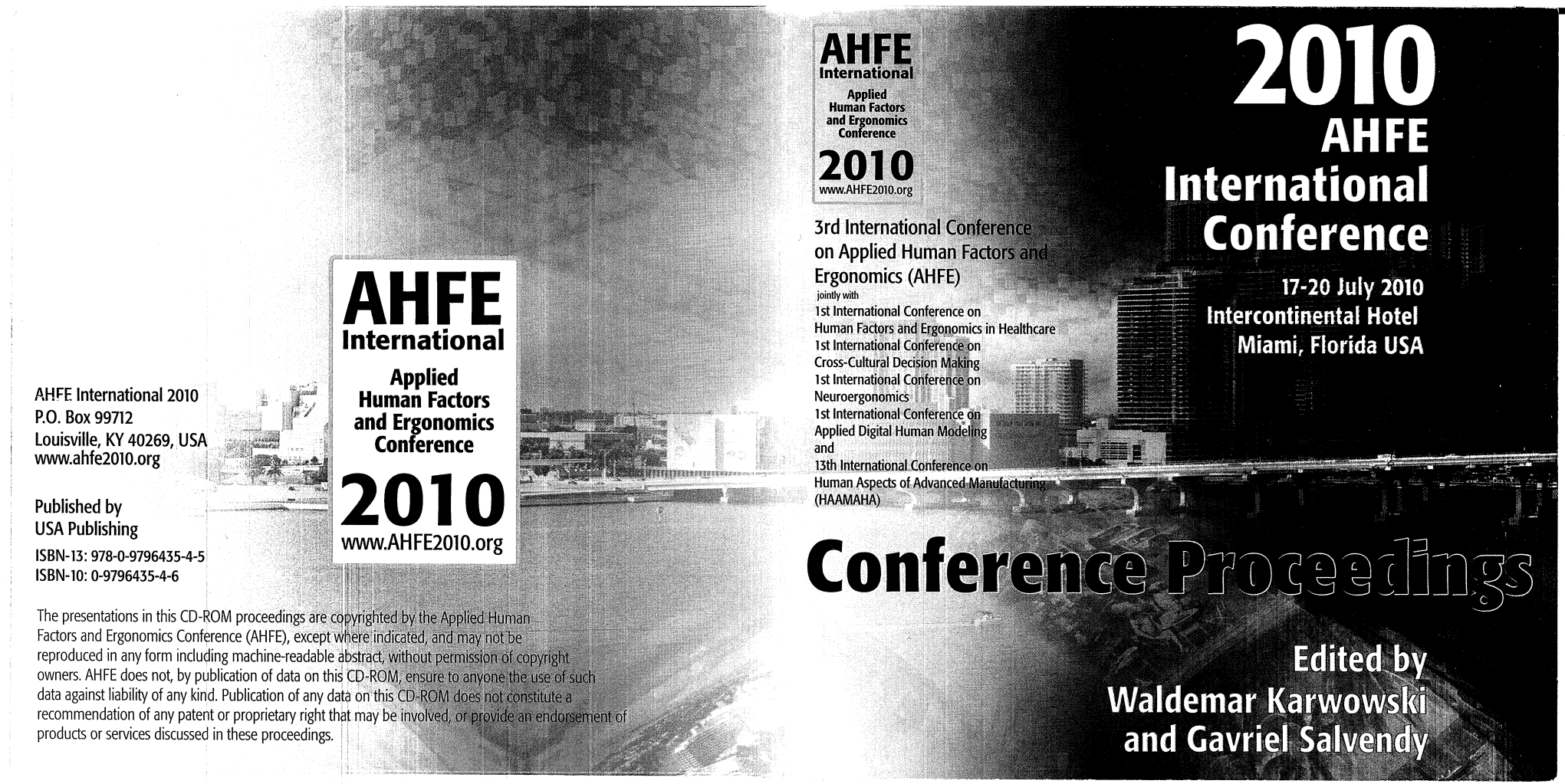

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# Ergonomic Design of School Furniture: Challenges for the Portuguese Schools

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## ABSTRACT

It can be observed an increased concern about the school classrooms, in particular about the study and design of school furniture fitting the students' needs and anthropometrics characteristics. The main aim of this study was to perform an anthropometric survey, considering the main anthropometric dimensions and, in accordance, to define the dimensions and characteristics of school furniture for Portuguese students of the 1st education cycle using valuable and validated ergonomic criteria. The analyzed sample includes, so far, 432 students. Obtained results seem to reinforce the need to consider the specificity of the anthropometric characteristics of the Portuguese students by adding an extra size mark for school furniture in a future revision of the corresponding standard.

**Keywords:** school, furniture, anthropometry, Portuguese.

# INTRODUCTION

It can be observed an increased concern about the school classrooms, in particular about the study and design of school furniture suitable to the needs of the students and with appropriate dimensions according to the students' anthropometrics characteristics. An important milestone in this increasing concern is the publication of the European standard EN 1729 (CEN - European Committee for Standardization., 2006), which determines the dimensions and characteristics of different types of school furniture for the whole European population.

In addition, there is a large number of studies worldwide that shows a clear mismatch between anthropometrics characteristics and the dimensions of classroom furniture (Castellucci et al.; Chung & Wong, 2007; Gouvali & Boudolos, 2006; J. F. M. Molenbroek et al., 2003; Panagiotopoulou et al., 2004; Parcells et al., 1999; Saarni et al., 2007). This mismatch might affect the learning process, even during the most stimulating and interesting lessons (Hira, 1980) and can produce some musculoskeletal disorders, such as low back pain and neck-shoulder pain (Grimmer & Williams, 2004).

Despite that, in Portugal there is still no specific legislation or standard for the definition of the appropriate furniture characteristics to be used by schoolchildren. This situation can be a consequence of both the lack of knowledge from the governmental authorities and the lack of a representative anthropometric database of the population in concern (Molenbroek et al., 2003). Therefore, it seems that Portuguese schoolchildren are using school furniture that has been acquired without any ergonomic criteria, which most likely will result in some changes and problems in their musculoskeletal system, as well as in a possible decrease in their education performance.

The main objective of this ongoing project is to perform an anthropometric survey of the most important anthropometric dimensions regarding the use of the furniture and, in accordance, to define the dimensions and characteristics of school furniture for Portuguese students of the 1st education cycle, by using valuable and validated ergonomic criteria. Currently, the work is centered on a specific aim, which comprises the definition of the furniture dimensions for the mentioned students.

# METHODS AND MATERIALS

## SAMPLE

The studied sample includes, so far, 432 volunteer students (216 male and 216 females) from 9 schools belonging to the 1st cycle of the Portuguese educational system. The students aged 7 to 10 years, with an average of 8.5 (±1.2) years old. After giving written and verbal information about the study to the headmaster of the school, written authorization was obtained from the teachers, parents and students.

It should be noted that the sample was a sample of convenience and so far, the measurements were taken only in the Northern part of the country, near the city of Porto.

## INSTRUMENTS

One of the specific objectives of this study was the design and validation of a new anthropometric chair. This developed tool should allowed to gather more anthropometric data than previous similar models, such as the model developed by Gouvali et al (2006).

For the validation of this new tool, 20 subjects were measured with a Holtain portable anthropometer (exception made with subjects' stature) and with a fixed (or wall) anthropometer. Afterward, these measures were compared with those obtained by using the developed anthropometric chair (Figure 1).

**a** **b** **c**

FIGURE 1. Instrument used during this study. (a) Portable anthropometer. (b) Fixed or wall anthropometer. (c) Developed anthropometric chair.

## ANTHROPOMETRIC VARIABLES CONSIDERED

A group of 13 anthropometric variables were defined and collected using the anthropometric chair. Anthropometric variables were taken with the student wearing a t-shirt and shorts, and without shoes.

All measurements were made by the same measurer and recorded in centimeters by an assistant along nine different sessions. Accuracy and reliability of the measurements were achieved by undergoing through a specific training with a certified anthropometrics specialist and practice in performing measurements at the pilot study carried out previously.

Body anthropometric variables with the subject seated were collected while they were sitting in a relaxed and erect position on the anthropometric chair, with their upper and lower legs at a 90$^{o}$ angle, and with their feet flat on an adjustable footrest.

The following anthropometric variables (ISO 7250, 1996; Pheasant, 2003) (Fig. 2) were considered and collected in this study:

- Stature (S): determined as the vertical distance between the floor and the top of the head, and measured with the subject erect and looking straight ahead (Frankfort plane).
- Shoulder Height (SHH): determined as the vertical distance from the floor to the acromion.
- Eye Height (EH): Vertical distance from the floor to the inner canthus (corner) of the eye and measured with the subject erect and looking straight ahead (Frankfort plane).
- Sitting Height (SH): vertical distance between the top of the head and the subject's seated surface, and measured with the subject erect and looping straight ahead (Frankfort plane).
- Elbow Height Sitting (EHS): taken with a 90° angle elbow flexion, as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.
- Shoulder Breadth (bideltoid) (SHB): Maximum horizontal breadth across the shoulders, measured to the protrusions of the deltoid muscles.
- Popliteal Height (PH): measured with 90° knee flexion, as the vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface).
- Buttock-Popliteal Length (BPL): taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the popliteal surface.
- Buttock-Knee Length (BKL): Horizontal distance from the back of the uncompressed buttock to the front of the kneecap.
- Hip Width (HW): the horizontal distance measured in the widest point of the hips in the sitting position.
- Thigh Thickness (TT): the vertical distance from the highest uncompressed point of thigh to the subject's seated surface.
- Sitting Eye Height (SEH): vertical distance from the seat surface to the inner canthus (corner) of the eye and it was determined with the following calculation: SH-(S-EH).
- Sitting Shoulder Height (SSHH): Vertical distance from the seat surface to the acromion, determined with the following calculation: SH-(S-SHH).

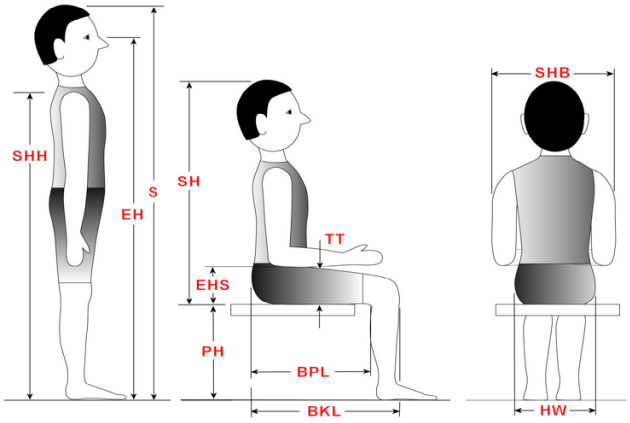


FIGURE 2. Selected anthropometric variables.

## APPLICATION OF THE MEASURES

During the design of school furniture many aspects of human comfort must be taken into consideration to make it suitable for the students. Furthermore, the furniture dimensions are one of the main aspects and, amongst these, the seat height is typically the starting point for the design of this type of furniture.

In order to illustrate how the dimensions can be applied to define the furniture dimensions, it is possible to present the potential relationship between anthropometric data and furniture and defining criteria for the furniture design.

As an example, it is typically that PH should be higher than the SH (J. Molenbroek & Ramaekers, 1996; Parcells et al., 1999), but it does not have to be higher than four centimeters (Gutiérrez & Morgado, 2001) or 88% of the PH (Parcells et al., 1999). This mentioned limitation is due to the need to avoid the compression of the buttock region (García-Molina et al., 1992).

Accordingly, it is possible to define a criteria for establishing seat height, using the criteria described by Gouvali and Boudolos (2006). Besides, it also possible to include a correction related with a shoe height of 2.5 centimeters. Using this data, seat Height (SH) can be defined according to equation 1.

Eq. [1] $(PH+2.5)\cos 30^{o} \bullet SH \bullet (PH+2.5)\cos 5^{o}$

Similarly, it is possible to establish a criterion for the Seat to Desk Height (SDH). Based on available evidence, EHS is the major criterion for SDH (García-Acosta et al., 2007; Milanese et al., 2004; J. F. M. Molenbroek et al., 2003; Sanders et al., 1993). Additionally, Parcells et al. (1999) suggested that SDH may also depends on the shoulder flexion and abduction angles. Other researchers recommended that desk should be 3 to 5 cm higher than the EHS (Pheasant, 1991; Poulakakis and Marmaras, 1998). Using this data, the defined criterion for the dimension of the SDH can be obtained through a modified equation that accepts EHS as the minimum height of SDH, in order to provide a significant reduction on

spinal loading (Occhipinti et al., 1985). Simultaneously, the equation considers that the maximum height of SDH should not be higher than 5 cm above the EHS, as represented in equation 2.

Eq. [2]. $EHS \bullet SDH \bullet EHS + 5$

# RESULTS AND DISCUSSION

## VALIDATION OF THE ANTHROPOMETRIC CHAIR

An Independent t-test (with 95% confidence interval) was performed to examine the differences in measurements between the different applied tools for gathering the anthropometric data. Obtained results show that no statistical significant difference ( $p>0.05$) was identified between the three measurement methodologies/tools for all the anthropometric variables gathered.

Although it is not possible to quantify, it is important to mention the easiness of using the developed anthropometric chair. Nevertheless, there are still some problems related with the use of this tool, in particular the difficulty to carry the device from the laboratory to the different schools.

## ANTHROPOMETRIC VARIABLES

According to the obtained results (Table 1), it is worth to mention that the current anthropometric variables are normally distributed. Moreover, it also possible to notice the existence of a strong Pearson correlation coefficient between stature and a group of other anthropometric variables, such as the popliteal height ($r$=0.90), buttock-popliteal length ($r$=0.84), sitting height ($r$=0.92), shoulder breadth ($r$=0.74) and buttock-knee length ($r$= 0.89). The correlation between variables can be an important point, as most of recommendations for furniture selection tend to use, as reference, the stature, assuming that all the other characteristics will be also appropriate, However, some authors, such as Molenbroek et al. (2003), suggests that the furniture selection can be carry out using the politeal height instead of stature.

**Table 1.** Anthropometric data obtained from the studied sample (cm).

| Anthropometric variables | Mean | S.D | Percentile | | |
|---|---|---|---|---|---|
| | | | 5th | 50th | 95th |
| Stature (S) | 131.3 | 8.9 | 117.1 | 131.2 | 145.3 |
| Shoulder Height (SHH) | 106.4 | 10.4 | 93.6 | 106.6 | 119.9 |
| Eye Height (EH) | 122.1 | 8.8 | 108.2 | 122.3 | 135.7 |
| Sitting Height (SH) | 67.0 | 4.2 | 60.1 | 67.0 | 73.7 |
| Elbow Height Sitting (EHS) | 16.5 | 2.0 | 13.4 | 16.3 | 20.0 |

| | | | | | |
|---|---|---|---|---|---|
| Shoulder Breadth (SB) | 31.9 | 2.8 | 27.9 | 31.5 | 36.7 |
| Popliteal Height (PH) | 33.8 | 3.0 | 29.2 | 33.6 | 38.8 |
| Buttock-Popliteal Length (BPL) | 38.2 | 3.3 | 33.2 | 38.3 | 43.7 |
| Buttock-Knee Length (BKL) | 45.9 | 3.9 | 40.0 | 45.9 | 52.6 |
| Hip Width (HW) | 28.2 | 3.0 | 24.2 | 27.8 | 33.8 |
| Thigh Thickness (TT) | 11.4 | 1.6 | 9.2 | 11.1 | 14.4 |
| Sitting Shoulder Height (SSH) | 44.0 | 7.6 | 38.8 | 44.5 | 50.6 |
| Sitting Eye Height (SHE) | 59.8 | 4.1 | 53.4 | 59.8 | 66.3 |

## CLASSROOM FURNITURE DIMENSIONS

Considering the data of popliteal height and elbow height sitting gathered from the 432 subjects, as well as the definition of the appropriate height for furniture, both for chair and table, it is possible to compare it and establish different sets of furniture to cover the entire observed population.

According to the obtained data, it is necessary to development 4 different sets of furniture to allow students to be seated in the correct position (table 2).

**Table 2.** Proposed dimensions for each type of furniture (cm) and % of match.

| Type of furniture | Seat height | Table height | Users (%) |
|---|---|---|---|
| Furniture #1 | 28 | 45 | 10.0 |
| Furniture #2 | 32 | 51 | 50.0 |
| Furniture #3 | 36 | 56 | 36.3 |
| Furniture #4 | 40 | 61 | 3.7 |

From table 2, it is possible to verify that furniture #2 and #3 together can fit 86.3% of the analyzed students. Moreover, it is also possible to highlight that these two types of furniture have similar dimensions with the Size mark 2 and 3 from the EN 1729 (Table3).

According to the BS EN 1729 (British version of the standard), if it is assumed that the entire group of students is comprised between 7 and 10 years old, one third of the chairs and tables should be size mark 3 and two thirds should be size mark 4. However, if data of the obtained study is compared with the size mark scheme proposed in EN 1729, it is also possible to compute the percentage of match population for ach size mark, as presented in table 3.

**Table 3.** EN 1729 size mark dimensions for seat height needed to fit 100% of the studied population.

| | Size mark 1 | Size mark 2 | Size mark 3 | Size mark 4 |
|---|---|---|---|---|
| Seat Height (cm)* | 26 | 31 | 35 | 38 |
| Users (%) | 3.7 | 43.0 | 44.6 | 8.7 |

* Considering an angle of -5º to +5º +for the seat

Considering the recommendation of BS EN 1729 for 7 to 10 years-old students and table 3, it is possible to notice the difference between the English and the Portuguese population. It seems that the low stature of the Portuguese student population will imply the need to revise the size mark scheme presented in the EN 1729. This change in the size mark scheme was already noticed by Molenbroek et al. (2003), for the Dutch population, but in the case during the revision of the design of a standard for the dimension of school furniture.

What seems to result from this analysis is the possible inadequacy between the dimensions of desks and chairs proposed in the EN1729 and the Portuguese students population, in particular for the population younger than then studied age range, 7 to 10 years-old. Accordingly, it seems also possible to admit that this inadequacy is most notorious for younger populations, for children between 3 and 6 years old. As the standard presents only one size mark smaller than the size mark presented in the table 3, which is the size mark 0, it is possible that there will be a need to revise the size mark scheme. This revision may include the need to establish an extra size mark, below the size mark 0, as also suggested for the Dutch population (Molenbroek et al., 2003), but in that specific case, to be above the largest one.

## CONCLUSION

The obtained results allowed, among other things, the identification of all the static anthropometric measures needed to develop the school furniture, which so far indicates the need of 4 different types of furniture sets to cover the observed variability within students, against the currently existing 2 types. Furthermore, and as expected, a low stature has been observed for the studied Portuguese students population, particularly when compared with other European countries. This seems to highlight the need to consider specific Portuguese anthropometric characteristics in the future adaptation of the EN 1729, which will result, most likely, in the need to define an additional size mark, below the existing ones.

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