Evaluation of Chair Dimensions, Anthropometric Measurements and Subjective Comfort Among Filipino High School Students: A Structural Equation Modelling Approach

Yogi Tri Prasetyo
School of Industrial Engineering and Engineering Management
Mapúa University
Metro Manila, Philippines
ytprasetyo@mapua.edu.ph

Ashutosh Kumar, Alyza Joy P. Alyza Joy P., Karl Timothy Andrew M. Ong, Ma.Karylle Ashlie S. Siochi, and Ardvin Kester S. Ong
Young Innovators Research Center
Mapúa University
Metro Manila, Philippines
k.ash60@yahoo.com , alyza.canlas@gmail.com , karlong281@gmail.com , karylle.siochi@gmail.com , ardvinkester@yahoo.com

Abstract

The chair has become a fundamental workstation for students around the world. The purpose of this study was to investigate the causal relationship between chair dimensions, anthropometric measurements, and subjective comfort by utilizing Structural Equation Modelling (SEM) approach. Fifty-two senior high school students were recruited to evaluate three fixed-type chairs and the anthropometric data were measured. In addition, they were asked to fill the subjective comfort questionnaire and rate the chair by utilizing pairwise comparison. SEM revealed that chair dimension was found to have a significant on effect on subjective comfort. In addition, anthropometric latent variable was also found to have a significant positive effect on subjective comfort. Regarding the indicators, backrest height of the chair dimension was found to be a significant predictor for subjective comfort. Finally, stature height, eye height, shoulder height, and elbow height of the anthropometric dimensions were found to be significant predictors for subjective comfort. This study is one of the first studies that investigated the causal relationships among chair dimensions, anthropometric measurements, and subjective comfort simultaneously. The results would be very beneficial for academicians, human factors engineers, and even chair manufacturers particularly related to designing a good fixed-type chair.

Keywords
Chair, Anthropometry, Structural Equation Modelling, Subjective Comfort.

1. Introduction
Chairs has become a fundamental workstation for students around the world. Nowadays, most universities utilized traditional fixed-type chairs due to the price efficiency and the availability on the market compared to the adjustable chairs. “Ergo chair” has been a trending topic in 2020 particularly when the chair is compatible with the anthropometric data (Underwood and Sims 2019).

Anthropometric data in both school furniture and body dimension is very essential to enhance the user’s comfort and safety. The fundamental part of human factors and ergonomics particularly involves systematic measurement of human body with regard to product designs (i.e. school furniture). Academicians, human factors engineers and even chair manufacturers are actively engaged in chair related research (Underwood and Sims 2019; Yanto et al. 2017;

Vergara and Page 2002; Lee et al. 2018), aiming to maximize the subjective comfort while also considering the anthropometric data.

In the Philippines, most of the available chairs in the university are fixed-type chairs. Students are forced to sit in a traditional chair which less comfortable due its low quality compared to adjustable chairs. Since students spend most of their time in classrooms sitting, these traditional chairs force the students to sit in inconvenient positions, which then leads to discomfort in the long run. Moreover, having inconvenient sitting positions can result in several physical disorders among students. This leads to complications between the dimensions of the furniture and body of the students resulting in an anthropometric mismatch.

An anthropometric mismatch is defined as the incompatibility between a student's body measurement and furniture dimensions (Yanto et al. 2017). If a mismatch is found between the user and the furniture, it leads to complications in the body and discomfort. Various studies have identified an anthropometric mismatch between different fixed-type chairs and student's body dimensions (Lee et al. 2018; Kahya 2019; Castellucci et al. 2010). Since fixed type chairs have only one size, it cannot provide the same level of comfort due to the diversity of its users in terms of their body dimensions. In addition, the discomfort was discovered to be its resulting factor (Khaspuri et al. 2007). Furthermore, using basic anthropometric data, dimensions that could be used to design more comfortable school furniture was proposed (Dianat et al. 2013).

Despite the availability of many studies related to anthropometry, there have been limited studies about the link between body anthropometrics with subjective or comfort measurement. In addition, there has been little work about the correlation between furniture and anthropometric dimensions regarding Filipino body dimensions. A further investigation is highly required particularly related to the causal relationships between chair dimensions, anthropometric measurements, and subjective comfort.

The purpose of this study was to investigate the causal relationship between chair dimensions, anthropometric measurements, and subjective comfort by utilizing Structural Equation Modelling (SEM) approach. SEM is an advanced statistical technique that can explore the causal relationship among selected factors (Prasetyo 2020; Prasetyo 2020; Hair 2014). This study could contribute as a theoretical foundation for designing a good chair and it would be very beneficial for academicians, human factors engineers, and even chair manufacturers.

2. Method

2.1. Participants

Fifty-five senior high school students aged between 15-19 years old voluntary participated in the study (Table 1). All participants were from Mapúa University Senior High School. They were not paid not compensated with academic credits. All participants were free from musculoskeletal disorders.

Table 1. Demographic profile of the respondents.

Characteristics	Category	N	%
Gender	Male	40	76.9
	Female	12	23.1
Age	16	3	5.77
	17	20	38.46
	18	26	50
	19	3	5.77

2.2. Apparatus and Procedures

Three different fixed-type chairs were selected in the current study: a) wooden chair b) red chair c) black chair (Figure 1). These chairs are common chairs in the academic institutions in the Philippines. Six chair dimensions were collected: backrest height, seat height, seat depth, seat width, lumbar support height, and footrest height. Table 2 represents the chair dimensions in cm collected in the study.

During data collection, participants were asked to sit in the chair. Following Prado-Lu (2007), several anthropometric dimensions were collected during sitting position such as stature (height), eye height, shoulder height, elbow height, knuckle height, height (sitting), eye height (sitting), elbow rest height (sitting), thigh clearance height, knee height, buttock-knee length, popliteal height, chest depth, elbow-to-elbow breadth, and hip breadth (Table 3). The tape measure was utilized to measure all dimensions. In addition, all participants were asked to sit in a way that the upper leg and lower leg remains at a right angle to each other with their knees bent at 90°, their feet stuck on the floor, and their arms were also positioned at a right angle according to the measurement. Finally, a subjective comfort questionnaire (0: no comfort; 10: maximal comfort) (Kyung et al. 2008; Anjani et al. 2020) and a pairwise comparison test to derive the most favoured chair were given after the anthropometric measurements.

Figure 1. Three different fixed-type chairs in the current study:
a) wooden chair b) red chair c) black chair.

Table 2. Chair dimensions (cm).

Variable	Chair A	Chair B	Chair C
Backrest Height	17.5	17.0	16.9
Seat Height	16.0	18.3	18.4
Seat Depth	14.6	6.7	16.9
Seat Width	17.0	18.0	18.1
Lumbar Support Height	8.0	9.0	7.5
Footrest Height	4.5	5.5	7.0

3. Conceptual Framework and Structural Equation Modelling

Figure 2 represents the conceptual framework of the current study. The main focus of the framework was to derive the causal relationships among chair dimensions, anthropometric dimensions, and subjective comfort. In addition, the type of chair was hypothesized to have a direct effect on the chair dimensions, which subsequently affect subjective comfort.

As mention before, this study utilized SEM for the statistical analysis. Following our previous studies which applied SEM (Prasetyo 2020; Prasetyo 2020), the model fit was measured by several indicators: p-value for chi-square, Normed Fit Index (NFI), Tucker Lewis Index (TLI), Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), and Root Mean Square Error Approximation (RMSEA). In general, SEM requires more than 200 respondents to derive a good model fit (Prasetyo 2020; Prasetyo 2020; Hair 2014). Since only 52 participants rated three different chairs, a total of 156 data were analysed, therefore, it was required to run the bootstrapping technique since the data were less than 200 to enhance the model fit. Finally, several modification indices were also applied to enhance the model fit and derive a better model.

Table 3. Anthropometric data for Filipino high school students aged 15-19 (cm).

Variable	Mean	St Dev.	Minimum	Q1	Median	Q3	Maximum
STR Height	65.377	2.675	59.400	63.775	65.000	67.425	71.000
Eye Height	61.110	2.847	54.400	59.050	61.050	63.425	66.500
Shoulder Height	54.010	2.618	48.200	51.925	53.950	56.075	59.500
Elbow Eight	41.803	2.072	37.500	40.000	42.000	43.188	46.000
Knuckle Height	28.673	1.725	22.800	27.500	28.850	29.875	32.000
Sitting Height	34.254	1.693	30.000	33.200	34.350	35.650	37.600
Eye Height Sitting	30.006	1.767	27.000	28.575	29.900	31.150	33.400
Elbow Rest Height	10.960	1.537	7.500	9.550	11.000	12.300	13.800
Thigh Clearance	6.555	1.098	4.400	5.825	6.825	7.275	9.400
Knee Height	20.690	1.779	18.000	19.525	20.450	21.175	30.000
Buttock Knee Height	21.630	1.516	18.400	20.500	21.700	22.300	28.500
Popliteal Height	18.175	2.743	13.700	16.500	18.350	19.475	30.300
Chest Depth	33.256	3.878	23.500	30.575	32.950	36.000	42.500
Elbow to Elbow Height	17.579	1.941	13.500	16.025	17.550	19.000	22.000
Hip Breadth	13.656	1.704	10.900	12.350	13.750	14.500	18.000

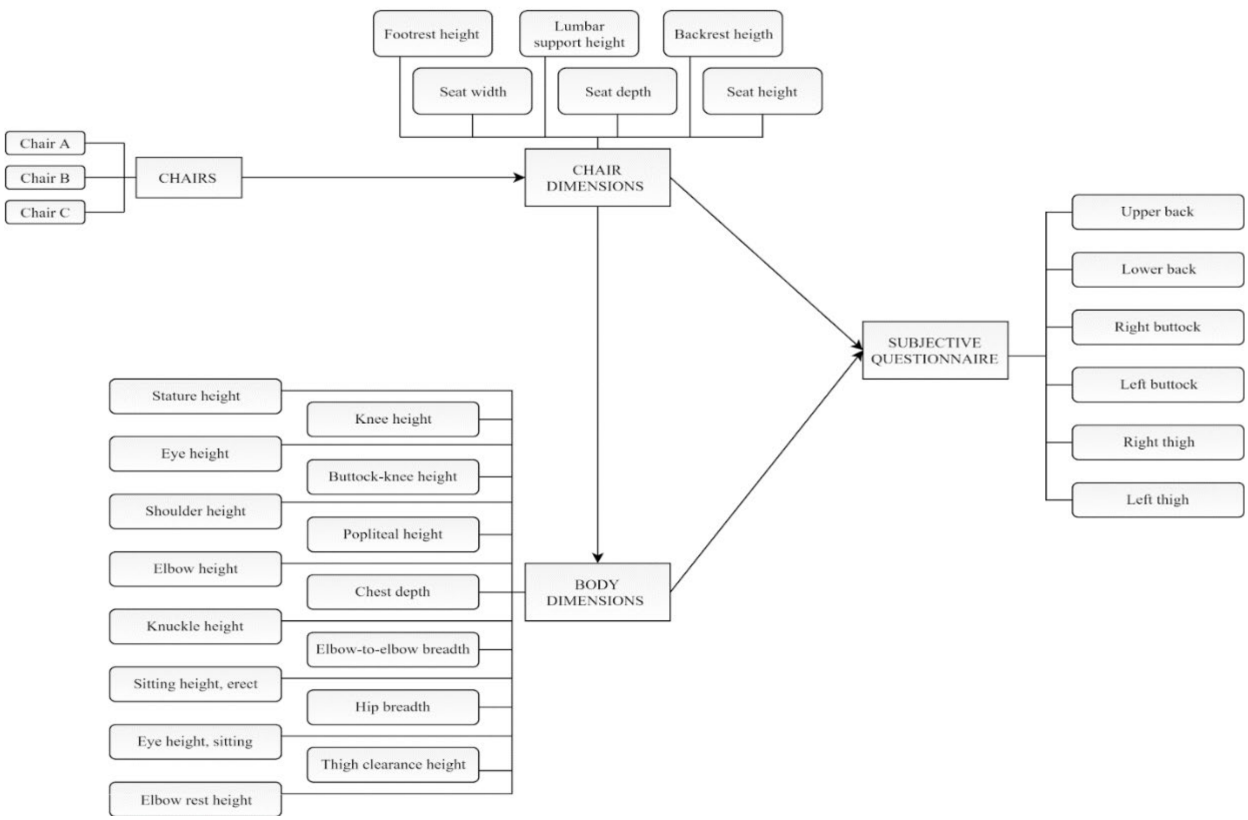

Figure 2. Conceptual framework of the study.

4. Results and Discussion

Table 4 represents the mean value for the subjective comfort. Based on this table, chair A was found to have the lowest overall rating scale with the value of 4.125, therefore, chair A had the highest level of discomfort. Interestingly, no significant difference between chair B and chair C with the overall rating scale values of 6.304 and 6.337 respectively. Table 5 represents the pairwise comparison results of three fixed-type chairs. Identical to subjective comfort, chair A had the least favoured score compare with chair B and chair C. Finally, following some of our previous studies, which applied SEM (Prasetyo 2020; Prasetyo 2020; Hair 2014), Table 6 represents the correlation matrix between subjective comfort and chair type as a foundation to derive the SEM.

Table 4. Mean values of subjective comfort.

Variable	Mean		
	Chair A	**Chair B**	**Chair C**
Upper Back	3.942	6.269	6.231
Left Buttock	3.615	6.250	6.250
Left Thigh	4.712	6.538	6.481
Lower Back	3.731	6.000	6.173
Right Buttock	3.942	6.365	6.442
Right Tigh	4.808	6.404	6.442
Overall Rating Scale	4.125	6.304	6.337

The final SEM of the current study is presented in Figure 3 and the model fit is presented in Table 7. All goodness of indices was found to pass the minimum cut-off indicating the model was very good. SEM indicated that chair dimensions were found as the most predicting latent to subjective comfort. Chair (coded 1 for chair A, 2 for chair B, and 3 for chair C) was found to have a negative associated with the backrest which subsequently lead to discomfort. It could also be interpreted as chair A was found to have the shortest backrest, which subsequently lead to the discomfort.

Anthropometric dimension latent variable was found to have a significant positive effect on subjective comfort. Participants with bigger anthropometric dimensions were found to experience a higher level of comfort. Interestingly, buttock was found to be the most predicting subjective comfort. Rosaria et al. (2020), who mentioned that buttock was the most sensitive part to temperature changes at the interface, also supported this finding. Left buttock and right buttock were found to have the highest factor loadings indicating that buttock was a key consideration for evaluating a chair. Finally, stature height, eye height, shoulder height, and elbow height of the anthropometric dimensions were found to be significant predictors for subjective comfort.

Table 5. Pairwise comparison results.

Chair A or B	***N***	**Chair B or C**	***N***	**Chair A or C**	***N***
Chair A	1	Chair B	20	Chair A	2
Neutral	8	Neutral	8	Neutral	8
Chair B	43	Chair C	24	Chair C	42
Total	52	Total	52	Total	52

Table 6. Correlation analysis between type of chair and subjective comfort

Pearson Correlation								
	Upper Back	Left Buttock	Left Thigh	Lower Back	Right Buttock	Right Thigh	Overall Rating Scale	Chair Type
Upper Back	1	.713**	.719**	.742**	.679**	.689**	.732**	.381**
Left Buttock		1	.723**	.745**	.904**	.703**	.808**	.440**
Left Thigh			1	.700**	.765**	.883**	.754**	.333**
Lower Back				1	.739**	.688**	.766**	.377**
Right Buttock					1	.740**	.807**	.420**
Right Thigh						1	.723**	.280**
Overall Rating Scale							1	.481**
Chair Type								1

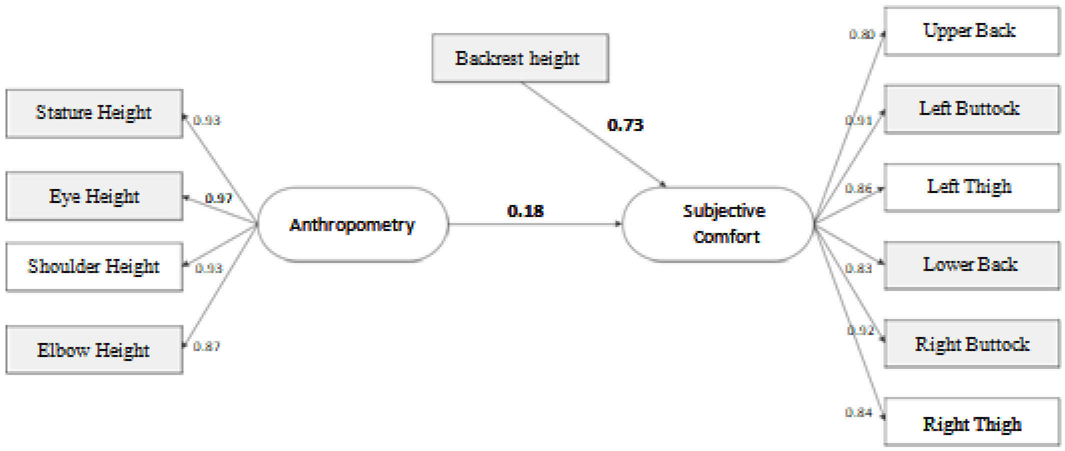

Figure 3. The final SEM of the current study.

Table 7. The goodness of fit measures of the SEM.

The goodness of fit measures of the SEM	**Parameter Estimater**	**Suggested cut-off**	**Recommended by**
p-value for Chi-square (χ^2)	0.165	> 0.05	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Chi-square statistic (χ^2)	8.460		
Degree of freedom (df)	6		
Normed chi-square (χ^2/df)	1.410	< 2.0	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Normed Fit Index (NFI)	0.974	> 0.95	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Tucker Lewis Index (TLI)	0.965	> 0.95	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Comparative Fit Index (CFI)	0.988	> 0.96	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Goodness of Fit Index (GFI)	0.932	> 0.95	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Adjusted Goodness of Fit Index (AGFI)	0.906	> 0.90	(Prasetyo 2020; Prasetyo 2020; Hair 2014)
Root Mean Square Error of Approximation (RMSEA)	0.066	< 0.07	(Prasetyo 2020; Prasetyo 2020; Hair 2014)

ANOVA was applied in order to investigate the effect of the chair type on several variables (Table 8). Based on ANOVA, the type of chair was found to have significant effects on all subjective comforts. Finally, post-hoc Tukey test was applied to derive the significant difference among the three chairs (Table 9). Based on post -hoc Tukey test, wooden chair (chair A) was found to have a significant difference compared with two other chairs.

Table 8. ANOVA test result for type of chair to subjective comfort.

		Sum of Squares	df	Mean Square	F	Sig.
Upper Back	Between Groups	184.654	2	92.327	17.965	.000
	Within Groups	786.288	153	5.139		
	Total	970.942	155	-		
Left Buttock	Between Groups	240.628	2	120.314	26.609	.000
	Within Groups	691.808	153	4.522		
	Total	932.436	155	-		
Left Thigh	Between Groups	112.167	2	56.083	12.834	.000
	Within Groups	668.577	153	4.370		
	Total	780.744	155	-		
Lower Back	Between Groups	193.167	2	96.583	19.764	.000
	Within Groups	747.673	153	4.887		
	Total	940.840	155	-		
Right Buttock	Between Groups	210.205	2	105.103	24.524	.000
	Within Groups	655.712	153	4.286		
	Total	865.917	155	-		
Right Thigh	Between Groups	90.500	2	45.250	9.165	.000
	Within Groups	755.423	153	4.937		
	Total	845.923	155	-		
Overall Rating Scale	Between Groups	20535.269	2	10267.635	31.889	.000
	Within Groups	49263.423	153	321.983		
	Total	69798.692	155	-		

Despite the clear and impactful findings, the authors would like to mention several limitations in our study. First, the sample size was very far from SEM standard. Future research to incorporate a larger sample would be required to derive a better model. Second, the anthropometric measurements were collected by tape measure, which could lead to possibility of inaccuracy. Last but not the least, the effect of the chair materials was not discussed further. A future research to discuss about the effect of chair materials would be a promising research topic.

Table 9. Post-hoc Tukey test result.

Dependent Variable	Chair Type	Chair Type	Mean Difference	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Upper Back	1	2	-2.28846*	.44459	.000	-3.3407	-1.2362
		3	-2.32692*	.44459	.000	-3.3792	-1.2747
	2	1	2.28846*	.44459	.000	1.2362	3.3407
		3	-.03846	.44459	.996	-1.0907	1.0138
	3	1	2.32692*	.44459	.000	1.2747	3.3792
		2	.03846	.44459	.996	-1.0138	1.0907
Left Buttock	1	2	-2.63462*	.41702	.000	-3.6216	-1.6476
		3	-2.63462*	.41702	.000	-3.6216	-1.6476
	2	1	2.63462*	.41702	.000	1.6476	3.6216
		3	0.00000	.41702	1.000	-.9870	.9870
	3	1	2.63462*	.41702	.000	1.6476	3.6216
		2	0.00000	.41702	1.000	-.9870	.9870
Left Thigh	1	2	-1.76923*	.40996	.000	-2.7395	-.7990
		3	-1.82692*	.40996	.000	-2.7972	-.8566
	2	1	1.76923*	.40996	.000	.7990	2.7395
		3	-.05769	.40996	.989	-1.0280	.9126
	3	1	1.82692*	.40996	.000	.8566	2.7972
		2	.05769	.40996	.989	-.9126	1.0280
Lower Back	1	2	-2.44231*	.43353	.000	-3.4684	-1.4162
		3	-2.26923*	.43353	.000	-3.2953	-1.2432
	2	1	2.44231*	.43353	.000	1.4162	3.4684
		3	.17308	.43353	.916	-.8530	1.1991
	3	1	2.26923*	.43353	.000	1.2432	3.2953
		2	-.17308	.43353	.916	-1.1991	.8530
Right Buttock	1	2	-2.50000*	.40600	.000	-3.4609	-1.5391
		3	-2.42308*	.40600	.000	-3.3840	-1.4622
	2	1	2.50000*	.40600	.000	1.5391	3.4609
		3	.07692	.40600	.980	-.8840	1.0378
	3	1	2.42308*	.40600	.000	1.4622	3.3840
		2	-.07692	.40600	.980	-1.0378	.8840
Right Thigh	1	2	-1.63462*	.43578	.001	-2.6660	-.6032
		3	-1.59615*	.43578	.001	-2.6275	-.5648
	2	1	1.63462*	.43578	.001	.6032	2.6660
		3	.03846	.43578	.996	-.9929	1.0698
	3	1	1.59615*	.43578	.001	.5648	2.6275
		2	-.03846	.43578	.996	-1.0698	.9929
Overall Rating Scale	1	2	-23.73077*	3.51909	.000	-32.0595	-15.4020
		3	-24.90385*	3.51909	.000	-33.2326	-16.5751
	2	1	23.73077*	3.51909	.000	15.4020	32.0595
		3	-1.17308	3.51909	.941	-9.5019	7.1557
	3	1	24.90385*	3.51909	.000	16.5751	33.2326
		2	1.17308	3.51909	.941	-7.1557	9.5019

5. Conclusions

The chair has become a fundamental workstation for students around the world. The purpose of this study was to investigate the causal relationship between chair dimensions, anthropometric measurements, and subjective comfort by utilizing Structural Equation Modelling (SEM) approach. Fifty-two senior high school students were recruited to evaluate three fixed-type chairs and the anthropometric data were measured. In addition, they were asked to fill the subjective comfort questionnaire and rate the chair by utilizing pairwise comparison. SEM revealed that chair dimension was found to have a significant on effect on subjective comfort. In addition, anthropometric latent variable was also found to have a significant positive effect on subjective comfort. Regarding the indicators, backrest height of the chair dimension was found to be a significant predictor for subjective comfort. Finally, stature height, eye height, shoulder height, and elbow height of the anthropometric dimensions were found to be significant predictors for subjective comfort. This study is one of the first studies that investigated the causal relationships among chair dimensions, anthropometric measurements, and subjective comfort simultaneously by utilizing SEM. The results would be very beneficial for academicians, chair-comfort researchers (Wegner et al. 2020; Fasulo et al. 2019; Fazlollahtabar 2010), and even chair manufacturers particularly related to designing a good fixed-type chair.

Acknowledgments

The authors would like to thank Almarose C. Villapando, Riañina D. Borres, and Venice Cristine C. Dangaran for their constructive suggestions.

References

Anjani, S., Li, W., Ruiter, I. A., and Vink, P., The effect of aircraft seat pitch on comfort, *Applied Ergonomics*, vol. 88, 2020.

Castellucci, H. I., Arezes, P. M., and Viviani, C. A., Mismatch between classroom furniture and anthropometric measures in Chilean schools, *Applied Ergonomics,* vol. 41, no. 4, pp. 563-568, 2010.

Dianat, I., Karimi, M. A., Hashemi, A. A., and Bahrampour, S., Classroom furniture and anthropometric characteristics of Iranian high school students: proposed dimensions based on anthropometric data, *Applied Ergonomics*, vol. 44, no. 1, pp. 101-108, 2013.

Fasulo, L., Naddeo, A., and Cappetti, N., A study of classroom seat (dis)comfort: Relationships between body movements, center of pressure on the seat, and lower limbs' sensations, *Applied Ergonomics,* vol 74, pp. 233-240, 2019.

Fazlollahtabar, H., A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry, *Applied Ergonomics,* vol 42, no 1, pp. 16-28, 2010.

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E., *Multivariate Data Analysis, Seventh Edition*, Pearson Education Limited, Edinburg, 2014.

Kahya, E., Mismatch between classroom furniture and anthropometric measures of university students, *International Journal of Industrial Ergonomics*, vol. 74, 2019.

Khaspuri, G.C., Sau, S.K., and Dhara, P.C., Anthropometric consideration for designing class room furniture in rural schools, *Journal of Human Ecology*, vol. 22, pp. 235-244, 2007.

Kyung, G., Nussbaum, M. A., and Babski-Reeves, K., Driver sitting comfort and discomfort (part I): Use of subjective ratings in discriminating car seats and correspondence among ratings, *International Journal of Industrial Ergonomics*, vol. 38, no. 5-6, pp. 516-525, 2008.

Lee, Y., Kim, Y. M., Lee, J. H., and Yun, M. H., Anthropometric mismatch between furniture height and anthropometric measurement: A case study of Korean primary schools, *International Journal of Industrial Ergonomics*, vol. 68, pp. 260-269, 2018.

Prado-Lu, J. L. D., Anthropometric measurement of Filipino manufacturing workers, *International Journal of Industrial Ergonomics*, vol. 37, no. 6, pp. 497-503, 2007.

Prasetyo, Y. T., Factors affecting fine dexterity: A structural equation modeling approach, *Proceedings of the 2020 2nd International Conference on Management Science and Industrial Engineering*, pp. 304-308, 2020.

Prasetyo, Y. T., Factors affecting gross manual dexterity: A structural equation modeling approach, *2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA)*, pp. 425-429, 2020.

Rosaria, C., Naddeo, A., and Chiara, C., Comfort seat design: Thermal sensitivity of human back and buttock, *International Journal of Industrial Ergonomics*, vol. 78, 2020.

Underwood, D., and Sims, R., Do office workers adjust their chairs? End-user knowledge, use and barriers to chair adjustment, *Applied Ergonomics,* vol. 77, pp. 100-106, 2019.

Vergara, M,. and Page, A. F., Relationship between comfort and back posture and mobility in sitting-posture, *Applied Ergonomics*, vol. 33, no. 1, pp. 1-8, 2002.

Wegner, M., Martic, R., Franz, M., and Vink, P., A system to measure seat-human interaction parameters which might be comfort relevant, *Applied Ergonomics,* vol. 84, 2020.

Yanto., Lu, C. W., and Lu, J. M., Evaluation of the Indonesian National Standard for elementary school furniture based on children's anthropometry, *Applied Ergonomics*, vol. 62, pp. 168-181, 2017.