

# Furniture dimensions and postural overload for schoolchildren's head, upper back and upper limbs

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**Abstract.** The aim of this study was to evaluate how the fixed furniture dimensions match with students' anthropometry and to describe head, upper back and upper limbs postures and movements. Evaluation was performed in 48 students from a Brazilian state school. Furniture dimensions were measured with metric tape, movements and postures by inclinometers (Logger Tecknologi, Åkarp, Sweden). Seat height was high for 21% and low for 36% of the students; seat length was short for 45% and long for 9% and table height was high for 53% and low for 28%. Regression analysis showed that seat/popliteal height quotient is explained by 90<sup>th</sup> percentile of upper back inclination ( $\beta=0.410$ ) and 90<sup>th</sup> percentile of right upper arm elevation ( $\beta=-0.293$ ). For seat/thigh length quotient the significant variables were 90<sup>th</sup> percentile of upper back velocity ( $\beta=-0.282$ ) and 90<sup>th</sup> percentile of right upper arm elevation ( $\beta=0.410$ ). This study showed a relationship between furniture mismatch and postural overload. When the seat height is low students increase upper back left inclination and right upper arm elevation; when the seat is short students decrease the upper back flexion velocity and increase right upper arm elevation.

**Keywords:** classroom, anthropometry, children, direct measurement techniques, inclinometer

## 1. Introduction

Schoolchildren spend as much as 30% of their waking hours at school, adopting sitting posture during considerable amount of time [20,21,28]. Frequently the furniture has dimensions not compatible with their anthropometric measures, which can lead to musculoskeletal disorders, such as pain, discomfort and postural deviations [28]. Pain in this age group is well described in the specialized literature, and could be related to ergonomic risk factors [23]. One of them is the mismatch between furniture and anthropometric measures [27]. This mismatch also can lead to lack of attention during classes, as children and

adolescents seek more comfortable positions, compromising learning and school performance [28].

Back pain complaints in childhood and adolescence are important risk factor for back pain in adulthood [19]. In this sense, studies strongly suggest the need for early initiatives in order to prevent the occurrence of chronic pain in schoolchildren [20].

The school furniture has an important role in maintaining the correct posture [21,17,22], facilitate learning through providing a comfortable and stress-free workstation [17] and preventing symptoms [10]. The use of adjustable furniture is essential for the healthy development of children [8] and for good postural habits in childhood [21].

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The adequacy of school furniture depends on the anthropometric measurements of its users. Specific measures are needed to determine the dimensions of furniture in order to allow a correct sitting posture [17,22]. According to Panagiotopoulos et al. [21] most children use chairs with height and length greater than recommended, generating an inappropriate adjustment to their anthropometric characteristics.

Although several studies have shown inadequacy of furniture for students, few of them evaluated the response of the individual, in terms of postural risk, during the use of furniture in a real situation, as Gil and Tunes [12] performed. Then, the aim of this study was to evaluate the suitability of school furniture and its relationship with head, upper back and upper limbs postures and movements of students from fifth and eighth grade of elementary education at a Brazilian state school.

## 2. Methods

### 2.1 Study settings and sample

The study was conducted in a state school in São Carlos, São Paulo, Brazil. The study sample was selected from the population of students from two classes, 5<sup>th</sup> and 8<sup>th</sup> grade of elementary school, enrolled in afternoon classes. These grades were chosen to represent the most extremes students, i.e., the lowest and highest ones. Twenty four students from each grade, being 12 female and 12 male, were randomly selected to participate, which represents 75% of two classes from the 5<sup>th</sup> and 8<sup>th</sup> grades. The parents or guardians signed an informed consent, following the recommendations of 196/96 Brazilian Ethics Resolution. This study was approved by the Ethics Committee of the Federal University of São Carlos (CAAE 0124.0.135.000-08, Opinion N. 039/2009).

The criteria for inclusion in the sample were attending the 5<sup>th</sup> or 8<sup>th</sup> grade of elementary school and to be right-handed. The exclusion criteria were not complete all the evaluation procedures and the occurrence of technical problems during the movement analysis.

### 2.2 Equipments and instruments

Anthropometric and furniture measurements were obtained from a metric tape and recorded in a standardized form. Inclinometers were used for recording postures and movements for the head, upper back and upper arms (Logger Tecknologi, Åkarp, Sweden). We

also used a digital camcorder (Sony DCR-SR85), tripod or other support materials.

### 2.3 Furniture evaluation

Only one kind of furniture with fixed dimensions was available in the classroom. The seat height of the chair was 39 cm and seat length 33 cm. The height of the table was 71.5 cm. The criteria used to classify the adequacy of the furniture were based on Parcels et al. [22]. Anthropometric measurements were obtained from popliteal height, thigh length, shoulder height and elbow height. From the quotient between seat height and popliteal height it was set the seat height match, and this value must be between 88 to 95% to an appropriate height seat. For the quotient between the seat length and thigh length, a value between 80 and 95% was considered appropriate. The adequacy of the table height was based at the elbow height and maximum recommended shoulder flexion and abduction angles, 25° and 20°, respectively [7]

### 2.4 Postural evaluation and audiovisual recordings

Four inclinometers and a data logger were used for recording postures and movements for the head, upper back and upper arms. The sampling rate was 20 Hz.

One inclinometer transducer was placed on the forehead and another to the right of the cervicothoracic spine at the C7-Th1 level. For the upper arms, the inclinometers were fixed to plastic plates that were placed along the upper arm just below the insertion of the deltoid muscle. For the head and upper back, the forward-backward and sideways projection of the inclination angle (flexion and inclination below) and their time derivatives were used to characterize postures and movements. Upper arm elevation and the time derivative of the position on the unit sphere (as described by spherical co-ordinates), were used for the postures and movements, respectively. Various percentiles of the angle and angular velocity distributions were calculated. The reference position for the head and upper back (flexion 0 degrees) was defined as the position obtained when the subject was standing upright and looking at a mark at eye level. The forward direction of the head and back was defined with the subject sitting, leaning straight forward, and looking at the floor. For the upper arms, the reference position (elevation 0 degrees) was recorded with the subject sitting, with the side of the body leaning towards the rest of the chair, with the arm

hanging perpendicular over the rest of the chair, and with a 2-kg dumbbell in the hand. The forward direction of the upper arms (elevation 90 degrees) was defined as the upper arms elevation at scapular plane. All data collection procedures were based on the protocol described by Hansson et al. [14].

After the calibration procedures, the student returned to the classroom and was instructed to perform their activities as naturally as possible. The researchers remained in the classroom and performed the audiovisual records with a digital camcorder. The mean recording duration was 78 min with standard deviation of 25 min. In this Brazilian state school, students have six classes a day, with duration of 50 minutes each and a lunch break of 20 minutes after the first three classes (150 minutes). During the recording period of regular classes the main tasks performed by students are attending to the teacher/blackboard, reading/writing and a combination of these two tasks (mixed task). In general, Brazilian schools adopt a traditional teaching model, which is based on individual tasks and long periods in seated posture.

### 2.5 Data analysis

Data were descriptively analyzed, using mean and standard deviation. Postural and movement data were treated as percentiles. Correlational statistical analysis between furniture mismatch and posture data was applied. Variables that presented a  $P$ -value  $\leq 0.25$  were included in a multiple linear regression model. This analysis was used to select explicative variables for furniture mismatch. Differences between groups and upper arms were tested by Mann Whitney and Wilcoxon tests, respectively. All analysis was performed using SPSS (version 11.5).

Two representative students, the lowest (5<sup>th</sup> grade) and the highest (8<sup>th</sup> grade), were selected for task analysis. The identified tasks were: 1. attending to the teacher/blackboard; 2. reading/writing and 3. a combination of these two tasks (mixed task).

## 3. Results

### 3.1 Sample characteristics

The final sample, after exclusion of two subjects due to technical problems, was composed by 46 students. The main subject's characteristics are presented in Table 1.

### 3.2 Furniture evaluation

The adequacy classification revealed that the seat height was inadequate in 57% of cases, the seat length in 56% and the table height in 81% of cases. Table 2 shows that for the 5<sup>th</sup> grade, the seat height was high for many students although it was low for half of the 8<sup>th</sup> grade students. Table height was high for most of the 5<sup>th</sup> grade and low for many of the 8<sup>th</sup> grade students. Considering the furniture as a conjunction, only one student had his seat and table adequate.

Spearman correlation coefficient ( $r_s$ ) was significant ( $P < 0.05$ ) for stature and seat/popliteal height quotient ( $r_s = -0.81$ ); seat/thigh length quotient ( $r_s = -0.78$ ) and table/upper arm height ( $r_s = -0.38$ ); indicating that stature is an important predictor for furniture/student match.

### 3.3 Postural evaluation and audiovisual recordings

Postures and movements of head, upper back and upper arms are presented at Table 3. It can be seen that head movements showed small variations between groups, as well as upper back flexion. Head and upper back inclination were more pronounced for the left side. Upper back inclination was inversely correlated with seat/thigh length quotient ( $r_s$  between  $-0.30$  and  $-0.38$ ), indicating that when the seat is short, the upper back left inclination increase.

Marked differences between groups were identified for upper back inclination and upper arms elevation. The 5<sup>th</sup> grade students showed higher left upper back inclination and upper arms elevation. Right upper arm elevation showed positive correlation with seat/popliteal height quotient ( $r_s = 0.34$  at 50<sup>th</sup> and 0.41 at 90<sup>th</sup> percentiles). Upper arms showed significant positive correlation with seat/thigh length quotient at 50<sup>th</sup> and 90<sup>th</sup> percentiles ( $r_s$  between 0.35 and 0.52). Right arm elevation at 90<sup>th</sup> percentile showed positive correlation ( $r_s = 0.30$ ) with table/arm height quotient. In general, velocities were low for all students and joints, with significant differences between groups at 90<sup>th</sup> percentile for head and upper back flexion. The 8<sup>th</sup> grade students showed higher velocities than 5<sup>th</sup> grade at 90<sup>th</sup> percentile. Multiple linear regression analysis showed that seat/popliteal height quotient is explained by 90<sup>th</sup> percentile of upper back inclination ( $\beta = 0.410$ ) and 90<sup>th</sup> percentile of right upper arm elevation ( $\beta = -0.293$ ).

Table 1  
Sample characteristics

CHARACTERISTIC	GROUPS	
	5th grade	8th grade
	(N = 24; 12 boys, 12 girls)	(N=22; 11 boys, 11 girls)
	mean (SD)	mean (SD)
age (years)	11.5(1.1)	14.9(0.9)
weight (kg)	41.7(10.7)	59.3(12.5)
height (m)	1.5(0.1)	1.7(0.1)
body mass index (kg/m <sup>2</sup> )	19.1(3.8)	21.7(4.7)

Table 2  
Subject's and furniture main characteristics

CHARACTERISTIC	GROUPS	
	5 <sup>th</sup> grade	8 <sup>th</sup> grade
	mean (SD)	mean (SD)
popliteal height (cm)	40.3(3.5)	44.9(2.1)
buttock-popliteal length (cm)	36.7(2.7)	44.2(3.9)
elbow height (cm)	25.1(5.9)	31.0(3.7)
shoulder height (cm)	47.6(3.8)	54.3(2.5)
match seat height-popliteal height	N(%) <sup>a</sup>	N(%)
low	5(23)	11(50)
adequate	8(36)	11(50)
high	9(41)	0(0)
match seat length-buttock-popliteal length	N(%) <sup>b</sup>	N(%)
short	1(5)	19(86)
adequate	16(76)	3(14)
long	4(19)	0(0)
match table height-elbow-shoulder height	N(%) <sup>a</sup>	N(%) <sup>c</sup>
low	4(18)	8(38)
adequate	2(9)	6(29)
high	16(73)	7(33)

<sup>a</sup>Two of the original 24 students were excluded due to the lack of antropometric measurement.

<sup>b</sup>Three of the original 24 students were excluded due to the lack of antropometric measurement.

<sup>c</sup>One of the original 22 students were excluded due to the lack of antropometric measurement.

For seat/thigh length quotient the significant variables were 90<sup>th</sup> percentile of upper back velocity ( $\beta=-0.282$ ) and 90<sup>th</sup> percentile of right upper arm elevation ( $\beta=0.410$ ).

### 3.4 Task analysis

Figures 1 and 2 shows the postural exposure of two representative subjects, the tallest one and the smallest one, performing different and common tasks at classroom. Total recording lasted 80 minutes for the 5<sup>th</sup> grade student and 41 minutes for the 8<sup>th</sup> grade student. Tasks duration were 11.3% and 9.8% of the total time for task 1 (watching classes, looking at the teacher or the blackboard), 48.8% and 17.1% for task 2 (writing or reading) and 28.8 and 39.0% for task 3 (mixed of tasks 1 and 2) for the 5<sup>th</sup> and 8<sup>th</sup> grade students, respectively. Students performed other activities during the recording time, as stand up and

walk (2.5% and 9.8%) and "unauthorized breaks" talking with friends (8.8% and 24.4%).

Task analysis showed an increased head and upper back flexion and left inclination for reading/writing task (task 2). Right upper arm elevation was higher for attending blackboard/teacher (task 1). Left upper arm showed small difference between tasks. In general, the lowest student showed greater exposure for all tasks.

## 4. Discussion

### 4.1 Furniture evaluation

Since the anthropometric dimensions differ between 5<sup>th</sup> and 8<sup>th</sup> grade students and the furniture dimensions are fix, most children have furniture that are inadequate, exposing them to ergonomic hazards.

In this study the mismatch between furniture dimensions/anthropometric measurements was high for both grades.

Only one child have match with the whole furniture, i.e. seat height and length and table height were adequate. The other students have mismatch in the seat height (64% for 5<sup>th</sup> grade and 50% for 8<sup>th</sup> grade), seat length (24% for 5<sup>th</sup> grade and 86% for 8<sup>th</sup> grade) and table height (81% for 5<sup>th</sup> grade and 71% for 8<sup>th</sup> grade). These problems may lead to compensatory postures and behaviors, like sitting sideways and rocking on chairs [17]. It is hypothesized that the low seat can push the children towards the back of the seat when they were writing or working on the table. It is harder to sit forwards, and then the legs have to be tucked uncomfortably underneath the low seat. Thus, the lumbar and hip flexion is increased placing even more strain on lumbar discs [23]. On the other

hand, long seat can leave the students away from the table, without using back support. This can increase neck and trunk flexion and upper arms elevation. The high table can also lead to higher upper arms elevation in order to reach the working surface.

Others studies found similar results. Panagiotopoulou et al. [21] found that none of the children measurements were in proportion to the chairs in length and the desk-chair combinations were inadequate for all the students in the 2<sup>th</sup> and 4<sup>th</sup> grades as well as the majority of those in the 6<sup>th</sup> grade. Saarni et al. [24] evaluated 101 children in 6<sup>th</sup> and 8<sup>th</sup> grade to check the mismatch between furniture and anthropometric measurements and their findings were similar to the present study. These authors indicate that the school furniture did not match up with the schoolchildren's anthropometric measures

Table 3

Positions and movements of head, upper back and upper arms during regular classes. Mean and (SD) are shown for all (n = 46) students, and those from 5<sup>th</sup> grade (n = 24), and those from 8<sup>th</sup> grade (n = 22), at different percentiles of the angular and velocity amplitude distributions. For inclination angles, positive values denote bending to the right.

Distribution (percentile)	Group of students	Head		Upper back		Upper arms elevation		
		Flexion	Inclination	Flexion	Inclination	Right arm	Left arm	
Positions (°)	10th	All	-7(7)	-15(8)	-2(7)	-14(6) <sup>†x</sup>	27(14) <sup>x</sup>	27(15) <sup>x</sup>
		5th grade	-7(7)	-17(7)	0(7)	-17(5)	32(15)	32(15)
		8th grade	-6(7)	-13(9)	-4(8)	-11(5)	22(12)	22(13)
	50th	All	9(9)	-2(6)	12(9)	-4(10) <sup>†x</sup>	52(12) <sup>*†x</sup>	54(14) <sup>†x</sup>
		5th grade	8(7)	-3(4)	14(7)	-7(5)	56(9)	59(13)
		8th grade	10(10)	-1(8)	10(10)	0(13)	47(13)	50(15)
	90th	All	33(11)	10(9)	28(8)	5(10) <sup>†x</sup>	68(10) <sup>*†#x</sup>	68(12) <sup>†x</sup>
		5th grade	31(11)	8(6)	28(8)	1(7)	71(9)	73(9)
		8th grade	35(10)	12(12)	27(8)	10(12)	64(11)	63(13)
Velocities (°/s)	10th	All	1(0)	1(0)	1(0)	1(0)	2(1)	2(1)
		5th grade	1(0)	1(0)	1(0)	1(0)	2(1)	2(1)
		8th grade	1(0)	1(0)	1(0)	1(0)	2(1)	2(1)
	50th	All	6(2)	9(3)	4(2)	4(2)	10(4)	9(4)
		5th grade	6(2)	9(2)	4(2)	4(1)	10(4)	9(3)
		8th grade	7(2)	9(3)	4(2)	4(3)	10(4)	9(4)
	90th	All	38(11) <sup>†x</sup>	50(14)	26(9) <sup>x</sup>	24(11)	58(16)	55(16)
		5th grade	33(9)	46(12)	24(7)	22(6)	56(16)	52(14)
		8th grade	43(11)	53(14)	29(10)	27(14)	61(16)	59(18)

\* Statistically significant correlation (Spearman rank order correlation) between seat/popliteal height quotient and posture (P<0.05)

† Statistically significant correlation (Spearman rank order correlation) between seat/thigh length quotient and posture (P<0.05)

# Statistically significant correlation (Spearman rank order correlation) between table/arm height quotient and posture (P<0.05)

x Statistically significant difference between grades (P<0.05, Mann Whitney test)

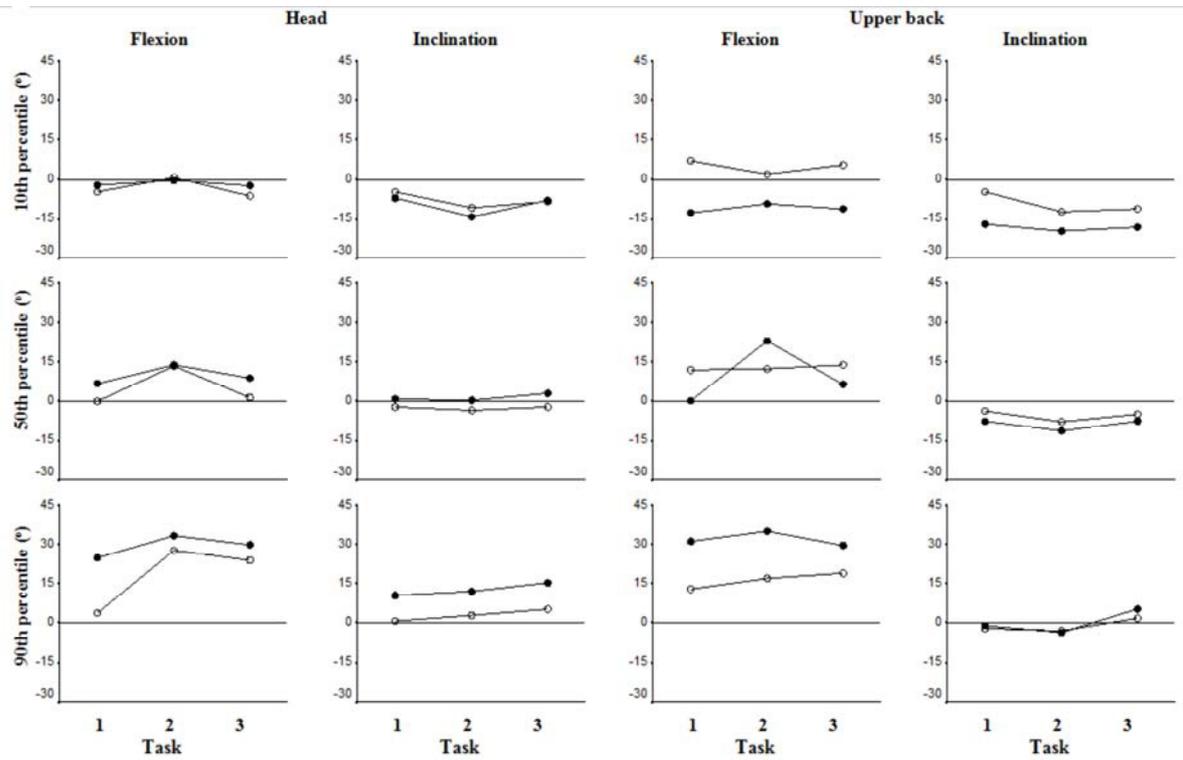


Fig. 1. Head and upper back posture and movements for three separate tasks. Full circle represents the lowest student (5<sup>th</sup> grade) and empty circle represents the highest student (8<sup>th</sup> grade). Task 1: watching classes, looking at the teacher or the blackboard; Task 2: writing or reading using the table how a support; Task 3: a mixed of previous tasks.

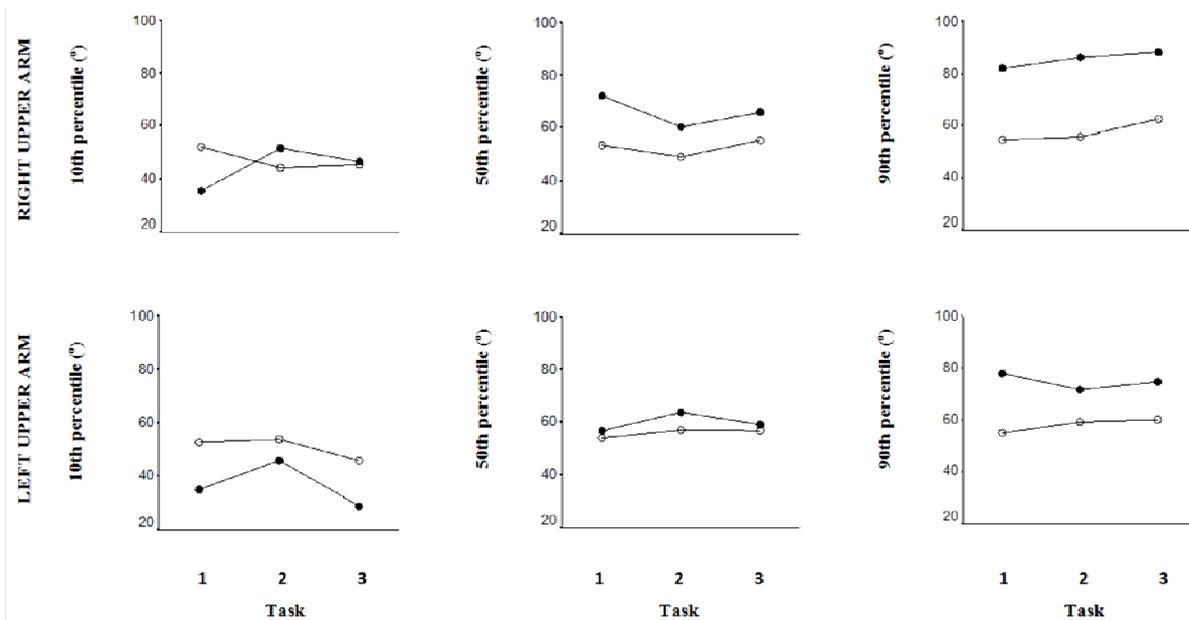


Fig. 2. Right and left upper arm elevation for three separate tasks. Full circle represents the lowest student (5<sup>th</sup> grade) and empty circle represents the highest student (8<sup>th</sup> grade). Task 1: watching classes, looking at the teacher or the blackboard; Task 2: writing or reading using the table how a support; Task 3: a mixed of previous tasks.

A wide prevalence range of thoracic spine pain was found in the literature, prevalence estimates in children described in a systematic review were up to 38% among males and up to 72% among females [6]. This review also describes that one of the risk factors for this is furniture mismatch.

Stature or body height is shown to be a good predictor of whether a student fits into a chair [22]. The significant correlation found in this study corroborate with the literature in this topic.

Others studies have evaluated the student's posture at classroom. Geldhof et al [11] studied the posture of 41 students of the 4<sup>th</sup> and 5<sup>th</sup> grade with PEO method (Portable Ergonomic Observation). The findings indicate the postural pattern of elementary schoolchildren was commonly prolonged sitting with a poor posture. Children sat statically for 85% of the time, while their trunk was bent over 45° for 28% of the lesson time. A possible biomechanical consequence of these findings may be increased intradiscal pressure resulting in decreased nutrition to the disc, a risk factor for early degenerative changes and back or neck pain. The association between observed postures and back/neck pain was weak, most likely because the effects of spinal loading do not occur until an older age.

#### 4.2 Postural evaluation

For each joint, standard postures can be defined on that maintenance requirements are minimal and anatomical structures are in favorable positions. Any deviation from these postures can lead to consequences for the musculoskeletal system if maintained for long time without muscular rest [13]. Posture affects comfort and performance at work [4] and may be an important cause of pain and discomfort [9]. As a result, the postural assessment is crucial when the goal is to increase comfort and reduce musculoskeletal symptoms. Different studies suggest favorable range of motion for head, upper back and upper arms postures for adults during occupational tasks; few of them report this data for children and adolescents.

Our findings indicate that students remain at highest degrees of head flexion  $\geq 33^\circ$  and upper back flexion  $\geq 28^\circ$  for 10% of the time; and  $\geq 7^\circ$  of head extension and  $\geq 2^\circ$  of upper back extension for 10% of the time. They also had a lateral inclination in much of the time, especially for left side. This can be explained by manual dominance, as all students are right-handed, so they are looking at what they are

doing with their right hand and bend their head/upper back towards the left to be able to do this.

Ariëns[3] states that head/upper back postures should be kept in between 0° and 25° of flexion and Hagberg et al. [13] suggest that head/upper back lateral inclination must be avoided during long periods of time. Akesson et al. [1] described that the combination of flexion and lateral inclination is more strained than the pure flexion and implies higher load on the cervical/upper back spine. According Smyth and Haslam [26] any range of head extension is considered unsafe. Sakakibara et al. [25] describe that work with fully extending of the head may lead to symptoms of vertebral artery insufficiency. Thus, schoolchildren are exposed to awkward head postures during classes and this exposure is higher during writing/reading task when the student is looking downwards. Results from occupational literature suggest that shoulder elevation greater than 30° is considered a risk factor of developing acute pain in the neck/shoulder and musculoskeletal disorders [5]. Another common exposure factor is long periods of time with the arm in an abducted or flexed position without support [15]. Jacobs and Baker [16] investigated the association between children's computer use and musculoskeletal discomfort and found that almost half of 6<sup>th</sup> grade students had experienced some musculoskeletal discomfort in at least one body part, with the most common areas of moderate to severe discomfort being the neck, back and shoulders.

Our findings showed high angles for upper arm elevation and significant correlation with seat length and table height match. Especially for 5<sup>th</sup> grade where the seat was long for 19% and the table was high for 73%. Both situations lead to high overload in the upper arms, reaching up to 68° of elevation for both arms. Results showed no difference between right and left upper arm elevation, indicating a symmetrical load at these joints.

#### 4.3 Task analysis and velocities

From the task analysis it can be seen that the students perform the tasks that offer higher postural risk (tasks 1 and 2) by 60% (5<sup>th</sup> grade) and 26.8% (8<sup>th</sup> grade) of the time. In accord with Knight and Noyes [17], a chair and table should be designed to provide support for the two major tasks of the students: attending to the teacher and writing on the working surface. These tasks require adoption of quite different physical positions by the child, and the furniture need to provide the better conditions for this.

In general, velocities were low for all students and joints. The 8<sup>th</sup> grade students showed higher velocities than 5<sup>th</sup> grade at 90<sup>th</sup> percentile, indicating that older students are more "active". One possible explanation for these is that they had 'off-task' periods (stand up and unauthorized breaks) longer than the 5<sup>th</sup> grade students. Knight and Noyes [17] also described that another function of the furniture should be to facilitate learning through providing a comfortable and stress-free workstation. In order to achieve this, it is generally accepted that classroom furniture needs to be designed to allow the children to move about in their seats, as it is unnatural to keep still for long periods [18].

This study showed a relationship between furniture mismatch and postural overload. The evaluated school offers only one type of furniture with fixed dimensions for all students. The ones from extreme grades are the ones that are more exposed to ergonomic risks at school. Thus, we can suggest for educational managers to consider the ergonomic risks that our children are exposed in school, providing different types and sizes of furniture.

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