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Predicting Anthropometric Dimensions Aimed at Ergonomic Design of Mounted Desktop Chairs for Thai University Students

Jirapon Promngam, Sutanit Puttapanom* and Panu Buranajarukorn

Industrial Engineering Department, Engineering Faculty, Naresuan University, Phitsanulok, Thailand

*Corresponding author e-mail: sutanitp@nu.ac.th

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Abstract

While mounted desktop chairs have gained popularity in Thai universities for their space-saving features and affordability, many users experience discomfort and fatigue due to inconvenient adjustments or limited mobility. Addressing these concerns through improved ergonomic design can enhance user experience and make these chairs even more valuable additions to educational environments. However, achieving ergonomic design in these chairs can present challenges as acquiring accurate anthropometric measurements proves to be difficult, time-consuming, and costly. Therefore, this study applies forward stepwise regression analysis to estimate anthropometric dimensions needed for the chair design. The sample involved 857 students (430 females and 427 males) with ages ranging from 18 to 25 years old. Nineteen anthropometric measurements were collected.

The data analysis results suggest two sets of linear regression models for predicting all anthropometric measurements needed by two sets of easy to measure inputs: {Stature, Body Mass Index} and {Forearm-fingertip length, Waist circumference}. All R^2-values are greater than 70%. The predicted results obtained by proposed models were confirmed by actual anthropometry data which yielded P-values of paired sample t-tests for all outputs greater than 0.05. Moreover, new criteria determinants for some chairs' dimensions and a recommended size are proposed.

Keywords: Anthropometry, Mounted Desktop Chairs, Linear Regression, Ergonomic Design, Predicting

1. Introduction

Mounted desktop chairs are popular and widely used in Thai universities. Khanam et al. (2006), Casas S et al. (2016) and Shohel Parvez et al. (2022) indicated so many problems with this kind of chair, including discomfort and fatigue during use due to inconvenient adjustments or movements. Many studies (Castellucci et al., 2016; Esht & Singh, 2021) stated that poorly designed educational institution furniture can have negative effects on students' health. For example, uncomfortable or improper furniture size leads to poor posture among students, which may result in neck, shoulder, and back pain. Prolonged sitting in furniture with ineffective support can cause musculoskeletal disorders (MSDs) such as stiffness, discomfort, or even long-term spinal problems. Irritation from sitting can distract students and reduce their ability to concentrate on their studies. Furniture that has limited movement can prevent students from adjusting position, which is important for maintaining comfort and focus. Also, poor posture or constant discomfort during childhood and adolescence leads to long-term health problems in life afterwards. Therefore, it is crucial for educational institutions to invest in ergonomic furniture designed with students' health and comfort in mind. Appropriate size, proper lumbar support, and furniture that promotes flexibility and movement can all contribute to a healthier and more comfortable learning environment.

Many researchers have shown interest in application of ergonomic principles to the design and assessment of furniture in educational environments. Notable contributions come from researchers such as Altaboli et al. (2023), Evans et al. (1988), Langová et al. (2021), Lu & Lu (2017), Lueder & Allie (1999), Mokdad & Al-Ansari (2009), Brewer et al. (2009), Obinna et al. (2021), Openshaw & Taylor (2006), Sahabo & Kabara (2023), Sejdiu et al. (2023), and Sousa et al. (2022).

Al-Hinai et al. (2018), Ansari et al. (2018), Igbokwe et al. (2019), Khoshabi et al. (2020), Shohel Parvez et al. (2022), Taifa and Desai (2017) and Thariq et al. (2010) specifically studied ergonomically mounted desktop chairs design. The most important data for ergonomic design is anthropometric data.

Anthropometric measurements are a foundational aspect of ergonomic school furniture design, ensuring that the furniture is personalized to the physiological needs of students. However, performing these measurements is challenging and time-consuming, especially for large populations, due to various constraints like time, cost, and expertise. Few publications tried to predict hard-to-measure data using easy-to-measure data. Jeong and Park (1990) examined students, aged between 6 to 17 and found that stature can

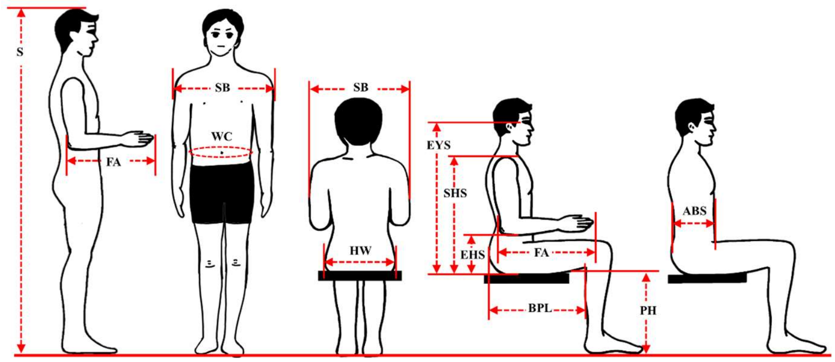

Figure 1 Anthropometric measurements

predict the body dimensions for school furniture design. However, sex differences significantly influenced interactions between body dimensions. Al-Haboubi (1992) considered different nationalities in East Asia in predicting body dimensions using stature and weight. Kaya et al. (2003) applied adaptive neuro-fuzzy inference system and stepwise regression analysis to predict anthropometric measurements. The six-dimensional outputs are still not enough to design chairs and desks for school children. The elbow-seat height is missing, which is used to define the seat to desk height and is one of the most crucial dimensions. Also, these input dimensions are not easy to measure. Chao and Wang (2010) proposed the process of using old anthropometric data to determine constant body ratio (CBR) and then applied a total of 483 CBR benchmarks to predict hard to measure body dimensions. To design classroom furniture for first graders, Oyewole et al. (2010) measured anthropometry of twenty first graders and built regression equations for predicting body dimensions. Agha & Alnahhal (2012) applied neural network and multiple linear regression to define five critical dimensions for primary school furniture design by four easy to measure anthropometry. They concluded that although neural networks have better performance, mathematical models from multiple linear regression can be applied by others. Ismaila et al. (2014) proposed models to obtain students' dimensions for the secondary school furniture design by using only stature. Castellucci et al. (2015) suggested using popliteal height over stature for school furniture selection. In Thailand, Pochana & Sungkhapong (2015) recommended to use age, stature, and weight as predictors for estimating primary school students' body dimensions. Wutthisrisatienkul & Puttapanom (2019) also used stature and weight to estimate anthropometric measurements for secondary school furniture. However, none of the literature proposed models for predicting all anthropometric dimensions necessary for the mounted desktop chairs design.

Therefore, the objective of this study is to propose linear regression models to predict Thai university students' anthropometric dimensions needed for the mounted desktop chairs design. There are two sets of inputs; the first set is stature and weight and the second set is easy to measure dimensions. Moreover, new criteria determinants for some chairs' dimensions and a recommended size are proposed.

2. MATERIALS AND METHODS

2.1 Anthropometric Measurements

Prior to starting the experiment, a consent form containing information about the study, topic, objectives, benefits, procedures, procedures' time duration, and possible risks involved with the experiment was given and signed by each student.

Table 1 Definition of anthropometric measurements

Anthropometry	Definition
Stature (S)	Vertical distance from the floor to the top of the head
Forearm-fingertip length (FA)	Horizontal distance from the back of the elbow to the tip of the middle finger, with a 90° angle elbow flexion
Waist circumference (WC)	Horizontal circumference of the trunk at the level of the navel
Shoulder breadth (SB)	Horizontal distance across the maximum side parts of the right and left deltoid muscles
Body mass (weight)	Total body weight
Eye height, sitting (EYS)	Vertical distance from the seat to the outer corner of the eye
Shoulder height, sitting (SHS)	Vertical distance from the seat to the acromion
Elbow height, sitting (EHS)	Vertical distance from the seat to the lowest point of the elbow, with a 90° angle elbow flexion
Buttock-popliteal Length (BPL)	Horizontal distance from the buttock to the popliteal surface, with a 90° angle knee flexion
Popliteal height, sitting (PH)	Vertical distance from the floor to the popliteal surface behind the knee, with a 90° angle knee flexion
Abdominal depth, sitting (ABS)	Depth of the abdomen (at the level of the navel) while sitting
Hip Width, sitting (HW)	Maximum horizontal distance across the hip while sitting

Anthropometric measurements were conducted on students wearing their light school uniforms with empty pockets and without shoes. They sat in a relaxed and upright posture on adjustable chairs. Their knees were bent at a 90-degree angle, and their feet were flat on adjustable footrests. The measurement procedure was conducted based on ISO 7250-1:2017 (Basic human body measurements for technological design) (ISO, 2017). Figure 1 shows all anthropometric measurements which were selected and collected for this study while Table 1 describes the definition of each measurement according to ISO 7250 (ISO, 2017).

2.2 Mounted Desktop Chairs Design Dimensions

The dimensions of the mounted desktop chairs are presented in Figure 2. Table 2 explains the definition of each dimension.

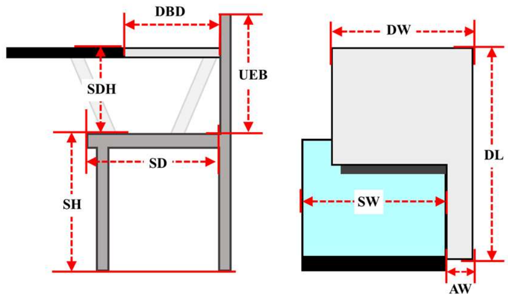

Figure 2 Mounted desktop chairs design dimensions

Table 2 Definition of mounted desktop chairs design dimensions

Chair dimension	Definition
Seat Height (SH)	Vertical distance from the floor to the highest point of the front edge of the seat
Seat to Desktop Height (SDH)	Vertical distance from the seat to the top of the desktop surface
Seat Depth (SD)	Horizontal distance for the front to the back of the seat
Seat Width (SW)	Horizontal distance from the left to the right edges of the seat
Upper Edge of Backrest (UEB)	Vertical distance from the seat to the top edge of the backrest
Desktop-Backrest Distance (DBD)	Horizontal distance between the desktop to the backrest
Desktop Length (DL)	Horizontal distance for the front to the back of the desktop
Desktop Width (DW)	Horizontal distance from the left to the right edges of the desktop
Armrest Width (AW)	Width of the armrest

2.3 Data Sample and Data Analysis

The volunteers were normal, healthy undergraduate students from two Thai public universities in the northern part of Thailand. The sample included 857 students (430 females and 427 males) aged between 18 and 25. After data collecting was done, the data of 800 subjects were used to create predictive models and the data of 57 subjects were used to validate the models.

According to mounted desktop chairs design dimensions, nine relevant anthropometric measurements needed for mounted desktop chairs designing (outputs): Eye height sitting (EYS), Shoulder height sitting (SHS), Elbow height sitting (EHS), Forearm-fingertip length (FA), Buttock-popliteal Length (BPL), Popliteal height sitting (PH), Abdominal depth sitting (ABS), Shoulder breadth (SB) and Hip Width sitting (HW) (Al-Hinai et al., 2018; Ansari et al., 2018; Igbokwe et al., 2019; Khoshabi et al., 2020; Shohel Parvez et al., 2022; Taifa & Desai, 2017; Thariq et al., 2010). In this study, there are twelve easy to measure anthropometric data (inputs); Stature (S), Eye height (EY), Shoulder height (SH), Elbow height (EH), Fist (grip axis) height (FIG), Waist circumference (WC), Forearm-fingertip length (FA), Upper arm length (UA), Grip reach (forward reach) (GRF), Popliteal height (PHST), Shoulder breadth (SB) and Body Mass Index (BMI). The BMI was calculated by dividing the subject's weight in kilograms by the square respective his/her stature in meters.

Linear regression was used to investigate the relationships between two or more anthropometric measurements. In this study, the first step is analyzing the relationship between each input and each output using Pearson's Correlation. Then, forward stepwise regression was applied to determine good and simple predictive models. The method of model fitting began with the highest correlation input first added to the models, tested each input as it was added to the model, then saved those inputs that helped to improve the model's coefficient of determination (R^2) and repeated the process until the R^2 and the adjusted R^2 were satisfactory.

3. Results and Discussion

After analyzing the relationship between each input and each output by using Pearson's correlation coefficient, the result shown in Table 3 yielded that Stature (S) and Forearm-fingertip length (FA) had high correlations with seven outputs; Eye height sitting (EYS), Shoulder height sitting (SHS), Elbow height sitting (EHS), Forearm-fingertip length (FA), Buttock-popliteal Length (BPL), Popliteal height sitting (PH), and Shoulder breadth (SB). Moreover, only Body Mass Index (BMI) and Waist circumference (WC) had high correlations with Abdominal depth sitting (ABS) and Hip Width sitting (HW). Therefore, S, FA, BMI and WC were selected to be inputs or predictors.

Table 3 shows Pearson's correlation Coefficients between these inputs and all outputs and the last two rows are correlations amongst inputs. Roebuck et al. (1975) showed that lengths of some body parts could be expressed as a fraction of stature. Oyewole et al. (2010), and Wutthisrisatienkul & Puttapanom (2019) presented that stature is a good input to predict PH, BPL, SHS, and EHS when BMI is a good input to predict HW. Since in Thailand, a student's record contains information of stature and weight, hence, the combination of stature and BMI were investigated.

Table 3 Pearson's correlation coefficient

Anthropometry	Pearson's Correlation Coefficient			
	S	BMI	FA	WC
EYS	0.893	0.117	0.795	0.256
SHS	0.905	0.082	0.785	0.227
EHS	0.842	0.095	0.799	0.232
BPL	0.890	0.087	0.896	0.255
PH	0.890	0.068	0.844	0.241
ABS	0.411	0.875	0.465	0.876
SB	0.783	0.380	0.750	0.511
HW	0.081	0.878	0.098	0.699
FA	0.887	0.110	-	0.272
WC	0.262	0.789	0.272	-

From Table 3, S has a high correlation with FA and BMI has a high correlation with WC. Consequently, two sets of inputs: {S, BMI} and {FA, WC}.

A linear regression model is widely measured by coefficient of determination (R^2). R^2 often rises when an input is added to the model, however it does not always mean the additional input helps to improve the model. Hence, an adjusted R^2 is used to verify the improvement. If the adjusted R^2 also increases, the model is improved and vice versa (Montgomery & Runger, 2010). Table 4 illustrates the R^2 and the adjusted R^2 of each simple or multiple linear regression equation. The red terms in the equations are added inputs that yield not better adjusted R^2 and the *P*-values are greater than 0.05 which means that these inputs have no significant effect on the models. For example, from the table, adjusted R^2 is 82, when using only stature (S) to predict shoulder height sitting (SHS) as Eq. (1). However, after BMI is added as Eq. (2), adjusted R^2 is decreasing to 81.9 and *P*-value for S and BMI are 0 and 0.924 respectively. Thus, it can be concluded that only S has a significant effect on predicting SHS, and Eq. (2) is not superior to Eq. (1).

$$SHS = 7.00 + 0.310*S \quad (1)$$
$$SHS = 7.01+0.310*S-0.00093*BMI \quad (2)$$

Table 4 Simple and multiple linear regression models

Output	Input	{S, BMI}					{FA, WC}				
		S		S, BMI			FA		FA, WC		
SHS	Eq	7.00+0.310*S		7.01+0.310*S-0.00093*BMI			18.5+0.890*FA		18.5+0.888*FA+0.00112*WC		
	P-Value	0.00	0.00	0.00	0.00	0.924	0.00	0.00	0.00	0.00	0.728
	R^2	82		82			86.9		86.9		
	R^2(adj)	82		81.9			86.9		86.8		
EYS	Eq	17.7+0.343*S		17.3+0.342*S+0.0258*BMI			33.8+0.899*FA		33.5+0.883*FA+0.0131*WC		
	P-Value	0.00	0.00	0.00	0.00	0.026	0.00	0.00	0.00	0.00	0.054
	R^2	79.7		79.8			72.8		73.1		
	R^2(adj)	79.7		79.8			72.7		73.1		
EHS	Eq	-14.4+0.230*S		-14.5+0.229*S+0.0119*BMI			-5.13+0.643*FA		-5.20+0.640*FA+0.00232*WC		
	P-Value	0.00	0.00	0.00	0.00	0.258	0.00	0.00	0.00	0.00	0.500
	R^2	73.8		73.9			70.4		70.4		
	R^2(adj)	73.8		73.8			70.4		70.3		
FA	Eq	-2.79+0.287*S		-3.05+0.286*S+0.0177*BMI			-		-		
	P-Value	0.001	0.00	0.00	0.00	0.076	-		-		
	R^2	78.7		78.8			-		-		
	R^2(adj)	78.7		78.8			-		-		
BPL	Eq	2.38+0.262*S		2.34+0.262*S+0.00264 BMI			9.21+0.816*FA		9.14+0.813*FA+0.00256*WC		
	P-Value	0.002	0.00	0.002	0.00	0.769	0.00	0.00	0.00	0.00	0.440
	R^2	79.1		79.1			80.2		80.2		
	R^2(adj)	79.1		79.1			80.2		80.2		
PH	Eq	1.91+0.243*S		1.93 + 0.243*S - 0.00137*BMI			10.9+0.697*FA		10.8 + 0.694*FA+0.00229*WC		
	P-Value	0.005	0.00	0.006	0.00	0.924	0.00	0.005	0.00	0.006	0.00
	R^2	80.4		80.5			71.2		71.3		
	R^2(adj)	80.4		80.4			71.2		71.2		
ABS	Eq	-4.29 + 0.152*S		0.85+0.0155*S+0.781*BMI			23.9-0.0862*FA		4.87-0.0604*FA+0.234*WC		
	P-Value	0.124	0.00	0.559	0.110	0.026	0.00	0.124	0.00	0.559	0.110
	R^2	17.1		77.8			0.3		72.9		
	R^2(adj)	16.9		77.7			0.0		72.7		
SB	Eq	-6.03+0.294*S		-9.41+0.283*S+0.230*BMI			3.11+0.882*FA		1.26+0.750 FA+0.0991*WC		
	P-Value	0.00	0.00	0.00	0.00	0.258	0.008	0.00	0.003	0.00	0.00
	R^2	63.1		73.2			58.4		71.1		
	R^2(adj)	63.0		73.1			58.3		71.1		
HW	Eq	29.4 + 0.0339*S		23.8 - 0.00248*S + 0.521*BMI			30.3+0.107*FA		25.4-0.0549*FA+0.155*WC		
	P-Value	0.00	0.00	0.00	0.589	0.076	0.00	0.00	0.00	0.00	0.00
	R^2	1.6		77.6			2.3		70.9		
	R^2(adj)	1.5		77.6			2.1		70.9		

Table 5 Linear regression predicting models

{S, BMI}			{FA, WC}		
Regression equations	R^2 **(%)**	**S**	**Regression equations**	R^2 **(%)**	**S**
SHS = 7.00 + 0.310*S	82	1.16112	SHS= 18.5 + 0.890*FA	86.9	0.792806
EYS = 17.7 + 0.343*S	79.7	1.3822	EYS = 33.8 + 0.899*FA	72.8	1.20000
EHS = - 14.4 + 0.230 S	73.8	0.9218	EHS= - 5.13 + 0.643*FA	70.4	1.05306
FA = - 2.32 + 0.284*S	78.7	1.3822	FA = FA	100	0
BPL = 2.38 + 0.262*S	79.1	1.07342	BPL = 9.21 + 0.816*FA	80.2	1.04489
PH = 1.91 + 0.243*S	80.5	0.95117	PH = 10.9 + 0.697*FA	71.2	1.14175
ABS = 3.04 + 0.797*BMI	77.8	1.34192	ABS = 2.30 + 0.234*WC	72.7	1.26319
SB = - 10.3 + 0.269*S + 0.369*BMI	73.2	1.4058	SB = 1.26 + 0.74*FA + 0.0991*WC	71.1	1.50831
HW = 23.5 + 0.521*BMI	77.6	0.90235	HW = 23.3 + 0.152*WC	70.4	0.979693

Therefore, using this analysis, Table 5 shows all final equations of the two input sets: {S, BMI} and {FA, WC}. All of R^2-values are greater than 70%, and the normal probability plot of the residuals, the residuals versus fitted values plot and the residuals versus orders plot were drawn for each equation and they all yielded that all the predictive equations are good and usable. To validate these equations, the data of 57 subjects which were not used in the model creation process was used for testing. Table 6 shows the means and standard deviations of the actual and predicted outputs; clearly, they are quite similar. To be sure, a paired sample t-test was conducted on testing data and the P-values are shown in Table 7. All the P-values for all outputs are greater than 0.05 which present that the mean difference is equal to zero, thus there is no significant difference between actual and predicted outputs. Moreover, comparison between two sets of outputs shows there is no significant difference either.

Table 6 Means and standard deviations of actual and predicted anthropometric measurements

Out-put	**Actual**		**Predicted**			
			{S, BMI}		{FA, WC}	
	Mean	StDev	Mean	StDev	Mean	StDev
SHS	58.89	11.39	58.81	10.50	59.03	10.58
EYS	74.93	13.39	75.03	12.86	74.74	10.80
EHS	23.97	5.08	24.04	5.78	23.81	3.91
FA	45.11	9.44	45.15	8.82	45.11	9.44
BPL	46.31	8.78	46.17	7.50	46.02	6.29
PH	42.61	7.02	42.52	6.45	42.34	4.59
ABS	21.62	10.08	21.61	10.41	21.42	9.04
SB	43.38	12.24	43.26	13.90	43.06	11.91
HW	35.58	4.08	35.59	4.42	35.66	3.76

Table 7 P-values of paired sample t-tests

Output	**Actual & {S, BMI}**	**Actual & {FA, WC}**	**{S, BMI} & {FA, WC}**
SHS	0.25	0.11	0.79
EYS	0.24	0.15	0.75
EHS	0.13	0.07	0.69
FA	0.74	1	0.65
BPL	0.07	0.06	0.82
PH	0.11	0.06	0.76
ABS	0.98	0.12	0.81
SB	0.58	0.1	0.83
HW	0.74	0.18	0.89

Table 8 presents criteria determinant for each mounted desktop chairs' dimension. Some criteria have been suggested and some criteria have just been introduced by this study. "Design for extreme" anthropometry principle was used for designing one size mounted desktop chairs for Thai university students.

In this study, a high seat is recommended that why 95th percentile of popliteal height is chosen over 5th percentile. Most literature (O Ismaila et al., 2013), (Esmaeel et al., 2020) suggested 5th percentile of popliteal height because a high chair leads the compression around the underside of the thigh causing blood circulation. However, Huang et al. (2016) discovered that low level seat pan height led to the maximum compressive loads on the lumbar joints compared with medium level and high level because when sitting on a lower level seat, only upper leg parts are supported. Hence most of the body weight goes down to the torso and feet since the knee angle is less than 90°. The reading distance of 40 cm (Bettencourt and Jacobs, 1995) is considered for Seat to Desktop Height. If the desktop pad is lower than the value of eye height sitting minus 40, a user will have a hard time seeing written letters. Salvendy (2012) showed that, 95th percentile shoulder breadth of male is wider than 95th percentile of hip width sitting of females. Thus, shoulder breadth should be considered in defining a seat width also. Al-Hinai et al. (2018) proposed using chest depth to define Desktop-Backrest Distance and this is only one study that mentioned Desktop-Backrest Distance. Therefore, Abdominal depth sitting is proposed and one quarter of the depth should be added to make a little bit more room. Since no literature mentions about Desktop Length, the idea of the length should be able to support Forearm-fingertip portion with 25° angle shoulder flexion (Chafin et al., 1991). The desk width should be the width of the opened book which is around 2 times of A4 paper width.

4. CONCLUSIONS

Mounted desktop chairs' users often encounter discomfort and fatigue due to inconvenient adjustments or restricted movements. These challenges underscore the importance of prioritizing ergonomic design principles and nine difficult-to-measure anthropometric measurements are necessary. However, in this study, these nine hard-to-obtain anthropometrics can be simply predicted using either Stature and Body Mass Index or Forearm-fingertip length and Waist circumference. Moreover, there are new criteria determinants that have not been suggested by any study such as Desktop-Backrest Distance (DBD), Desktop Width (DW), Desktop Length (DL). These new proposed criteria determinants should help to improve the design of mounted desktop chairs. Also, because the sample age is between 18 and 25, which is working age, the results of this study can be applied to office furniture or workstations that restrict movements.

Table 8 Recommended dimensions for Thai university students.

Dims.	Anthropometry	Criteria Determinants	Design Dims.
SH*	PH	95^{th} percentile of popliteal height + 2 cm for shoes allowance	43 cm
SDH*	EHS, EYS	Max {95^{th} percentile of elbow height sitting, 95^{th} percentile eye height sitting-40}	29 cm
SD	BPL	5^{th} percentile of Buttock-popliteal Length	39.90 cm
SW*	HW, SB	Max {95^{th} percentile of hip width sitting, 95^{th} percentile shoulder breadth}	47 cm
UEB	SHS	5^{th} percentile of shoulder height sitting	37.20 cm
DBD*	ABS	1.25 times 95^{th} percentile of Abdominal depth sitting	37.50 cm
DL*	FA, SHS, EHS	95^{th} percentile of Forearm-fingertip length, shoulder height sitting, and elbow height sitting	66.94 cm
DW*	-	2 times of A4 paper width	42 cm
AW	-	Literature review suggestion (Lueder & Allie, 1999)	10 cm

* New proposed criteria determinant

5. ACKNOWLEDGMENT

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