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Full Length Research Paper

An analysis of biomechanical and anthropometric parameters on classroom furniture design

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In this study, the necessary anthropometric measurements of classroom furniture used in Turkish higher education were carried out. The static anthropometric measurements of 13 dimensions from 1049 students were obtained while they are standing and sitting. The data obtained was analyzed to determine the limit values to be used in classroom and laboratory design. The dimensions of school desks and chairs were compared with the student's anthropometric measurements. For male students, the average weight was found as 69.50 kg, stature as 1749 mm, and popliteal height as 433 mm. For female students, the average weight was found as 56.02 kg, stature as 1618 mm, and popliteal height as 421 mm values. According to these anthropometric measurements, it was observed that there was a mismatch between popliteal height and seat height, knee height and desk clearance, buttock to popliteal length and seat depth. The percentile values concerning the ergonomic design of school desks and chairs in our classrooms were presented. The results show that there are significant differences between the anthropometric measures of Turkish students and other nations compared.

Key words: Anthropometry, biomechanics, ergonomic design, classroom furniture.

INTRODUCTION

The comfort, physical health, well-being, and performance of people can be increased by designing equipment, goods, furniture, and other devices according to the needs of the human body. One of the conditions to support productivity is to ensure that the work spaces and equipment that people use conform to the anthropometric and biomechanical characteristics of the users.

Anthropometric data are used in ergonomics to specify the physical dimensions of work spaces, equipment, furniture, and clothing (Bridger, 1995; Kayis and Ozok, 1991; Jeong and Park, 1990). Appropriate use of anthropometry in design may improve the well-being, health, comfort, and safety of a product's users (Pheasant, 1998; Barroso et al., 2005). The use of poorly designed furniture, especially school desks and tables, that fails to account for the anthropometric characteristics of its users has a negative influence on human health. A surprising number of grade school children and adolescents are reported to have regular bouts of back, neck, and headache pain (Salminen, 1984; Parcells et al., 1999).

These students use school furniture extensively during the most important period of their physical development (Paulsen and Hensen, 1994; Knight and Noyes, 1999). In the developed countries, middle-aged people who suffer from backache often report that their backache started when they were in their twenties, the period when many of them are still attending university (Watson et al., 2002). Based on these reports, researchers discovered that school children suffer from backaches, and in recent years a considerable amount of research has been performed on this matter (Burton et al., 1996; Watson et al., 2002; Murphy et al., 2004). The student's sitting posture is influenced by the activities performed in the classroom, but also by the anthropometric measures of the children and the measurements and design features of the school furniture they use (Yeats, 1997; Panagiotopoulou et al., 2004).

Specific measurements such as popliteal height, knee height, buttock to popliteal length and elbow height are necessary in order to determine the dimensions of school furniture that will enable students to maintain the correct

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sitting posture (Knight and Noyes, 1999; Parcells et al., 1999; Panagiotopoulou et al., 2004). Anthropometric data have been used in the design of school desks and tables in almost all modern developed countries (Parcells et al., 1999).

As we noted earlier, furniture has a significant effect on human health. Thus, it is essential to use anthropometric data to guide the design of school desks and chairs. However, because anthropometric measures vary among nations and ethnic groups and change over time as populations and their environmental conditions change. As a result, the anthropometric data used in the design of the equipment used in Turkish higher education are based on anthropometric data from other countries and thus do not represent the average body measurements of the Turkish people (Kayis, 1988; Turgut et al., 2004). Therefore, it is necessary to collect new data from this population to support ergonomic design.

In the present study, we obtained anthropometric measures that could be used in the design of the desks and chairs used in higher education for the Turkish people and calculated ranges for this data. We also compared the findings with the results of previous studies in Turkey and several other regions.

MATERIALS AND METHODS

To obtain the necessary anthropometric data, we studied the students in various faculties of Turkey's Zonguldak Karaelmas University in 2007 and summarized the anthropometric measurements to assist in the design of the equipment used in the higher education. Our sample included 1049 students (335 females, 714 males) with no physical disabilities. We found two main models of desk and chair in common use at the university, and measured their dimensions (seat height, seat depth, desk height, desk clearance) to allow a comparison of the students ergonomic needs with the design features of these desks and chairs. The dimensions of the classroom furniture that were measured are the following:

- Seat height: vertical distance from the floor to the highest point on the front of the seat.
- Seat depth: horizontal distance of the sitting surface from the back of the seat to the front of the seat.
- Desk height: vertical distance from the floor to the top of the front edge of the desk.
- Desk clearance: vertical distance from the floor to the bottom of the front edge of the shelf under the writing surface.

The data we obtained by measuring the different dimensions of the students' bodies in fixed positions represent static anthropometric data. In static anthropometry, the measurements are made either from one anatomical structure to another or with reference to a fixed point in space. Static anthropometric data are widely used in determining the dimensions of furniture (Ozok, 1988; Sabancı, 1999; Kaya et al., 2003; Dizdar, 2003). In the present study, we studied only static anthropometry.

In our study, we measured anthropometric characteristics directly, as this is an economical and practical empirical method; unlike indirect measurements, this empirical method makes no assumptions about the correlation between an indirect parameter and the direct parameter that it assesses (Sabancı, 1999; Kroemer, 1997). The simplicity greatly reduces the costs of the survey, and the mobility of the equipment makes it easy to record measurements at a range of locations. We obtained length measurements using an anthropometer, weight measurements using a balance accurate to 100 g, and the other measurements using measuring tapes.

Based on the results of our literature review, we selected the 13 most common anthropometric parameters and measured these parameters for each student involved in the study, wearing clothes, including their weight (Table 1).

The most important purpose of our study was to develop design standards suitable for almost all of the intended users of the products. In most studies concerning the body sizes, 90% of the users are targeted (Pheasant, 1998). In designs that depend strongly on volumes, 95% percentile values are used, versus 5% percentile values in studies of reach (Güler, 2003; Bridger, 1995; Barut et al., 2004). For school furniture, seat height and depth are determined according to the lowest 5% percentile values, whereas the breadth of the sitting surface is determined according to the 95% percentile values of hip breadth (Parcells et al., 1999; Su, 2001). In our study, we determined the upper and lower limits of the design parameters using the 5% values for female students and the 95% values for male students.

To compare our anthropometric measurements with the results of previous studies in Turkey and other regions, we used the average values of our 13 anthropometric measures and the key percentile values (5 and 95%). Anthropometric measures of students were compared to the relative furniture measures in order to identify a mismatch between the students and the furniture they use.

RESULTS

Descriptive and percentile values for the dimensional measurements of the students are provided in Table 2 for females and males. We obtained the following average values:

- For male students, a mean weight of 69.50 kg, stature of 1749 mm, and popliteal height of 433 mm.
- For female students, a mean weight of 56.02 kg, stature of 1618 mm, and popliteal height of 421 mm.

Moreover, we calculated the following values for the most important body measurements used in the ergonomic design of school desks and chairs: the 5% value for the buttock to popliteal length in a sitting position was 406 mm, the 95% value for shoulder breadth was 464 mm, the 5% value for popliteal height sitting was 386 mm, the 95% value for hip breadth was 391 mm, and the 95% value for knee height in a sitting position was 596 mm.

The classroom furniture under study consisted of two models of chair and desk. The dimensions of the chairs and desks are given in Table 3.

- Popliteal height and seat height mismatch: A mismatch was defined when the seat height was either > 95% or < 88% of the popliteal height. This allows for popliteal clearance of between 5 and 12% of popliteal height (Parcells et al., 1999). For Turkish students, the values should have been between 386 and 407 mm. However, according to the anthropometric measurements, it was observed that there was a mismatch.
- Buttock to popliteal length and seat depth mismatch: A mismatch was defined when the seat depth was either

Table 1. Definitions of the 13 measured anthropometric dimensions in the present study

Anthropometric dimensions		
W	Weight (kg)	Body weight
S	Stature (mm)	Vertical distance from the floor to the vertex (i.e., the crown of the head)
Sb	Shoulder breadth (mm)	Maximum horizontal breadth across the shoulders, measured to the protrusions of the deltoid muscles
Hb	Hip breadth (mm)	Maximum horizontal distance across the hips in the sitting position
Si	Sitting height (mm)	Vertical distance from the sitting surface to the vertex
Ey	Eye height, sitting (mm)	Vertical distance from the sitting surface to the inner canthus of the eye
Sh	Shoulder height (mm)	Vertical distance from the floor to the acromion (i.e., the bony tip of the shoulder)
Eh	Elbow height, sitting (mm)	Vertical distance from the seat surface to the underside of the elbow
Bk	Buttock to front of knee length, sitting (mm)	Horizontal distance from the back of the uncompressed buttock to the front of the kneecap
Bp	Buttock to popliteal length, sitting (mm)	Horizontal distance from the back of the uncompressed buttocks to the popliteal angle, at the back of the knee, where the back of the lower legs meets the underside of the thigh
Kh	Knee height (mm)	Vertical distance from the floor to the upper surface of the knee
Ph	Popliteal height, sitting (mm)	Vertical distance from the floor to the popliteal angle at the underside of the knee where the tendon of the biceps femoris muscle is inserted into the lower leg
Hf	Horizontal fingertip reach (mm)	Distance from the acromion to the fingertip with the elbow and wrist straight

> 95% or < 80% of the buttock to popliteal length (Parcells et al., 1999; Panagiotopoulou et al., 2004). For Turkish students, the values should have been between 406 and 430 mm. However, according to the anthropometric measurements, it was observed that there was a mismatch.

- Knee height and desk clearance mismatch: A mismatch was defined as occurring when a desk was < 20 mm higher than the knee height (Parcells et al., 1999; Panagiotopoulou et al., 2004). For Turkish students, the value should have been 616 mm. However, according to the anthropometric measurements, it was observed that there was a mismatch.

In Table 4, we compare the results of our study with those from previous studies. The parameters for the Turkish students were larger than those of some other countries and smaller than those of other countries. However, the key point revealed by this table is that each anthropometric parameter varied, often widely, between ethnic groups.

DISCUSSION

To compare our data with the anthropometric data in other recent studies, we began with a recent Turkish study (Turgut et al., 2004) carried out at Cukurova University. We then added data from studies conducted in other countries: Portugal (Barroso et al., 2005), the U.K. (Pheasant, 1998), Iran (Mououdi, 1997), China (Lee, 2000). In this comparison, we used the 13 anthropometric dimensions in the present study, as most of these dimensions were also used in the other studies. Table 4 presents the mean data for male and female adults of different ethnic groups.

Table 4 reveals that the anthropometric dimensions for the female and male students in the present study were similar to those reported by Turgut et al. (2004) but differed from those in other countries. For example, the male stature (1749 mm) was nearly the same as in the other Turkish study (1758 mm), but was smaller in China (1678 mm), Iran (1725 mm), Korea (1707 mm), Portugal (1690 mm), and the U.K. (1740 mm). In addition:

- Most results in the two Turkish studies were similar for each sex.
- For both sexes, the Turkish values for stature, eye height, elbow height, buttock to front of knee length, buttock to popliteal length, popliteal height, and horizontal fingertip reach were larger than the corresponding values for other nations.
- For both sexes, Turkish shoulder breadths were smaller than those of other nations.
- For Turkish females, the sitting height was

Table 2. Mean, standard deviation (SD), and 5 and 95% percentiles for anthropometric dimensions of the female and male population

	Female anthropometric dimensions						Male anthropometric dimensions					
	Mean	**SD**	**5%**	**95%**	**Max.**	**Min.**	**Mean**	**SD**	**5%**	**95%**	**Max.**	**Min.**
W	56.02	3.92	43.29	68.97	79.00	42.00	69.50	4.38	56.10	83.97	103.0	54.00
S	1618	3.72	1495	1739	1780	1450	1749	3.35	1640	1859	1940	1610
Sb	391	1.08	358	414	420	340	431	1.02	397	464	490	380
Hb	350	1.21	309	390	405	290	351	1.14	314	391	440	300
Si	835	2.17	760	898	900	730	912	5.04	744	1022	1040	730
Ey	761	2.17	692	835	890	660	814	2.62	738	911	960	650
Sh	593	2.13	524	665	740	510	612	1.62	558	665	700	400
Eh	265	1.42	223	317	380	210	237	1.21	197	276	330	190
Bk	573	2.20	502	646	700	480	609	1.98	546	674	710	440
Bp	481	2.43	406	561	640	400	488	1.95	424	551	590	320
Kh	507	1.68	457	571	610	450	547	1.53	496	596	660	480
Ph	421	1.42	386	463	510	370	433	1.12	405	461	500	400
Hf	815	2.30	742	897	960	730	863	2.75	775	954	970	530

Table 3. Chair and Desk Characteristics

	Chairs		Desks	
	Seat Height (mm)	**Seat Depth (mm)**	**Height (mm)**	**Clearance (mm)**
Type – 1	460	320	760	600
Type – 2	430	400	770	590

lower than in the other nations; for males, the sitting height values were generally similar.

The most important percentile values obtained from the anthropometric measurements in these studies (summarized in Table 4) are presented in Table 5. In the table, the most important dimensions of the students related to the ergonomic design of school desks and chairs are compared with the 5% values from the female measurements and the 95% values from the male measurements (Mououdi, 1997; Turgut et al., 2004; Barroso et al., 2005). We found the following key differences:

- For females, the 5% value for the buttock to popliteal length was 421 mm in Portugal, versus 390 to 406 mm in the Turkish studies. This means that seats designed for Portuguese females will be too long for some Turkish females.
- For males, the 95% value for shoulder breadth was 525 mm in Portugal and 497 mm in Iran, versus 464 to 507 mm in the Turkish studies. This means that the room available between seating positions at desks or chairs designed for Portuguese males would be wider than necessary for Turkish males, whereas the space provided by desks designed for Iranian males might be too narrow.
- For females, the 5% value for popliteal height was 327 mm in Portugal and 317 mm in Iran, versus 283 to 386 mm in the Turkish studies. This suggests that it might not be necessary to design for different popliteal heights for females in these countries.
- For males, the 95% value for hip breadth was 420 mm in Portugal and 377 mm in Iran, versus 391 to 431 mm in the Turkish studies. This suggests that it might not be necessary to design for different seat spacings for males in these countries.
- For males, the 95% value for knee height in a sitting position was 575 mm in Portugal and 571 mm in Iran, versus 581 to 596 mm in the Turkish studies. This suggests that desks should be designed to accommodate the greater knee heights in Turkey.

These data make it obvious that the results of the studies carried out in Turkey and in the five other countries differed. However, designers should remember that anthropometric dimensions also vary over time, even within a nation. For example, in North America and Europe, stature has increased by an average of 10 mm and weight has increased by an average of 2 kg every 10 years over the past 50 years (Bridger, 1995; Kroemer et al., 2001). Similarly, the stature of people in the Far East has increased considerably over the past 20 years (Helander, 1995). In this respect, designers should use the science of anthropometry to constantly monitor and

Table 4. Mean values for the anthropometric dimensions obtained for adult male and female populations from several regions of the world in comparison with the data obtained in the present study. (NA = data not reported or the definition of the measurement differed between studies)

	Turkey				China		Iran		Korea		Portugal		U.K.	
	Present study		Turgut et al.											
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
W	69.50	56.02	74.45	55.59	59.0	52.0	65.66	56.52	66.0	53.5	74	64	NA	NA
S	1749	1618	1758	1638	1678	1570	1725	1597	1707	1588	1690	1565	1740	1610
Sb	431	391	459	404	431	397	455	392	451	406	475	445	465	395
Hb	351	350	380	371	306	317	342	363	322	319	380	400	360	370
Si	912	835	888	854	908	855	912	861	921	866	920	865	910	850
Ey	814	761	NA	NA	798	739	805	753	809	758	810	760	790	740
Sh	612	593	591	550	NA	NA	620	598	NA	NA	630	595	595	555
Eh	237	265	229	217	263	251	259	259	265	263	255	250	245	235
Bk	609	573	605	580	554	529	530	487	553	528	590	570	595	570
Bp	488	481	459	440	457	433	NA	NA	470	449	485	470	495	480
Kh	547	507	533	491	493	458	NA	NA	508	470	525	480	545	500
Ph	433	421	NA	NA	413	382	431	364	410	384	400	365	440	400
Hf	863	815	862	793	826	757	775	698	821	760	NA	NA	NA	NA

Table 5. Anthropometric dimensions (5 and 95% percentiles) from different adult female and male populations

	Female anthropometric dimensions								Male anthropometric dimensions							
	Turkey				Portugal		Iran		Turkey				Portugal		Iran	
	Present study		Turgut et al.						Present study		Turgut et al.					
	5%	95%	5%	95%	5%	95%	5%	95%	5%	95%	5%	95%	5%	95%	5%	95%
Sb	358	414	370	439	394	496	359	437	397	464	410	507	425	525	419	497
Hb	309	390	325	418	355	445	318	411	314	391	329	431	340	420	311	377
Bp	406	561	390	490	421	520	NA	NA	424	551	408	510	432	538	NA	NA
Kh	457	571	449	533	435	475	451	493	496	596	485	581	475	575	493	571
Ph	386	463	283	342	327	403	317	431	405	461	287	400	358	442	400	465

assess body measurements in order to detect anatomical differences among individuals and groups that would lead to changes in product design (Helander, 1997; Kroemer, 1997; Akın and Sagır, 1998).

Although the individuals measured in the present study were chosen from the same university, they represent a partial example of Turkey as a whole, since the students have come from different regions of Turkey. The differences observed between the two Turkish studies suggest that these regional differenc-

es may be sufficiently great to require further research to clarify their magnitude.

Conclusion

Our results show that the chairs and desks in our classrooms were designed without accounting for the anthropometric measurements of Turkish students. Most students are sitting in chairs with seats that are too high and too shallow. Also desk clearances are too low. They were designed according to measurements of students from other nations, which differed greatly from those of Turkish students.

The studies that have been carried out thus far show that anthropometric measures vary widely among nations and (as shown by the Turkish data) within nations. Anthropometric measures should thus be determined through more detailed studies so that desks can be designed to provide better ergonomic conditions for Turkish university students. Despite this problem, it remains an obligation for manufacturers to account for anthropometric data in the design of their products. Manufacturers should remember that the protection of the physical and mental health of the users of their products depends on using equipment that has been produced according to ergonomic norms.

Our study provided additional data on the anthropometric dimensions of Turkish university students. This data will be very useful in guiding the design of future equipment to be used in the classrooms, libraries, laboratories, and theaters or conference halls of universities.

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