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Original Article

School furniture ergonomic assessment via simplified measurements and regression models

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Abstract

The anthropometric measurements needed for school furniture assessment can be difficult, time-consuming, and expensive to obtain. However, assessment can be important since sitting in the wrong position too long on inappropriate school furniture may lead to negative health effects in both the short- and long-term. Therefore, this paper proposes a relatively simple methodology to evaluate school furniture suitability using only height and weight measurements and simple linear regression models for the relevant anthropometric values. The models were used to examine possible incompatibility between student body dimensions and the dimensions of school furniture. The results obtained by the proposed method were confirmed by repeating the furniture assessment using actual anthropometry data from the population which yielded mis-match differences of 8% or less.

Keywords: school furniture, ergonomics, simple linear regression, anthropometric measurements, furniture mismatch

1. Introduction

On average students spend roughly 5-8 hours per day sitting in the classroom. In particular, the high degree of competition for entry to reputed schools forces many students in Thailand to take extra classes and as a result it increases the time spent in the classroom. If an education institute provides inappropriate desks and chairs that are not the correct sizes for students who spend a long time in the classroom each day, the students may suffer from body pains such as neck, lower back, shoulder, or head pains (Milanese & Grimmer, 2004; Murphy *et al.*, 2004). As a result of such discomfort, students may move frequently while sitting which results in lost concentration in the classroom (Hira, 1980). Sitting in the wrong position too long on inappropriate chairs can lead to lower back pains and aches (Genaidy & Karwowski, 1993). Therefore, the design of furniture with proper dimensions is critical to encourage appropriate postures (Straker *et al.*, 2010). Correct standing and sitting posture is an important factor for the prevention of musculoskeletal symptoms (Cranz, 2000). As an additional factor, human anthropometry varies across the diversity of races, nationalities, and habitats (Klamklay *et al.*, 2008; Lin *et al.*, 2004; Sampei *et al.*, 2003; Widyanti *et al.*, 2015; Yap *et al.*, 2001). Thus, an assessment of school furniture relative to the student population can help determine the suitability of the furniture and ultimately help prevent short- and long-term body pain.

However, a comprehensive anthropometric assessment is complicated, time-consuming, and possibly expensive for any substantial population. Additionally, the measurement tools will directly touch the bodies of the students in the measurement process, raising privacy and health concerns which can be amplified for young Thai people. Consequently, the dimensions of suitable desks and chairs for a given school population is rarely assessed.

This study proposes a new way to assess suitability of desk and chair dimensions for student anthropometry. It employs mathematic equations that collect only the weights and heights of the students to predict six sitting posture values that may be used to assess desk and chair sizes.

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1.1 Mismatch between school furniture and the anthropometry of students

Past research found that most furniture used in the classroom did not fit the bodies of students (Castellucci *et al.,* 2010; Evans *et al.,* 1988; Gouvali & Boudolos, 2006; Panagio topoulou *et al.,* 2004; Parcells *et al.,* 1999). Hänninen (2003) examined this issue and found that students who used unsuitable desks and chairs in school suffered from muscle aches, headaches, and neck and back pain.

1.2 School furniture design

Several research studies have shown that students often remain seated in the classroom for a considerable amount of time (Linton *et al.,* 1994). Prolonged sitting and a static posture in a forward bending manner were found to be the main cause of low back pain (Troussier *et al.,* 1994). School furniture plays a very important role in the maintenance of good sitting posture. Moreover, bad sitting habits that develop during childhood are not easy to change in later years (Yeats, 1997).

1.3 Ergonomic furniture design

Furniture design and user anthropometry have become a major concern in designing ergonomically proper furniture (Pheasant & Haslegrave, 2005). Appropriate furniture design helps to reduce user fatigue and discomfort. Various guidelines and design standards have been developed and recommended to improve school furniture, including European Standards for Classroom furniture (EN1729, Parts 1 and 2), the Standards for tables and chairs for educational institutions (ISO 5970-1979), and in Thailand, the Thai Industrial Standards Institute (TISI) for desks and chairs for educational institutions (TISI 1494-1495).

The ergonomic design defines the dimensions and characteristics for school furniture. Thus, anthropometric measurements are required to determine classroom furniture dimensions. The relevant anthropometric measurements include popliteal height, buttock-popliteal length, knee height, and elbow height (Agha, 2010; Chung & Wong, 2007; Gouvali & Boudolos, 2006; Knight & Noyes, 1999; Panagiotopoulou *et al.,* 2004; Parcells *et al.,* 1999).

2. Materials and Methods

2.1 Anthropometric measurements

Before the beginning of the experiment, a consent form was signed by each student. The consent forms contained information about the investigation, title, objectives, the benefits of this study, procedures, time duration of the procedures, and the list of possible risks involved with the experiment.

All anthropometric measurements were taken with the students wearing the student uniform without shoes. They were sitting in a relaxed and erect posture on an adjustable chair with their legs flexed at a 90° angle and their feet flat on the floor or on an adjustable footrest. The measurement procedure was developed from the recommendations of Pheasant and Haslegrave (2005). Accuracy and repeatability of the measurements were achieved by practice prior to the data collection sessions. The following anthropometric measurements were considered and collected in this study (Figure 1).

Standing measurement

1. Stature (S): The vertical distance from the floor to the top of the head, measured by standing in a straight posture.
2. Weight (W): The body mass, measured by standing on a weighing scale.

Sitting measurement

1. Shoulder height sitting (SHS): The vertical distance from the seat surface to the level of the shoulder at the acromion process.
2. Elbow height sitting (EHS): The vertical distance from the seating surface to the lowest part of the tip of the elbows (olecranon) and it was measured with a 90° elbow flexion.
3. Popliteal height (PH): The vertical distance from the footrest surface to the underside of the thigh directly behind the knee and it was measured with a 90° knee flexion.
4. Buttock-popliteal length (BPL): The horizontal distance from the buttock to the popliteal surface and it was measured with a 90° knee flexion.
5. Hip width (HW): The maximum horizontal distance across the hips while sitting.
6. Thigh thickness (TT): The vertical distance from the seating surface to the highest point of the thigh.

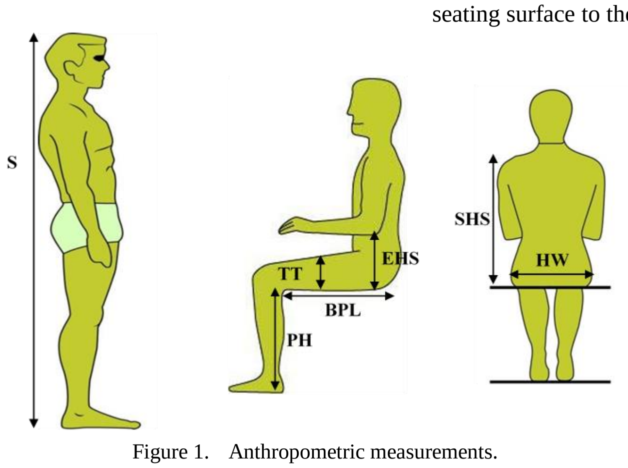

Figure 1. Anthropometric measurements.

2.2 Criteria equations for mismatch of school furniture

School furniture dimensions can be assessed by considering their degree of mismatch between the information of the student's body and the furniture measurements. Several studies have shown that different mismatch equations can be considered. Most of the equations are intervals, thus the results for these cases will be match, high mismatch or low mismatch. Only the results of seat width (SW) and underneath desk height (UDH) will be match or mismatch (Figure 2).

Castellucci *et al.* (2014) reviewed the literature describing the criteria equations for defining the mismatch between students and school furniture. The following section presents the mismatch equations which allow assessment of furniture dimensions through the use of corresponding anthropometric measurements.

Seat height (SH) should correspond to PH (Parcells *et al.,* 1999). Gouvali and Boudolos (2006) have further proposed that the seat height needs to be lower than popliteal height to allow the lower legs to form angles of 5°-30° vertically. Because wearing shoes enhances height to popliteal while sitting, the shoe correction (SC) was added to the match criteria as described in Equation 1.

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

The students in Thai public schools take off their shoes before entering the classroom. Thus, SC was set equal to zero.

Seat to desk height (SDH), i.e. the vertical distance from the seat surface to the desk surface, typically corresponds to EHS. Occhipinti *et al.* (1985) showed that having arms on the desk significantly reduces the burden on the spine. Parcells *et al.* (1999) additionally proposed that the minimum SDH should be at EHS level and the maximum should be at where the shoulder flexion and shoulder abduction angles are 25° and 20°, respectively. This limit is presented in Equation 2 based on SHS.

$$EHS \leq SDH \leq EHS*0.8517 + SHS*0.1483 \quad (2)$$

Seat depth (SD) should be correlated with BPL. To make the use of the backrest which helps to support the lumbar, SD should be a little bit less than BPL, but SD should not be too much less or it will be insufficient to support the thigh. Parcells *et al.* (1999) have suggested that SD should lie between 80% and 95% of BPL as presented in Equation 3.

$$0.80BPL \leq SD \leq 0.95BPL \quad (3)$$

SW should be larger than HW to provide comfort and reduce pressure on the buttocks (Evans *et al.,* 1988; Orborne, 1996; Oyewole *et al.,* 2010) as shown in Equation 4.

$$HW < SW \quad (4)$$

The upper edge of backrest (UEB) has to be lower than the scapula (Orborne, 1996) to avoid compression on it and increase flexibility for arm and truck. However, it is not easy to locate one's scapula. Gouvali and Boudolos (2006) suggested that the bottom and the top levels of the scapula are estimated right around 60%-80% of SHS. This match interval is shown in Equation 5.

$$0.6SHS \leq UEB \leq 0.8SHS \quad (5)$$

UDH should be high enough to allow space for leg movement once the chair is pushed under the desk. Thus, Castellucci *et al.* (2010) suggested that UDH should be greater than TT by at least 2 centimeters. The match interval is presented in Equation 6.

$$TT + 2 < UDH \quad (6)$$

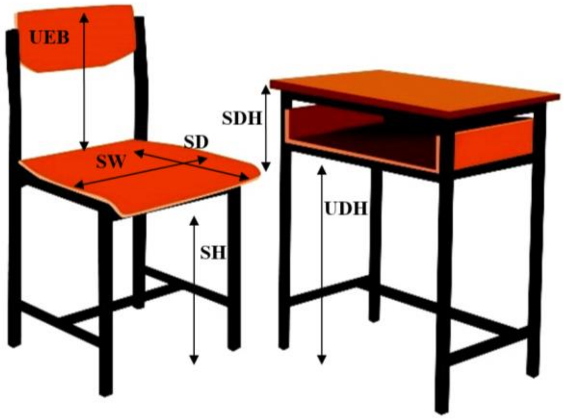

Figure 2. School furniture dimensions; UEB=upper edge of backrest; SW=seat width: SD=seat depth; SH=seat height; SDH=seat to desk height; UDH=underneath desk height.

2.3 Data sample and analysis

The sample included 349 volunteer students from a secondary school (grades 10-12) in the northern part of Thailand. This group of students was chosen because these grades are assigned the same size furniture and because in these grades the typical student growth rate is not very high compared with, for example, grades 7-9. Following Oyewole *et al.* (2010), the data of 20 students were randomly selected for use as the basis of the prediction models. Anthropometric measurements (PH, BPL, HW, SSH, ESH, and TT) of these students were used to establish regression models. The regression models were used to convert the heights and weights of all students to their sitting anthropometric measurements. The regression models were partially evaluated against the anthropometric data of five students.

Two standard school furniture sizes were selected for assessment. The selected sizes were the TISI sizes 4 and 6, the minimum and maximum recommended sizes for the student ages considered in this study. The student volunteers of this study attended a school which used the desk and chair furniture of size 6.

For each dimension of interest, the mismatch between the student population and the school furniture was evaluated based on both (A) the predicted anthropometric values obtained from the regression models and (B) the actual measured anthropometric values. The model-based assessment methodology was evaluated by comparing the furniture assessments provided by results (A) and (B).

2.4 Statistical analysis

The statistical analysis was conducted using Minitab 14 and Microsoft Excel in order to determine whether the sitting anthropometric measurements were normally distributed. Linear regression techniques were used to develop predictive models of sitting anthropometry measurements based on stature and body mass index (BMI).

The sitting anthropometric measurements of five randomly selected students whose data were not used in the creation of the regression models were predicted by the developed models and compared with the actual measurements. The acquired values were calculated to find the mean and standard deviation. After that the developed models were used to assess unsuitability between the student anthropometric data and school furniture as seen in Equations 1 through 6.

3. Results and Discussion

3.1 Anthropometry distribution

The results of the investigation of the distribution anthropometry found that all sitting anthropometry dimensions were normally distributed using the Shapiro-Wilk test. The significant levels are presented in Table 1 which shows that all sitting anthropometric measurements had significant values more than 0.05. Thus, the data are normal distributed.

Table 1. Significant levels of normal distribution data of sitting anthropometric measurements.

	PH	BPL	HW	SHS	EHS	TT
Sig.	.199	.259	.130	.197	.430	.229

PH=popliteal height; BPL=buttock-popliteal length; HW=hip width; SHS=shoulder height sitting; EHS=elbow height sitting; TT=thigh thickness.

3.2 Linear regression model

Roebuck *et al.* (1975) proposed that some parts of the body can be expressed in terms of stature. Oyewole *et al.* (2010) stated that stature is a good predictor for PH, BPL, SSH, and EHS while the BMI (body mass index) is a good predictor of HW and TT. The BMI was obtained by dividing the weight of each subject by the square of his/her respective stature. By using regression techniques and sitting anthropometry measurements from 20 students, the predictive models were obtained as shown in Equations 7 through 12.

PH (popliteal height) = 0.252(S) - 1.48 (7)
BPL (buttock-popliteal length) = 0. 224(S) + 9.12 (8)
HW (hip width) = 0.500(BMI) + 22.1 (9)
SHS (shoulder height sitting) = 0.360(S) - 1.28 (10)
EHS (elbow height sitting) = 0.166(S) - 4.21 (11)
TT (thigh thickness) = 0.323(BMI) + 9.513 (12)

The adjusted coefficient of determination (R^2adj) of the predictive models for PH and SHS were 92.7% and 92.4%, respectively. Overall, the values of R^2adj for the rest of the predictive models were very good because the values were higher than 80% and the variances were low (Table 2). Thus, they were good equations to predict sitting anthropometric measurements (Table 3).

Table 2. Variance (S) and adjusted R^2s of predictive models.

Sitting anthropometric measurements	S	R^2(adj)
PH	0.665	0.924
BPL	0.642	0.911
HW	0.532	0.881
SHS	0.923	0.927
EHS	0.477	0.910
TT	0.731	0.803

PH=popliteal height; BPL=buttock-popliteal length; HW=hip width; SHS=shoulder height sitting; EHS=elbow height sitting; TT=thigh thickness.

Table 3. Predicted and actual means and standard deviations for all sitting anthropometric measurements.

Variable	Predicted		Actual	
	Mean	SD	Mean	SD
PH	40.22	1.79	39.62	2.27
BPL	46.19	1.59	46.60	2.88
HW	31.65	0.37	31.40	1.52
SHS	58.29	2.55	58.82	2.80
EHS	23.26	1.18	23.00	1.87
TT	16.29	1.19	16.36	1.49

SD=standard deviation; PH=popliteal height; BPL=buttock-popliteal length; HW=hip width; SHS=shoulder height sitting; EHS=elbow height sitting; TT=thigh thickness.

3.3 Comparison between predicted and actual sitting anthropometric measurements

After the predictive models were constructed, the anthropometric data of five different randomly selected students were used to check the accuracy of these equations. The means and standard deviations of predicted and actual sitting anthropometric measurements were calculated. All sitting anthropometric measurements had insignificant differences between the predicted and actual values (Table 4).

Table 4. P-values of two-sample t-test to compare the differences between actual and predicted mean of sitting anthropometric measurements.

	PH	BPL	HW	SHS	ESH	TT
P value	0.632	0.756	0.708	0.738	0.852	0.861

PH=popliteal height; BPL=buttock-popliteal length; HW=hip width; SHS=shoulder height sitting; EHS=elbow height sitting; TT=thigh thickness.

3.4 Mismatch between student anthropometry and classroom furniture

The predictive models were used to convert heights and weights of all students (349 students) to their sitting anthropometry values. The two furniture sizes considered were assessed using both the predicted and actual anthropometry data. The results are presented in Table 5.

A comparison of the two sets of assessments revealed a strong correlation between the results obtained using the predicted anthropometric values and the measured data. Assessment results were within 8% across all dimensions considered and within 7% in the critical dimensions of SH and SDH.

The results suggest that the proposed assessment methodology offers sufficient accuracy to evaluate the suitability of school furniture. Using full anthropometric measurements for only a small subset of the student population enabled a model-based assessment of the furniture. Those assessment results were consistent with results obtained using data from the full student population. In particular, both assessments found that the TISI Size 6 furniture was mismatched to the student population in the critical dimensions of SH, whereas TISI size 4 was found to be a match for the majority of the population. The maximum disagreement of 8% between the two assessments occurred in the UEB dimension which is not a critical dimension for student health and comfort.

The proposed method focused on furniture assessment and not on the related task of selecting appropriately sized furniture for a given population which is a problem that was previously treated (Wutthisrisatienkul & Puttapanom, 2017).

4. Conclusions

This study presented a new mismatch estimation technique using height and weight values to predict the sitting anthropometry measurements that are typically difficult and time-consuming to measure. Application of the developed statistical models to the student population and their school furniture suggested that most students use higher desks and chairs than they actually need, possibly leading to increased pressure on the surface behind the knee and an asymmetrical spinal posture. Use of the models was validated by comparing the assessment results against a similar assessment made using actual anthropometric data collected from the students.

The predictive equation models might not be applicable to all schools that have different mean values of height and weight. This difference may come from the basic features, such as people who live in different countries, ethnicity, sex, age, and geography. The developed models can be used when the mean of height and weight are not different.

The statistical modeling method developed in this paper has the potential to be applied to more anthropometry metrics than those considered here. Additionally, improved modeling methods, e.g., more sophisticated modeling techniques, could be applied. Doing so could lead to improved results and more accurate findings with a broader range of applicability.

Table 5. Match/mismatch results based on predicted and measured anthropometric data.

Furniture Dimension	Size			
	TISI Size 6		TISI Size 4	
SH	45 cm		38 cm	
	Predicted Data	Measured Data	Predicted Data	Measured Data
Too Low	0 (0%)	0 (0%)	10 (3%)	32 (9%)
Match	0 (0%)	0 (0%)	231 (66%)	205 (59%)
Too High	349 (100%)	349 (100%)	108 (31%)	112 (32%)
SDH	30 cm		30 cm	
	Predicted Data	Measured Data	Predicted Data	Measured Data
Too Low	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Match	46 (13%)	40 (11%)	108 (31%)	119 (34%)
Too High	303 (87%)	309 (89%)	241 (69%)	230 (66%)
SD	40 cm		38 cm	
	Predicted Data	Measured Data	Predicted Data	Measured Data
Too Shallow	0 (0%)	8 (2%)	61 (17%)	85 (24%)
Match	346 (99%)	316 (91%)	288 (83%)	264 (76%)
Too Deep	3 (1%)	25 (7%)	0 (0%)	0 (0%)
SW	38 cm		38 cm	
	Predicted Data	Measured Data	Predicted Data	Measured Data
Too Narrow	5 (1%)	15 (4%)	5 (1%)	15 (4%)
Match	344 (99%)	334 (96%)	344 (99%)	334 (96%)
UEB	42 cm		35 cm	
	Predicted Data	Measured Data	Predicted Data	Measured Data
Too Low	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Match	346 (99%)	336 (96%)	237 (68%)	210 (60%)
Too High	3 (1%)	13 (4%)	112 (32%)	139 (40%)
UDH	20 cm		19 cm	
	Predicted Data	Measured Data	Predicted Data	Measured Data
Less	25 (7%)	15 (4%)	65 (19%)	58 (17%)
Match	324 (93%)	334 (96%)	284 (81%)	291 (83%)

TISI=Thai Industrial Standards Institute; SH=seat height; SDH=seat to desk height; SD=seat depth; SW=seat width; UEB=upper edge of backrest; UDH=underneath desk height.

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Appendix

Equations of average and standard deviation

$$\bar{X} = \frac{\Sigma X_i}{N}$$

$$SD = \sqrt{\frac{\Sigma_{i=0}^{N} \overline{x_i - (x)^2}}{N}}$$

Where X_i is the sitting anthropometric measurements

$\bar{X}$ is mean of X_i

SD is standard deviation of X_i