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Full Length Research Paper

Ergonomically adjustable school furniture for male students

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The need for adjustability in school furniture, in order to accommodate the variation in anthropometric measures of different genders, cultures and ages is becoming increasingly important. Four chair-table combinations, different in dimensions, with adjustable chair seating heights and table heights were designed, manufactured and distributed to schools in Riyadh city. The number of the student participants was 28 (6 to <9 years), 30 (9 to <12 years), 30 (12 to <15 years) and 30 (≥ 15 years) in first, second, third and fourth age-group sets respectively. Muscular activity signals (EMGs) for both neck dorsal muscles and upper trapezius muscles, posture measures in terms of neck angle, viewing angle, back angle and discomfort ratings were considered as dependent factors. New designed adjustable sets versus current sets available in the schools were the independent variables. The results indicated that EMGs signals for both neck dorsal and upper trapezius muscles in the new sets were significantly lower when compared to the current sets. The three posture measures associated with the new sets were significantly improved when compared to the current sets. Finally, the participants' ratings of discomfort were significantly low for sitting on the new sets compared to sitting on the current sets.

Key words: School furniture, adjustable seat, EMG, discomfort rating, anthropometry.

INTRODUCTION

Children remain seated at school for a considerable amount of time (Alnaser and Wughalter, 2009). Prolonged static posture puts an extreme physiological strain on the muscles, the ligaments and in particular on the discs (Bendix, 1987; Straker et al., 2002). Correct sitting posture is an important factor for the prevention of musculoskeletal symptoms (Cranz, 2000; Gadge and Innes, 2007; Soares et al., 2012). Recent researches have documented an increase in health problems related to poor sitting (Chung and Wong, 2007; Saarni et al., 2009; Corlett, 2009). Neck, shoulder and back pain problems are common among school children (Taimela et al., 1997; Alnaser and Wughalter, 2009). Students experience such problems due to low-quality design school tables and chairs (Troussier et al., 1999). Non-adjustable school furniture forces the students to adapted poor sitting postures (Vikat et al., 2000; Koskelo, 2007; Mokdad and Al-Ansari, 2009).

Murphy et al. (2002, 2004, 2007) identified the associations between ergonomics and other factors with back and neck pain among schoolchildren. Neck, upper back, and lower back pain were significantly associated with school furniture features (Wingrat and Exner, 2005). Panagiotopoulou et al. (2004) and Gouvali and Boudolos (2006) proved that desk and seat height were bigger than the accepted limits for most children, while seat depth was appropriate for less children. Saarni et al. (2007) and Ramadan (2011) indicated that there was a mismatch between school furniture and the anthropometrics of schoolchildren.

Matching furniture to anthropometric measurements is an important factor that should be taken into account in

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school furniture design (Cotton, 2002; Ramadan, 2011). Specific measurements, such as popliteal height, knee height, butttock–popliteal length, abdominal depth and elbow height are necessary in order to determine school furniture dimensions that enable the correct sitting posture (Knight and Noyes, 1999; Parcells et al., 1999; Miller, 2000). Using furniture that promotes proper posture is more important to children than adults because it is at this young age that sitting habits are formed. Poor sitting habits acquired in childhood are very difficult to change later in adolescence or adulthood (Yeats, 1997).

Children's anthropometric measures vary widely across different age groups, within the same age groups, between genders and between different races (Jeong and Park, 1990). Children's dimensions vary not only between the different classes but also within the same class (Barrero and Hedgewith, 2002). Thus, it is unlikely that school furniture with fixed dimensions would be compatible with the majority of students. The need for adjustability in school furniture, in order to accommodate the variation in anthropometric measures is supported by the work of Evans et al. (1988), Jeong and Park (1990), and Parcells et al. (1999).

Several studies (Jung, 2005; Vos et al., 2006; Acosta and Morales, 2007; Koskelo et al., 2007; Savanur et al., 2007) compared the traditional non-adjustable and the new adjustable school tables and chairs on the sitting postures, muscle tension and pain levels. When the students started to use their adjustable tables and chairs, muscle tension levels were reduced significantly in lumbar and trapezius muscles. The intervention corrected the posture much as expected, when the students were sitting in their new units. The intervention students reported that they experienced benefits from the adjustable tables and chairs. The results support the necessity of ergonomic approach in furniture planning of school classes and individual adjustment possibility of tables and chairs. According to Panagiotopoulou et al. (2004), Parcells et al. (1999), Evans et al. (1988), Chung and Park (1986) and Mandal (1994); the need for adjustable school furniture is becoming increasingly important. Sanders and McCormick (1993) pointed out that adjustable furniture is fundamental to develop and maintain good posture.

The suggested sets in this research were aimed at accommodating a wide range of students' sizes to enable the students to carry out their work effectively in a comfortable posture. Thus, a range of furniture sizes must be developed for Saudi standard to satisfy six primary school classes (ages approximately 6 to 12 years), three middle school classes (ages approximately 13 to 15 years) and three secondary school classes (ages approximately 16 to 18 years). Evans and Lee (1982) suggested that a range of five sizes of chairs and tables would accommodate Hong Kong school students from first primary class to the secondary seventh class, ranging in age from 6 years old to 18 years old. Oxford (1969) suggested that a range of six sizes of seats and desks would accommodate Australian school students from kindergarten to secondary in the age range from 4 to 20 years old. Considering economics, manufactur-ability and ergonomics views, four different sets' dimensions with adjustable chair heights and table heights were thought to be reasonable to be provided to schools. Therefore, the aim of this study was to design and manufacture a prototype and then compare the current nonadjustable school chairs and tables with the new proposed adjustable school chairs and tables with respect to sitting postures, muscle tension and subjective ratings of pain level.

METHODOLOGY

Designing the school furniture sets

When designing school furniture, it is necessary to know the potential height of the student's body and applying ergonomics principles (Panagiotopoulou et al., 2004; Parcells et al., 1999; Evans et al., 1988; Chung and Park, 1986; Mandal, 1994). Based on the Saudi school students' anthropometric data of Al-Harkan et al. (2005), anthropometric data related to furniture design requirements were considered for the design process. These anthropometric dimensions included sitting height, elbow height standing, elbow rest height (sitting), popliteal height, forward arm reach, scapula height (sitting), buttock-knee length, buttock-popliteal length, thigh depth, breadth across elbows and hip breadth.

Based on literature, economic and ergonomic considerations; four different prototype sets of furniture were fabricated. The 4 prototype sets of chair and table heights were adjustable and reasonable choices were provided for the students. As shown in Figure 1, the design guideline principles are described based on Evans et al. (1988) and Oxford (1969) as follows.

Chair height (C_h)

The chair height was measured from the floor level to the highest point on the centerline at the front of the chair area. The range of adjustability for the chair height was from the 5th percentile to the 95th percentile of popliteal height of the target group of the population. A value of 2.5 cm was considered reasonable for shoes allowance.

Chair depth (C_d)

The effective depth of the chair was measured on the centerline of the chair plane from the front edge to a line perpendicular to the backrest. The 5th percentile buttock-popliteal length was used to determine the recommended dimension.

Chair width, max. (C_w)

The chair width applies to the forward part of the chair, which may project under the table. This dimension is constrained by the minimum distance between table supports. So, the recommended dimension was determined by the 95th percentile breadth across hips plus a clearance value. An arbitrary clearance of 7 cm was adopted in this study.

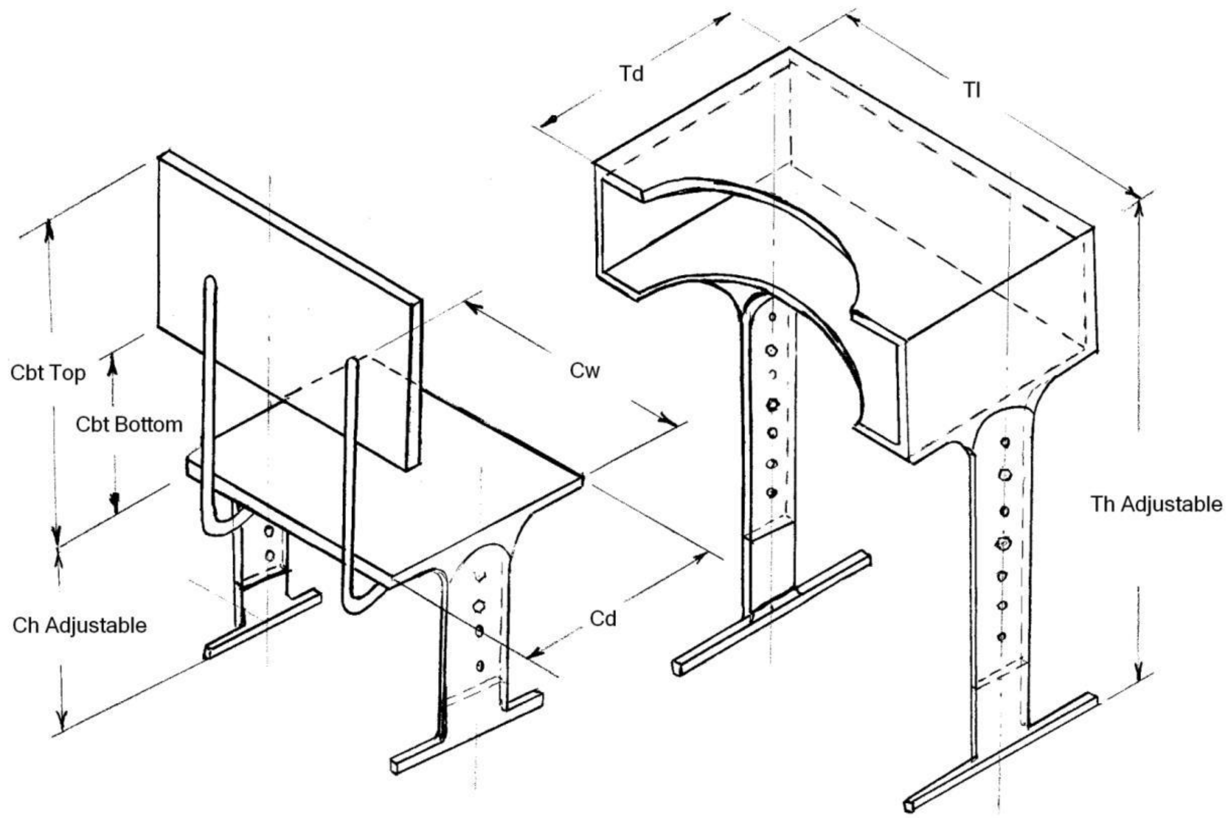

Figure 1. Sketch of school furniture dimensions.

Chair plane to bottom of backrest (C_{bt}(Bottom))

This dimension was measured from the center of the chair plane at the lowest part of the chair surface to the lower limit of the backrest. The lower edge should be well rounded. This dimension is determined by the lumbar height. Unfortunately, it was difficult to establish the position of the lumber curve so it was not measured in the present study. The measure was adopted for the Saudi students, with some proportional adjustments based on sitting height of the target groups.

Chair plane to top of backrest (C_{bt}(Top))

This dimension was measured from the center of the plane from the lowest part of the chair surface to the upper limit of the backrest. This dimension should be maintained at approximately 10 cm below shoulder height to prevent restriction of the movement of the arms. This criterion was also achieved by utilizing scapula height as the upper limit. Scapula height (sitting) was measured in the study. So, the upper edge of the backrest was determined by the 5th percentile scapula height of the target groups.

Table height (T_h)

5th percentile to the 95th percentile of the elbow rest heights of the target groups is added to chair heights.

This means that the table heights for the majority of the population will be slightly higher than elbow rest height, thus requiring some abduction of the upper arm. However, this should not cause excessive stress on the shoulder muscles since most schoolwork can be carried out with the forearms resting on the table surface.

Table depth (T_d)

The minimum depth of the tabletop was determined by the 95th percentile of arm reach of the target groups.

Length of table top (T_l)

The minimum length of the tabletop was determined by the 95th percentile of elbow-to-elbow length for the target groups.

The new four suggested sets of school furniture were designed based on the data presented in the Al-Harkan et al. (2005) study about student's measurements and the explanation of how the design dimensions were determined.

The dimensions of the four sets are reported in Table 1. It is worth mentioning that only chair height and table height were adjustable in a range of 5 to 95% percentile of the age population group.

The four sets prototypes were manufactured in a local workshop based on the suggested values shown in Table 1 and the suggested features shown in Figure 1.

The school furniture of the study consisted of two types, the ‘‘current" which was used in public primary, middle and high schools at the time of this research and the ‘‘new’’ four prototypes. The "current" school furniture was comprised of two sets as shown in Table 2. The first set of the "current" school furniture was used in

Table 1. Proposed new school furniture dimensions in centimeters.

Chair dimensions		**Age group**			
		6 - <9 years	**9 - <12 years**	**12 - <15 years**	**>15 years**
1	Chair height (C_h), adjustable	27.8 - 29.8	32.4 – 33.8	36.1 - 39	39.1 - 41.9
2	Chair depth (C_d)	28.8	35	40.8	44.8
3	Chair width (C_w)	36.1	40.1	44.2	47.0
4	Chair plane to bottom of backrest (C_{bt})	12	13	14	15
5	Chair plane to top of backrest (C_{bt}(top))	33.4	37.9	38.6	39.2
Table dimensions					
1	Table height (T_h),adjustable	46.3 – 49.1	52.9 – 54.9	57.8 – 62.6	65 -71.5
2	Table depth, (T_d)	45	50	52.5	57
3	Length of table (T_l)	37	41	46	51

Table 2. Current school furniture dimensions in centimeter.

Set characteristic	**Current sets**	
	I	**II**
Chair height	40	46
Chair depth	40	45
Table height	60	67

all grades of the primary school while the second set was used in middle and high schools.

Adjustable school furniture validating and testing

Participants

The appropriate sample size for a population-based survey is determined largely by three factors: (i) the estimated prevalence of the variable of interest - subject's height in this instance, (ii) the desired level of confidence and (iii) the acceptable margin of error.

For a survey design based on a simple random sample, the sample size required can be calculated according to the following formula.

$$n = (z\sigma / h)^2$$

where: **n** = required sample size. **z** = confidence level at 90% (standard value of 1.65); in a case of the sample size is less than 50 and the normality of the population is not likely, an appropriate value of t must be used. **σ** = estimated standard deviation (Al-Harkan et al., 2005). **h** = the precision requirement in the actual dimension (x - μ = 1 cm), (Shiang, 1999).

The previous formula yields to a sufficient sample size of 112 participants. Ten male students from each grade (that is, from first to twelfth grade) were randomly selected from three schools in Riyadh. Participating schools' permission and parents and students agreements were obtained. Collectively, a hundred and eighteen (n=118) male students, based on the availability, aged from 6 to 17 years old participated in the study. The participants were divided into four different age groups, (6 to <9), (9 to <12), (12 to <15) and (≥15). The numbers of student participants were 28, 30, 30 and 30 in the first, the second, the third and the fourth group, respectively.

Experimental design

Each student participated in six treatments (e.g., two sets by 3 activities) in the same day in a random order. The levels of set type were new sets (proposed) versus current sets. The levels of studying activities were reading, writing and looking to the blackboard. Looking at the blackboard was considered to be similar to listening to the teacher. Muscular contractions (electromyography = EMG) were the main dependent variables. Finally, age groups were within the set number factor (e.g., the first set for ≤8 years, the second set for 9 to 11 years, the third set for 12 to 14 years, and the fourth set for ≥15 years).

Statistical analysis was performed using the Statistical Package for the Social Sciences software (SPSS Version 16; *www.spss.com*). Multiple repeated measures MANOVA's were conducted to test dependent measures. Factors which were identified as significant were further analyzed using the Tukey's test to differentiate between factor levels. In addition, simple effect technique (Keppel, 1982) was employed to further analyze the interaction between factors. A 4 age groups × (2 of furniture types × 2 of studying activities × subjects) mixed within-subject design was implemented to analyze the experiment. Only absolute mean and root mean square of the EMGs signals for both neck dorsal and upper trapezius muscles were considered.

In addition, in a case of significant of main variables and a significant of their higher level of interaction; only higher level of interaction was analyzed neglecting their main effects (Keppel, 1982).

Experimental protocol

Each participant was asked about whether or not he had any physical discomfort before the experiment in order to minimize any prior condition that might affect the experimental results. The students who expressed any physical discomfort were excluded from this experiment.

Each participant participated in two sessions. Before the beginning of the first session, the participant was asked to wear suitable light clothes. Then, the participant was asked to remove his shoes in order to measure his weight. Anthropometric data and age were recorded (shown in Table 3).

During the second session, reflective markers were attached to the participant's wrist, elbow, shoulder and hip joints. Furthermore, EMG electrodes were attached to the participant's neck and shoulder and reference electrodes were attached to bony positions. To exclude any interference of the signal due to specific postures or

Table 3. A summary information on the student body dimensions for the 4 age groups. Measures 4 - 8 are measured while subject was sitting.

Student dimension	Age group 1 Mean (SD)	Age group 2 Mean (SD)	Age group 3 Mean (SD)	Age group 4 Mean (SD)
	N = 28	N = 30	N = 30	N =30
1. Age (years)	7.6 (0.68)	10.8 (1.08)	13.5 (1.07)	16.3 (0.97)
2. Weight (N)	24.0 (4.04)	367 (8.68)	55.3(5.9)	69.98(2.6)
3. Stature (cm)	123.2 (6.8)	141.2(7.5)	154.4(12.6)	165.3(5.9)
4. Sitting height (cm)	75.9 (6.9)	86.3(5.1)	98.2(7.1)	106.8(4.4)
5. Elbow height (cm)	17.8 (2.1)	19.0 (3.7)	22.3(5.3)	28.0 (5.9)
6. Knee height (cm)	35.5 (3.5)	40.2 (4.8)	46.5(6.2)	46.9 (8.7)
7. Popliteal height (cm)	29.1 (3.1)	33.3 (6.8)	39.8(9.9)	43.6 (6.6)
8. Buttock-popliteal length (mm)	39.1 (9.6)	41.4 (8.4)	42.4(6.7)	47.8 (4.0)
9. Hip breadth (cm)	30.4 (6.5)	33.2 (6.7)	35.1(7.3)	36.9 (5.8)

movements of the hand-arm systems, the two electrodes were attached to the body on the opposite side to the arm. To reduce possible order effects due to a repeated-measure aspect of the experimental design, the presentation order of the experimental conditions to the participants was randomized. Each participant was tested in all experimental conditions at the same day without removing the fixed electrodes (that is, only one participant was observed studying all day long). Therefore, each participant was asked to use the new assigned age group set which was adjusted based on his anthropometric dimensions. Before the beginning of the class, the position of the experimental set was in the last row and near the class exit door so that the experimenter had the opportunity to work free. The participant was then watched while doing the three activities: writing, reading and focusing on the blackboard in both sets (that is, new and current ones) randomly.

Muscular activity (EMG) was recorded for 5 seconds using disposable pre-jelled surface electrodes. The measurements were performed bilaterally for the neck dorsal muscles (level C2-3) and shoulder muscles (trapezius). Electromyography was recorded using the averaged mode, a time interval of 0.1 s and a bipolar setting of disposable surface electrodes. The attained signals of the EMG values (in micro-volts) were recorded using "CASSY Sensor, Ag/AgCl" and were applied in a standardized manner (Proakis and Manolakis, 1996) with an inter-electrode center distance of 30 mm, impedance <20 kΩ. The signals were amplified (Mespec 4000 System, CASSY Lab., Leybold Didactic Gmbh, Germany), band-pass filtered 20–500 Hz, A/D converted and sampled at 1000 Hz (CASSY LAB Win 5.0, Leybold Didactic Gmbh, Germany).

A relative muscle activity level, which indicates the differences in the muscle effort at different activities, can be calculated by a simple comparison of the amount of the mean value (average rectified value) (Marras, 1990). Bauer and Wittig (1998) also argued that normalization, e.g., the MVC value, is not required, if a direct comparison is to be made between different working conditions (doing different activities in both sets in this case) as long as the electrode positions are identical within the test series. However, this approach does not necessarily allow sight about the muscle force, as the signal can be influenced by factors such as the length-tension relationship of the muscle and muscular movements. However, these factors can be largely excluded with a quasi-static posture of head and upper trunk. As in all measurements of the muscle activity, the skin resistance of a participant should not be changed while a test series is in progress, as this could lead to incorrect conclusions in the comparison of the activity level under different working conditions.

When the participant finished doing the assigned activity for the assigned set type for about an hour for each activity, he was asked to rank the assigned set with that activity. Perceived musculo-skeletal strain intensity levels were measured using a modified Borg Category Ratio Scale (CR-10 Scale, Borg, 1998). The scale of strain intensity levels ranged from 0 (nothing at all) to 10 (extremely strong, maximal strain). Strain in different body areas was elicited with: ''How strained do you feel at this moment in the following body areas?'' The body areas measured were neck-shoulder, upper back, low back, upper limbs and lower limbs. A body map marking the areas was provided next to the Borg-scale in the questionnaire. Fernandez and Poonawala (1998) reported that 3 h of work should be used for the subjective evaluation of a chair for a typical work day. Therefore, one hour for each activity was enough to represents 3 h for evaluating new set versus current one. Only the average of the three ratings was considered for the analyses.

Also, a digital camera was placed orthogonal to the participant's workstation in order to capture the siggital plane images of the student, and at a height matching the center of rotation of the shoulder. Camera height and the participant's far distance were measured and fixed to ensure consistent placement for all the participants. No restrictions were placed on the participants except they were asked to take the most comfortable posture at each activity while experiencing reading, writing, and looking at the blackboard. Images were taken and considered for the analysis if the activity lasted around 15 min.

Captured images were used for posture assessment; they were sampled based on the participant's activities for both set types. To determine the effect of set type on posture; angles were only quantified when the participant was seated orthogonal to the camera and doing one of the comparison activities at the most comfortable posture he felt. The neck angle was defined as the angle formed by the horizontal plane and the Reid's line directed towards the center of the book that he is viewing. The Reid's line is defined by a line connecting the margo infraorbitalis and the centre of the outer canal of the ipsilateral ear. The viewing angle was defined as the angle formed by the horizontal plane and the line between the margoinfraorbitalis and the centre of the book. The back angle was defined as the angle formed by the vertical plane and the line between hip and shoulder joints.

RESULTS

EMG activity analysis

As dependent variables, EMG values (rectified absolute

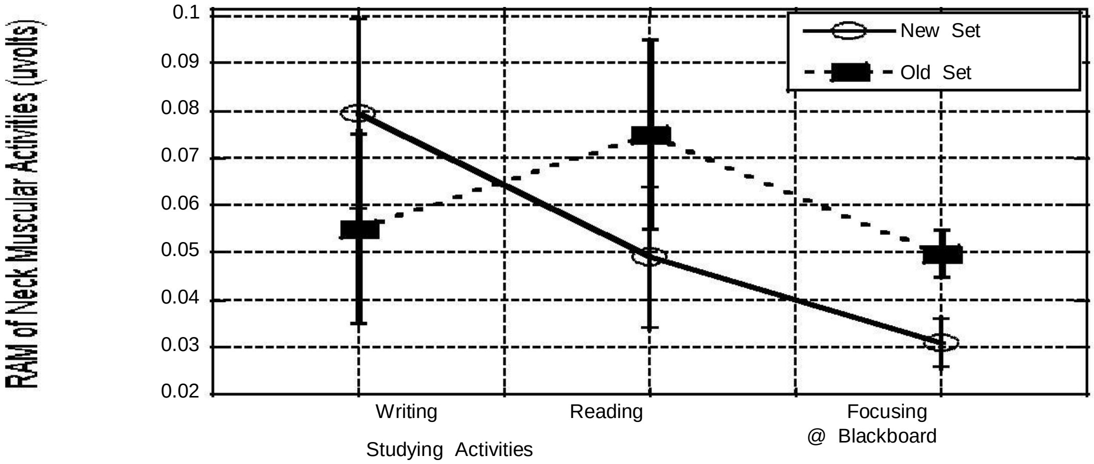

Figure 2. Effect of set type by studying activity interaction on neck muscular activity.

mean (RAM) and root mean square (RMS)) were measured while the participant was performing the three main studying activities (reading, writing and focusing on the blackboard) in both settings (new versus current sets). ANOVA tests were performed to assess the effect of the independent variables on muscular activities.

Neck muscular activities

Absolute mean (RAM) of the neck muscular activity

The studying activities variable was the only variable which had a significant effect on neck muscular activity, F (2, 54) = 15.987, p<0.0001. Furthermore, the interaction between set type by studying activities had significant effect on the neck muscular activity, F (2, 54) = 6.128, p<0.004. As shown in Figure 2, the current sets elicited significantly less EMG activities than the new sets did at writing activity, p<.026. However, at reading level as well as focusing on the blackboard, the new sets elicited significantly less EMG activity than the current sets did, p<.0001, p<.0001, respectively.

Root mean square (RMS) of the neck muscular activity

Only two main variables had significant effects on neck muscular activity; set type, F (1, 27) = 4.755, p<0.038; and studying activities, F (2, 54) = 11.762, p<0.0001. The results indicated that the neck muscular activities of the participants at new sets elicited significantly less EMG activities (mean = 0.374 µvolts, SD = 0.013) than the neck muscular activities of the participants at current sets did (mean = 0.424 µvolts, SD = 0.014), p<.0001. As shown in Figure 3, the neck muscular activities of the participants at writing and reading activities had significantly higher EMGs than the neck muscular activities of the participants at focusing on the blackboard (p<0.004, and p<0.0001, respectively). There were no significant differences between neck muscular activities of the participants while performing writing and reading activities.

Shoulder muscular activities

Absolute mean (RAM) of the upper shoulder muscular activity

Only set type main factor had a significant effect on upper shoulder muscular activity, F (1, 27) = 23.911, p<0.0001. The upper shoulder muscular activities of the participants while sitting on the new sets (mean = 0.031 µvolts, SD = 0.002) elicited significantly less EMGs than the muscular activities of the participants while sitting on the current sets did (mean = 0.05 µvolts, SD = 0.003), p<.0001.

Root mean square (RMS) of the shoulder muscular activity

Only the main variables had significant effects on upper shoulder muscular activity; set type, F (1, 27) = 23.165, p<0.0001; and studying activities, F (2, 54) = 4.894, p<0.011. The upper shoulder muscular activities of the participants while sitting on the new sets (mean = 0.534µvolts, SD = 0.017) elicited significantly less EMGs than the muscular activities of the participants while sitting on the current sets did (mean = 0.65µvolts, SD = 0.018), p<.0001.

As shown in Figure 4, the shoulder muscular activities of the participants while focusing on the blackboard had

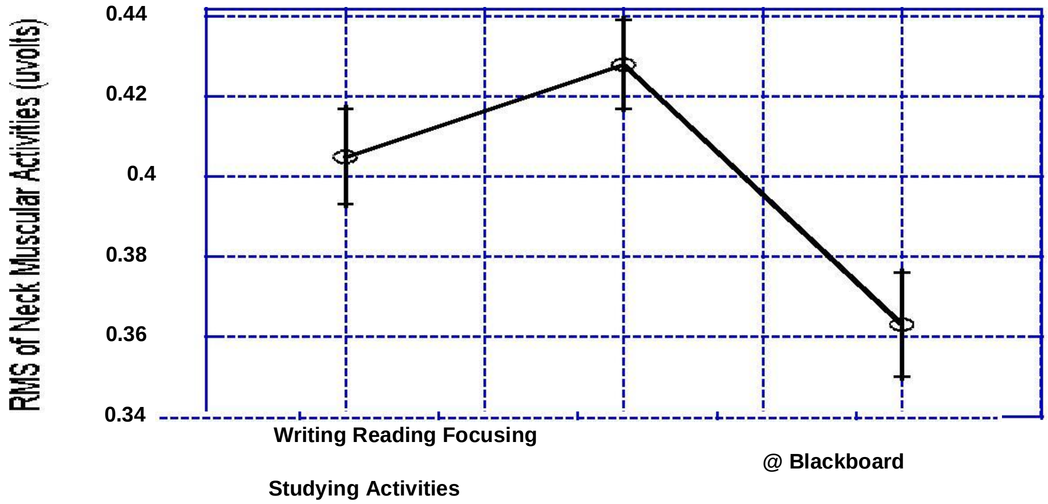

Figure 3. Effects of studying activities on the RMS of neck muscular activity.

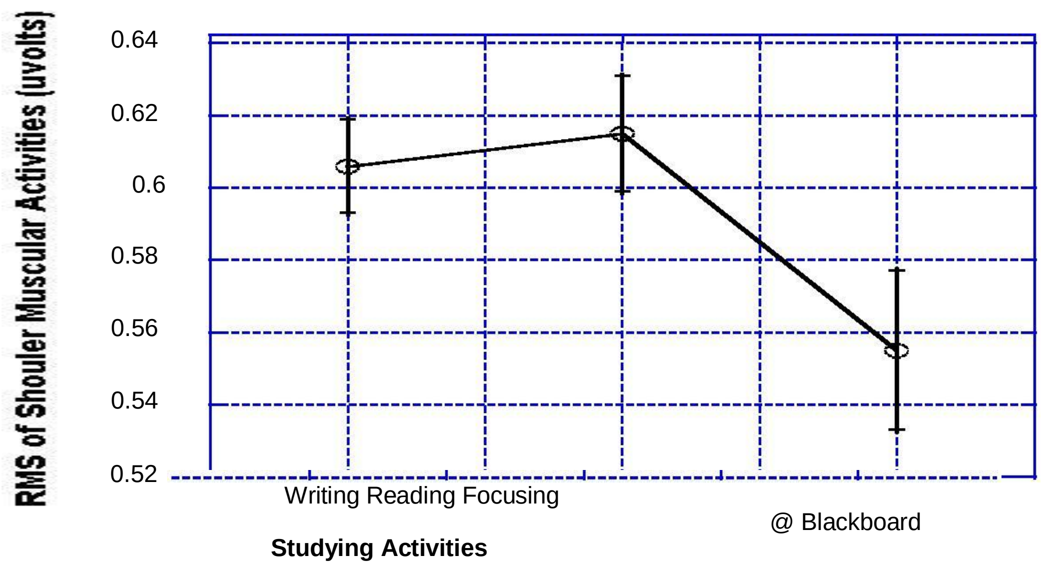

Figure 4. Effects of studying activities on RMS of upper shoulder muscular activities.

significantly less EMGs than the shoulder muscular activities of the participants while performing both writing and reading activities, $p<0.05$, $p<0.029$, respectively.

Posture assessment

Neck angle analysis

All main variables had significant effects on mean neck angles; age-group, $F(3, 81) = 8.868$, $p<0.0001$; studying activities, $F(2, 54) = 207.147$, $p<0.0001$ and set type, $F(1, 27) = 32.135$, $p<0.0001$. Set type by studying activity interaction had a significant effect on mean neck angles, $F(2, 54) = 6.15$, $p<0.04$. Furthermore, age-group by set type by studying activity interaction had a significant effect on mean neck angles, $F(6, 162) = 2.939$, $p<0.01$.

Simple effect technique (Keppel, 1982) was employed to analyze the higher level of interactions. In the first age group, the main variables had significant effects on neck angles; set type, $F(1, 27) = 10.747$, $p<0.003$ and studying activities, $F(2, 54) = 36.797$, $p<0.0001$. Also, set type by studying activity interaction had a significant effect on mean neck angles, $F(2, 54) = 4.688$, $p<0.013$. As shown in Table 4, mean neck angle was significantly higher in the new set when compared with the current set

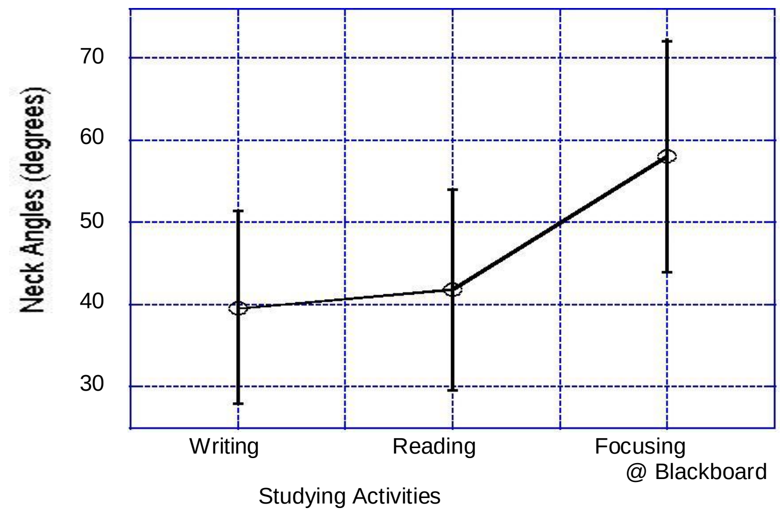

Figure 5. Effects of studying activities on neck angles.

at writing activities as well as at reading activities. In the second age group, the main variables had significant effects on neck angles; set type, $F (1, 29) = 12.47$, $p<0.001$ and studying activities, $F (2, 58) = 64.875$, $p<0.0001$. Furthermore, set type by studying activity interaction had a significant effect on mean neck angles, $F (2, 58) = 4.882$, $p<0.012$. Finally, as shown in Table 4, mean neck angle was significantly higher in the new set when compared to the current set at writing activities as well as at reading activities. In the third age group, the main variables had significant effects on neck angles; set type, $F (1, 29) = 10.872$, $p<0.003$ and studying activities, $F (2, 58) = 65.339$, $p<0.0001$. Furthermore, set type by studying activity interaction had a significant effect on mean neck angles, $F (2, 58) = 3.266$, $p<0.045$. Finally, as shown in Table 4, mean neck angle was significantly higher in the new set when compared to the old set at writing activities as well as at reading activities.

In the fourth age group, only studying activity main variable had a significant effect on neck angles; $F (2, 58) = 76.375$, $p<0.0001$. As shown in Figure 5, mean neck angle was significantly higher at focusing on the backboard when compared to either writing or reading activities.

Back angle analysis

Studying activities had a significant effect on mean back angles, $F (2, 54) = 105.584$, $p<0.0001$. Furthermore, set type by studying activity interaction had significant effect on mean back angles, $F (2, 54) = 32.128$, $p<0.0001$.

As shown in Figure 6, mean back angles of the participants in the three main activities (e.g., writing, reading, and focusing on the blackboard) in the new sets had better angles when compared to the current sets, $p<0.0001$, $p<0.035$, and $p<0.0001$, respectively. The participants at the new sets had better mean back angles with more relaxed positions than the participants at the current sets even at looking at the blackboard. The reason for more back to back position in focusing on the blackboard was that the chair heights of the current sets were less than the appropriate heights at which they should be.

Eye angle analysis

The studying activity factor had a significant effect on mean eye angles; $F (2, 54) = 781.26$, $p<0.0001$. Furthermore, set type by studying activity interaction had a significant effect on mean eye angle, $F (2, 54) = 54.61$, $p<0.0001$. Furthermore, age-group by set type by studying activity interaction had a significant effect on mean eye angle, $F (6, 162) = 2.807$, $p<0.013$.

Simple effect technique was employed to analyze the higher level of interactions. In the first age group, main studying activity variable had a significant effect on eye angle; $F (2, 54) = 153.671$, $p<0.0001$. Also, set type by studying activity interaction had a significant effect on mean eye angles, $F (2, 54) = 10.297$, $p<0.0001$. As shown in Table 5, mean eye angle was significantly less at the new set when compared to the current set at focusing on the blackboard activity. In the second age group, main studying activity variable had a significant effect on eye angle; $F (2, 58) = 181.806$, $p<0.0001$. Furthermore, set type by studying activity interaction had a significant effect on mean eye angles, $F (2, 58) = 27.283$, $p<0.0001$. As shown in Table 5, mean eye angle was significantly less at the new set when compared to the current set at focusing on the blackboard activity. In the third age group, main studying activity variable had a

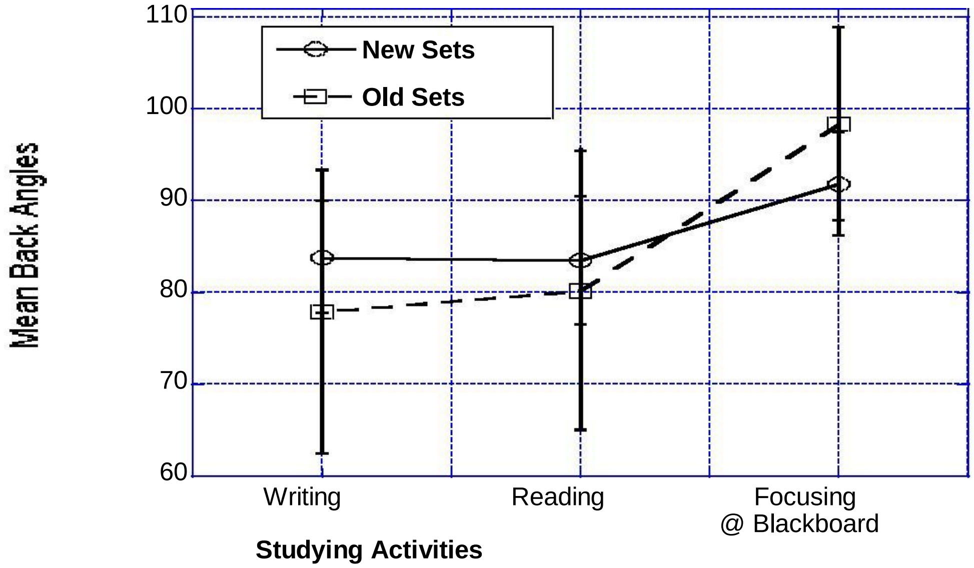

Figure 6. Effect of set type by studying activity interaction on mean back angles.

Table 4. Means, standard deviations, and statistics results for neck angles between new and old set types at different activities.

	New set		Old set		t (1, N-1)	p
	M	SD	M	SD		
At age-group one (N=28)						
Writing activity	55.61	10.52	45.50	12.07	3.676	<0.001
Reading activity	52.32	12.13	47.32	12.80	2.777	<0.01
Focusing to backboard	65.11	9.15	63.75	7.53	0.561	= 0.579
At age-group two (N=30)						
Writing activity	52.07	12.23	41.37	12.33	4.244	<0.0001
Reading activity	50.67	13.04	44.83	13.68	2.907	<0.007
Focusing to backboard	67.40	9.70	64.67	8.09	1.095	= 0.282
At age-group three (N=30)						
Writing activity	48.33	12.23	40.33	10.98	4.001	<0.0001
Reading activity	50.17	11.41	45.67	11.80	2.340	<0.026
Focusing to backboard	63.80	8.66	61.83	10.30	0.944	= 0.353

significant effect on eye angle; F (2, 58) = 176.044, p<0.0001. Also, set type by studying activity interaction had a significant effect on mean eye angles, F (2, 58) = 13.860, p<0.0001. As shown in Table 5, mean eye angles were significantly less at the new sets when compared to the current sets at writing and focusing at blackboard activities. In the fourth age group, main studying activity variable had a significant effect on eye angle; F (2, 58) = 257.701, p<0.0001. Also, set type by studying activity interaction had a significant effect on mean eye angles, F (2, 58) = 28.174, p<0.0001. As shown in Table 5, mean eye angles were significantly less at the new sets when compared to the current sets at reading and focusing on the blackboard activities.

Subjective assessment

To assess the effect of set type factor on subjective ratings, a Tukey's honestly significant difference test was performed. Participants' ratings while sitting on the new sets were significantly more comfortable and less strain than when they sat on the current sets at neck– shoulder [4.68(1.3) versus 8.13(1.7), p<.000], upper back [4.96

Table 5. Means, standard deviations, and statistics results for eye angles between new and old set types at different activities.

	New set		Old set		t (1, N-1)	p
	M	SD	M	SD		
At age-group one (N=28)						
Writing activity	-6.429	4.686	-7.679	8.551	0.736	= 0.468
Reading activity	-6.214	4.058	-7.964	6.185	1.493	= 0.147
Focusing to backboard	5.964	5.978	11.250	7.281	-4.26	<0.0001
At age-group two (N=30)						
Writing activity	-7.500	5.374	-10.167	9.955	1.532	= 0.136
Reading activity	-6.467	3.245	-7.833	7.032	1.257	= 0.219
Focusing to backboard	5.500	5.710	14.433	7.069	-6.854	<0.0001
At age-group three (N=30)						
Writing activity	-8.333	3.497	-11.667	8.339	2.235	<0.033
Reading activity	-7.567	4.646	-9.767	7.537	1.558	= 0.130
Focusing to backboard	4.667	5.492	10.600	7.079	-4.958	<0.0001
At age-group four (N=30)						
Writing activity	-8.967	6.687	-11.533	10.133	1.496	= 0.145
Reading activity	-6.233	5.341	-11.333	9.371	3.101	<0.004
Focusing to backboard	5.500	5.309	15.467	5.631	-8.246	<0.0001

(1.3) versus 7.70(1.3), p<.000], low back [5.24(1.3) versus 8.25(1.6), p<.000], upper limbs [5.22(1.2) versus 8.02(1.4), p<.000] and lower limbs [4.99(1.5) versus 8.13(1.4), p<.000].

DISCUSSION

According to Sanders and McCormick (1993), fixed-height general-purpose chairs with fixed seat heights should suit everyone with shoes on. This recommendation was aimed to allow even the lowest 5^{th} percentile child to sit comfortably. The British Standard for Educational Furniture (BS 5873: Part I: 1980) provides a range of five sizes (size marks 1, 2, 3, 4, and 5) to satisfy the 3 to 18 years age range of students in UK schools. Evans and Lee (1982) suggested that a range of five sizes of chairs and tables would accommodate Hong Kong school students from first primary to the secondary seventh form in the age range of 6 to 18 years old. Oxford (1969) suggested that a range of six sizes of seats and desks would accommodate Australian school students from kindergarten to secondary sixth in the age range of 4 to 20 years old. Comparing the previous recommendations with the findings of this study, it is thought that the proposed adjustable school furniture in this study will most likely be appropriate.

The most critical dimensions for school furniture design are chair height and table height. Comparing those values presented in Table 6, it is obvious that this study has proposed four size ranges for the Saudi students. However, the Saudi Arabian Standards Organization (SASO#1307) recommended six sizes. Furthermore, the chair and table dimensions of the sizes proposed in this study are larger than those dimensions recommended in SASO 1307 in the first set; however, those dimensions are smaller than those dimensions recommended in SASO 1307 in the last set. It is known that the SASO 1307 is the translation of the British Standard (BS 5873, 1980). The British Standard is designed to cater for students from 3 years of age, whereas the current study recommendations apply to 6 years old students and over. Furthermore, the anthropometric values of British students are generally higher than those of Saudi students, especially in late childhood range. The recommended size ranges are applicable to all Saudi government and private schools which are categorized on an age basis. The mean popliteal height of Saudi participants is lower than that of British population (1980). Therefore, the seat height should be low enough to avoid excessive pressure on the underside of the thigh.

In this study, the range of school students' sizes accommodated in each furniture size category is reasonably well distributed. The great majority of students in a particular class are thought to find the recommended sizes appropriate. However, there is obviously some overlap and it may be possible to provide students who are exceptionally tall or exceptionally small for their age group with the larger or smaller furniture size. To avoid this potential problem, it is probably prudent to stick to the

Table 6. Comparison of current Saudi study with the recommendations of SASO.

SASO 1307 recommendations	I	II	III	IV	V	VI
Chair Height	26	30	35	38	41	45
Table Height	46	52	58	64	70	76

Study recommendations	I	II	III	IV
Chair Height	27.8-29.8	32.4-33.8	36.1-39.0	39.1-41.9
Table Height	46.3-49.1	52.9-54.9	57.8-62.6	65.0-71.5

recommended size combinations on a form basis. It is also recommended that the chair and table combinations be coded in some way. The color coding system used in the British Standard may be adopted. Green, blue, orange, and yellow are suggested code color for the four suggested Saudi school furniture sets.

This study focused on prototypes of an adjustable table and chair that meet the needs of students' physical dimensions based on ergonomic design criteria. The study also took cost efficiency into consideration. The most critical design criteria of the developed prototypes is to compensate for the demerits of existing adjustable tables and chairs by applying an ergonomic design, and considering the functional size provided by the Al-Harkan et al.' (2005) study.

The results of the comparative evaluations and fitting trials proved that such standards could be applied to the prototypes. They were developed to help the students improve their learning ability and maintain proper growth by preventing abnormal body posture. This study was performed to determine the functional dimensions, adjustment range criteria, and fitting trials of the developed prototypes.

It is important to note that there is no guarantee that a dimensionally correct chair will be perceived as comfortable (Shackel et al., 1969). However, in this study the overall intensity level of musculoskeletal symptoms was very low at new sets when compared to the current traditional ones. In addition, it is important to evaluate the comfort ratings, adjustability, stability, solidity, durability, and safety by conducting tests on actual user groups. Since modern societies value a better quality of life, it is recommended that the user-friendly design concept rather than the economical theory be applied to school furniture designs. Therefore, later research will require further development of school furniture designs, designs that are considered aesthetic, comfortable and convenient.

The new design of the individually adjustable chairs and tables increased the upright, neutral back and neck postures during sitting at school lessons compared to the conventional sets. This is an improvement from the musculoskeletal issue. The increase was the result of proper adjustments and the new set design. The new adjustable chairs and tables increase the angle between trunk and thigh, thus enabling a more neutral lumbar position. Despite the somewhat limited adjustability of the new design desks and chairs, optimal relationship between anthropometrics and sets was mostly obtained. Moreover, the adjusting mechanism was ''user-friendly'' compared to the conventional sets.

The schools in this study, being composed of various cultural features, were continuity of education within the same school complex and grounds for grades 1 to 12. At schools, most lessons were held in the same classroom. For practical reasons, the new adjustable chairs and tables were placed with conventional sets in the same classrooms.

Consequently, of the total exposure time, only 3 h of all sitting hours were spent at the new sets, which may have diluted the effects. In the participant group, desks and chairs were adjusted according to the anthropometric dimensions of the participants. Substantial variations were found by the individual response to the neutral posture of the lumbar posture. Despite the new design of adjustable chairs and tables, schoolchildren still have their individual sitting and working habits during lessons. Consequently, posture analysis in this study allowed a certain degree of individual sitting posture variation owing to the neutral posture angle definition tolerances. Moreover, it is possible that additional instructions for the volunteer group of the optimal sitting postures might have enabled those showing a poor sitting posture to avail them better of the new design.

A sitting posture photograph analysis is an appropriate method to evaluate postures of the back and the neck, position of the buttocks on the seat, and position of the upper limbs. It should be noted that the potential bias associated with the participants being aware that they are being observed may have appeared during the early stage, photograph analysis in particular, but it is unlikely that it should have been extended over the whole observation period of following-up.

Conclusions

The study aim was to design a group of chair and table sets appropriate for students' aged from 6 to 17 years. Four sets were proposed to fit the students. Testing and validating those sets was the second phase of the study. The results indicated a good match between body dimensions of the students who participated in this study and the four proposed sets based on the student's age. However, there was a mismatch between body dimensions of the students and the school furniture available to them in their schools.

In the current sets, the majority of the students were found to be sitting on chairs that are too high, too low, or too deep. In addition, other students were found to be using desks that were too high for them. Only desk clearance was found to be acceptable for the majority of the students in the current sets. An adjustment was performed to the table and chair heights to improve the new sets performance. The results of the EMGs analysis revealed that the newly developed sets are less stressful in terms of dorsal neck muscular contraction as well as upper trapezius muscular contraction. The EMGs signals for both muscles were expressed in absolute mean and root mean square. Of course, as expected, reading and writing were more stressful than looking at the blackboard or listening to the teacher.

The results of the student posture analysis revealed that the new sets had better and comfortable angles when compared to the current sets in terms of neck, back, and eye angles. In addition, subjective opinions showed that the students were more comfortable using the new sets when compared to the current ones.

The dimensions of the new four sets proposed in this study are far from the dimensions of the six sets proposed in the SASO documentations (1997). The new sets were tested in this study in terms of matched criteria, EMGs, and posture analysis. However, The SASO documentations were based on British students' anthropometric data available in the literature. In addition, the dimensions of the four sets of chair-table combinations are now available for Saudi school furniture manufacturers.

Even with some limitations reported in the study such as: 1) only male students participated in the study; 2) all six treatments were done in the same day and the participant's behavior may be influenced by the observers. The findings of this study provided new information about the suitability of the new sets' dimensions, the produced prototypes, and testing the effects of new sets' designs on musculoskeletal health among schoolchildren. In order to obtain long-term benefits of ergonomically designed sets, teachers and school health care professionals should draw the attention of schoolchildren to their own sitting habits. In addition, the individual's response to the upright, neutral posture caused by adjustable chair-table combination needs consideration, remembering that, regardless of the new designs, children have a tendency to sit in stooped postures during lessons. There is a distinct need for future long-term studies on the relationship between poor postures and musculoskeletal pain in children and adolescents extending to effects into adulthood.

This study has implications for schools regarding the design of school furniture. Different sitting postures may contribute to discomfort at different sites. School furniture may contribute to postural variation but children do adopt various postures regardless of the furniture. It may be the case that sitting is not a risk factor but certain types of sitting contribute to postural discomfort. Further research is required to examine the association between sitting posture and discomfort reported at different spinal locations and the long-term implications of postural discomfort.

In summary, given the variability in students' bodily dimensions, the only two currently available sizes of school furniture cannot accommodate all children in school life. Providing a variety in furniture sizes so that students could select the proper one at the beginning of the school term could be a solution to this problem, though this is not likely to be feasible economically. In addition, selecting the proper furniture for a large group of children at the same time is both impractical and difficult for the teachers, and for this reason adjustable school furniture would be preferable.

It is important to note that there is no guarantee a dimensionally correct chair will be perceived as comfortable (Shackel et al., 1969). Therefore, it is important to evaluate the comfort ratings, adjustability, stability, solidity, durability, and safety by conducting tests on actual user groups. Since modern societies value a better quality of life, it is recommended that the adjustability concept rather than the economical theory be applied to educational furniture designs. Therefore, later research will require further development of school furniture designs, designs that are considered aesthetic, comfortable and convenient. Recommendations on the size of chairs and desks to be used by boys were given.

Finally, it cannot be forgotten that dimensional compatibility is just one factor in the generation of student health problems. Bad postural habits and a lack of education in teachers and students as far as ergonomic postural principles are concerned increase the risks already mentioned. Therefore, as in every ergonomic action that really aims to succeed and to generate positive long-term changes, the introduction and distribution of this furniture must be viewed as a health promotion programme, one which includes the training of administrative personnel, teachers and students as pointed out by Knight and Noyes (1999), the respective indicators for measuring effects and feedback mechanisms so that a system of continuous improvement can be established.

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