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# School furniture match to students' anthropometry in the Gaza Strip

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# School furniture match to students' anthropometry in the Gaza Strip

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This study aimed at comparing primary school students' anthropometry to the dimensions of school furniture and determining whether the furniture used matches the students' anthropometry. A sample of 600 male students, whose ages were between 6 and 11 years, from five primary schools in the Gaza Strip governorates participated in the study. Several students' body dimensions were measured. The dimensions measured included elbow–seat height, shoulder height, knee height, popliteal height and buttock–popliteal length. Measurements of the dimensions of the classroom furniture indicated that there was a considerable mismatch between the students' body dimensions and the classroom furniture. The mismatches in seat height, seat depth and desk height occurred for 99% of the students, while the mismatch for the back rest height was only 35%. Two design specifications were proposed in order to decrease the mismatch percentage based on the data obtained. The two proposed designs showed a considerable improvement in the match percentages as compared to the existing design.

**Statement of Relevance**: Having identified mismatches between the dimensions of the school furniture used in primary schools in the Gaza Strip, two new design specifications are proposed and shown to improve match with the students' anthropometric dimensions. The findings of the study are also an important addition to local knowledge on school children's anthropometry.

**Keywords:** anthropometry, school furniture; students



## 1. Introduction

Most students often sit in a forward bending position, thus exerting physiological strains on the muscles, ligaments and discs (Brunswick 1984, Bendix 1987). Therefore, school children are at risk of suffering negative effects from ill-fitting furniture (Parcells *et al.* 1999). The use of proper furniture design reduces fatigue and discomfort in the sitting posture. According to Cranz (2000), correct standing and sitting postures would help in the prevention of musculoskeletal symptoms. A student's sitting posture is influenced not only by the activities performed in the classroom and the individual's anthropometric dimensions but also by the design features of the school furniture (Yeats 1997). Anthropometric measurements are an important factor that should be taken into account in designing school furniture. The anthropometric dimensions needed to determine school furniture dimensions that will promote a correct sitting posture include popliteal height, knee height, buttock–popliteal length and elbow height (Knight and Noyes 1999, Parcells *et al.* 1999, Panagiotopoulou *et al.* 2004, Gouvali and Boudolos 2006, Chung and Wong 2007). Poor posture while sitting, writing, typing or playing can cause pain in the back, shoulders, neck, legs and eyes (Gierlach 2002). Repetitive strain injuries, which afflict many people worldwide, are appearing in college students, teenagers and even primary school children. The lifetime prevalence of low back pain has been estimated at nearly 70% for industrialised countries and much of this is related to poor posture when sitting (Anderson *et al.* 1991). Poor sitting posture can also contribute to the poor positioning of other parts of the body, such as the arms and legs (Hedge *et al.* 1999). One focus of ergonomic research during the past decade has been on the design of work furniture based on the biomechanics of the human body. Many researchers have dealt with the principles of the design of chairs and desks in the workplace, particularly for computer system users (Kumar 1994, Naqvi 1994, Villanueva *et al.* 1996, Cook and Kothiyal 1998, Burgess-Limerick *et al.* 1999). However, little interest has been shown in the design of school furniture. It is noted that using furniture that promotes proper posture in childhood is more important than using it in adulthood because it is at this young age that sitting habits are formed and bad sitting habits acquired in childhood are difficult to change later in adulthood (Yeats 1997). School furniture designs that take anthropometry into account have been reported in

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Denmark and Sweden, Germany, France and Switzerland (Mandal 1982) in addition to Finland (Saarni *et al*. 2007).

In the Gaza Strip, the United Nations Relief and Works Agency – United Nations Educational, Scientific and Cultural Organization (UNRWA-UNESCO) schools use one design of desks with the same dimensions for students from class 1 to class 6. It is known that students' dimensions increase with age but this fact seems to have been ignored. In fact, there have been no previous studies dealing with this topic in Gaza Strip and, therefore, there was a need for this study.

The aims of this study were to compare students' anthropometry to the dimensions of school furniture in Gaza Strip primary UNRWA-UNESCO schools and to determine whether the furniture is well designed and promotes a good sitting posture. The dimensions of classroom furniture and children's anthropometry were measured and used to find whether or not there is a match between them. This information can then be used in designing classroom furniture according to children's anthropometry to achieve a good sitting posture for children at school. The findings of the study will also be an important addition to local knowledge on schoolchildren's anthropometry. At the international level, the data presented here provide basic data for other researches in the field.

## 2. Relationships between school furniture dimensions and body dimensions

The use of anthropometric data for designing school furniture requires a simultaneous evaluation of ergonomic principles, which are used to define the range in which each furniture dimension is considered appropriate.

### 2.1. Seat height

Seat height needs to be related to popliteal height (Oxford 1969, Corlett and Clark 1995, Helander 1997, Dul and Weerdmeester 1998) in such a way as to allow the knee to be flexed so that the lower leg forms a maximum of 30° angle relative to the vertical axis (Molenbroek *et al*. 2003). Parcells *et al*. (1999) considered a seat height of $>95\%$ or $<88\%$ of the popliteal height as 'a mismatch'.

Equation (1) shows that seat height should be lower than popliteal height so that the lower leg forms a 5–30° angle relative to the vertical and the shin–thigh angle is between 95 and 120° (Occhipinti *et al*. 1985). In this study, a 2 cm correction for shoe height was added to popliteal height (Evans *et al*. 1988, Sanders and McCormick 1993). Thus:

$$(\mathrm{N}+2)\cos 30^\circ \leq \mathrm{SH} < (\mathrm{N}+2)\cos 5^\circ \qquad (1)$$

where SH is seat height and N is popliteal height.

### 2.2. Seat depth

According to many researchers, seat depth should be designed for the 5th percentile of the popliteal–buttock length distribution (Occhipinti *et al*. 1985, Pheasant 1991, Khalil *et al*. 1993, Sanders and McCormick 1993, Oborne 1996, Helander 1997, Milanese and Grimmer 2004). Poulakakis and Marmaras (1998) suggested that seat depth be at least 5 cm shorter than popliteal–buttock length. For children, Parcells *et al*. (1999) defined as a mismatch the case when seat depth does not satisfy the relationship in Equation (2).

$$80\,\%\,\mathrm{M} \leq \mathrm{SD} < 95\,\%\,\mathrm{M} \qquad (2)$$

where SD is seat depth and M is popliteal–buttock length.

### 2.3. Backrest height

Backrest height is considered appropriate when it is below the scapula (Evans *et al*. 1988, Oborne 1996) to facilitate mobility of the trunk and arms (Khalil *et al*. 1993). Therefore, it is recommended to keep the backrest lower than or at most on the upper edge of the scapula, complying with the relationship in Equation (3):

$$60\%\ \mathrm{H} \leq \mathrm{BH} < 80\%\ \mathrm{H} \qquad (3)$$

where BH is backrest height and H is shoulder height (scapula height).

### 2.4. Desk height

Several researchers have considered elbow height as the major determinant for desk height (Oxford 1969, Sanders and McCormick 1993, Dul and Weerdmeester 1998, Milanese and Grimmer 2004), due to the fact that a significant reduction of the load on the spine will be achieved when arms are supported on the desk (Occhipinti *et al*. 1985, Bendix and Bloch 1986, Pheasant 1991). Poulakakis and Maramaras (1998) concluded that the desk should be 3–5 cm higher than the elbow–seat height. Evans *et al*. (1988) proposed a desk height that is 95% of sitting elbow height. Parcells *et al*. (1999) suggested that desk height be adjusted to elbow–floor height, so that it would be minimal when arms are not flexed or abducted and maximal when upper arms are at 25° flexion and 20° abduction (elbow rest height × 0.8517 + shoulder height × 0.1483). Therefore, the relationship would be as follows:

$$K + (N + 2)\cos(30) \leq DH < (N + 2)\cos(5) + 0.8517\,K + 0.1483\,H \quad (4)$$

where DH is desk height, K is elbow–seat height, N is popliteal height and H is shoulder height.

### 2.5. *Under-surface of desk height*

The under-surface of desk height should be such that there is space between the knee and the under-surface of the desk (Sanders and McCormick 1993, Helander 1997, Dul and Weerdmeester 1998, Evans *et al.* 1988). According to Corlett and Clark (1995) and Helander (1997), this space should also allow for knee crossing. Poulakakis and Marmaras (1998) proposed at least 5 cm of clearance. Mandal (1997) and Parcells *et al.* (1999) proposed at least 2 cm between the knee and the under-surface of the desk. Therefore, the relationship can be written as:

$$(O + 2) + 2 \leq UDH \quad (5)$$

where UDH is the under-surface of desk height and O is the knee height.

Due to the fact that this was a preliminary study, the author used the most commonly used and recommended relationships in the literature, which are those in Equations (1)–(5). However, it is important to note that the relationships used in this study are not the only ones available. Therefore, other relationships may be used for comparison purposes until there is a consensus among researchers.

## 3. Methodology

Primary education in the Gaza Strip is divided into two types, UNRWA-UNESCO primary schools and government primary schools. The numbers of male students in each of the five governorates of the Gaza Strip are shown in Table 1.

### 3.1. *Data collection*

A sample of 600 students voluntarily participated in this study. Students aged between 6 and 11 years old were randomly selected from five UNRWA-UNESCO primary male schools. Since a primary school consists of six classes, 120 students were randomly selected from each school. As shown in Table 2, 20 students were selected from each class. The measurements were performed by two teams, each consisting of two people. They were trained before data collection by showing them a video tape of the anthropometric measurements and having them measure the required dimensions.

### 3.2. *Instruments*

The instruments used in the study included small and large Lafayette anthropometers (Lafayette Instruments Company, West Lafayette, IN, USA), a steel tape, a wooden chair, flat wooden pieces and a 90° wooden angle. The flat wooden pieces were used as an adjustable foot rest in order to accommodate students of different heights. The 90° wooden angle was used to fix the elbow at 90° as needed for the measurements.

### 3.3. *Measurements*

Anthropometric measurements were taken while each student was sitting on a chair of fixed height with knee and elbow bent at 90° (Figure 1). The flat wooden pieces were placed under the feet to fix the knee at 90°. The body dimensions listed below were measured in the study. The dimensions were measured without shoes and 2 cm was added to each relevant dimension to compensate for shoe heel thickness.

Elbow–seat height (K): The vertical distance from the tip of the olecranon to the seat while the elbow

Table 1. UNRWA-UNESCO and government primary male schools.

| Governorate | North | Gaza | Middle area | Khanyounis | Rafah | Total |
|---|---|---|---|---|---|---|
| UNRWA-UNESCO primary boys' schools | | | | | | |
| No. of boys' schools | 9 | 12 | 9 | 6 | 7 | 43 |
| No. of boy students | 11562 | 11115 | 9281 | 6263 | 8291 | 46512 |
| Government primary boys' schools | | | | | | |
| No. of boys' schools | 10 | 32 | 3 | 8 | 2 | 55 |
| No. of boy students | 8559 | 25665 | 1742 | 7206 | 1302 | 44474 |

was flexed at 90° and shoulder was flexed at 0°, as shown in Figure 1.

Knee height (O): The vertical distance from the footrest surface to the top of the knee cap with knee flexed at 90°, as shown in Figure 1.

Shoulder height (H): The vertical distance from the seat surface to the top of the shoulder, as shown in Figure 1.

Popliteal height (N): The vertical distance from the footrest surface to the popliteal space (which is the posterior surface of the knee) at 90° knee flexion, as shown in Figure 1. It is noted that (O–N) (as defined in Figure 1) approximates the thigh thickness.

Buttock–popliteal length (M): The horizontal distance from the rear surface of the buttock to the internal surface of the knee, or popliteal surface, with the knee flexed at 90°, as shown in Figure 1.

Table 2. Primary schools selected for students' measurements.

| School name | Sample size | Number of students selected per class |
|---|---|---|
| Jabalia boys' school – morning shift | 120 | 20 |
| Jabalia boys' school – evening shift | 120 | 20 |
| Imam Shafi boys' school – morning shift | 120 | 20 |
| Imam Shafi boys' school – evening shift | 120 | 20 |
| Deir El balah boys' school – evening shift | 120 | 20 |
| Total | 600 | 100 |

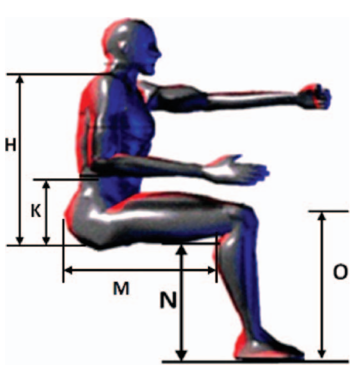


Figure 1. Anthropometric dimensions measured: elbow-seat height (K); shoulder height (H); buttock-popliteal length (M); popliteal height (N); knee height (O).

UNRWA-UNESCO uses one design of classroom furniture with the same dimensions for all primary schools classes. The dimensions are shown in Figure 2.

Seat height (SH): The distance from the highest point on the front of the seat to the floor.

Seat depth (SD): The horizontal distance from the back of the sitting surface of the seat to its front edge.

Backrest height (BH): The vertical distance from the desk seat to the top edge of backrest, as shown in Figure 2. This dimension is the one that would guarantee a full shoulder support.

Desk–seat height (DH): The vertical distance from the seat to the top of the front edge of the desk.

Under-surface of desk height (UDH): The vertical distance from the floor to the bottom of the front edge of the shelf under the writing surface.

## 4. Results

Table 3 gives a summary of the students' anthropometric measurements. The data show the maximum, minimum, mean and standard deviation values for the 600 students from class 1 to class 6.

It is expected that an anthropometric measurement with small variation (i.e. a small standard deviation) would be more easily matched by relevant dimensions of the furniture (have a higher match percentage) than a measurement with greater variation (i.e. a large standard deviation).

The mismatch percentages between the classroom furniture dimensions (seat height, seat depth, backrest height, under-surface of desk height and desk height) and the students' anthropometry for each of the six classes are shown in Table 4.

### *4.1. Seat height mismatch*

The minimum and maximum students' dimensions of the popliteal height were 21.5 and 43.5 cm respectively (SD 3.36) as shown in Table 3. It is clear from Table 4

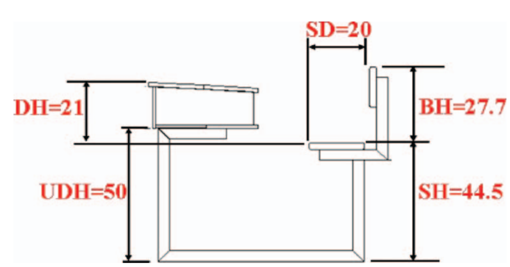


Figure 2. Furniture dimensions (cm) showing the current UNRWA-UNESCO classroom furniture dimensions. SD = seat depth; BH = backrest height; SH = seat height; UDH = under-surface of desk height; DH = desk height.

Table 3. Summary of students' anthropometric measurements (cm).

| | Stature | Shoulder height | Elbow–seat height | Buttock–popliteal (thigh) length | Popliteal height | Knee height |
|---|---|---|---|---|---|---|
| Class 1 | | | | | | |
| Max. | 131.5 | 46.2 | 20.5 | 41.8 | 30 | 48.8 |
| Min. | 106.8 | 32.5 | 7.9 | 25.5 | 21.5 | 31.5 |
| Mean | 117.67 | 39.64 | 13.79 | 31.51 | 25.48 | 35.51 |
| SD | 5.661 | 2.636 | 2.377 | 2.418 | 1.905 | 2.346 |
| Class 2 | | | | | | |
| Max. | 138 | 50.3 | 21.5 | 45 | 32.5 | 44 |
| Min. | 110 | 35.9 | 11.2 | 23.2 | 21.7 | 33 |
| Mean | 123.57 | 42.24 | 15.19 | 33.31 | 26.59 | 37.99 |
| SD | 6.233 | 2.886 | 2.168 | 2.822 | 1.971 | 2.256 |
| Class 3 | | | | | | |
| Max. | 143.5 | 50 | 21 | 44.5 | 33.4 | 45.5 |
| Min. | 114.5 | 35.5 | 11 | 30.6 | 22.6 | 33.7 |
| Mean | 129 | 43.45 | 15.38 | 35.63 | 28.4 | 39.65 |
| SD | 6.613 | 3.123 | 2.226 | 2.391 | 2.226 | 2.469 |
| Class 4 | | | | | | |
| Max. | 145 | 49.6 | 21 | 47 | 35 | 45.7 |
| Min. | 112.3 | 35.7 | 9 | 31 | 24.1 | 33 |
| Mean | 133.41 | 44.46 | 14.68 | 38.14 | 29.84 | 41.65 |
| SD | 5.645 | 2.760 | 2.470 | 3.262 | 1.944 | 2.406 |
| Class 5 | | | | | | |
| Max. | 155 | 53 | 23.5 | 45.2 | 37.4 | 49.8 |
| Min. | 120.7 | 38.4 | 10.4 | 33.4 | 25.9 | 37.5 |
| Mean | 138.06 | 46.72 | 16.04 | 39.007 | 31.1 | 43.54 |
| SD | 7.433 | 2.889 | 2.481 | 2.699 | 2.402 | 2.803 |
| Class 6 | | | | | | |
| Max. | 158 | 54 | 24 | 45.7 | 43.5 | 52 |
| Min. | 127.6 | 42.5 | 11.2 | 35.5 | 27.7 | 39.7 |
| Mean | 142.75 | 48.61 | 17.59 | 40.31 | 32.4 | 45.29 |
| SD | 6.737 | 2.541 | 2.315 | 2.549 | 2.578 | 2.552 |
| Overall | | | | | | |
| Max. | 158 | 54 | 24 | 47 | 43.5 | 52 |
| Min. | 106.8 | 32.5 | 7.9 | 23.2 | 21.5 | 31.5 |
| Mean | 130.74 | 44.19 | 15.44 | 36.32 | 28.97 | 40.60 |
| SD | 10.612 | 4.046 | 2.614 | 4.139 | 3.258 | 4.125 |

Table 4. Mismatch percentages for each class.

| | Seat height (%) | Seat depth (%) | Backrest height (%) | Desk height (%) | Under-surface of desk height (%) |
|---|---|---|---|---|---|
| Class 1 | 100 | 100 | 5 | 100 | 1 |
| Class 2 | 100 | 99 | 8 | 100 | 0 |
| Class 3 | 100 | 100 | 22 | 100 | 0 |
| Class 4 | 100 | 100 | 32 | 100 | 0 |
| Class 5 | 100 | 100 | 62 | 100 | 18 |
| Class 6 | 99 | 100 | 81 | 99 | 35 |
| Overall average | 99.83 | 99.83 | 35 | 99.83 | 9 |

Figure 3. Student sliding forward on seat of class room furniture.

that the current seat height only matches one student out of the 600 students, which is obviously greatly below the lower limit of the acceptance range. In other words, students are sitting on seats that are too high for them. This mismatch forces students to slide forward on the seat of the classroom furniture as shown in Figure 3. Many students were observed sitting with their legs not touching the floor or crossed beneath the desk seat or standing while writing, as shown in Figures 4 and 5. These positions can place

Figure 4. Leg between seat surface and buttocks.

Figure 5. Students standing up while writing.

high amounts of stresses on the popliteal arc that runs through the underside of the thigh and may cause serious discomfort and possibly risk injury.

### 4.2. *Seat depth mismatch*

The minimum and maximum values of the popliteal–buttock length were 23.3 and 47.0 cm respectively (SD 4.14). For a student's popliteal–buttock length to match the current seat depth, its value would be within the range 21.05–25.00 cm. As can be seen from the furniture dimensions given in Figure 2 and the students' anthropometric data in Figure 6a,b,c, the mismatch for the total sample size was 99.83%, which is well beyond the upper limit of the acceptance range for the current seat depth. Seat depth mismatch with thigh length creates strong stresses on the thigh.

### 4.3. *Backrest height mismatch*

The minimum and maximum values obtained for shoulder height were 32.5 and 54.0 cm respectively. It is clear from Figure 7a,b,c that backrest height is acceptable for about 65% of the students. Of the 35% mismatch, more than 99% are below the lower limit of the acceptance range. It is noted that the number of children whose measurements had a bad fit with the backrest height of the school furniture increased with age. For example, the match percentage for class 1 was 95 and this decreased with age until it reached only 19% for class 6. Figures 8 and 9 show the transition from match to mismatch from class 1 to class 6. Moreover, Figures 8 and 9 show that the seat is not deep enough for the majority of the students.

### 4.4. *Desk height mismatch*

The minimum and maximum values recorded for the elbow–seat height for all students were 7.9 and 24.0 cm respectively. In total, 99.83% of students had a mismatch between desk height and their elbow–seat heights. The mismatch is a result of students having dimensions much smaller than the lower limit of acceptance for the height of the desk provided. Such a mismatch forces students to bend their bodies forward when the desk height is lower than the elbow–seat height and to lift their arms when the desk height is higher than the elbow–seat height and also to bend the neck while writing. When the weight of the head is not properly supported, it can cause discomfort and risk of injury to the neck and shoulders (Hedge *et al*. 1999).

### 4.5. *Under-surface of desk height mismatch*

The under-surface of desk height had an average of 9% mismatch with the anthropometric dimension of seat height plus thigh thickness for all six classes. As can be seen from Table 4, the mismatch occurred mainly in classes 5 and 6. In class 5, the mismatch was 18% and then it almost doubled in class 6. When knee height exceeds the under-surface of desk height, the front of the thigh will strike the underside of the desk. This led the students to extend and position their legs forward.

## 5. Proposed designs

An alternative design for the furniture is proposed according to the anthropometric data obtained. Such a design would attempt to maximise the match percentages for all students from class 1 to class 6. Table 5 shows the dimensions of the proposed design along with the match percentages of each dimension. It

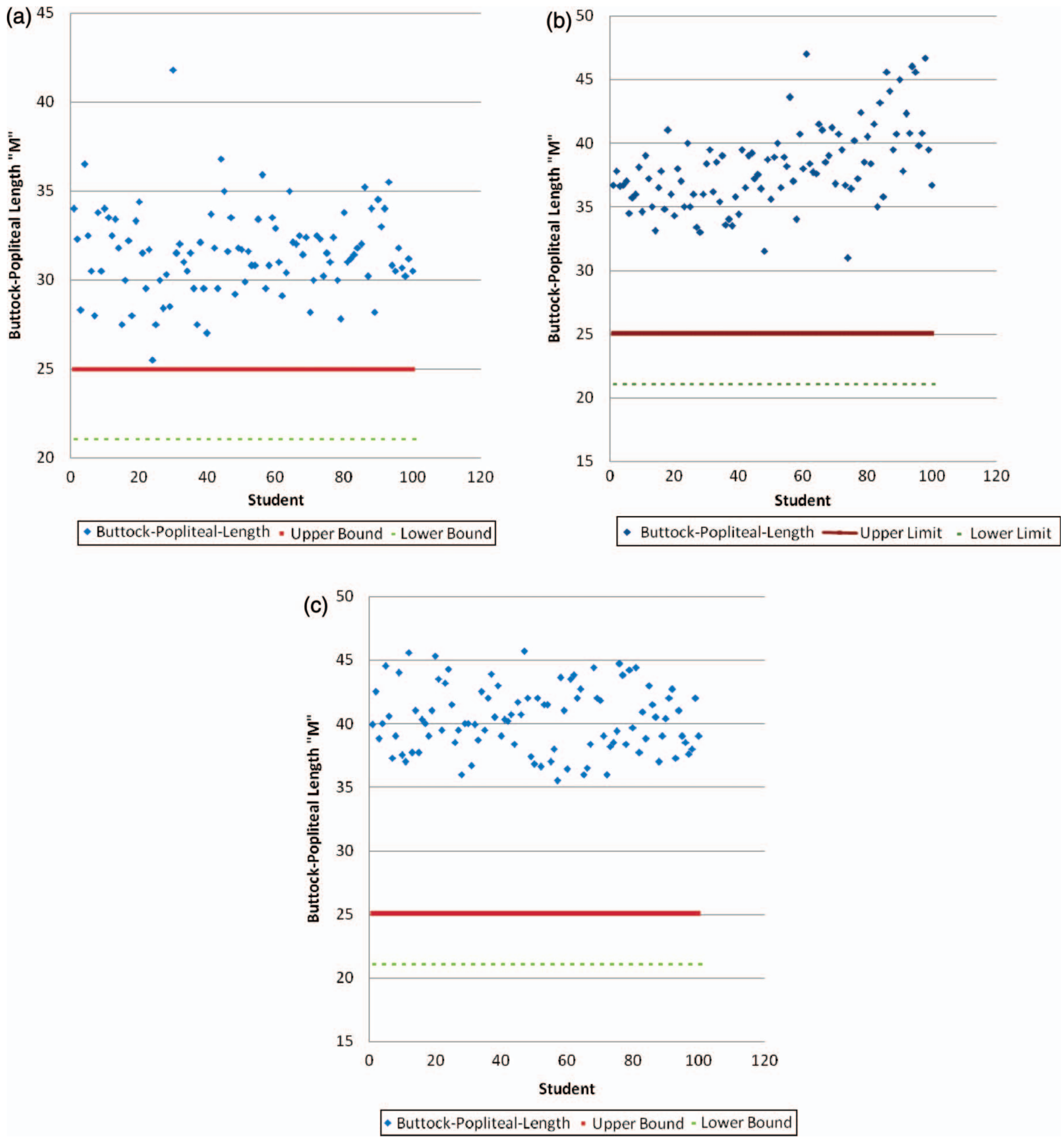


Figure 6. (a) Fitness of seat depth for class 1 students – with upper and lower bounds of this dimension defining the sizes of students for whom the furniture would be suitable; (b) fitness of seat depth for class 4 students – with upper and lower bounds of this dimension defining the sizes of students for whom the furniture would be suitable; (c) fitness of seat depth for class 6 students – with upper and lower bounds of this dimension defining the sizes of students for whom the furniture would be suitable.

is clear that the new proposed design better matches the students' anthropometry as compared with the existing design. It is noted from Table 5 that backrest height match is about 89%, which is relatively good given the variability of the students' dimensions. Further, the table shows that other students' dimensions match the furniture dimensions, although at lower match percentages. These percentages range from 47.5 to 63.

This relatively low match led the researcher to study the impact of having two designs for the students instead of a single design. Therefore, the mismatch percentages above and below the acceptance limits were calculated in order to gain some insight into the nature of mismatch and thus help in deciding what the suitable dimensions would be to obtain the greatest match for all dimensions. Therefore, a new design called design 2 was proposed. This design called for a

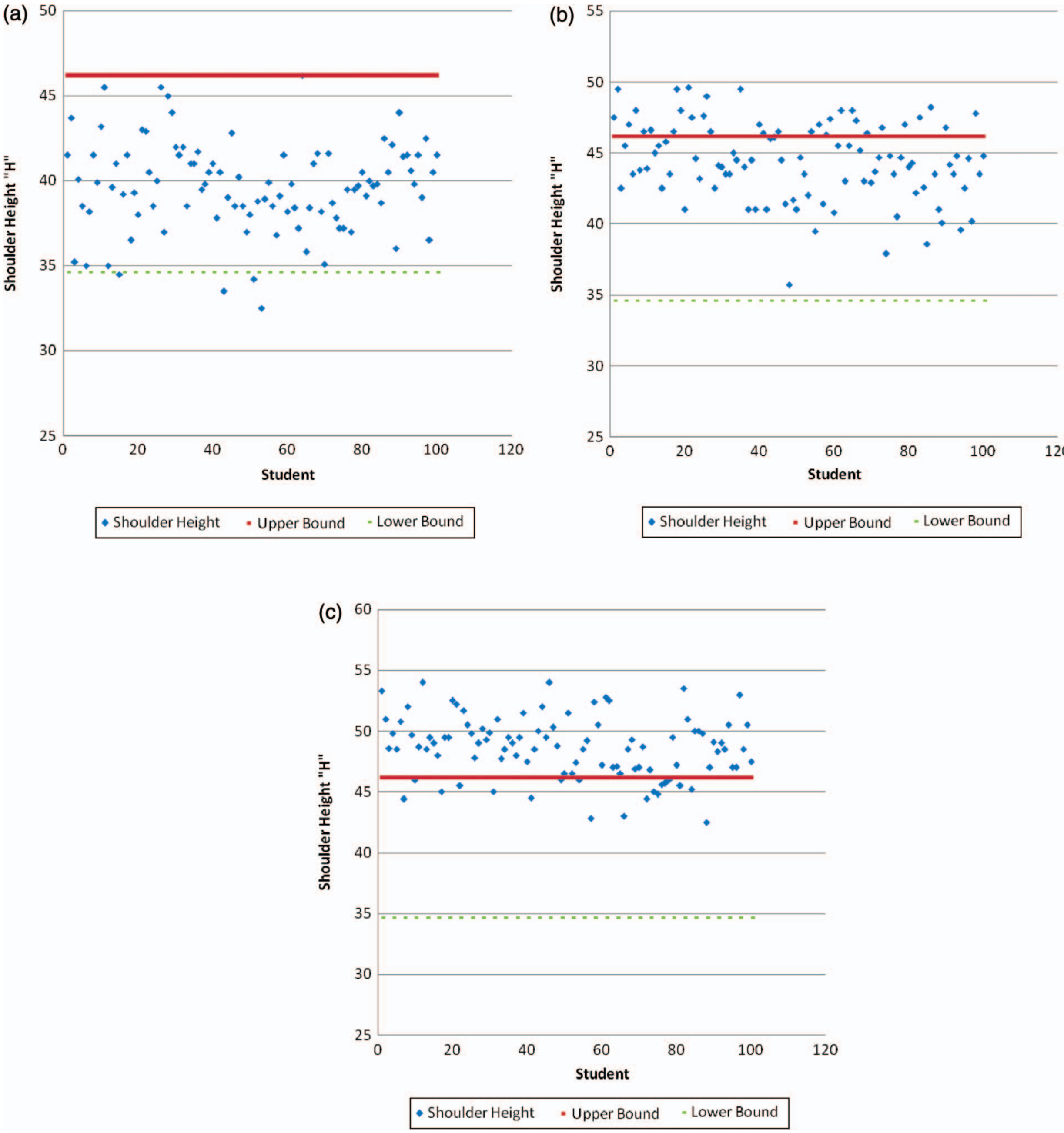


Figure 7. (a) Fitness of back rest height for class 1 students – with upper and lower bounds of this dimension defining the sizes of students for whom the furniture would be suitable; (b) fitness of back rest height for class 4 students – with upper and lower bounds of this dimension defining the sizes of students for whom the furniture would be suitable; (c) fitness of back rest height for class 6 students – with upper and lower bounds of this dimension defining the sizes of students for whom the furniture would be suitable.

design '2A' for students from class 1 to class 3 and another design '2B' for students from class 4 to class 6. Table 6 shows the dimensions of the new designs and the match percentages in the case where design '2A' is exclusively used by students from class 1 to class 3 and design '2B' is exclusively used by students from class 4 to class 6. It is clear that the new design 2 significantly improves the match percentages as compared to the single design 1 case.

An interesting although less feasible alternative in practice would be to allow cross assignments of the designs to classes. In other words, it was found that if design '2A' were available for students from classes 4 to 6 it would result in an increase in the match

Figure 8. Backrest height mismatch (class 1).

Figure 9. Backrest height match (class 6).

Table 5. Dimensions of proposed furniture design 1 and match percentages.

| Design parameter | Dimension (cm) | Match (%) | Mismatch (%) Below the lower limit | Mismatch (%) Above the upper limit |
|---|---|---|---|---|
| Seat height | 30 | 47.5 | 40.5 | 12.0 |
| Seat depth | 32 | 51.5 | 29.0 | 19.5 |
| Backrest height | 30 | 89.3 | 4.7 | 6.0 |
| Desk height | 46 | 63.0 | 18.0 | 19.0 |
| Under-surface of desk height | 45 | 55.2 | 0.0 | 44.8 |

percentages of those who did not have a match when using design '2B', as shown in Table 7. For example, an additional 11.7% in the seat height match would be obtained. It is clear from the table that the match percentage differs for different design parameters.

Table 6. Dimensions of proposed furniture design 2 and match percentages with restriction to the designated classes

| | Design 2 | | | |
|---|---|---|---|---|
| | Design 2A (classes 1 to 3) | | Design 2B (classes 4 to 6) | |
| | Dimension (cm) | Match (%) | Dimension (cm) | Match (%) |
| Seat height | 26.3 | 57.7 | 31.3 | 68.0 |
| Seat depth | 28.9 | 66.3 | 34.0 | 75.0 |
| Backrest height | 29.5 | 93.0 | 32.0 | 96.7 |
| Desk height | 43.5 | 73.3 | 50.3 | 73.7 |
| Under-surface of desk height | 40.0 | 33.0 | 49.0 | 73.0 |

Table 7. Match percentages for furniture design 2A with no class restriction.

| | Match (%) (classes 1 to 3) | Match (%) (classes 4 to 6) |
|---|---|---|
| Seat height | 57.7 | 11.7 |
| Seat depth | 66.3 | 12.3 |
| Backrest height | 93.0 | 2.0 |
| Desk height | 73.3 | 0.0 |
| Under-surface of desk height | 33.0 | 19.0 |

Table 8. Match percentages for furniture design 2B with no class restriction.

| | Match (%) (classes 1 to 3) | Match (%) (classes 4 to 6) |
|---|---|---|
| Seat height | 16.7 | 68.0 |
| Seat depth | 21.7 | 75.0 |
| Backrest height | 26.0 | 96.7 |
| Desk height | 22.7 | 73.7 |
| Under-surface of desk height | 97.7 | 73.0 |

Table 9. Numbers of students whose dimensions match all furniture dimensions for the alternative designs.

| Design | Number of students | Percentage |
|---|---|---|
| Current design | Zero | Zero |
| Design 1 | 66 | 11 |
| Design 2A (classes 1 to 3) | 29 | 9.7 |
| Design 2B (classes 4 to 6) | 119 | 39.7 |

Table 8 shows the results of another case, which called for assigning design '2B' to students in classes 1 to 3 who did not find a match using design '2A'. From the table, it is seen that for the seat depth, the match improves by 21.7%.

Finally, the designs were compared to each other with regard to how many students would find that the desks matched them in all aspects, as shown in Table 9. The number of students whose dimensions would match all desk dimensions is zero for the current design, while for design 1, the number of students is 66. As for design 2A, the number of students is 29, while design 2B was found to match 119 students as shown in Table 9.

## 6. Discussion

The results indicated a mismatch between body dimensions of the students who participated in this study and the school furniture available to them. It is seen that seat depth, seat height and desk height all have a mismatch percentage of 99.8.

A mismatch in this context implies that the students' dimensions are not within the upper and lower limits set by the researchers for the suitability of the existing desk dimensions. For example, for the given seat depth of 20 cm, the range of buttock–popliteal length for which the seat was acceptable would be 21.05–25.00 cm. Therefore, for any student whose dimensions are not within this range, it is labelled 'mismatch'. The same discussion can be extended in a similar fashion to other dimensions.

The effects of unsuitable classroom furniture on the spine have been known for a long time (Zacharkow 1988). Structurally, the tuberosities form an unstable two-point support system due to the fact that the centre of gravity of a seated person's body above the seat may be directly over the tuberosities (Branton 1969). Therefore, the seat alone is insufficient for stabilisation and the use of legs, feet and back in contact with other surfaces, as well as muscular forces, is necessary to produce equilibrium (Branton 1969). Leg support helps in distributing and reducing buttock and thigh loads. Feet need to rest firmly on the floor or on a foot support so that the lower leg weight is not supported by the front part of the thighs resting on the seat (Chaffin and Anderson 1991). Without proper design, sitting will require greater muscular force and control to maintain stability and equilibrium. This, in turn, results in fatigue and discomfort and is likely to lead to poor postural habits as well as neck and back pains (Chaffin and Anderson 1991).

The majority of the students are sitting on seats that are too high and not deep enough and at desks that are too high for them. As for the suitability of the proposed new design specifications, it is clear that the single design (design 1) would improve the match percentages of all dimensions, while the suggested solution of two sizes would greatly improve the suitability as compared to the single design. A more attractive option would be to use an adjustable workstation. However, instructors and parents need to teach students and stress good seating habits even in the presence of ergonomic designs. As attractive as it may seem, the adjustable design may cause problems when used by students since they may need to change more than one dimension (and particularly the five dimensions addressed in the present study).

In addition to the factors considered above, seats and desks may have slopes to improve upright sitting and viewing (Bendix 1987). Since sharp edges are stress concentrators, desk and seat edges should be curved in order not to restrict blood circulation. Further, a fabric or a leather piece may be used to cover the backrest. Therefore, it is recommended that UNRWA-UNESCO schools change their designs into the proposed single design that better matches the students' anthropometry or better adopt the two size design options in order to improve the match percentages further.

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## References

Anderson, G.B.J., *et al.*, 1991. Epidemiology and cost. *In*: M. Pope, ed. *Occupational low back pain*. St. Louis, MO: Mosby Year Book.

Bendix, T., 1987. Adjustment of the seated workplace – with special reference to heights and inclinations of seat and table. *Danish Medical Bulletin*, 34 (3), 125–139.

Bendix, T. and Bloch, I., 1986. How should a seated workplace with a tiltable chair be adjusted? *Applied Ergonomics*, 17, 127–135.

Branton, P., 1969. Behaviour, body dynamics and discomfort. *Ergonomics*, 12, 316–327.

Brunswick, M., 1984. Ergonomics of seat design. *Physiotherapy*, 70 (2), 40–43.

Burgess-Limerick, R., Plooy, A., and Ankrum, D., 1999. The influence of computer display height on head and neck posture. *International Journal of Industrial Ergonomics*, 23 (3), 171–179.

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

Chung, J. and Wong, T., 2007. Anthropometric evaluation for primary school furniture design. *Ergonomics*, 50 (3), 323–334.

Cook, C. and Kothiyal, K., 1998. Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users. *Applied Ergonomics*, 29 (6), 439–443.

Corlett, E. and Clark, T., 1995. *The ergonomics of workplaces and machines*. A design manual. London: Taylor and Francis.

Cranz, G., 2000. The Alexander technique in the world of design: posture and the common chair. *Journal of Bodywork Movement Therapy*, 4 (2), 90–98.

Dul, J. and Weerdmeester, B., 1998. *Ergonomics for beginners. A reference guide*. London: Taylor and Francis.

Evans, W., Courtney, A., and Fok, K., 1988. The design of school furniture of Hong Kong school children an anthropometric case study. *Applied Ergonomics*, 19 (2), 122–134.

Gierlach, P., 2002. Physician perspectives on children musculoskeletal and vision disorders in Geneva, Switzerland. *Proceedings of the XVI annual international occupational ergonomics and safety conference*, 9–12 June 2002, Toronto, Canada, 1–4.

Gouvali, M.K. and Boudolos, K., 2006. Match between school furniture dimensions and children anthropometry. *Applied Ergonomics*, 37 (6), 765–773.

Hedge, A., *et al*., 1999. *Ergonomic evaluation* [online]. Cornell University. Available from: http://ergo.human.cornell.edu/cityofithaca/intro.html. [Accessed 13 April 2007].

Helander, M., 1997. Anthropometry in workstation design. *In*: M. Helander, ed. *A guide to the ergonomics of manufacturing*. London: Taylor and Francis, 17–28.

Khalil, T., *et al*., 1993. *Ergonomics in back pain: A guide to prevention and rehabilitation*. New York: van Nostrand Reihold.

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

Kumar, S., 1994. A computer desk for bifocal lens wearers, with special emphasis on selected telecommunication tasks. *Ergonomics*, 37, 1669–1678.

Mandal, A., 1982. The correct height of school furniture. *Human Factors*, 24, 257–269.

Mandal, A., 1997. Changing standards for school furniture. *Ergonomics in Design*, 5, 28–31.

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

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

Naqvi, S., 1994. Study of forward sloping seats for VDT work-stations. *Journal of Human Ergonomics*, 23 (1), 43–49.

Oborne, D., 1996. *Ergonomics at work: Human factors in design and development*, 3rd ed. Chichester: John Wiley & Sons.

Occhipinti, E., *et al*., 1985. Sitting posture analysis of lumbar stresses with upper limbs supported. *Ergonomics*, 28, 1333–1346.

Oxford, H., 1969. Anthropometric data for educational chairs. *Ergonomics*, 12 (2), 140–161.

Panagiotopoulou, G., *et al*., 2004. Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics*, 35 (2), 121–128.

Parcells, C., Manfred, S., and Hubbard, R., 1999. Mismatch of classroom furniture and body dimensions. Empirical findings and health implications. *Journal of Adolescent Health*, 24 (4), 265–273.

Pheasant, S., 1991. *Ergonomics, work and health*. Hong Kong: Macmillan.

Poulakakis, G. and Marmaras, N., 1998. A model for the ergonomic design of office. *In*: P. Scott, R. Bridger, and J. Charteris, eds. *Proceedings of the ergonomics conference in Cape Town: Global ergonomics*. Amsterdam: Elsevier Ltd., 500–504.

Saarni, L., *et al*., 2007. The working postures among schoolchildren – a controlled intervention study on the effects of newly designed workstations. *Journal of School Health*, 77 (5), 240–247.

Sanders, M. and McCormick, E., eds., 1993. *Human factors in engineering and design*, 7th ed. Singapore: McGraw-Hill.

Villanueva, M., *et al*., 1996. Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal. *Ergonomics*, 39, 933–945.

Yeats, B., 1997. Factors that may influence the postural health of schoolchildren (K-12). *Work*, 9 (1), 45–55.

Zacharkow, D., 1988. *Posture: sitting, chair design and exercise*. Springfield, IL: CC Thomas.