Assessing the Ergonomic Status of Commonly Used Chairs in Iran's Universities Based on Combinational Equations and Anthropometric Indices

Hamidreza Mokarami[a], Samira Ansari[b], Rosanna Cousins[c], Sakineh Varmazyar[d,*]

[a] Department of Ergonomics, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran.
[b] Student Research Committee, Department of Occupational Health Engineering, Faculty of Health, Qazvin University of Medical Sciences, Qazvin, Iran.
[c] Department of Psychology, Liverpool Hope University, Liverpool, UK.
[d] Department of Occupational Health Engineering, Faculty of Health, Qazvin University of Medical Sciences, Qazvin, Iran.

*Corresponding author: Sakineh Varmazyar, Department of Occupational Health Engineering, Faculty of Health, Qazvin University of Medical Sciences, Qazvin, Iran. Email: Svarmazyar@qums.ac.ir

ABSTRACT

BACKGROUND: Inappropriate design of chairs and disproportion with students' body dimensions can influence their physical and mental health as well as their educational efficiency and concentration.

OBJECTIVE: The aim of this study was to examine the ergonomic status of commonly used chairs in Iran's universities using combinational equations and anthropometric indices.

METHODS: Participants in this cross-sectional study were 166 students in Iran. Eleven anthropometric parameters of the students and nine dimensions in seven types of commonly used chairs in Iran's universities were measured. Combinational equations were used to determine the fitness of the chairs.

RESULTS: There was a major mismatch between most students' anthropometric measurements and the dimensions of the chairs. Backrest height and seat height were the best and the worst features, respectively, according to ergonomic recommendations for chairs. The recommended measurements of seat height, seat depth, seat width, desk height, desk width, desk length, backrest width, backrest height, and desk distance were 332, 420, 436, 245, 95, 511, 426, 550, and 281 mm, respectively.

CONCLUSION: None of the commonly used chairs in Iran's universities were found to be a good fit to the students' anthropometric dimensions. Therefore, in order to prevent inappropriate body postures, chairs designs have to reviewed, and made to fit with Iranian students' anthropometric data. The recommended measurements obtained in this study can be used to design a suitable ergonomic chair to match with a high percentage of Iranian students.

Keywords*:* Ergonomics, Anthropometric measurements, Student chair, Musculoskeletal disorders

1. Introduction

People interact with various tools and equipment in everyday life. Any disparity between the required bodily movements, including associated physical and mental effort, in the use of equipment can be harmful [1, 2]. It can lead to complications and damage to various aspects of life [1-3]. Therefore, it is necessary to include ergonomic considerations in the design of workstations. To be appropriately functional, the design of a workstation should consider the users' physique, and the psychological demands of the work [4, 5]. Users' physical capabilities and limitations should be incorporated into workstation design [6].

Sitting down is a preferred posture for most people in the modern world. Thus, the chair is an important piece of equipment in many work environments, especially educational settings. Students spend a major part of their time sitting on chairs in classrooms [7]. Therefore, they are exposed to risks associated with prolonged sitting in static and awkward postures [8]. A static posture reduces flexibility and softness of intervertebral discs and causes severe tension in the muscles due to reduced disc feeding and restricted blood flow [9, 10]. Unsuitable design of chairs – in terms of their function – is one of the reasons for inappropriate sitting positions. Many complications can result from using inappropriate chairs. These include low back pain and numbness [11]. Moreover, inappropriate design of chairs and disproportion with body dimensions can initiate the adoption of awkward postures which can lead to musculoskeletal disorders in long run [12]. Poorly designed chairs can also indirectly influence educational efficiency and concentration [12, 13]. It has been also shown that disproportion between users' anthropometric dimensions and furniture generally serves to reduce concentration and increase stress in users [14]. Therefore, efficient furniture is expected to improve learning through providing a stress-free and comfortable workstation [15].

Equipment should be designed based on principles of ergonomic and anthropometric design to reduce accidents and physical symptoms and increase efficiency [16]. Equipment designed based on anthropometric dimensions can be used by a variety of individuals. Generally, anthropometry involves measurement of body size, motion spaces, and various motion angles [1, 6]. Anthropometric parameters are important factors in designing desks and chairs for students [15, 17]. When anthropometric data are used in the design of a product it can prevent the waste of various resources, including human, time, and financial resources [1], and a variety of people with different body dimensions can feel comfortable when using such equipment [1, 6]. In this regard, when a chair is correctly fitted with students' anthropometric characteristics then both the quality of their education and correct posture is promoted [18].

Given the shortcomings in the design of the chairs currently being used in universities in Iran, and the negative effects of such inappropriate chairs on students' physical and mental health, there is a need to align the dimensions of classroom chairs to students' dimensions. To the best of our knowledge, very few studies have been conducted on assessing the ergonomic status of commonly used educational chairs in Iran and measurement of anthropometric parameters of Iranian students for designing ergonomic educational chairs. Hence, this study aimed to examine the ergonomic status of commonly used chairs in Iran's universities using combinational equations and anthropometric indices.

2. Method

This descriptive and cross-sectional study was conducted among students studying at Qazvin University of Medical Sciences in November 2018 (total number of students = 2563). Based on equation 1, the required sample size for the study was estimated to be 132. However, 166 students were selected for more certainty of sufficient power for the study.

Eg.1. $$n = \frac{Nz^2\delta^2}{Nd^2+z^2\delta^2}$$

Anthropometric parameters were measured by an anthropometer sheet (1.85×2.5, 1.85×1, and 1×1.5 meters), an adjustable chair, a footrest, a ruler, a goniometer, and digital calipers with the precision of 0.1 and 0.5 mm. Then, the measured parameters were recorded in the anthropometric checklist. The measurements were done while the students wore light clothes and no shoes and sat completely upright in the chair. Eleven anthropometric dimensions were measured to determine the fitness of the chairs (**Figure 1**): shoulder height (sitting), elbow height (sitting), popliteal height, knee height, shoulder breadth, hip width, elbow-fingertip length, buttock-popliteal length, abdominal width, forearm width, and thigh thickness. These dimensions were measured in accordance with the relevant International Organization of Standardization standard (ISO 7250-1:2017) [19].

Seven types of educational chairs commonly used in Iran's universities were selected based on field observations. These were assessed based on nine parameters, including seat height, seat depth, seat width, desk height, armrest width, desk width, desk length, backrest width, and backrest height (**Figure 2**). The dimensions of the examined chairs are shown in **Figure 3**.

Anthropometric data were entered into the SPSS statistical software, version 22 (SPSS Inc., Armonk, NY, USA) in order to determine mean, standard deviation, minimum, maximum, and

5^{th}, 50^{th}, and 95^{th} percentiles. To assess the ergonomic status of the chairs and to determine the appropriate dimensions to design students' chairs, it was necessary to measure the chairs' dimensions and the students' anthropometric parameters. The percentiles associated with each anthropometric dimension were used to determine the standard dimensions (guidelines) of the chairs. Combinational equations developed by Gouvali and Boudolos were also used to evaluate the fitness of the chairs based on the students' anthropometric dimensions and to determine the minimum and maximum acceptable dimensions of the chairs [17] (**Table 1**).

Ethical approval for the study was granted by the Ethics Committee of Qazvin University of Medical Sciences (ID: IR.QUMS.REC.1395.187). The research objectives and procedures were explained to the students prior to the study and written informed consent to participate in the study was obtained from all students.

3. Results

68 students (41%) were male and 98 (59%) were female. The students' mean age was 20.78±1.61 years and their mean weight was 62.89±12.1 kg. Mean height was 162±5.45 cm and 177.26±6.47 cm in females and males, respectively.

Anthropometric measurements of male, female, and all students are presented in **Table 2.** The dimensions of the examined chairs are presented in **Table 3.** The recommended ergonomic measurements to design an appropriate chair matched with a higher percentage of students are shown in **Table 4**. Accordingly, the percentiles associated with each anthropometric dimension were used to determine the standard dimensions of the chairs.

The acceptable limits of the chairs' dimensions based on the students' anthropometric dimensions and the percentages of the dimensions above or below the acceptable limits are shown in **Figure 4.** Among the assessed eleven chairs' dimensions, it was seat height that was the most out of line with the ISO standard. The height of chairs 2, 5, and 7 was not in the acceptable limit for any of the students, and the height of chairs 3, 4, 1, and 6 was appropriate for only 14.5%, 13.8%, 4.8%, and 2.4% of students, respectively.

The seat depth of chairs 5, 1, and 7 was a good fit for 84.3%, 83.1%, and 83.1% of the students, respectively. Chairs 3, 2, 6, and 4 were an acceptable fit with 75.9%, 74.6%, 57.2%, and 31.3% students, respectively. The depth of chair 6 was 42.2% greater than the acceptable limit, which caused difficulty in using the backrest. In contrast, the depth of chair 4 was 68.7% lower than the standard, which can produce undue pressure on the posterior thighs when sitting on the chair.

Considering seat width, chairs 7, 1, and 5 had the highest fitness with the acceptable limit (74%), and chairs 2 (70.5%), 6 (63.9%), 4 (49.4%), and 3 (33.1%) an increasingly less acceptable fit. Moreover, the seat widths of chairs 1 to 7 were respectively 10.8%, 27.7%, 50.6%, 50.6%, 7.2%, 4.2%, and 21.1% lower than the acceptable limit. The width of chair 6 was an excellent fit for almost all students, as although the seat width of this chair was higher than acceptable for 31.9% of students, this does not cause discomfort.

Chairs 1 and 6 had the highest (68.7%) fitness in terms of desk height. The next ranks belonged to chairs 5 (56%), 4 (50.6%), 3 (39.2%), 7 (37.3%), and 2 (12%). Furthermore, desk heights of chairs 1 to 7 were respectively 28.9%, 88%, 59.6%, 48.2%, 42.8%, 28.9%, and 61.5% higher than the acceptable limit. Finally, chairs 2, 3, and 7 had the highest fitness in terms of backrest height (99.3%). Chairs 6 (86.1%), 4 (84.9%), 1 (75.9%), and 5 (24%) were ranked next. The backrest height in chair 5 was 76% higher than the acceptable limit.

4. Discussion

The results of this study showed that none of the examined chairs was a perfect fit with students' anthropometric dimensions. Falahati et al. [20] and Dianat et al. [8] also found that the dimensions of the existing chairs did not match with Iranian students' anthropometric data. Since most activities of students are performed sitting on chairs, an ergonomic design for the chairs used is important for students.

In this study, the seat height of a standard chair was determined based on the 5^{th} percentile of popliteal height. This was different from the heights of the assessed chairs. The seat height of a chair should be matched with the 5^{th} percentile of popliteal height so that short students are also able to put their feet on the floor easily with no pressure exerted on different parts of their bodies when sitting on the chair. The standard seat height without considering shoes was 33 cm, which is consistent with results of the study by Zarei et al. [18]. The results showed that the seat height was higher than the standard in all seven types of chairs, thus it can be concluded that the assessed chairs were designed based on the 95^{th} percentile of popliteal height. According to the students' anthropometric dimensions, most students could not place their full feet on the floor even when wearing shoes with 2.5-3 cm heels. This could lead to pressure on the posterior thighs as well as legs and knees muscles. Consequently, this can decrease blood supply to the lower extremities and lead to pain and numbness [11].

In the current study, the seat depth was calculated to be 41.98 cm based on the 5^{th} percentile of the buttock-popliteal length. Similarly, Zarei reported the seat depth to be 40.9 cm [18]. In the study performed by Khanam (and a population of Indian students), this dimension was lower

than the results obtained in the present study [21]. In contrast, some studies reported this dimension to be higher compared to the present investigation [15, 22, 23]. In this study, the seat depth of chair 5 was perfectly matched with the standard seat depth, and in the acceptable limit nearly 85% students. It was found that chairs 4 and 6 had the lowest fitness in terms of seat depth, which could result in bending the trunk and head and extending the arm forward, resulting in back, shoulder, and arm pain in long term as well as problems in using the backrest. Generally, high seat depth leads to pressure on the thighs and disruption of the circulatory system, while low seat depth leads to pressure on the back and knees to avoid falling [24].

The standard seat width was determined based on the 95th percentile of the hip width. Zarei et al. [18] and Kashif et al. [22] reported this dimension to be 41 cm and 30.03 cm, respectively, which were both less than 43.55 cm found in the present study. This conflict could be due to differences in the number of students participating in these studies, the number of female and male students, and even students' body dimensions in various countries. On the other hand, Taifa and Desai [23] and Thariq et al. [15] indicated that seat widths were 43 and 43.6 cm, respectively, measurements which are in line with the results of the present study. Chairs 1, 5, and 6 had the highest fitness, while chair 3 had the lowest fitness with the students' anthropometric data in terms of seat width. The seat width of chair 3 was 50.6% less than the acceptable limit, which can cause a significant number of the students who have to use this type of chair to feel pressure on their hips and sides of their thighs when sitting.

The 50th percentile of elbow height was used to determine the height of the desk, because moving one's shoulders up and down when working can cause shoulder and neck problems [25]. In this study, the appropriate desk height was calculated as 24.5 cm. This is higher than the estimated dimension of 22.9 cm in the study carried out by Thariq [15]. This conflict could result from the difference in body dimensions in various countries. The desk height in chair 1 was closer to the standard compared to the other chairs. Desk height was very high in chairs 2 and 3, which causes the shoulders and hands to remain up during writing and leads to fatigue and tension in the shoulder muscles. The mismatch between the sitting elbow height and desk height can lead to pain in the shoulders and neck [26]. Elbow height was calculated as 25.5 and 24 cm in males and females, respectively. Therefore, the desk height of chair 4 was a suitable fit for male students. In chairs number 2 and 3, the desk height was higher than the elbow height in both males and females. Desk heights of chairs 1 and 5 were lower than the elbow height in both females and males, which would lead to bending forward to work and could lead to pain in students' arms, elbows, and necks. In the research performed by Zarei et al., the desk height of wooden chairs was only fitted for males, and the desk height of plastic chairs was fitted for

females. Indeed, a discrepancy between the desk height and elbow height has been widely observed in the literature [18]. Considering the combinational equations, chair 1 had the best fit (68.7%) in terms of desk height, and other chairs were less fitted for the students. In the study by Bayatkashkoli and Nazerian, the height of the chair's desk was suitable for a mere 23% of the students' anthropometric dimensions [27].

According to Molenbroek et al. [28] and Parcells et al. [29], there should be a minimum of 2 cm between the top on one's thigh and the underneath of the desk for comfort. Almost all the chairs had a 100% fitness in terms of sufficient free space underneath the desk. Only chair 5 did not fit with 5.5% of the students. This is similar to a study by Gouvali and Boudolos, where the underneath desk height was below the acceptable limit for 5.8% of students. They reported that their participants' thighs were in contact with the desk, and they were not able to move their legs [17]. This aspect of chair design seems to be accounted for.

The 95th percentile of abdominal depth was used to determine the horizontal distance that was observed in the majority of the chairs. This distance was low only in chairs 2 and 5, which would be problematic for the few individuals who have a high abdominal depth. The desk of chair 6 had horizontal adjustment, which caused no problems. The width of the end portion of the chair's desk was determined based on the 95th percentile of the forearm width. The results showed that chairs number 3 and 7 had the least width in the elbow area, which could lead to pain in the elbow and forearm and discomfort while leaning the hand on the desk or when writing.

In this study, the desk length was less than the standard only in chairs 1 and 5. Desk length was equal to or greater than the recommended limit in the other chairs and that does not cause problems. Zarei et al. also reported that the seat dimensions and students' dimensions were matched only in desk length. It was calculated to be 50 cm [18], which was one centimeter different from the measure obtained in the present study. However, contradictory results were found in the studies performed by Taifa and Desai [23] and Thariq et al. [15]. An explanation for this contradiction might be the difference in dimensions and percentiles used in these studies; they used buttock-knee length [23] and the 50th percentile of elbow-fingertip length [15].

The backrest width was compared and determined by the 95th percentile of the users' shoulder width. This dimension was lower than the standard in chairs 2 and 4, which can lead to fatigue of the scapula and pain in various parts of shoulders. In the same line, Zare et al. demonstrated that the backrest width was less than the students' shoulder width [18]. To achieve a proper backrest design to support the shoulders, backrest height should be 60-80% of the

shoulder height [17], or it can be 100 mm lower than the shoulders so as not to restrict the arms movement [1]. In some cases, the 5th percentile of the shoulder height was used, which facilitates the movement of the waist and arms [30]. According to the results of combinational equations, the means of acceptable minimum and maximum backrest height were reported to be 36.3 and 48.4 cm, respectively. According to study of Gouvali and Boudolos, the backrest height should be between these two limits, and it is more appropriate if the backrest height is less than the shoulder height and lower than the scapula [17]. In the current study, the backrest height was computed as 46 cm. Examination of the chairs showed that chairs 2, 3, and 7 were an almost perfect fit for the students (99.3%). In the study by Bayatkashkoli and Nazerian, the chairs' backrest height was appropriate only for 14% of students, which was lower than for any chair in the current study [27].

5. Conclusions

Matching the dimensions of chairs with users' anthropometric dimensions and ergonomic indices could result in more comfort for university students in Iran. In the present study, investigation of the match between the chairs' dimensions and the students' anthropometric dimensions showed that none of the commonly used chairs in Iran's universities was completely fitted with anthropometric dimensions of the students. Chair 3 had the highest fitness in terms of seat height and the lowest fitness with regard to seat width. To prevent inappropriate body postures, chairs designs have to be fitted with Iranian students' anthropometric data. This can also ultimately reduce the risk of musculoskeletal disorders and increase the students' efficiency and concentration in classrooms.

Acknowledgements

The authors would like to thank the students at Qazvin University of Medical Sciences and laboratory staff at the Department of Occupational Health who cooperated in the study. They are also grateful for Ms. A. Keivanshekouh at the Research Improvement Center of Shiraz University of Medical Sciences for improving the use of English in the manuscript

Conflict of interest

The authors declare that there is no conflict of interest.

Contributors

All the authors have contributed substantially to data collection and manuscript preparation. No writing assistance from any agency has been employed in the preparation of this manuscript.

References

[1] Pheasant S, Haslegrave CM. Bodyspace: Anthropometry, ergonomics and the design of work (3rd Ed). CRC Press; 2018.

[2] Vink P. Comfort and design: principles and good practice. CRC press; 2004.

[3] Zare S, Hemmatjo R, Allahyari T, Hajaghazadeh M, Hajivandi A, Aghabeigi M, et al. Comparison of the effect of typical firefighting activities, live fire drills and rescue operations at height on firefighters' physiological responses and cognitive function. Ergonom. 2018;61(10):1334-44.

[4] Mahoney JM, Kurczewski NA, Froede EW. Design method for multi-user workstations utilizing anthropometry and preference data. App Ergonom. 2015;46:60-6.

[5] Mokarami H, Varmazyar S, Kazemi R, Taghavi SM, Stallones L, Marioryad H, Farahmand F. Low cost ergonomic interventions to reduce risk factors for work related musculoskeletal disorders during dairy farming. Work. 2019;64(2):195-201.

[6] Daneshmandi H, Kee D, Kamalinia M, Oliaei M, Mohammadi H. An ergonomic intervention to relieve musculoskeletal symptoms of assembly line workers at an electronic parts manufacturer in Iran. Work. 2018;61(4):515-21.

[7] Grimes P, Legg S. Musculoskeletal disorders (MSD) in school students as a risk factor for adult MSD: a review of the multiple factors affecting posture, comfort and health in classroom environments. J Human Environ System. 2004;7(1):1-9.

[8] Dianat I, Karimi MA ,Hashemi AA, Bahrampour S. Classroom furniture and anthropometric characteristics of Iranian high school students: proposed dimensions based on anthropometric data. App Ergonom. 2013;44(1):101-8.

[9] Vergara M, Page A. Relationship between comfort and back posture and mobility in sitting-posture. App Ergonom. 2002;33(1):1-8.

[10] Singh R, Yurteri-Kaplan LA, Morrow MM, Weaver AL, McGree ME, Zhu X, et al. Sitting versus standing makes a difference in musculoskeletal discomfort and postural load for surgeons performing vaginal surgery. Int Urogynecol J. 2019;30(2):231-7.

[11] Huang Y, Wang S, Wang T, He L. Effects of backrest density on lumbar load and comfort during seated work. Chin Med J. 2012;125(19):3505-8.

[12] Parvez M, Rahman A, Tasnim N. Ergonomic mismatch between students anthropometry and university classroom furniture. Theoretical Issues Ergonom Sci. 2019:1-30.

[13] Jung HS. A prototype of an adjustable table and an adjustable chair for schools . International J Ind Ergonom. 2005;35(10):955-69.
[14] Woo E, White P, Lai C. Ergonomics standards and guidelines for computer workstation design and the impact on users' health–a review. Ergonom. 2016;59(3):464-75.
[15] Thariq MM, Munasinghe H, Abeysekara J. Designing chairs with mounted desktop for university students: Ergonomics and comfort. Int J Indust Ergonom. 2010;40(1):8-18.
[16] Oyewole SA, Haight JM, Freivalds A. The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. Int J Indust Ergonom. 2010;40(4):437-47.
[17] Gouvali M, Boudolos K. Match between school furniture dimensions and children's anthropometry. App Ergon. 2006; 37(6):765-73.
[18] Zarei F, Vafaei B, Nikpey A, Varmazyar S, Safari-Variani A. Review the proportion of university seats with body dimensions of students at the School of Public Health of Qazvin University of Medical Sciences in 1388. Iran Occup Health. 2011;8(3):39-47.
[19] Basic human body measurements for technological design -- Part 1: Body measurement definitions and landmarks (ISO 7250-1:2017). Available at: https://www.iso.org/standard/65246.htm
[20] Falahati M, Zokaei M, Sadeghi Naeini H, Moradi GR. Determination of variables and anthropometric indicators for classroom chair design (Study group: Tehran University Medicine Science–2011). Iran Occup Health. 2013;10(2):99-108.
[21] Khanam CN, Reddy MV, Mrunalini A. Designing student's seating furniture for classroom environment. J Human Ecol. 2006;20(4):241-8.
[22] Kashif M, Bhattacharya A, Banerjee D. Design of Adjustable Desks and Chairs for University Classrooms Suitable For Students of Jadavpur University, India. Ergon Rural Develop. 2015:238-43.
[23] Taifa IW, Desai DA. Anthropometric measurements for ergonomic design of students' furniture in India. Engineer Sci Technol, an International Journal. 2017;20(1):232-9.
[24] Huang M, Hajizadeh K, Gibson I, Lee T. The Influence of Various Seat Design Parameters: A Computational Analysis. Human Factors and Ergonomics in Manufacturing & Service Industries. 2016;26(3):356-66.
[25] Hossein E, Reza K, Abolfazl M. Comparative survey of work related musculoskeletal disorders (WRMDs) prevalence and related factors in Iranian welders. Pak J Med Sci April-June. 2011;27(2):282-5.

[26] Grimes P, Legg S. Musculoskeletal disorders (MSD) in students as a risk factor for adult MSD: a review of the multiple factors affecting posture, comfort and health in classroom environments. J Human Environ System. 2004;7(1):1-9.
[27] Bayatkashkoli A, Nazerian M. Determination of proper college student chair dimension and comparison with the prevalent model. Iran J Wood Paper Sci Res. 2012;26(4):772-84.
[28] Molenbroek JFM, Kroon-Ramaekers YMT, Snijders CJ. Revision of the Design of a Standard for the Dimensions of School Furniture. Ergonom. 2003;46 (7):681-94.
[29] Parcells C, Stommel M, Hubbard RP. Mismatch of classroom furniture and student body dimensions: empirical findings and health implications. J Adolescent Health. 1999;24(4):265-73.
[30] Mokdad M, Al-Ansari M. Anthropometrics for the design of Bahraini school furniture. Int J Indust Ergonom. 2009;39(5):728-35.

Table 1. Combinational equations to determine the minimum and maximum acceptable dimensions of the chairs

Chair dimensions	**Equations**	**Body dimensions**
SH: Seat height	$(P+2)\cos 30° \leq SH \leq (P+2)\cos 5°$	P: Popliteal height
SD: Seat depth	$0.8PB \leq SD \leq 0.99PB$	PB: Popliteal-buttock length
SW: Seat width	$1.1H \leq SW \leq 1.30H$	H: Hip width
B: Backrest height	$0.6S \leq B \leq 0.8S$	S: Shoulder height (sitting)
D: Desk height	$E+[(P+2)\cos 30°] \leq D \leq [(P+2)\cos 5°] + (E0.8517) + (S0.1483)$	E: Elbow height (sitting)

Table 2. Anthropometric measurements of male, female, and all students

Anthropometric parameters*	Male					Female					All students				
	5th	50th	95th	Min-Max	Mean ± SD	5th	50th	95th	Min-Max	Mean ± SD	5th	50th	95th	Min-Max	Mean ± SD
Shoulder height (sitting)	57.4	64	68.5	55-70	63.6 ± 3.1	54.9	58	64	52-65	58.2±2.4	55	60	67	52-70	60.4±3.8
Elbow height (sitting)	18.5	25.2	29	18-36	25.1 ± 3.1	19.9	24	29	17-31	24.2±2.5	19.1	24.5	29	17-36	24.5±2.8
Popliteal height	36	41	44.7	34-63	41.2 ± 3.5	33	38	41	29-43	36.7±2.4	34.1	39	44	29-63	39.1±3.4
Knee height	47	52	57.1	46-59	52 ± 2.8	43.9	48	53	43-57	48.4±2.4	45	50	55.6	43-59	49.8±3.1
Shoulder breadth	33.6	37.2	42.6	32-44.4	37.7 ± 2.2	32.1	35.5	39.2	31.3-42.9	35.5±2.0	32.3	36.4	40.5	31-44	36.5±2.4
Hip width	32.3	36.4	40.9	31.4-42.3	36.4 ± 2.3	32.5	36.4	43.5	31.2-45.2	36.8±2.9	32.3	36.4	41.6	31-45	36.6±2.6
Elbow-fingertip length	44.1	47.2	51.1	42.5-52.3	47.4 ± 2.1	38.7	42.3	45.7	34.2-47.1	42.2±2.1	39.2	44.0	49.9	34-52	44.4±3.3
Buttock-popliteal length	47	50	58.5	44-61	50.8±3.2	41.9	46.5	51.1	38-55	46.6±3.0	43	48	55	38-61	48.3±3.7
Abdominal depth	20.4	24	28	30-20	24.5±2.1	18.9	22	28	16-34	22.9±2.8	20	23	28	16-34	23.5±2.7
Forearm width	6.8	8.2	9.5	6.4-9.9	8.3±0.8	6.1	7.1	8.4	4.4-9.4	7.15±0.6	6.3	7.5	9.3	4-10	7.6±0.9
Thigh thickness	12.3	15.2	19.7	11.2-23	15.9±2.2	11	14	18	9-20	13.8±2.0	11.3	14.5	19	9-23	14.6±2.3

*All dimensions are in cm.

Table 3. Dimensions of the studied university chairs

Dimensions*	Type of chair						
	Cream (1)	**Blue (2)**	**Brown (3)**	**Yellow (4)**	**Brown (5)**	**Red (6)**	**Pink (7)**
Seat height	45.5	48	44	44.5	49	46	48
Seat depth	43	40	40.5	37.5	42	48	43
Seat width	44	41.5	39	40	45	46	42
Desk height	23	28	27.5	25.5	20.5	23	24
Armrest width	10.5	11.5	6.5	9	9	11	5
Desk width	28	27.5	32	25.5	31.5	35	28
Desk length	48	51	60	51	50	51	60
Backrest width	47	40	45	40.5	49	46	43
Backrest height	38	41.5	43	45.5	51	45	43

*All dimensions are in cm.

Table 4. The recommended ergonomic measurements of the chair dimensions

Chair dimensions	Anthropometric parameters	Ergonomic chair dimensions	
		Criteria determinant	Design dimension*
Seat height	Popliteal height	5th percentile of female popliteal height	332
Seat depth	Buttock-popliteal length	5th percentile of female buttock-popliteal length	420
Seat width	Hip width	95th percentile of female hip width	436
Desk height	Elbow height (sitting)	50th percentile of all elbow height	245
Desk width	Forearm width	95th percentile of male forearm width	95
Desk length	Elbow-fingertip length	95th percentile of male elbow-fingertip length	511
Backrest width	Shoulder breadth	95th percentile of male shoulder breadth	426
Backrest height	Shoulder height (sitting)	5th percentile of female shoulder height	550
Desk distance	Abdominal depth	95th percentile of male abdominal depth	281

*All dimensions are in mm.

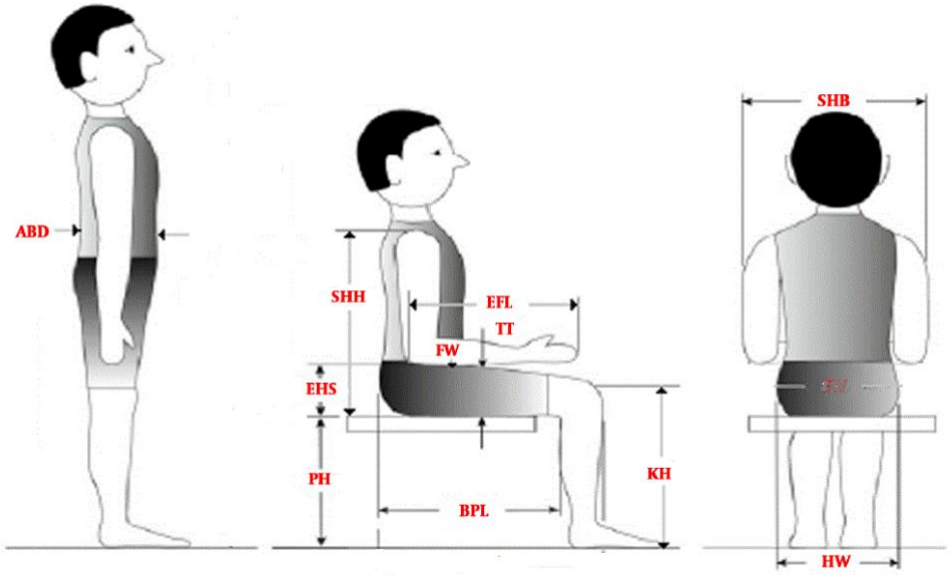

Figure 1. Anthropometric dimensions of the students

SHH, shoulder height; EHS, elbow height sitting; SHB, shoulder breadth; PH, popliteal height; KH, knee height; HW, hip width; EFL, elbow-fingertip length; BPL, buttock-popliteal length; ABD, abdominal depth; FW, forearm width; TT, thigh thickness.

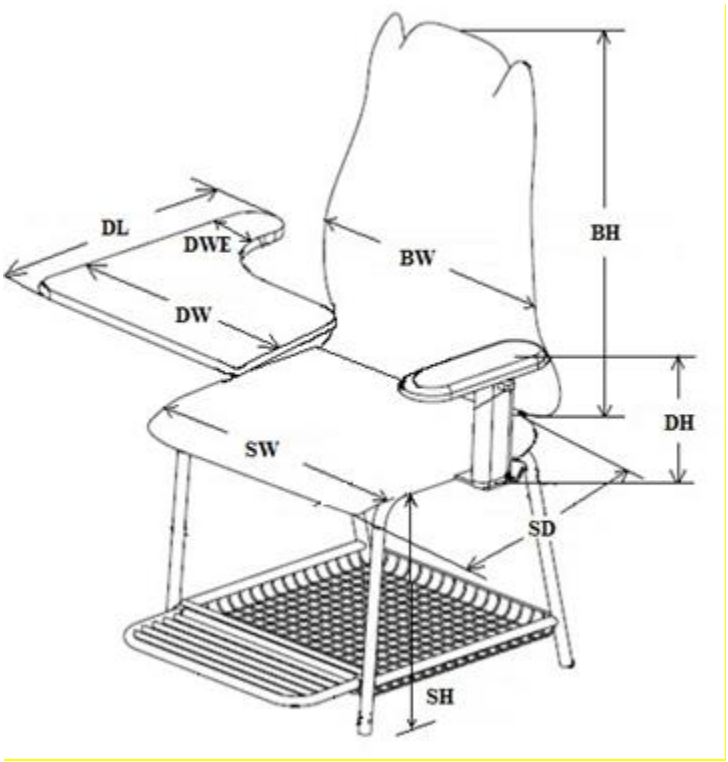

Figure 2. Dimensions of the classroom chairs

SH, seat height; SD, seat depth; SW, seat width; DH, desk height; DWE, armrest width elbow; DW, desk width; DL, desk length; BW, backrest width; BH, backrest height.

1 2 3 4

5 6 7

Figure 3. The chairs examined in the study

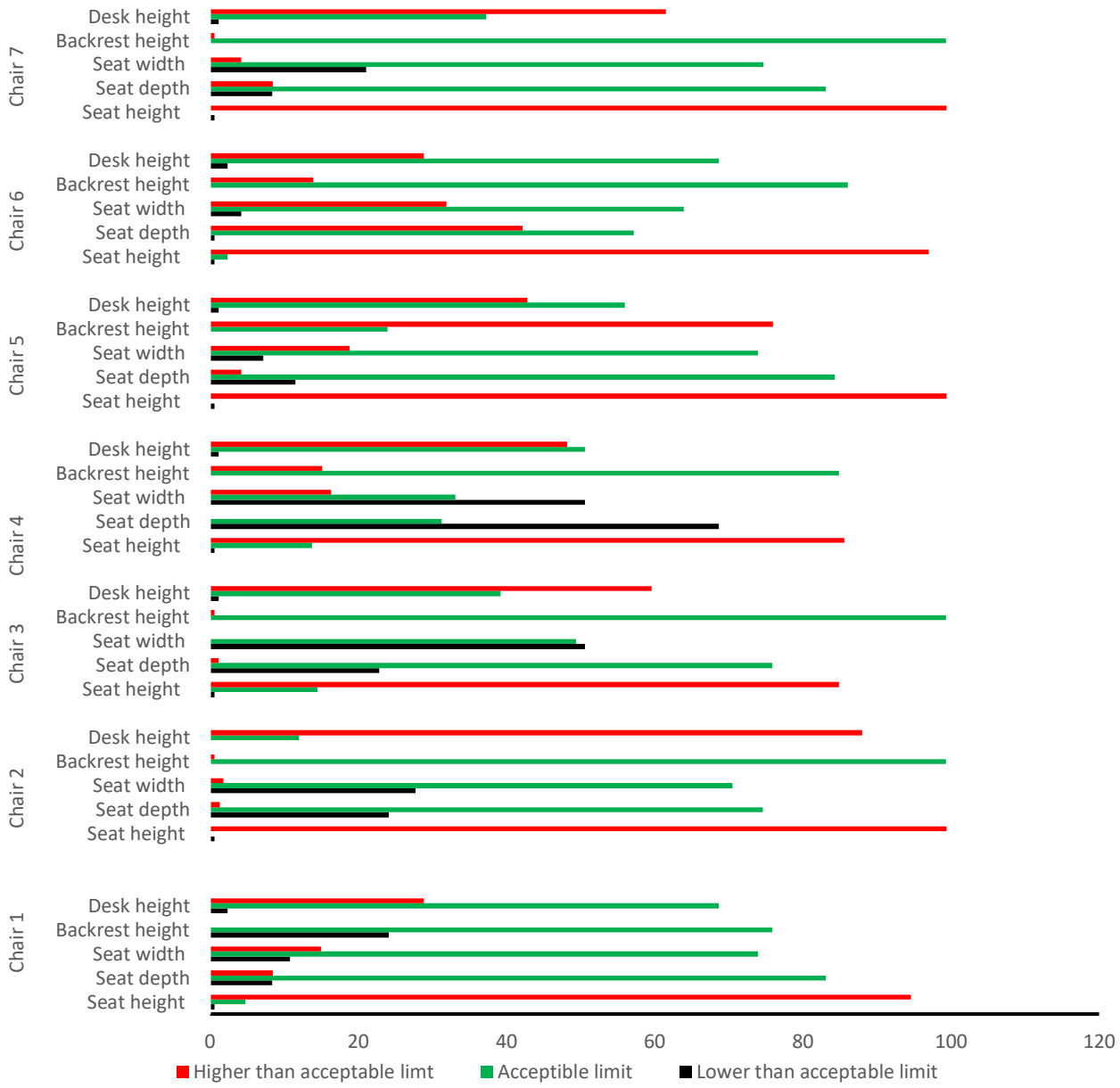

Figure 4. Percentage of match between the chairs' dimensions and the students' anthropometry