Applied Anthropometrics in School Furniture Design: Which Criteria Should be Used for Standardization?

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ABSTRACT

Students most likely have one of the most sedentary occupations, one where permanent habits of sitting are formed. However, there is much more concern regarding office furniture. The mismatch between students and school furniture is likely to result in a number of negative effects, such as uncomfortable body posture, pain, and ultimately, it may also affect the learning process. This situation has provoked an increased concern about school classrooms, particularly regarding the study and design of school furniture. An important milestone is setting standards for school furniture, where a series of furniture sizes are defined with the aim of accommodating students with different anthropometric dimensions. Despite that, and with the exception of Europe, where the development of school furniture standards has been most actively pursued, there is a lack of standardization for the design of classroom furniture for educational settings in many countries. The aim of this study is to describe the process of designing school furniture by considering the students' anthropometric data. The adopted methodology was to perform a literature review regarding different issues, such as setting standard, the design of school furniture, and equations for defining the mismatch between students and school furniture. There are some activities that need to be done before starting to gather the anthropometric measurements. These activities include, for example, identifying the target population, defining the sample size, determining the anthropometric measures, preparing the evaluation team(s), and obtaining the approval from the ethics committee. During the anthropometric measurements it is important to follow a standard procedure, where the measures are collected from the right side of the subjects while they are sitting in a standard position, without shoes and using light clothes. After collecting the measurements, it is important to check the data by using: observation of mean, minimum and maximum values, as well as the calculation of the different measures (for example: Buttock knee length - Buttock popliteal length), and observation of scatter plot graphics of stature with the other variables. To determine the dimensions and characteristics of different types of school furniture, seat height should be the starting point and the designs need to be based on a bottom-top approach. This dimension will split the sample in, at least, five different sizes of school furniture to accommodate students from 6 to 18 years of age. Some characteristics of the furniture have to also be considered, since the presence of a drawer will influence two important dimensions – the desk height and the seat to desk clearance. Finally, special attention should be given to the needed anthropometric measurement for furniture size

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selection. This is usually done by using Stature; however, some authors suggest that furniture selection can be done more efficiently if popliteal height is used instead.

Keywords: School, furniture, anthropometry, standard.

INTRODUCTION

Students take part in one of the most sedentary occupations, one where permanent habits of sitting are formed (Lueder, 2008; Zacharkow, 1987). Being seated for a long period of time on school furniture is being associated with reports of musculoskeletal discomfort and pain (Fallon & Jameson, 1996). School furniture is a key factor for the adoption of proper posture and consequently, of greater productivity for the individual. For example, the high level of mismatch between students and school furniture is being associated with adolescent low back pain (Milanese & Grimmer, 2004). Other authors, such as Linton et al. (1994), verified that the use of a chair with curved seats and a desk with an inclination produced a reduction in musculoskeletal symptoms in comparison to the use of a desk with a flat top (parallel to the floor) and a detached chair with a straight back and seat placed at a 90° angle.

Murphy et al. (2007), concluded that chairs that are too low have a significant association with the occurrence of neck pain, upper back pain, and lower back pain. A chair's backrest that is too high has been significantly associated with lower back pain. While it is acknowledged that there is a multifactorial nature of causality of adolescent spinal symptoms, it is contended that the degree of mismatch between child anthropometry and school furniture set-up should be further examined as being a strong and plausible factor in the occurrence of adolescent lower back pain (Milanese & Grimer, 2004).

This situation has provoked an increased concern about school classrooms, particularly regarding the study and design of school furniture suitable to the needs of the students, with furniture that has the appropriate dimensions according to the students' anthropometric characteristics. This concern is made clear by the large number of studies published worldwide; these studies show a clear mismatch between anthropometric characteristics and the dimensions of the furniture under study (Brewer et al. 2009, Castellucci et al. 2010, Cotton et al. 2002, Dianat et al. 2013, Feathers et al. 2013, Panagiotopoulou et al. 2004, Ramadan 2011, Van Niekerk et al. 2013).

However, considering the words of Lueder and Rice (2008): "There is a lack of standardization for the design of classroom furniture for educational settings in many countries, with the exception of Europe, where the development of school furniture standards has been most actively pursued. There is a European Standard that gives very general requirements and an Austrian Standard. Currently, there is also discussion of a European draft educational furniture Standard PrEN 1729. Given the anthropometric diversity of many countries, the development of an International Standard could be of benefit".

The aim of this study is to describe the process of designing school furniture by considering the students' anthropometric data.

GATHERING THE ANTHROPOMETRIC MEASURES

Before data collection

The first thing to consider is ethics. Before beginning, the study needs to be approved by a Committee of Ethics. Also, permission to conduct this research must be obtained from the headmaster of each of the schools to be considered. Finally, written consent has to be obtained from parents and students before starting the measurement procedures.

The sample of the study is also a key factor in gathering a representative sample of the population. There are some characteristics that need to be considered, such as age, gender, socio-economic levels, and ethnicity.

Age is important since the student’s growth differs with age. For example, before puberty, the legs grow more rapidly than the trunk and, in adolescents, the growth spurt is largely in the trunk (Bass et al., 1999). Also, Lueder and Rice (2008) recommend that for designing school furniture, it may be useful to consider how children develop and mature, as well as to incorporate features that accommodate a wide range of ages in good postures.

Gender is a very important characteristic that needs to be considered since most of the students’ worldwide show a statistical difference between females and males (Jeong and Park, 1990; Mirmohammadi et al, 2013).

Growth seems to be clearly influenced by socio-economic aspects, where it has been observed that children from higher socio-economic levels are taller than those of lower and medium socio-economic levels (Castellucci et al., 2010; Muzzo, 2003).

Another point to consider is ethnic group, defined as a population of individuals who inhabit a specified geographical distribution and who have certain physical characteristics in common, which serve, in statistical terms, to distinguish them from other such groups of people. These characteristics may be presumed to be predominantly hereditary, although the extent to which this is the case is sometimes contentious (Pheasant, 2003). Lin et al. (2004) show that most of the average dimensions and all of the bodily proportions have significant differences among four East Asian peoples (Chinese, Japanese, Korean, and Taiwanese).

Finally, considering all of this information, the Cluster sampling is the recommended technique.

Another important aspect is the preparation of the evaluation team(s). The team must be composed of four people: a measurer, a recorder, an organizer, and another person to support the measurer. Also, to avoid fatigue and monotony, the team members need to be able to switch from measurer to organizer and from recorder to measurer support.

It is relevant that before starting the collection process, the measurement teams undergo a training session of at least two weeks, including a theoretical approach about anthropometrics as well as practical instructions. At the end of the training sessions, both inter-measurer and intra-measurer reliability need to be addressed by paired sample t-tests (with a 95% confidence interval).

Anthropometric measurements and school furniture dimensions

A standard procedure needs to be follow to collect the anthropometric measurements. The procedure indicates that the anthropometric measures need to be performed from the right side of the subjects while they are sitting in an erect position on a height-adjustable chair with a horizontal surface, with their legs flex at a 90° angle, and with their feet flat on an adjustable footrest. During the measurement process, the subjects will be without shoes and wearing shorts and t-shirts. The following anthropometric measures (Figure 1), from the ISO 7250 (1996), needs to be considered to estimate the most important furniture dimensions (Figure 2):

<u>Stature (S):</u> vertical distance between the floor and the top of the head, and measured with the subject erect and looking straight ahead (Frankfort plane).

<u>Shoulder Height Sitting (SHS)</u>: vertical distance from subject’s seated surface to the acromion.

<u>Elbow Height Sitting (EHS):</u> 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.

<u>Subscapular Height (SUH):</u> the vertical distance from the lowest point (inferior angle) of the scapula to the subject’s

seated surface.

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).

Thigh Thickness (TT): the vertical distance from the highest uncompressed point of the thigh to the subject's seated surface.

Hip Width (HW): the horizontal distance measured at the widest point of the hip in the sitting position.

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): taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the front of the kneecap.

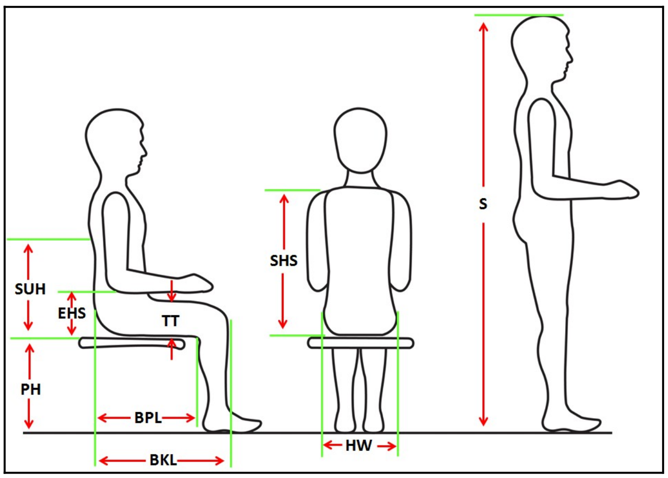

Figure 1. Essential anthropometric measures

The most important furniture dimensions (with the corresponding description) need to be considered (Figure 2):

Seat Height (SH): the vertical distance from the floor to the middle point of the front edge of the seat.

Seat Depth (SD): the distance from the back to the front of the sitting surface.

Seat Width (SW): the horizontal distance between the lateral edges of the seat.

Upper Edge of Backrest (UEB): the vertical distance between the middle points of the upper edge of the backrest and the top of the seat.

Desk Height (DH): the vertical distance from the floor to the top of front edge of the desk.

<u>Seat to desk Clearance (SDC):</u> the vertical distance from the middle point of the front edge of the seat to the lowest structure point below the desk.

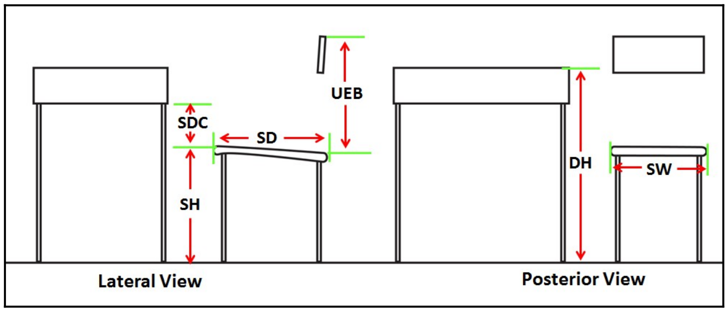

Figure 2. The most important furniture dimensions

Check the data

Before applying the data, it is very important to check it since some errors can be made during the collection process, such as adding the wrong anthropometer extension, changing the number order, and adding an extra zero or misplaced comma. Some of the methods that can be used are:

- Observation of mean, minimum, and maximum values.
- Calculation of the different measurements, since it is not possible that the values of the following calculations present values less than 0:
  - SHS - SUH
  - SUH - EHS
  - BKL - BPL
- Observation of Scatter plot graphics of stature with the other variables. Also, weight with the other variables (see the example in Figure 3)
- Observation of Scatter plot graphics between the following variables:
  - SHS - SUH
  - BKL - BPL
  - HW - BMI
  - Abdominal depth – BMI
- Finally, with border subjects, a Percentiles Profile can be done.

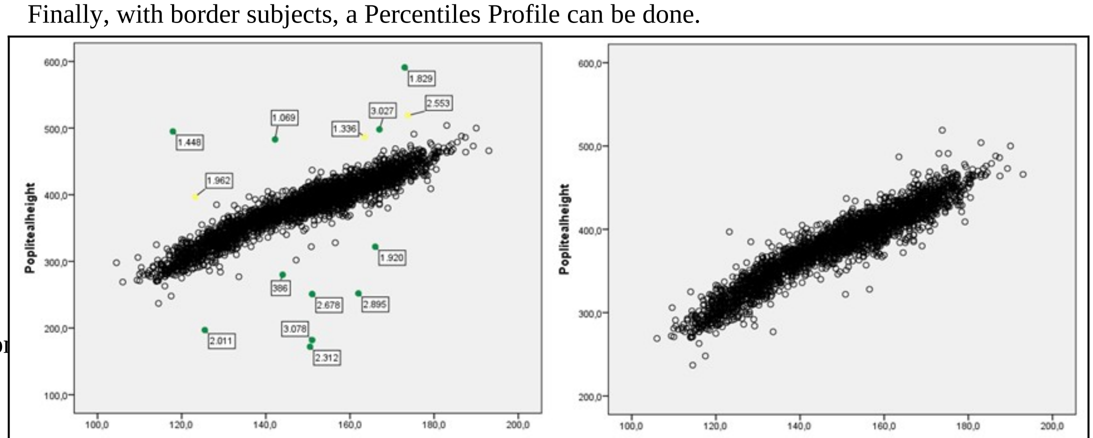

Figure 3. Example of the observation of Scatter plot graphics. The results before (left) and after (right) the process

Defining the levels of school furniture

To determine the dimensions and characteristics of different types of school furniture, SH should be the starting point and the design needs to be based on a bottom-top approach.

Seat Height: Most of the researchers have concluded that popliteal height (PH) should be higher than SH (Mokdad & Al-Ansari 2009, Parcells et al. 1999, Molenbroek & Ramaekers 1996), otherwise most students will be unable to rest their feet on the floor properly, thus causing compression of vascular and neural structures going along the popliteal space (Milanese & Grimmer 2004). However, if SH is significantly lower than PH, more than 4 cm (UNESCO, 2001), this will increase the compression in the buttock region (García-Molina et al. 1992). Equation 1 shows that SH has to be higher than cos30° of PH plus the shoe correction (SC) to avoid an extension of more than 30° relative to the vertical. This is relevant, since with more extension, the feet will not be placed flat on the floor or the thighs would not be supported enough, causing discomfort. On the other hand, SH has to be lower than cos5° of PH plus SC to ensure that the student will sit in a chair high enough so that both feet are placed entirely on the floor, but also avoiding compression in the buttock region (García-Molina et al., 1992). SC may naturally vary according to culture, fashion, and country. Different values are presented in the literature, for example: 2 cm (Agha, 2010; Dianat et al., 2013; Gouvali & Boudolos, 2006), 2.5 cm (Herzberg, 1972), 3 cm (Castellucci et al., 2010), and 4.5 cm (Pheasant, 1984).

$$(PH + SC) \cos 30^{\circ} \leq SH \leq (PH + SC) \cos 5^{\circ} \quad \text{(Eq. 1)}$$

After applying the equation, the students will have low and high limits. The method of splitting the sample regarding PH is recommended (Evans et al., 1988; Gutierrez & Apud, 1995; UNESCO, 2001). For example:

- One possibility is to take the highest limit of the lower PH value and that will be our first size of school furniture.
- Then, 4 cm can be added to the previous value to generate the second size and then 4 cm more need to be add to the subsequent levels.
- Once all of the levels are determined, the sample will be split regarding their PH limits.
- Some students will be able to fit into SH in two different school furniture sizes, due to the low and high limit from Eq. 1.

Once the samples have been split into the different SH sizes, the following recommendation needs to be considered for each group to define the most important furniture dimension:

Seat Depth (SD): Buttock-popliteal length (BPL) is the anthropometric measure used to designate the size of the SD (Helander 1997, Khalil et al. 1993, Orborne 1996). If the SD is greater than the BPL, the student will not be able to use the backrest of the seat to support the lumbar spine without compression of the popliteal surface (Milanese & Grimmer 2004). To avoid this, it is likely that the student will generally move their buttocks forward toward the edge of the seat, as suggested by Panagiotopoulou et al. (2004). This improper usage of the backrest causes kyphotic posture (Khalil et al. 1993, Pheasant 1991). On the other hand, if the SD is considerably shorter than the BPL of the student, then the thigh will not be fully supported and extra pressure will be distributed on the back of the thighs, causing discomfort (Pheasant 2003). The applied equation is:

$$SD = 0.95BPL \text{ from the P5 of each group} \quad \text{(Eq. 2)}$$

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<u>Seat Width (SW):</u> To avoid discomfort and mobility restrictions, the SW should be higher than hip width (HW) (Evans et al. 1988, Helander 1997, Orborne 1996, Oyewole et al. 2010). In this case, the corresponding equation is:

$$SW > HW \text{ from the P99 of each group} \quad \text{(Eq. 3)}$$

<u>Upper Edge of Backrest (UEB):</u> When students use a chair with UEB higher than Subscapular Height (SUH), this will result in compression of the scapula and a reduction in arm and trunk mobility (Garcia-Acosta & Lange-Morales, 2007; Orborne 1996). As a result, the equation is:

$$UEB < SUH \text{ from the P1 of each group} \quad \text{(Eq. 4)}$$

<u>Seat to Desk Clearance (SDC):</u> SDC is considered appropriate when it is higher than thigh thickness (TT) (Molenbroek et al., 2003). Also, Mandal cited by Garcia-Acosta and Lange-Morales (2007) proposes that the SDC should be 2 cm higher than TT. The equation for this furniture dimension is:

$$SDC > 2 + TT \text{ from the P99 of each group} \quad \text{(Eq. 5)}$$

In the literature it is possible to observe different equations or criteria regarding DH:

- Elbow Height Sitting (EHS) is the major criterion for DH (Garcia-Acosta & Lange-Morales, 2007; Milanese& Grimmer, 2004; Molenbroek et al., 2003; Sanders & McCormick, 1993). It is also accepted that EHS + SH can be considered as the minimum height of DH in order to provide a significant reduction on spinal loading (Occhipinti et al., 1985).
- If the P5 of EHS is applied, the students with higher values of EHS are forced to bend their torso forward, with their body weight supported by the arms. This will result in a kyphotic spinal posture with round shoulders (Zacharkow, 1988).
- Molenbroek et al (2003), proposed the P95 of the EHS + SH. This could cause some problems since the students with the lowest values of EHS will be forced to flex and abduct their upper arms as well as raise their shoulders. Which, in the opinion of García-Molina et al. (1992), may result in more muscle work load, discomfort, and pain in the shoulder region. If this is the case for only one upper limb, it will result in an asymmetrical spinal posture (Zacharkow, 1988).
- To avoid the aforementioned problem, Parcells et al. (1999) consider that acceptable DH depends not only on EHS, but also on the shoulder flexion and abduction angles. The minimum DH is defined by EHS. In the case of the maximum DH, Chaffin and Anderson’s principles (1991) were considered with shoulder flexion and shoulder abduction angles of 25° and 20°, respectively.

Despite all these arguments, it is not possible to define a convincing equation or special criteria for DH. Also, Castellucci et al. (2014) shows that the interrelation between the criteria for DH and SDC can be contradictory, even in ideal conditions. From the data of 2,261 students, the results show that 37% of the students will use a high DH if Chaffin and Anderson’s principles are considered. This situation also can be explained by the different values of TT and EHS.

However, as mentioned before, the design of school furniture begins with SH. Secondly, the students need an under table space that should be large enough to push the chair under the table and have enough space to allow for the movement of their legs (Eq. 5). A possible equation could be:

$$DH = (2 + TT \text{ from the P99 of each group}) + (\text{table thickness}) \quad \text{(Eq. 6)}$$

To attenuate the problem of students using higher DH, low values of table thickness are recommended. Also, it is not recommend that there be the presence of a drawer, used normally to store books and school materials during the class, since this will generate greater values of table thickness and decrease the room for leg space.

Establish the measurement for the furniture selection

Furthermore, most of the standards that are published worldwide for furniture selection tend to use, as a reference, Stature (S) as the anthropometric dimension for school children, assuming that all the other anthropometric characteristics are also appropriate. However, it is important to remember that student growth differs with age. For example, before puberty, the legs grow more rapidly than the trunk and in adolescents, the growth spurt is largely in the trunk (Bass et al., 1999). Also, Lueder and Rice (2008) recommended that for designing school furniture, it may be useful to consider how children develop and mature, as well as to incorporate features that accommodate a wide range of ages in good postures. Furthermore, Reis (2012) indicates that at the different school phases until the beginning of puberty, one should pay more attention to the height of the seat and, during puberty, the height of the desk deserves more attention, since after six years old, lower limbs grow more significantly and continue to grow faster than other body segments until the onset of puberty, which, in turn, causes the trunk to grow faster again.

Some authors (Cho, 1994; Hibaru & Watanabe, 1994; Molenbroek et al., 2003; Noro & Fujita, 1994) suggest that the furniture selection can be done more efficiently if the Popliteal Height (PH) is used instead of S. Molenbroek et al. (2003), demonstrated, by using ellipses, that the seat height proposed in the standard PrEN 1729 is too high for most of the children with S of 1,200 mm. Hibaru and Watanabe (1994) found that the chair size selection was strongly correlated with the PH in 124 students from the fourth grade. Another, more complex system was also developed to allocate school furniture by Noro and Fujita (1994). This system is based on the physical images of students and it considers the different variables like PH, S, school grade, and physical condition (slim, average, and obese). However, there is a controversial point raised between the authors that proposes PH for allocation to the school furniture, namely the fact that, as reported by Noro and Fujita (1994), there is the need to make an accurate measurement of PH and that this requires experience and skills. On the other hand, Molenbroek et al. (2003) suggest that the current knowledge about the use and the measurement of PH in a school class is absent. Nevertheless, the authors assumed that this is not necessarily more difficult and/or time consuming compared to the measurement of S if some measurement strategies are applied, such as the example shown in Figure 4 (Molenbroek et al., 2003).

Figure 4. Evaluation of Popliteal Height with the “Peter lower leg meter”

Continuous update of school furniture standards

Another issue in these kind of studies is the well-known positive secular trend or growth observed in some populations, which has been defined as an increase in mean body S or height among persons of the same age of successive generations. Whether this increase is equally distributed over the whole body or only in certain segments

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is not yet completely known (Steenbekkers, 1993). This positive secular trend has been observed in different countries, with an average growth between 0.7 cm and 4 cm per decade (Gutiérrez & Apud, 1992, Fredriks et al., 2000). It is generally assumed that this secular trend is elicited by a change in environmental conditions, in particular by removing factors that had blocked full expression of the biologic potential, such as infectious diseases, inadequate nutrition, poverty, and suffering (Tanner, 1992). The growth of a population can therefore be assumed to be a “mirror of conditions in society” (Tanner, 1986). A positive secular trend is assumed to reflect changes in living standards and dietary habits (Hauspie et al., 1996). In the scope of this study, a positive secular trend is a very important factor to consider because it could indicate that the standard data may be out of date. Also, secular trends cause temporal changes in the accommodation levels afforded by long-lifetime products. Utilising forecasts of trends and their impact on target populations, anthropometry can help make designs suitable for future populations (Nadadur & Parkinson, 2013).

FINAL REMARKS

The current paper does not aim to present data from a field study; instead, it aims to describe the whole process of considering applied anthropometrics when designing/selecting furniture for school classrooms. Therefore, the study was mainly focused on describing both the relevant students’ anthropometric measures for this process as well as the relevant furniture dimensions to be considered.

Considering the data presented in the paper, some final remarks can be summarized as follows in the next paragraphs.

It is essential to consider some aspects before the data collection. Among these is the need to define clear procedures to consider before data collection, such as the need to approve the study in the corresponding ethics commissions, the definition of the sampling strategy, as well as the training that should be provided to the team involved in data collection.

After defining the pertinent anthropometric data to be collected as well as the furniture dimensions to be considered, it is also important to make a preliminary data analysis and filter some common errors that are frequently observed in anthropometric data collection.

This paper as also highlights the need to consider carefully the measure to be used as a starting point, which, in the authors’ opinion, should be SH.

Finally, one important aspect that has also emerged from this discussion is the need to consider the secular trend or growth observed in some populations in successive generations. Although there are still some aspects to be clarified, it seems that the so-called secular trend is a factor to consider, mainly because this might imply that data considered on the current available standards might well be outdated.

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