seat surface, and backrest are important to design and construct healthy and comfortable chairs for tertiary education institutes.

Objectives

The aim of the study is to contribute towards the development of design specifications to chairs for tertiary education institutes to improve the comfort and the match between the users and chairs for the user population of Sri Lanka.

Specific objectives:

To investigate the anthropometric characteristics of students of tertiary education institutes

To compare the body sizes to be developed with the existing local design specifications and with some other foreign standards as well.

To strengthen the furniture design degree course at the University of Moratuwa by improving the ergonomics and anthropometry so that the only Design School at the University will become centre of excellence in the field

To complete Doctoral dissertation

Methodology

Literature review:

Thorough literature review relevant to the study was undertaken. The research student was trained on principles of ergonomics. The training was given by Prof. John Abeysekera, Sri Lanka Swedish ergonomic expert.

Data collection on existing institutional chairs:

The existing local institutional chair design specifications i.e. seat height (from floor), backrest height (from seat), back rest breadth, lumbar support height (from seat), seat width, seat depth, armrest height (from seat), backward title of the seat surface, backrest angle and materials for backrest and seat of institutional chairs was collected from local Universities. The existing specifications were collected from state and selected private owned furniture manufacturers by visiting the places. The standard specifications of institutional chairs of some other foreign countries and international standards were collected from the literature.

Anthropometric survey:

To carry out the anthropometric survey, research student, two measurers and a university technical assistant were trained on the techniques of anthropometric measurements by Prof. John Abeysekara. The following anthropometric data were recoded i.e. weight, stature, seat height, backrest height; lowest rib bone height (sitting), upper hipbone height (sitting), shoulder height (sitting), backrest

breadth; chest breadth, biacromial breadth, armrest height; elbow rest height (sitting), seat surface dimensions; hip width, buttock to back of knee (sitting) and armrest length; forearm length. An anthropometer and an adjustable stool were used to take most of the measurements. Vernier calipers and tapes (canvas and metallic) were used to take few measurements. A weighing scale was used to take weights of the subjects.
A trained research student, a male technical assistant and a female technical assistant carried out the anthropometric survey. The measurements were taken among ---- healthy students randomly selected from Peradeniya and from Moratuwa of males and females regardless of their age. The measurements obtained were statistically analyzed.

Important Results:
Mismatch between present institutional chairs and users body dimensions were established.
Design dimensions for institutional chairs were recommended.
(Please refer the papers for the details.)

Conclusions:
The evaluation of prototype chairs with recommended design dimensions in long term and short term is needed to be undertaken.
(Please refer the papers for the details.)

Acknowledgement:
The project was partially funded by the Senate Research Committee of the University of Moratuwa. My thanks go to SRC of University of Moratuwa.

Paper published:
Thariq, M.G. and 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): 2005.

ABSTRACT

COMPARATIVE STUDY OF EXISTING INSTITUTIONAL CHAIRS USED IN SRI LANKA WITH SPECIAL REFERENCE TO DESIGN DIMENSIONS

The Institutional chair dimensions used at present may not match the body dimensions of the users of institutional chairs. Several research studies showed that the dimensions of chairs should fit to users' body dimensions with respect to the task to be performed and the chairs with inappropriate dimensions lead to discomfort and low back pain (Oxford, 1969: Mandal, 1982: Evans et al, 1988 and Parcels et al, 1999). Here the data on dimensions for institutional chairs were surveyed and compared with Abeysekara's (1985) work seat and the educational chair of British Standards (1980) to investigate the dimensional fit of the chairs to the users.

Most of the seat and backrest dimensional values were higher than the values recommended by Abeysekara (1985) and British Standards (1980), except the backrest dimensions of Abeysekara's (1985) which are comparable to institutional chairs. The entire institutional chair seats were constructed horizontally compared to the backward tilt of Abeysekara (1985) and British Standards (1980). The backrests were constructed with improper location, shape and angle of lumbar support compared to Abeysekara (1985) and British Standards (1980). The desktop/armrest heights of the existing institutional chairs are comparable to Abeysekara's (1985) recommendations but lower than values of British Standards (1980).

The dimensions presently used to design institutional chairs are not based on the body dimensions of the user population but some of the dimensions used seem to have been copied and modified from British Standards. Hence the dimensions used do not match the body dimensions of the user populations. It is suggested to undertake research study on body dimensions of students to develop correct design dimensions for institutional chairs, and to test the present institutional chairs for their fit to the students.

COMPARATIVE STUDY OF EXISTING INSTITUTIONAL CHAIRS USED IN SRI LANKA WITH SPECIAL REFERENCE TO DESIGN DIMENSIONS

INTRODUCTION

Teachers, students, and educational materials are considered basic ingredients of the teaching and learning process, but the physical environment in which learning occurs where furniture has become an
Important component is often neglected. Evans at al (1988) stated that the designs of school furniture appropriate to the anthropometric characteristics of the users are very important since it relates to academic performance and physical development of school children and in the development of good postural behavior. In matching the seat to the users, anthropometric factors of users are of major importance for its comfort (Pheasant, 1992). The design dimensions of chairs i.e. seat height (from floor), seat width, seat depth, backrest height, armrest/desktop height (from seat), seat angle (to horizontal), backrest angle (to horizontal) and backrest curve dimensions are essential for chairs with regard to users health and comfort aspects while in use performing different tasks i.e. reading and writing etc.

Many research works have revealed the consequences of mismatch of furniture to the users. A small body of research has implicated the mismatch between school furniture and body size as a causative factor for musculoskeletal discomfort and low back pain among school students (Parcel et al, 1999 and Mandal, 1982). Colombini et al (1985) reported the increasing number of people spends their working days sitting down, many of them complain back and neck pain. Evans et al (1988) concluded in their study that bad posture is associated with badly designed chairs and tables unfitting to children in schools.

To design chairs etc., for Sri Lankans, anthropometric data of Sri Lankan population are very limited. Abeysekara (1985) did a large-scale anthropometric survey for Sri Lankan workers population. According to his findings he recommends dimensions for work seat design. Designers or manufacturers in the furniture industries in Sri Lanka do not presently use the recommendations made by Abeysekera (1985) as they are not probably aware of the availability of this data. The recommendations made by Abeysekara for work seat design are based on the anthropometric data of specified worker population. It may not fit the institutional student population of Sri Lanka. Presently confusions remain among Sri Lankan furniture designers and manufacturers in setting design dimensions i.e. seat height (from floor), seat width, seat depth, backrest height, armrest and desktop height (from seat), seat angle (to horizontal) and backrest angle (to horizontal) for institutional chairs, as a result of this, the dimensions used at present may not match the body dimensions of student user population.

Therefore, the present study is an attempt to investigate the application of design dimensions for institutional chairs used in Sri Lanka, and to compare them with dimensions recommended by British Standards for educational chairs and the dimensions recommended by Abeysekara for workseat design with the intention of developing standard dimensions of student seat design for Sri Lankan. With the conclusion of the study, it is expected to open up the venue for research on furniture ergonomics in Sri Lanka.

METHOD OF STUDY

Sketches and dimensions of lecture hall chairs that are being used in the universities were collected from the University of Peradeniya, University of Kelaniya, south Eastern University of Sri Lanka, and University of Moratuwa and the dimensions were taken. The dimensions recommended by Abeysekara (1985) for work seat and the functional dimensions for educational chairs given by British Standards (1980) were collected from relevant sources and converted to inches for the purpose of comparison with the other dimensions. The design dimensions for each design parameter were tabulated and investigated.

RESULTS AND DISCUSSIONS

Table 1 shows the dimensions of existing institutional chairs, dimensions recommended by Abeysekara (1985) for work seat design and dimensions recommended by British Standards (1980) for educational chairs (size mark 5) and their comparisons for fixed seats (non-adjustable).

Table 1 Dimensions of existing institutional chairs, dimensions recommended by Abeysekara (1985) for work seat design and dimensions recommended by British Standards (1980) for educational chairs.

	South Eastern uni. of Sri Lanka	University of Peradeniya	University of Kelaniya	University of Moratuwa	Abeysekara (1985)		British Standards 5873 (1980)
	-----	----------	----------	------	Males	Females	---------
Seat height (from floor) (inches)	18	16	18	19½	15⅝	14⅜	16⅝
Seatdepth (inches)	17½	18¼	17	16	14⅜-16 ⅜	13½ –15½	14⅝-15⅝
Seat width (inches)	18	21½ Front width 16½ Rear width	18 Front width 14 Rear width	18	15¾	15⅞	13½ –17
Seat angle (to horizontal)	0°	0°	0°	0°	14° - 24°	14° - 24°	4°
Backrest height (from seat surface to bottom of backrest) (inches)	9	12½	9½	7¼	0	0	6 ⅜- 6¾
Backrest height (from seat surface to top of backrest) (inches)	18	17½	17	17	17¾– 8½	15 ⅞-16¾	13-14¼
Height of lumbar support from seat (inches)	8	5½	7½	11	6½ - 10½	6⅜ -10¼	6⅝ -7½
Backrest angle (to horizontal)	90°	90°	90°	110°	110°- 30°	110°- 130°	91° -96°
Backrest curve (radius) (inches)	40	50	-	32	-	-	15 ¾
Desktop height (inches)	8	6½	7¼	7¼	7 ⅞	7 ⅜	11
Armrest height (inches)	8	6½	7¼	7¼	7 ⅞	7 ⅜	-

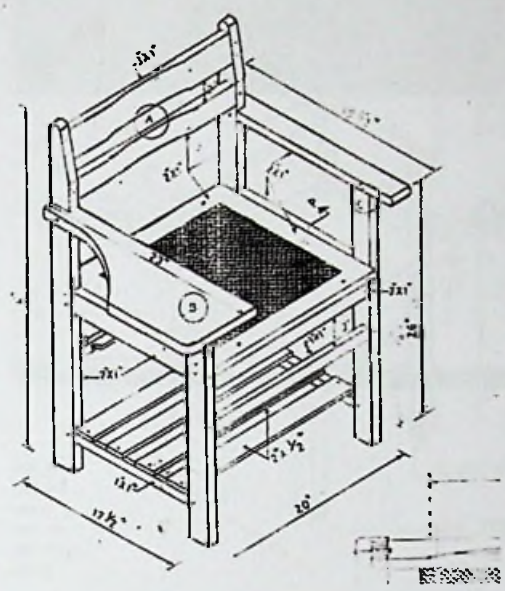

Figure 1 Lecture room chair, South Eastern University of Sri Lanka.

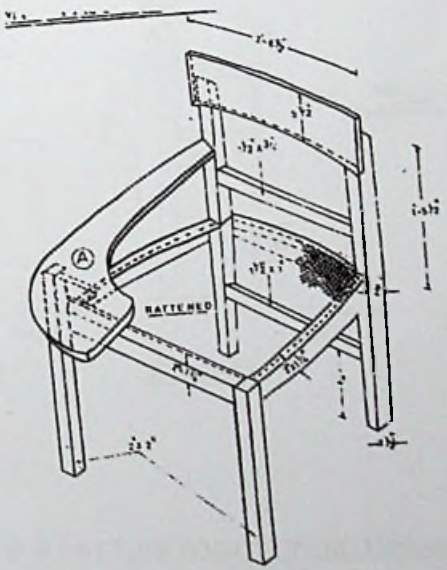

Figure 2 Lecture room chair, University of Peradeniya.

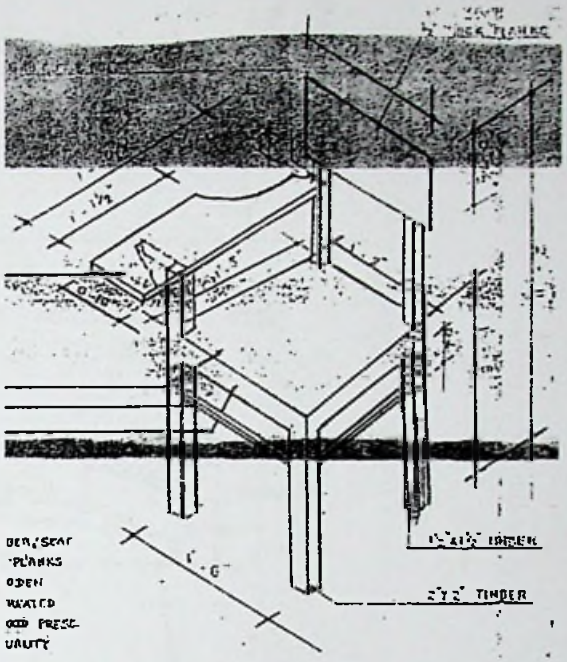

Figure 3 Lecture room chair, University of Kelaniya.

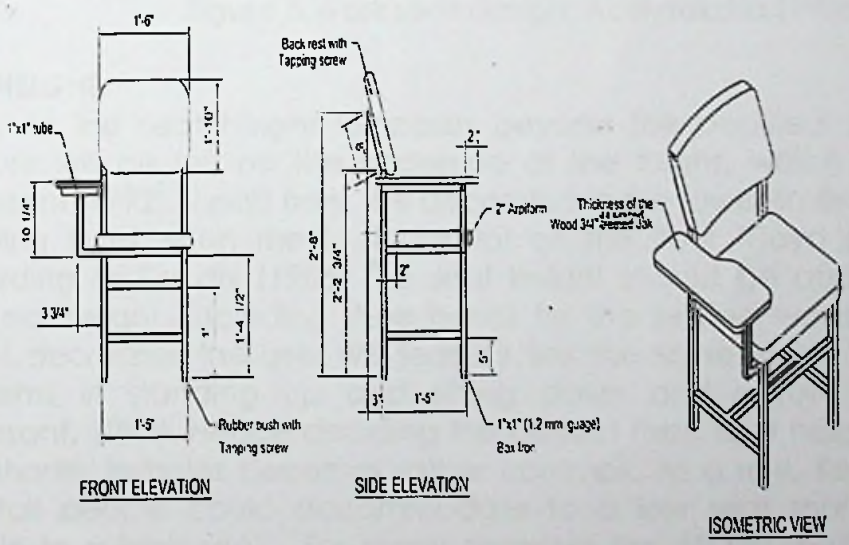

Figure 4 Lecture room chair, University of Moratuwa.

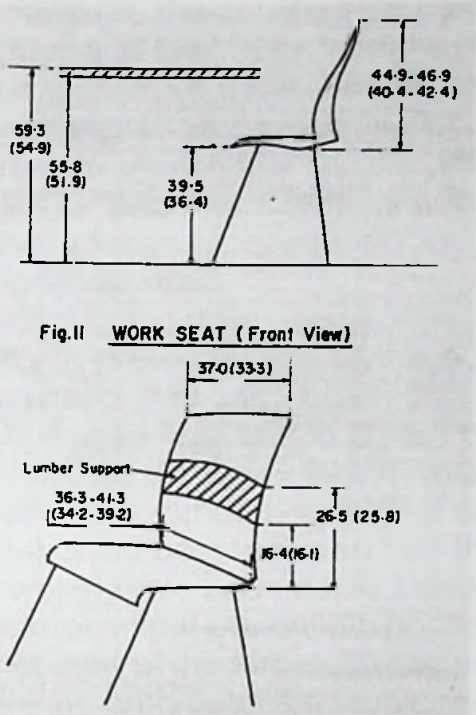

Figure 5 Work seat design, Abeysekara (1985).

SEAT HEIGHT

As the seat height increases beyond the popliteal height of the user, pressure will be felt on the underside of the thighs, which lead to discomfort (Pheasant, 1992). Apart from the discomfort in the lower limbs this position is more fatiguing than when the feet are flat on the floor (Floyd and Roberts, 1958). According to Bendix (1986) the seat height should be about 3 – 5cm above popliteal height (including shoe heels) for the seated workstation. As the seat height decreases the user will tend to flex the spine more, experience greater problems in standing up and sitting down and require greater leg room (Pheasant, 1992). Hence deciding the correct fixed seat height to fit taller males and shorter females becomes rather complex. As a rule, Keegan (1962) stated that tall people could accommodate to a low seat more easily than short people to a high seat. For many purposes the 5th percentile female popliteal height represents the best compromise with 25mm heels for both sexes (Pheasant, 1992).

In view of above statements, seat heights of the university chairs have been compared. According to the results obtained (see Table 1 and Figures 1, 2, 3 & 4), seat height from floor varies from 16" to 19½" among the chairs from different universities. Abeysekara (1985) recommended seat height for work seat design through an anthropometric survey among workers population of Sri Lanka. According to his recommendations (see Table 1 and Fig. 5), seat heights for males and females are15 ⅝" and 14 ⅜" respectively. Though it is not practicable making institutional chairs for males and females separately, the recommendations give a useful idea about the seat height for Sri Lankans and those data might be used to develop the fixed design dimensions. In the mean time the recommendations may not suit the recent student population of Sri

Lankan institutes. However, the varying seat heights of existing institutional chairs (16" to 19½") are found to be higher than the Abeysekara's recommendations. Authors' personal experiences show that 18" of seat height is widely used by designers and manufacturers for institutional chairs, office chairs, and conference chairs etc. According to the British Standards for educational furniture, seat height for size mark 5 (tertiary educational chairs) is 16 ⅝" which is higher than the Abeysekara's recommendations but it falls within the seat height range of institutional chairs used.

British Standards are according to the body dimensions of British student population so it would not match Sri Lankan student population under investigation. According to Abeysekara (1988), only 35% of Sri Lankans could be accommodated to the design which was designed with the British anthropometric data accommodating 90% of British population. However, from these comparisons it could be concluded that the seat height presently used for institutional chairs would have been copied and modified from British Standards. The chairs, with the seat height presently in application, are taller and that will not fit to the body dimensions of the target Sri Lankan student population. To arrive at the correct seat height, anthropometric survey has to be carried out among the user population. The present non-matching seat height dimensions might have developed health related consequences among users; hence a study on the health consequences in using the present chairs can reveal the problems experienced by users.

SEAT DEPTH

The recommended seat depth is determined by the 5th percentile buttock popliteal length (Evans et al, 1988). For seat depth, the primary considerations are that the ischial tuberosities should be supported (Floyd and Roberts, 1958). If the depth is increased beyond buttock-popliteal length (5th percentile female) the user will not be able to engage the back rest effectively without unacceptable pressure on the back of the knees and the deeper the seat the greater the problems of standing up and sitting down (Pheasant, 1992). The depth of the seat (buttock to popliteal) is important as the seat height, because the deep seat, combined with excessive seat slope, force a child to perch (Oxford, 1969).

The Seat depths for existing institutional chairs vary from 16" to 18¼" among the chairs of different universities. The authors experienced varying seat depths used by designers and manufacturers for lecture hall chairs, which lack proper scientific basis, that are to be used by particular target group. Abeysekara (1985) recommended a seat depth range of 14⅜"- 16⅜" for males and 13 ½"- 15 ½" for females based on his findings.

The existing seat depths of most of the institutional chairs (see Table 1) are higher than the Abeysekara's seat depth recommendation. According to the results obtained, 17" and more are used as seat depth widely. Where as British Standards of educational chairs recommended minimum 15" and maximum 17". However the maximum seat depth of 17" recommended by British Standard falls within the seat depth dimensions used in existing chairs. Half of the existing chairs' seat depths are higher than the maximum seat depth dimensions of British Standards for educational chairs. From the results of the study, it can be stated that most of the existing institutional chairs have higher seat depth dimension

values, which will not fit the user population. As a result of this, the user population may find difficulties in effectively using the backrest without pressing on the back of the knees. The present seat depth dimensions may have health-related problems in the lower limbs when engaged with backrest. From the results of the study it can be further stated that the seat depth dimensions of existing chairs would have been copied and modified from British Standards. Hence it is important to design comfortable seat depth through an anthropometric survey of the user population. It is also recommended to test the chairs for their comfort.

SEAT WIDTH

It is necessary that the 95th percentile hip width of the target population is taken for seat width, which will be the minimum requirement (Abeysekara, 1985). Floyd and Robert (1958) cited a study, which concluded that for the seat width it is necessary to make an allowance for lateral movement beyond the requirements for accommodating "subjects of maximum dimension". The minimum width is clearly determined by the need for support of the ischial tuberosities but for stability of posture a relation to the trochantric width appears to give a more realistic estimate (Floyd and Robert, 1958).

According to the results obtained (see Table 1), half of the chairs are found with seat width which narrow down from front towards rear of the seat width (see Fug. 2 and 3). Taken these variations into consideration, seat widths for the chairs under study vary in the front of the seat from 18" to 21½" and in the rear of the seat it varies from 14" to 18". The designers did not provide the scientific evidence how these varying seat width dimensions from front to rear were designed. Available literature on chair design recommended the seat widths, which are parallel in front and rear of seats.

Abeysekara (1985) recommended seat width of 15¾" for males and 15 ⅞" for females. According to the British Standards (1980) for educational chairs, the seat width is 15¾" for educational chairs-size mark 5. The seat width dimensions of institutional chairs used were found to be higher in the front of the seat than the recommendations specified by Abeysekara (1985) and British standards (1980) (see Table 1). Hence the correct dimension for seat width should be fixed based on the anthropometric data which could comfortably accommodate specified target population.

SEAT ANGLE (TO HORIZONTAL)

A positive seat angle helps the user to maintain in contact with backrest and helps to counteract any tendency to slide out of the seat and excessive tilt reduces hip/trunk angle as ease of standing up and sitting down (Pheasant, 1992). Mandal (1981) argued that the seat surface should slope forward hence diminishing the need for hip flexion (particularly in task such as typing and writing) and encouraging lumber lordosis. Scientific studies as have been done on forward tilt seating do not suggest that the kneeling chair (forward tilt seat) offer any particular material advantages. This is when compared with a well-designed chair of the conventional sort, both with regard to sitting in general and with regard to office use in particular. There is little to be said in favour of forward tilt sitting (Pheasant, 1992).

Certain types of clerical work, among other activities demand an upright forward leaning trunk. These postures preclude the use of the backrest in chairs of conventional design. When the person using the chair spending a considerable

proportion of his time in such operations, a backward tilt to the seat is a disadvantage. A horizontal seat or one with a slope of less than 3° is probably more suitable for these situations. The backward tilt of the seat appears to be advantage only in the situation where there is forward pressure on the trunk from the backrest (Floyd and Roberts, 1958).

The chairs presently used in the universities were constructed with no seat angle (to horizontal) hence the seats are horizontal. Here the task performed is the writing with the support of a plank mounted to the position of armrests with frequent forward viewing. The chances for forward leaning may be a rare occurrence since no table available in front. However, the postural behavior for this kind of chair while performing the tasks is a matter to be investigated.

Abeysekara (1985) recommended 14°- 24° seat angle (to horizontal) to prevent the buttock from sliding forward for work seat design. The backward seat tilt angle specified by Abeysekara (1985) is for worker population whose requirements are different from students while performing the tasks. According to the British Standards (1980) for educational chairs, seat angle (to horizontal) is given as 0°- 5°. The horizontal seat of existing chairs seems to be acceptable according to the literature referred. If the trunk is kept largely upright and unsupported or slumped and unsupported, as occurs in sitting on a bench, there is no tendency to slide on the seat, and the seat for mechanical reasons should be horizontal (Floyd and Robert, 1958).

In horizontal seat there is a less acute angle between thighs and trunk, the onset of activity in the back muscles is hastened if the seat is sloped and retarded if it is horizontal as shown electromyographically (c. by Floyd and Robert, 1958). The designers or manufacturers of lecture hall chairs under our investigation did not give justifications how the horizontal seat came into design. From the comparison with British Standards (1980) for educational chairs, it can be stated that the horizontal seat design might have been copied from British Standards.

BACKREST DIMENSIONS

Chairs should incorporate the backrest satisfactorily in position and shape. The lower portion of the backrest should be clear of the sacral region so that the sitter can comfortably support his lumbar region to the backrest. An adequate criterion for determining the height of the upper edge of the backrest is the height of the shoulder blades (Floyd and Robert, 1958). The lower level of backrest provides support for lumbar and lower thoracic regions only and finishes below the level of shoulder blades, thus allowing freedom of movement for the shoulders and arms (Pheasant, 1992). Pheasant (1992) further elaborated that it will generally be preferable and sometimes essential for backrest to be contoured to the shape of the spine, and in particular to give positive support to the lumbar region in the form of convexity or pad.

Mandal (1986) stated that in the forward bent posture, in which most precision work is done, there is hardly any affect of the lumbar support. Postural behavioral observations for classroom activities directly on 84 school pupils were studied by Floyd and Ward (1969). According to the results, 30 percent of their time in the classroom was spent by some of them, where the trunk was slumped forward and the arms were both resting on the desk surface whether they were writing or not. At this posture, the backrest becomes unworthy.

But where as Pheasant (1992) argues that in tasks such as writing which entail leaning and in which the supports of the backrest will tend to be lost, however the backrest remains important in these activities during rest pause. Unsupported upright sitting involves the worst of all worlds, this destabilizes postures, increasing loads acting on the ligaments, can cause the ligaments to deform, weakening the structure of the joints and increasing the loads on the spine (Lueder, 2002). It is obvious to anyone sitting unsupported upright posture takes more muscle work than sitting with the back supported (Anderson et al, 1974). Grandjean (1988) describes a study of office workers using time – lapse photography, which showed them to be in contact with the backrest for 42% of the time.

According to the results obtained for the present institutional chairs, the height from seat surface to bottom of backrest varies from 7½" to 12½" and the height from seat surface to top of the backrest varies from 17" to 18" among the chairs. The authors' experiences in this regard show that, in most cases the same type of backrest specified for institutional chairs by the designers when they make manufacturing orders where the manufacturer have no say to amend or correct the specifications given by the authority. None of the chairs used by the universities incorporated correct positions and shapes recommended by the research works and experts (see Table 1 and Figures 1, 2, 3 & 4). The backrests are higher than the required level and they will disturb the free movement of shoulders of the users.

Abeysekara (1985) recommended a backrest, from seat surface to the top of the backrest
17 ¾" – 18 ½" for males and 15 ⅞" to 16 ¾" for females. Where he recommended a lumbar support with a height of 6½" - 10½" for males and 6⅜"-10¼" for females which contoured to the shape of the spine (see Fig. 5). Whereas the British standards (1980) for educational chairs recommended the height of backrest from seat surface to bottom of backrest 6 ⅜" – 6 ¾", and from seat surface to top of backrest
13" – 14 ¼" with the lumbar support (see table1). The backrests were found to be not supporting lumber region and constructed above the lumber region when contrast to the recommendation made by Abeysekara (1985) and British Standards (1980). Hence it is important to establish the comfortable backrest dimensions to fit the user population. For this purpose anthropometric data of user population are needed. The existing chairs should be tested for their comfort in use by students.

BACKREST ANGLE (TO HORIZONTAL)

The writing is the most important task of the chair under consideration. The most common writing posture is a forward one, although some people write while reclined. When writing people are more likely to sit upright, even to the point of being unsupported in the back which is the posture associated with lower back fatigue but lean backward during rest. For this particular chair and with respect to the task to be performed, establishing the comfortable backrest angle is required. As the backrest angle increases, a greater proportion of the weight of the trunk is supported, hence the compressive forces between the trunk and pelvis are diminished, and furthermore, increasing the angle between trunk and thighs improves lordosis (pheasant, 1992). Reclined postures simultaneously reduce loads on the spine (intra-discal pressure) and muscle work

(Anderson et al, 1974). Umezana (1970) showed that leaning back could promote neutral posture. With regard to the backrest angle, Mandal (1986) argues, when sitting on 5° backward sloping seat, neck has to be bent even more to get visual contact with items lying on the table. Consequently, office workers today have far more complaints from the neck and shoulder than from the lumbar region.

In the case of existing institutional chairs presently in use, chairs only from one university were constructed with reclined backrest angle of 110° and the chairs from the other universities constructed with backrest angle of 90°, vertical backrest. Abeysekara (1985) recommended backrest angle (to horizontal) of 110°- 130° for work seat since the requirements of work seat is different from that of student's. According to British Standards for educational chairs, the backrest angle of (to horizontal) 91°- 96° is recommended. Though the chairs from one university constructed with backrest angle of 110°, the improper positioning and shape may not give the expected comfort. The vertical backrest of the rest of the chairs may not be comfortable in reclining posture during rest. Ultimately chairs may not be comfortable due to its backrest construction. The present lecture room chairs require a backrest with correct angle in their design. And also the present chairs have to be tested for their comfort.

BACKREST CURVE

Floyd and Roberts (1958) proposes a backrest support with an anteriorly convex surface in sagittal section to help in accommodating persons of different size as well as to assist the fit of the backrest into the lumbar region and prevent undue pressure at the upper and lower edges of backrest. The pressure applied to the backrest should be distributed over as large an area as possible. To achieve this, the transverse curve should conform to the lateral curvature of the lumbar region of the body but too deep curve unsatisfactory (c. Floyd and Roberts 1958). For general use a radius of not less than 12 inches and usually of 16 inches to 18 inches is to be preferred (Floyd and Roberts 1958).

Except chairs from one university, the chairs from rest of the universities were constructed with backrest curvature where the radius varies from 32" to 50". Abeysekera (1985) in his recommendations for work seat has not recommended backrest curvature and in the mean time for the short time use backrest curvature may not be necessary. In the British Standards for educational furniture for size mark five, radius was given as 15¾". When the backrest curve of the institutional chairs are compared with the British Standards (1980), the radii are higher in existing institutional chairs and it will probably be ineffective while using since the curve will not conform to the lateral curvature of the lumbar region. Ultimately the backrest curves of existing chairs become less useful adding additional cost in construction. The correct backrest curvature can be recommended to support the lateral curvature of the lumbar region with the help of anthropometric data and the available literature.

DESKTOP HEIGHT

The writing planks were mounted to the same height of armrest mainly to the right side in existing lecture hall chairs. This design becomes complicated since both armrest and writing top are fixed in the same height. Available literature suggests as follows. Pheasant (1992) states for writing, the working surface (desktop) should be somewhat above the users elbow height, as

measured in the standard upright sitting position in order to write with a relaxed and natural action. The work table must be of such a height as to suit the body length and the activity of the operator (Grandjean, 1987). The height of the horizontal table top should be 4 – 6cm above elbow level, measured with the subjects seated, the shoulders relaxed and the elbows at 90° (Bendix, 1986). The higher work surfaces will require excessive abduction of the upper arm which will lead to fatigue (Tichauer, 1978).

The tabletop height contradicts with visual requirements of the task in maintaining the healthy posture. Mandal (1982) states that school children have a visual distance of approximately 200 to 400mm. He argues that when using tables designed at elbow height, they must consequently sit bent over the table surface with excessive flexion of their backs. He recommends a higher table surface which enables the children to sit more upright position whilst maintaining an adequate visual distance.

The tabletop height or writing top height of the lecture hall chairs (from seat) varies from 6 ½" to 8". The difference among the chairs in armrest/desktop heights are 1½" (see table 1) which shows the complications in setting the dimensions. From Abeysekara's (1985) recommendations tabletop height from seat can be worked out as 7 ⅝" for males and 7 ⅜" for females and he recommended the same for armrest height for males and females respectively. From British standards (1980) for educational chairs, table height from seat can be calculated, which is 11". When the existing chairs are compared with Abeysakara's (1985) recommendations for writing top, chairs from one university were constructed with 6 ½" desktop height which is less than the Abeysekara's (1985) recommendations. The British Standards' (1980), tabletop is much higher than the tabletop height of existing chairs and Abeysekara's (1985) recommendations. The results of the comparisons show the complications remaining in fixing the writing top height for lecture hall chairs.

Generally the writing top/table is located in front of the sitter. It is interesting and becomes important in making design recommendations for lecture hall chair's desktop since the desktop is fixed to the armrest side. Hence the writing posture becomes distinguishable in this case when compared with the writing posture of table in front. For designing and using this kind of lecture hall chair in Sri Lanka, the cost is the main factor considered where the cost for manufacture of separate table is cut down. From this study it is suggested, in addition to investigating the anthropometric characteristics of user group for this chair, the health and comfort aspects in using this kind of chairs have to be studied.

CONCLUSIONS

It is concluded from the findings of the study that various design dimensions are used to design institutional chairs for a same user group to perform a same particular task. The design dimensions presently used to design institutional chairs are not based on body dimensions of the user population. Some of the design dimensions used seems to be copied and modified from British Standards. Hence the present institutional chairs do not match to student user population. It is suggested from the findings of the study to undertake research studies on body dimensions of institutional students to develop correct design dimensions for institutional chairs, which would fit to the user population and to test the present chairs for their fit to the students. Further any prototype

chair designed in the future which fit the body dimensions of the users has to be evaluated and tested among the users population both short term and long term before finally recommending to the manufacturers.

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Paper Submitted:

A paper submitted to ***International Journal of Industrial Ergonomics*** on the title of "Designing Chair with Mounted Desktop for University Students: Ergonomics and Comfort" Now the paper is under review.

Designing Chair with Mounted Desktop for University Students: Ergonomics and Comfort

Abstract

The chairs with mounted desktops are widely used in lecture halls of Sri Lankan universities. An anthropometric survey was carried out among the university students in Sri Lanka to assess the comfort levels by design dimensions for mounted desktop chairs to be used in their lecture halls. The first part of the study focused on design dimensions for mounted desktop and recommended the dimensions for the mounted desktop chair. The study further suggested to investigate the postural behaviors while sitting in this chair and also to evaluate the prototype in the lecture hall.

Introduction

The chairs with mounted desktops are widely used in lecture halls of Sri Lankan universities. The desktops are mainly mounted in the right side of the chairs to where the armrests are fitted. The mounted desktops are used for writing purposes instead of using tables in front of the sitters. Two main advantages (i.e. saving the spaces that are occupied by tables and reducing the cost incurred in purchasing tables) associated with this kind of lecture hall chairs and they therefore, are important for country like Sri Lanka. University authorities are influenced by these advantages in making furniture procurement decisions.

The chairs have become as important physical element of the learning environment. The educational furniture is expected to facilitate learning by providing a comfortable and stress free workstation. Studies in other countries revealed the problems associated with the school furniture. Troussier et al (1999) found a 23% of children experienced back pain in the sitting position, and the frequency of back pain increased with the duration of the sitting posture at school. School children are at special risk for suffering negative effects from badly designed and ill-fitting furniture owing to the prolonged periods spent seated during school (Parcells et al, 1999). Discomfort and bad postures associated with badly designed chairs and tables used in schools are factors which may affect academic performance and physical development of school children (Evans et al, 1988). Anthropometric parameter is one of the factors associated with low back pain (Balague et al., 1993). Hence, in developing comfortable posture, chair design dimensions which are derived from anthropmetric parameters play a vital role.

University students spend about 3-4 years in the universities' lecture halls. They spend most of their time in the sitting position. Fewer attentions have been paid for designing ergonomically - correct mounted desktop chairs for university students. Thariq and Munasinghe (2005) found that the present day university lecture room chairs do not fit the body dimension of the students. The availability of anthropometric characteristics of Sri Lankan is very limited. A national anthropometric survey of workers population was carried out by Abeysekara (1985). He recommends design dimensions for work seat. But those dimensions are not used by furniture designers or manufacturers to design work seat as they

are not aware of the availability of this data. The recommendations made by Abeysekara (1985) for work seat design are based on the anthropometric data of specified worker population. It may not fit the present university student population of Sri Lanka.

The design dimensions presently used to construct lecture room chairs are found to be 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 design dimensions to construct educational furniture for university students. Hence the intention of the study is to develop design dimensions for mounted desktop chairs for university students in Sri Lanka to use in their lecture rooms. Further the study mainly focused on the design of mounted desk top.

Method of study

Anthropometric measurements were taken from the normal healthy undergraduate students of two Sri Lankan Universities; University of Peradeniya and University of Moratuwa. The measurements were taken during the period at the last quarter of 2005 and first quarter of 2006. The students from first year to final year were selected for taking measurements. The sample consists of 385 subjects; 222 males and 165 females.

The anthropmetric measurements taken were stature, elbow height (standing), sitting eye height, sitting height, acromial height (sitting), Sitting elbow height, lowest rib bone height (sitting), upper hip bone height (sitting), upper leg height (sitting), seat surface height, buttock width, forward arm reach, elbow-finger tip length, buttock-popliteal length, buttock-knee length, buttock heel length and weight (Please refer figure 1 and annex). Two anthropometers were used. Both anthropometers were tested with each other for consistency in measurements and found they were 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 cloth, pockets were emptied, and shoes were removed. All sitting measurements were taken with subjects sitting comfortably erect posture so that the knees and ankle formed right angles. The data were cross checked for their consistency and inconsistent data were deleted. Data obtained were analyzed using MINITAB statistical package.

Results and discussions

Table 1: Anthropometric measurements of the subjects for chair design, mean values and percentile values

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
Buttock width	346(28)	303	343	381	396	415
Buttock poplitial 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
Acromial height	545(37)	485	547	590	604	630
Sitting elbow height	206(27)	160	205	242	252	263
Upper leg height	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
Elbow 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
Sitting eye height	730(48)	651	733	786	806	827
Weight	56(12)	38	55	71	77	88

Table 2: chair features and recommended chair feature dimensions for fixed mounted desktop chair

Chair features	Design Dimensions (mm)	Determinants
1. seat surface height	413	5%le + 45mm allowance
2. seat depth	434	5%le of Buttock poplitial length
3. seat width	436	95%le + 40mm allowance
4. bottom of backrest height	163	5%le upper hip bone height
5. top of backrest height	296	95%le lowest rib bone height
6. backrest width	436	Same as seat width
7. lumber support height	133	Distance between 4 & 5
8. armrest height	160	5%le sitting elbow height
9. desktop height	252	95%le sitting elbow height
10. armrest length	405	5%le elbow-finger tip length
11. desktop length	453	50%le elbow-finger tip length
12. desktop angle to horizontal	10°	
13. seat angle (to horizontal)	0°	
14. backrest angle (to horizontal)	96°	

Mounted desktop is the main feature of this chair. The desktops are fitted to the place where the armrests are fitted. Furniture manufactures on arbitrary basis assemble 95% of the desktops to the right side and 5% to the left side in the chairs. This is done with the assumption of that around 5% of the users are left hand writers. But determining correct position for desktop is a critical aspect in the design process; this may affect comfort and health of the students.

Almost all of the research work carried out and the recommendations made are to the work surface positioned right in front of the occupant. The majority of researches recommended that the work surface height should correspond to the seated elbow height or slightly lower (e.g. Floyd and Robert, 1958 and 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 or light assembly work, precision work and fine work. Ayoub's general principle appears to be that a higher work surface is required for more visually demanding precision tasks which admit the visual requirements in sitting and writing mentioned by Mandel (1997).

The BSI standards (BS5873: Part 1, 1980) on school furniture recommended table heights which are slightly higher than elbow rest height for most of the target population. For the Hong Kong standards, 95th percentile elbow rest heights of the target groups have been added to the seat height (Evans et al.,

1988). Molenbroek et al (2003) used 95th %le of sitting elbow height for table height for school students. Hence based on the literature; we conclude that the school table height should be 95th %le of sitting elbow rest height. Accordingly 95th percentile of elbow rest height is 252mm, which is the desk top height/table height for university students.

The mounted desk top is used mainly for writing purpose by the students and it is non- adjustable. The desk top height of 250mm was obtained based on the findings and recommendations from the literature. The design criteria proposed in past research work are for the tables located just opposite to the users. But the question is whether this desk top height (i.e.250mm) can be used for mounted desktop. In our chair design, the desktop is attached to the position of armrest and it is found mainly in the right side of the students. As a result, the mounted desk top may develop different postures. The writing postural demand may be different in this chair.

The mounted desk top chair may not develop the following postures observed by Floyd and Ward (1969); three types of postural behaviors were most frequently observed in the class room; sitting without support from the backrest (the backrest of a chair was most often used when only one arm was resting on the desk or when arms were not in contact with the desk at all), the trunk inclined forward, and this forward inclination with both arms supported by leaning them on the desk. Floyd and Ward (1969) claimed that the latter posture was adopted not only when writing, but for a considerable amount of the time during other activities. And also some pupils were spending up to 80% of their time in this forward sloping position. This claim may not be materialized in this chair.

Forward stretching of arms may not be required in this chair. Writing arm can be kept closer to the body. The rise of the writing upper arm around the shoulder may occur in this chair depending on the height of the desk top. It is expected that this chair may develop different set of postures while students using this chair. The location and the height of the desk top are two main factors in developing comfortable postures while using this chair. We propose the desk top height of 250mm for this chair since it is going to be used as writing surface. The postural behavior and postural comfort of the mounted desk top chair study should be evaluated. Knight and Noyes (1999) stated that the school furniture should be able to facilitate learning by providing a comfortable and stress free workstation. This evaluation some times may lead to revision of the mounted desk top height.

Another aspect with this chair is to what extent it will support the learning activities of the students. The mounted desk top chair is in compact form by its design. The school furniture has to support several activities carried out by the students in their class room. The main purpose of the mounted desk top is meant for writing. Conceptually, since there is no table with this chair, this chair has to fulfill the functions of both chair and table. The activities displayed by the students were identified by Floyd and Ward (1969) during their seated working position. The mounted desk top chair may support the activities such as listening, following text, reading, looking up (concentrating attention to teacher), writing, speaking. It may also support standing up and sitting down and absent temporarily from class room. It may not support the preparation for lessons (assembling books etc.) and reaching for contents of satchel since the space of mounted desk top is limited. We believe that the facilitation role in the leaning process while working on the mounted desk top chair has to be investigated.

The position of mounted desktop may draw a conflict between mounted desktop height and armrest height. Several researches have studied the armrests. A comprehensive review has been carried out by Leuder (2006). She has stated that; armrests have been shown to improve posture and promote freedom of movement which stabilizing one's position; reduce the muscle load on the neck, shoulder and arms; reduce pressures on the spine; distribute pressures on the seat, support rising and sitting in the chair and support task-related movements. Feng et al. (1997) found that all kinds of arm supports (fixed, horizontal, and spring loaded) reduced EMG levels of the shoulder muscles, but the horizontal movable support was most effective in reducing shoulder EMGs when tasks were set at table height.

The mounted desktop though it mainly supports writing activities, the writing arm can be supported by this desk top. But the conflicting aspect may be its height at first. Since it is positioned at higher level than the arm rest, it may not allow the shoulder to take its neutral anatomical position. The proper positioning of armrest is an important design criterion in harnessing the benefits of armrests. As stated above in this text, the rise of the writing upper arm around the shoulder may occur while using this chair. Secondly, its surfaces are hard and flat. Therefore the desktop may not fulfill the requirements to act as armrest.

In the other side of the chair, arm rest can be fitted. The existing mounted desk top chairs are used with or without armrest. If the armrest is required, it may be fixed at the height of 160mm in contrast to the desktop height (252mm). Accordingly the armrest and the mounted desktop will be found in different heights in a same chair. The recommended arm rest height 160mm is as per the 5^{th} %le of sitting height. From the literature (Leuder, 2006; Collins, 1999; and US Army Natick, 1989) it can be argued that lower armrest can be easily used by taller users than the higher armrests by shorter users. In the existing lecture hall chairs, both armrest and desktop are fixed in same height that is equal to armrest height, table 3 provides the data on existing chair dimensions (Thariq and Munasinghe, 2005).

Table 3: Dimensions of existing institutional chairs and dimensions recommended by Abeysekara (1985) for work seat design

Chair features	South Eastern [illegible]	University of Peradeniya	University of Kelaniya	University of Moratuwa	Abeysekara (1985)	
	----	----------	----------	------	Males	Females
Seat height (from floor) (inches)	18	16	18	19½	15⅝	14⅜
Seat depth (inches)	17 ½	18¼	17	16	14⅜-16 ⅜	13½ – 15½
Seat width (inches)	18	21½ Front width	18 Front width	18	15¾	15⅞
		16½ Rear width	14 Rear width			
Seat angle (to horizontal)	0°	0°	0°	0°	14° - 24°	14° - 24°
Backrest height (from seat surface to bottom of backrest) (inches)	9	12½	9½	7¼	0	0
Backrest height (from seat surface to top of backrest) (inches)	18	17½	17	17	17¾ – 18½	15 ⅞- 16¾
Height of lumbar support from seat (inches)	8	5½	7½	11	6½ - 10½	6⅜ - 10¼
Backrest angle (to horizontal)	90 °	90°	90°	110°	110° - 130°	110° - 130°
Desktop height (inches)	8	6½	7¼	7¼	7 ⅞	7 ⅜
Armrest height (inches)	8	6½	7¼	7¼	7 ⅞	7 ⅜

Adopted from (Thariq and Munasinghe, 2005)

School children have a visual distance of approximately 20 – 40cm. When writing tables designed at elbow height, students must sit bent over the table surface with excessive flexion of their backs (Mandel, 1997).

A question arises here is that do the students bend forward only because of the lower tables (tables designed at elbow height). We believe that the table

placed in front of students also causes for the forward leaning of students. Because we have observed the use of mounted desk top chairs during the lecture sessions (English and mathematics subjects). The students use the backrest for fairly higher amount of time (80%). The desk top attached to the chair to the location where armrest is found. Hence students do not need to lean forward. The reduction in leaning forward is due to use of the mounted desktop. The mounted desk top chair promotes straight back and may increase the back comfort. This is an advantage associated with this chair.

The inclination of the mounted desk top is the other consideration in designing mounted desk top. Mandel (1982) recommended an inclination of 10 – 15 degrees when an inclined surface is required. But the edge towards the student will be maintained approximately to the same height as of the specified horizontal surface as per recommendation of Evans et al. (1988). We recommend a horizontal and flat surface desk top for this chair. The inclined desk top and higher chair are used to promote the straight back. Since the mounted desk top itself promotes straight back, the inclined desk top may no not be required. Neck flexion and turning the neck to right or left side may be required by these chairs while writing. However, lumber, neck and hip flexion for the mounted desktop chairs have to be investigated.

Conclusions and recommendations

The mounted desktop height for the lecture hall chairs for the university students is recommended as 252mm from the seat surface height. If arm rest is required, it can be fixed at the height of 160 mm from seat surface. The postural behaviors/the postural advantages and disadvantages of this mounted desktop chair should be investigated. Further any prototype chair constructed using the recommended dimensions has to be evaluated and tested among the users population both short term and long term before finally recommending to the manufacturers.

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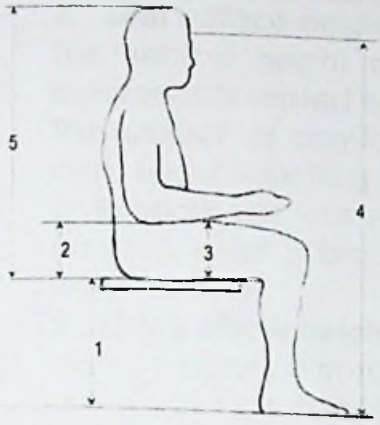

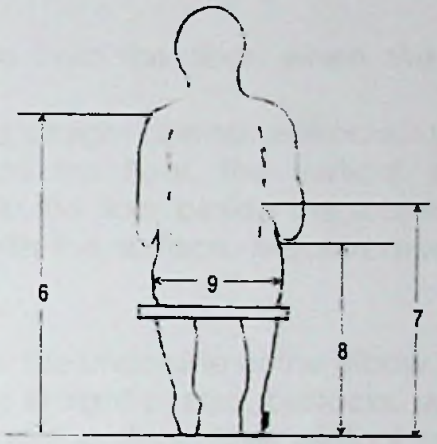

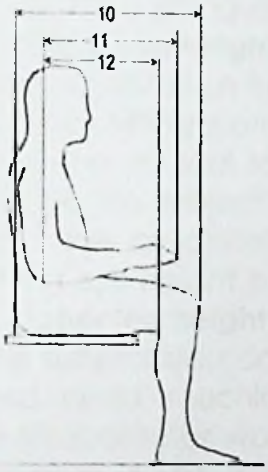

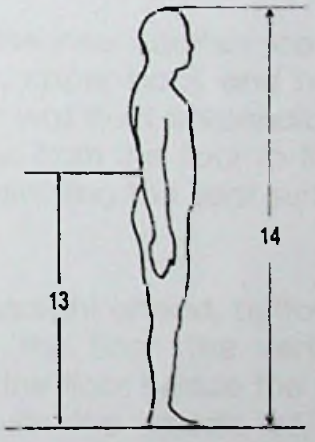

1. Seat surface height
2. Sitting elbow height
3. Sitting eye height
4. Upper leg height
5. Sitting height
6. Acromial height (sitting)
7. Lowest rib bone height (sitting)
8. Upper hip bone height
9. Buttock width
10. Buttock knee length
11. Elbow finger tip length
12. Buttock poplitial length
13. Elbow height (standing)
14. Stature

Figure 1: Anthropometric measurements

Annexure

Anthropometric measurements

1. Seat surface height:-

The vertical height of the sitting surface from the floor, when the subject is comfortably seated erect.

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar point is brought into contact with the surface. Measurement is taken from the floor.

2. Sitting elbow height:-

Vertical distance from the sitting surface to the underside of the elbow.

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar point is brought into contact with the inferior surface of the olecranon process. Measurement is taken from the floor, by subtracting the seat surface height; the sitting elbow height is obtained.

3. Sitting eye height:-

Vertical distance from the sitting surface to the inner canthus (corner) of the eye.

Subject sitting comfortably erect, buttocks, upper back and head touching a wall, the vertical rod of the anthropometer was held perpendicular to the floor beside the subject. Measurement was taken from the floor to the corner of the right eye by adjusting the crossbar. By subtracting the seat surface height, the sitting eye height is obtained.

4. Upper leg height (sitting):-

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar point is brought into contact with the middle of the upper leg. Measurement is taken from the floor, by subtracting the seat surface height; the upper leg height is obtained.

5. Sitting height (normal):-

Vertical distance from the sitting surface to the vertex (i.e. the crown of the eye).

The subject sits comfortably erect, hands in lap, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar is brought down into contact with the top of the head, in the midline and the measurement is taken from the floor, by subtracting the seat surface height; the sitting height is obtained.

6. Acromial height (sitting):-

Vertical distance between the sitting surface and the acromion land mark on the tip of the shoulder.

The subject sits comfortably erect, hands in lap, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar point is brought into contact with the acromion landmark. Measurement is taken from the floor, by subtracting the seat surface height, the acromial height is obtained.

7. Lowest rib height (sitting):-

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar point is brought into contact with the lowest rib bone. Measurement is taken from the floor, by subtracting the seat surface height; the lowest rib bone height is obtained.

8. Upper hip bone height (sitting):-

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject and the crossbar point is brought into contact with the upper hip bone. Measurement is taken from the floor, by subtracting the seat surface height; the upper hip bone height is obtained.

9. Buttock width (sitting):-

Distance between the widest parts of the buttock in horizontal line in sitting position.

The subject sits comfortably erect, looking straight ahead, feet flat on the floor. Anthropometer is held horizontally beside the buttock from the back side and cross bar points were brought in light contact with widest parts of the buttock and the measurement is taken.

10. Buttock – knee length (sitting):-

Horizontal distance from the back of the uncompressed buttock to the front of the kneecap.

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor and thigh parallel to the floor. Main anthropometer bar held parallel to the thigh, measurement was taken from the wall.

11. Elbow –finger tip length (sitting):-

Distance from the back of the elbow to the tip of the middle finger in the standard sitting position.

Subjects sitting comfortably erect, upper arm in relaxed position, forearm parallel to the floor, anthropometer held parallel to the forearm, measurement is taken by adjusting the crossbar points from back of the elbow to the tip of the middle finger.

12. Buttock – popliteal length (sitting):-

Horizontal distance from the back of the uncompressed buttock to the popliteal angle, at the back of the knee where the back of the lower legs meet the underside of the thigh.

The subject sits comfortably erect, looking straight ahead, buttocks, upper back and head touching a wall, feet flat on the floor and thigh parallel to the floor. Main anthropometer bar held parallel to the thigh, measurement was taken from the wall.

13. Elbow height (standing):-

Vertical distance from the floor to the radiale (the radiale is the bony landmark formed by the upper end of the radius bone which is palpable on the outer surface of the elbow).

The subject stands erect, looking straight ahead in a normal way, with his shoulders relaxed and forearms parallel to the floor. The vertical rod of the anthropometer was held perpendicular to the floor beside the subject. Measurement was taken from the floor to the inferior surface of the olecranon process of the right arm by adjusting the crossbar in light contact with the inferior surface of the olecranon process.

14. Stature:-

The vertical distance from the floor to the vertex (i.e. the crown of the head). The subject stands erect against a wall, heels together, and toes at an angle of 45°. Heels, buttocks, upper back and head touching the wall, head facing forwards in a horizontal plane. The vertical rod of the anthropometer was held perpendicular to the floor with the standing base at the top. The subject standing beside the rod, measurement was taken from standing surface to datum probe at vertex or highest point, compressing the hair if necessary, in the mid line of the head.

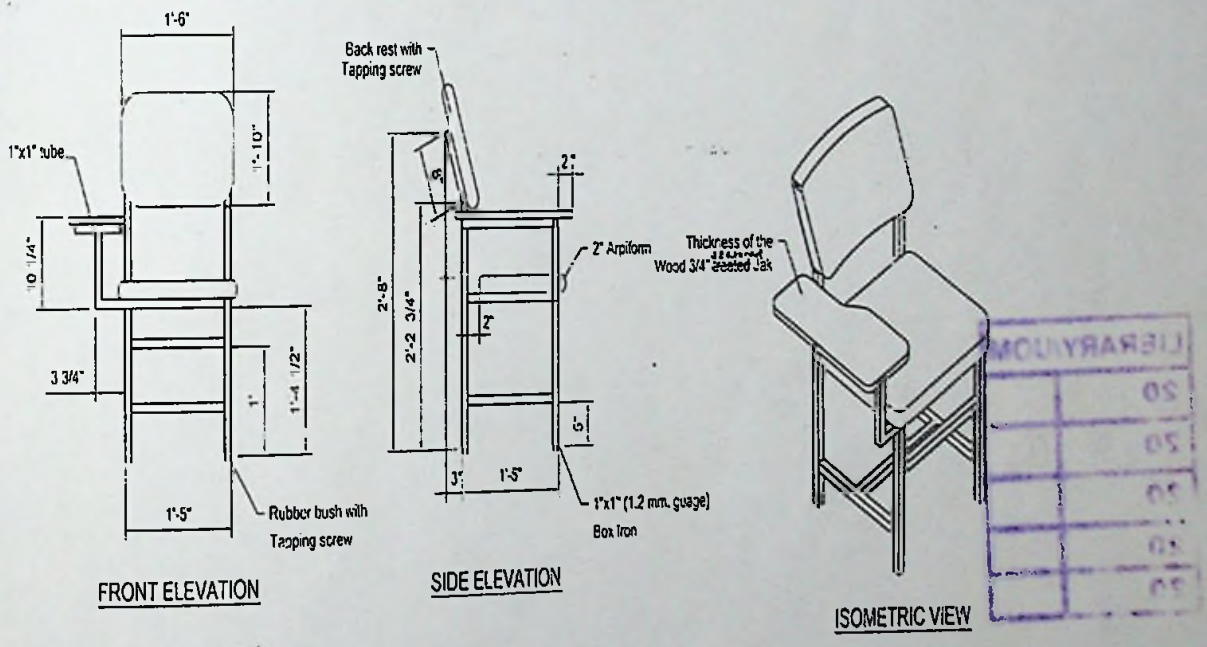

Figure 2: Existing lecture hall chair, University of Moratuwa, Sri Lanka