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Match between school furniture dimensions and children's anthropometry

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Abstract

The purpose of the study was to examine whether school furniture dimensions match children's anthropometry. Children aged 6–18 years ($n = 274$), divided into 3 groups on the basis of the used furniture size, were subjected into anthropometric measurements (shoulder, elbow, knee and popliteal height, buttock-popliteal length and hip breadth). Combinational equations defined the acceptable furniture dimensions according to anthropometry and match percentages were computed, according to either the existing situation—where children use the size assigned for their grade—or assuming that they could use the most appropriate of the sizes available. Desk and seat height were bigger than the accepted limits for most children (81.8% and 71.5%, respectively), while seat depth was appropriate for only 38.7% of children. In conclusion, the assumption that children could use the most appropriate yet available size significantly improved the match, indicating that the limited provision of one size per cluster of grades does not accommodate the variability of anthropometry even among children of the same age.

Keywords: Anthropometry; School; Furniture

1. Introduction

Ergonomics in work environments has gained high attention from researchers over recent decades. One main concern is that equipment should be designed according to principles of anthropometry, biomechanics and hygiene (Grieco, 1986) and should help to reduce accidents and overuse syndromes in order to promote productivity. Although school environment represents the "work" environment for billions of children, it has not attracted the proper attention from ergonomists.

Uncomfortable postures could be painful due to the prolonged periods children spend at school (Aagaard-Hansen and Storr-Paulsen, 1995; Murphy et al., 2004) and several researchers have reported posture-related syndromes in students (Knight and Noyes, 1999; Milanese and Grimmer, 2004; Troussier et al., 1999). Moreover, it is possible that children may maintain those postural behaviors for the rest of their lives (Cardon et al., 2004; Floyd and Ward, 1969).

Many authors have tried to establish theoretical recommendations for the principles that relate school furniture design to children's anthropometry, and some have also attempted to define the "appropriate" dimensions for school furniture based on anthropometric measurements. In Iran (Mououdi and Choobineh, 1997), Korea (Jeong and Park, 1990), Seoul and Pousan (Cho, 1994), there have been studies related to school furniture design that have investigated differences in body dimensions due to age and gender. In some countries there were attempts to design desks and chairs based on anthropometric data (Evans et al., 1988; Hibaru and Watanabe, 1994; Hira, 1980; Noro and Fujita, 1994; Oxford, 1969; Shih et al., 1966). Parcells et al. (1999) studied the mismatch between furniture and students' dimensions by measuring anthropometric characteristics of American

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children aged 11–13 years and the dimensions of their classrooms' desks and chairs, reporting that only 18.9% of students could find an appropriate match.

Molenbroek and Ramaekers (1996) stated that, based on anthropometric data, every country can design fitting furniture for school children. This would require up-to-date measures from the relevant population (age 4–20 years), including at least 40 subjects from each age group and gender. They further attempted to apply such a system to Dutch, English and German children (Molenbroek et al., 2003). However, the existing anthropometric data cannot be properly utilized by any population because of two major restraints: racial/ethnic and socio-economic differences in anthropometry, as well as periodic changes in anthropometry (Corlett and Clark, 1995; Evans et al., 1988; Molenbroek et al., 2003; Orborne, 1996; Oxford, 1969; Ray et al., 1995; Sanders and McCormick, 1993; Shih et al., 1966).

In Greece, anthropometric research for design purposes has yet to be conducted on students of any grade. Instead, school furniture dimensions are based on anthropometric data from other countries. Therefore, the purpose of the present study was to examine the match between the dimensions of school desks and seats and the anthropometric characteristics of Greek children.

2. The study

2.1. Participants

Six schools in Athens were selected and permission was obtained by the Greek Ministry of Education and the Institute of Pedagogy to conduct the study. The sample covered every school grade and consisted of 274 children (6–18 years old). It was divided into three groups with regard to the furniture size used by each grade (Greek Organization for School Buildings, 1996). Therefore, children from 6 to 9 years old were included in group J1 (size 1), children from 9 to 12 years old participated in group J2 (size 2) and 12 to 18 years old in group H (size 3). Table 1 shows the sample characteristics.

2.2. Methods

Anthropometric measures were collected with children sitting on a specially designed anthropometric chair (see Fig. 1a). They were instructed to sit in such a way that their thighs were in full contact with the seat, their lower and upper legs were at right angles, their feet were placed on a moving footrest and their trunk was upright. The backrest was then moved so that it contacted the back and the buttocks (see Fig. 1b and c).

2.3. Equations relating body dimensions to school furniture dimensions

The use of anthropometric data for designing school furniture requires a simultaneous evaluation of pedagogical, financial, anatomical and ergonomic principles. Theoretical and practical ergonomic principles were utilized in the modulation of combinational equations that define the minimum and maximum limits between which each dimension is considered appropriate:

Seat height (*SH*): SH needs to be adapted relatively to popliteal height (Corlett and Clark, 1995; Dul and Weerdmeester, 1998; Helander, 1997; Occhipinti et al., 1993; Oxford, 1969), allowing knees to be flexed so that the lower legs form a maximum of 30° angle relative to the vertical axis (Molenbroek et al., 2003). Parcells et al. (1999) considered seat heights of >95% or <88% of the popliteal height as "mismatched".

The equation below declares that seat height should be lower than popliteal height so that (1) the lower leg constitutes a 5–30° angle relative to the vertical and (2) the shin-thigh angle is between 95 and 120°. In our case, a 2 cm correction for shoe height was added to popliteal height (Evans et al., 1988; Occhipinti et al., 1993; Sanders and McCormick, 1993; Shih et al., 1966).

$$(P+2)\cos 30^\circ \leqslant \mathrm{SH} \leqslant (P+2)\cos 5^\circ. \quad (1)$$

Seat depth (*SD*): Most researchers report that seat depth should be designated for the fifth percentile of popliteal-buttock length distribution, including even the shorter users (Helander, 1997; Khalil et al., 1993; Milanese and Grimmer, 2004; Occhipinti et al., 1993; Orborne, 1996; Pheasant, 1991; Sanders and McCormick, 1993; Shih et al., 1966). Poulakakis and Marmaras (1998) mentioned that depth should be at least 5 cm shorter than popliteal-buttock length. For children, Parcells et al. (1999) defined as mismatch the case when depth was ⩽80% or ⩾95% of popliteal-buttock length. Since the present study represented an initial attempt to examine the potential

Table 1
Mean(±SD) age (years), body stature (cm) and body mass (kg) for all groups (J1, J2, H) and per gender (B: boys, G: girls)

Group	Age	Body stature			Body mass		
		B	G	Total	B	G	Total
J1	7.4±0.9	126.5±7.3	124.6±7.4	125.6±7.3	30.1±6.8	27.9±5.2	29.0±6.1
J2	10.2±0.8	140.8±8.5	141.4±10.3	141.1±9.4	39.4±9.4	38.5±9.2	39.0±9.3
H	14.8±1.7	169.0±10.7	161.0±6.8	165.0±9.7	64.3±14.2	56.1±9.8	60.2±12.8

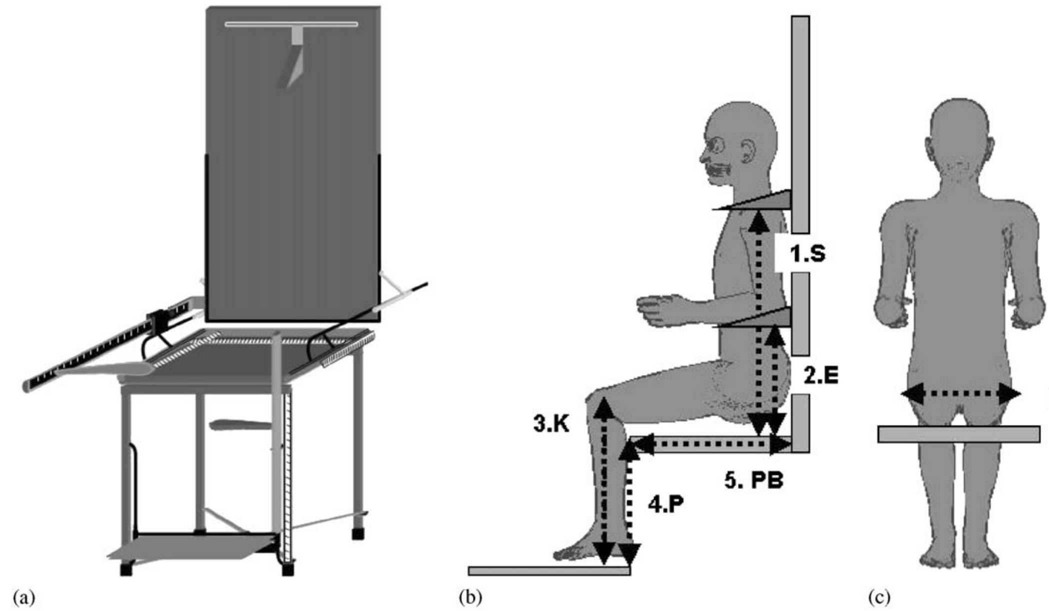


Fig. 1. Visual representation of (a): anthropometric chair, (b) anthropometric measurements (lateral view) and (c) anthropometric measurements (posterior view). (1) Shoulder height (*S*): from seat to acromioclavicular joint, (2) *Elbow rest height* (*E*): from seat to humeroulnar edge (forearms parallel to the seat and elbows at right angles), (3) *Knee height* (*K*): from footrest to the top of the knee—between femoral condyles (thighs and shins at right angles), (4) *Popliteal height* (*P*): from footrest to the poples (thighs and shins at right angles), (5) *Popliteal-buttock length* (*PB*): from backrest to the tendon of thighs biceps and (6) *Hip breadth* (*H*): the distance between buttocks.

mismatch, the upper limit was further increased to 99% of popliteal-buttock length and the equation was modified as follows:

$$0.80PB \leqslant \mathrm{SD} \leqslant 0.99PB. \quad (2)$$

Seat width (*SW*): SW should be enough to support ischial tuberosities in order to achieve stability and allow space for lateral movements (Corlett and Clark, 1995; Khalil et al., 1993; Shih et al., 1966) and for that, it should be large enough to accommodate even the users with the largest hip breadth (Evans et al., 1988; Helander, 1997; Occhipinti et al., 1993; Orborne, 1996; Sanders and McCormick, 1993). The modified equation proposes that seat width should be at least 10% (to accommodate hip breadth) and at the most 30% larger than hip breadth (for space economy):

$$1.1H \leqslant \mathrm{SW} \leqslant 1.30H. \quad (3)$$

Backrest height (*B*): *B* is considered appropriate when it is below scapula (Evans et al., 1988; Orborne, 1996; Shih et al., 1966) to facilitate mobility of the trunk and arms (Karvonen et al., 1962; Khalil et al., 1993).

As a result, the equation recommends keeping the backrest lower than the scapula, or at most on the upper edge of the scapula (60–80% of shoulder height):

$$0.6S \leqslant B \leqslant 0.8S. \quad (4)$$

Desk height (*D*): Most researchers consider elbow rest height as the major criterion for desk height (Dul and Weerdmeester, 1998; Milanese and Grimmer, 2004; Oxford, 1969; Sanders and McCormick, 1993), based on the fact that there is a significant reduction in the load on the spine when arms can be supported on the desk (Occhipinti et al., 1985). Evans et al. (1988) proposed a relatively low desk height, at 95% of sitting elbow height. Bendix and Bloch (1986), Pheasant (1991), and Poulakakis and Marmaras (1998) concluded that the desk should be 3–5 cm higher than the elbow. Parcells et al. (1999) suggested that desk height should be adjusted to elbow-floor height, so that it would be minimum when shoulders are not flexed or abducted, and maximal when shoulders are at 25° flexion and 20° abduction (elbow rest height × 0.8517 + shoulder height × 0.1483; Parcells et al., 1999). The equation has further been modified based on the fact that elbow-floor height is the sum of elbow rest height and seat height (as it has been defined in Eq. (1)):

$$E + [(P+2)\cos 30^\circ] \leqslant D \leqslant [(P+2)\cos 5^\circ] + (E0.8517) + (S0.1483). \quad (5)$$

Underneath desk height (*UD*): UD should be enough so that there is space between the knees and the underneath surface of the desk (Dul and Weerdmeester, 1998; Evans et al., 1988; Helander, 1997; Sanders and McCormick, 1993). Mandal (1997) and Parcells et al. (1999) proposed that the desk clearance should be at least 2 cm, while Poulakakis and Marmaras (1998) proposed at least 5 cm of clearance. According to Corlett and Clark (1995) and Helander (1997), this space should also allow for knee crossing.

In accordance with the above, the equation considered as appropriate the case that underneath desk height was at least 2 cm higher than knee height (but not higher than

Table 2
Dimensions (cm) of the three furniture sizes (Greek Organization for School Buildings, 1996) and means (SD) of minimum (min) and maximum (max) accepted limits (cm) for each group and gender

Furniture dimensions	Gender	Group J1			Group J2			Group H		
		Size 1	Min	Max	Size 2	Min	Max	Size 3	Min	Max
Seat height (SH)	B	35.0	28.9±2.0	33.3±2.3	39.0	32.8±2.3	37.8±2.7	44.5	38.7±2.7	44.5±3.1
	G		28.4±2.1	32.6±2.4		32.6±2.3	37.5±2.7		36.4±1.8	41.8±2.1
Seat depth (SD)	B	34.0	27.6±2.1	34.1±2.6	34.0	31.6±2.5	39.2±3.1	36.0	39.2±3.0	48.5±3.7
	G		27.7±2.1	34.2±2.6		32.3±2.9	40.0±3.5		37.8±2.4	46.8±3.0
Seat width (SW)	B	39.2	31.0±3.3	36.6±3.9	39.2	34.0±3.9	40.2±4.7	41.7	38.3±3.5	45.3±4.1
	G		29.9±2.5	35.4±2.9		34.2±3.4	40.4±4.0		39.1±2.8	46.2±3.3
Backrest height (*B*)	B	35.0	26.2±1.6	34.9±2.2	37.0	28.7±2.2	38.3±2.9	39.0	35.1±2.7	46.8±3.6
	G		26.0±1.7	34.7±2.2		29.3±2.5	39.1±3.4		34.2±1.8	45.6±2.4
Desk height (*D*)	B	60.0	45.4±2.8	53.8±3.2	66.0	50.3±3.9	59.7±4.5	74.0	61.5±4.1	72.6±4.8
	G		45.4±3.1	53.5±3.5		51.4±4.3	60.8±4.9		60.1±3.1	70.5±3.3
Underneath desk height (UD)	B	47.0	42.6±2.8	49.8±3.2	53.0	48.0±3.2	55.7±4.5	61.0	56.9±3.5	68.6±4.8
	G		41.6±2.9	49.5±3.5		47.7±3.2	56.8±4.9		53.3±2.7	66.5±3.3

desk height plus its thickness −4 cm):

$$(K+2)+2 \leqslant \mathrm{UD} \leqslant [((P+2)\cos 5^{\circ}) + (E0.852) + (S0.148) - 4. \quad (6)$$

2.4. Data treatment

Equations relating body dimensions to school furniture dimensions determined a minimum (min) and a maximum (max) accepted limit (AL) for each dimension, individually for each student. Those limits were compared to the dimensions of the existent school furniture (Table 2, Greek Organization for School Buildings, 1996), defining the match, the smaller dimension (below minAL), and the larger dimension (above maxAL).

The exact deviations of the existent dimensions from the limits were further calculated in cm.

The occurrence frequency of each case was calculated as a percentage with a confidence interval of 95% ($z = 1.96$) estimated as follows:

$$\text{Confidence\_Interval} = \pm z\sqrt{\frac{p_{\text{sample}}(1-p_{\text{sample}})}{N}}. \quad (7)$$

The examination of match was conducted according to the existing allocation of sizes (Situation 1: one size per each group), and also assuming that all three sizes could be provided to all three groups (Situation 2: three sizes per each group). At the difference of the occurrence frequencies between the two situations, the confidence interval was calculated as indicated by Eq. (7), so that it was possible to examine if the potential improvement should also be expected in the whole population.

3. Results

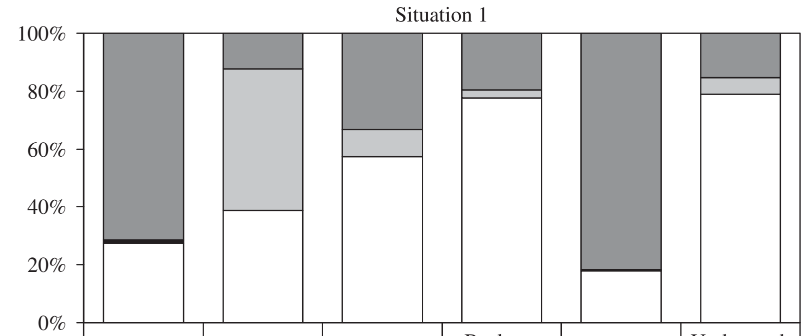
Descriptive statistics of the minimum and maximum accepted limits are presented in Table 2 for each group and gender.

The frequencies of match, below minAL and above maxAL cases were calculated in percentages for the two allocation situations. The match (with 95% confidence interval), above maxAL and below minAL percentages are presented in Fig. 2 for the whole sample and in Table 3 for each group and gender.

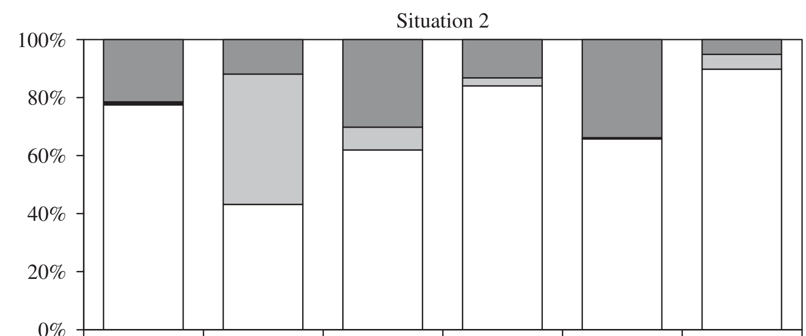
For Situation 1, seat height was appropriate for only 27.4% (±5.3) of children, while 71.5% (±5.3) used higher seats (see Fig. 2). Below minAL cases existed only for 4.2% (±4.6) of boys from group H (see Table 3), but this frequency was not significant. The means of the exact deviations from the maxAL for seat height were between 2.2 cm (boys, H) and 3.2 cm (girls, J1). However, there were boys in group J2 and girls in group H for whom those deviations were 7.7 cm. For 90.3% (±6.8) of girls in group H, seat height was above maxAL (see Table 3) and the deviation from the max limit was more than 3 cm for 81% of those. In Situation 2, the improvement of match in seat height was 50% (from 27.4 to 77.4%, see Fig. 2) and significant (confidence interval: 5.9%) and can be almost entirely attributed to the decrease of above maxAL cases frequency. This improvement was significant only in groups J2 (B: 57.1±16.4%, G: 44.1±16.7%) and H (B: 50±11.5%, G: 90.3±6.8%).

Seat depth matched more than 50% of group J2 and of boys from group J1 in Situation 1 (see Table 3). Considering only the mismatch cases, seat depth was only larger for children in group J1, both larger and smaller in group J2, and only smaller in group H. In Situation 2, significant reduction in below minAL cases frequency was observed only in girls from group J2 for whom below minAL cases were limited from 32.4% to 8.8%, resulting in a decrease of 23.5% (confidence interval: 14.3%).

Seat width was satisfactory even in Situation 1, 57.3% (±5.9), as most mismatch cases concerned wider than maxAL chairs (see Fig. 2). Narrower seats existed only in 12.5% (±7.6) of boys and 15.3% (±8.3) of girls from group H (see Table 3).



	Seat Height	Seat Depth	Seat Width	Backrest Height	Desk Height	Underneath Desk Height
Above maxAL	71.5	12.4	33.2	19.7	81.8	15.3
Below minAL	1.1	48.9	9.5	2.6	0.4	5.8
Match	27.4	38.7	57.3	77.7	17.9	78.8



	Seat Height	Seat Depth	Seat Width	Backrest Height	Desk Height	Underneath Desk Height
Above maxAL	21.5	12	30.3	13.1	33.9	5.1
Below minAL	1.1	44.9	7.7	2.9	0.4	5.1
Match	77.4	43.1	62	83.9	65.7	89.8

Fig. 2. Percentages (%) of match, above maxAL and below minAL cases for the two allocation situations: Situation 1: one size per each group, Situation 2: three sizes per each group.

Backrest height satisfied 77.7% (±4.9) of the children in Situation 1 and 83.9% (±4.4) in Situation 2, resulting in an improvement of 6.2% (confidence interval: 2.9%) (see Fig. 2). Significantly bigger backrests existed only in students from group J1 (B: 45.2% (±17.5), G: 53.3% (±17.9)) and J2 (B: 34.3% (±15.7), G: 29.4% (±15.3)) and that frequency was decreased by 22.9% (±13.9) for boys and by 17.6% (±12.8) for girls from group J2 in the Situation 2 (see Table 3).

In Situation 1, only 17.9% (±4.5) of children used desks of suitable heights, while the majority of the rest used inappropriately higher desks (see Fig. 2). Desks were higher for every boy in group J1 with a mean deviation from maxAL of 6.2 cm (±3.2). For the girls of the same group, the corresponding mean deviation was 7.0 cm (±3.1). In group J2, the mean deviation was 6.9 cm (±4.1) for boys and 7.1 cm (±3.4) for girls. Desk height was considered relatively appropriate only for 37.5% (±11.2) of boys in group H (see Table 3). In Situation 2, there was a significant improvement of desk height match (47.8%), with a confidence interval of 5.9% (see Fig. 2). This improvement was entirely attributed to the reduction of the frequency of higher desks. The match was significantly increased in groups J2 (B: 42.9%(±16.4), G: 32.4%(±15.7)) and H (B: 61.1% (±11.3), G: 84.7% (±8.3)).

Underneath desk height was satisfactory, 78.8% (±4.8), in Situation 1. The main interest should focus in below minAL cases, where desk is lower than knees. Such cases existed only in 13.9% (±8.0) of boys from group H (see Table 3) and were not eliminated during Situation 2.

4. Discussion

4.1. Allocation of sizes according to the present situation

The desk height was above maxAL for the majority of children (81.8%) and accordingly was the seat height (71.5%). Seat depth was in most cases below minAL (48.9%). Those mismatch cases were generalized for the

Table 3
Percentages (%) of match (confidence interval 95%), above maxAL and below minAL cases in all furniture dimensions for the two situations

	Gender	Situation 1						Situation 2					
		Match		Below minAL		Above maxAL		Match		Below minAl		Above maxAL	
Seat height													
	Total	27.4	±5.3	1.1	±1.2	71.5	±5.3	77.4	±5.0	1.1	±1.2	21.5	±4.9
J1	B	25.8	±15.4	0.0	±0.0	74.2	±15.4	29.0	±16.0	0.0	±0.0	71.0	±16.0
	G	16.7	±13.3	0.0	±0.0	83.3	±13.3	16.7	±13.3	0.0	±0.0	83.3	±13.3
J2	B	31.4	±15.4	0.0	±0.0	68.6	±15.4	88.6	±10.5	0.0	±0.0	11.4	±10.5
	G	32.4	±15.7	0.0	±0.0	67.6	±15.7	76.5	±14.3	0.0	±0.0	23.5	±14.3
H	B	45.8	±11.5	4.2	±4.6	50.0	±11.5	95.8	±4.6	4.2	±4.6	0.0	±0.0
	G	9.7	±6.8	0.0	±0.0	90.3	±6.8	100.0	±0.0	0.0	±0.0	0.0	±0.0
Seat depth													
	Total	38.7	±5.8	48.9	±5.9	12.4	±3.9	43.1	±5.9	44.9	±5.9	12	±3.8
J1	B	54.8	±17.5	0.0	±0.0	45.2	±17.5	58.1	±17.4	0.0	±0.0	41.9	±17.4
	G	43.3	±17.7	0.0	±0.0	56.7	±17.7	43.3	±17.7	0.0	±0.0	56.7	±17.7
J2	B	80.0	±13.3	14.3	±11.6	5.7	±7.7	88.6	±10.5	5.7	±7.7	5.7	±7.7
	G	64.7	±16.1	32.4	±15.7	2.9	±5.7	88.2	±10.8	8.8	±9.5	2.9	±5.7
H	B	15.3	±8.3	84.7	±8.3	0.0	±0.0	15.3	±8.3	84.7	±8.3	0.0	±0.0
	G	20.8	±9.4	79.2	±9.4	0.0	±0.0	20.8	±9.4	79.2	±9.4	0.0	±0.0
Seat width													
	Total	57.3	±5.9	9.5	±3.5	33.2	±5.6	62	±5.7	7.7	±3.2	30.3	±5.4
J1	B	25.8	±15.4	3.2	±6.2	71.0	±16.0	29.0	±16.0	0.0	±0.0	71.0	±16.0
	G	13.3	±12.2	0.0	±0.0	86.7	±12.2	13.3	±12.2	0.0	±0.0	86.7	±12.2
J2	B	51.4	±16.6	5.7	±7.7	42.9	±16.4	54.3	±16.5	2.9	±5.5	42.9	±16.4
	G	52.9	±16.8	8.8	±9.5	38.2	±16.3	58.8	±16.5	2.9	±5.7	38.2	±16.3
H	B	75.0	±10.0	12.5	±7.6	12.5	±7.6	81.9	±8.9	12.5	±7.6	5.6	±5.3
	G	76.4	±9.8	15.3	±8.3	8.3	±6.4	81.9	±8.9	13.9	±8.0	4.2	±4.6
Backrest height													
	Total	77.7	±4.9	2.6	±1.9	19.7	±4.7	83.9	±4.4	2.9	±2.0	13.1	±4.0
J1	B	54.8	±17.5	0.0	±0.0	45.2	±17.5	54.8	±17.5	0.0	±0.0	45.2	±17.5
	G	46.7	±17.9	0.0	±0.0	53.3	±17.9	50.0	±17.9	0.0	±0.0	50.0	±17.9
J2	B	65.7	±15.7	0.0	±0.0	34.3	±15.7	88.6	±10.5	0.0	±0.0	11.4	±10.5
	G	70.6	±15.3	0.0	±0.0	29.4	±15.3	88.2	±10.8	2.9	±5.7	8.8	±9.5
H	B	88.9	±7.3	9.7	±6.8	1.4	±2.7	90.3	±6.8	9.7	±6.8	0.0	±0.0
	G	98.6	±2.7	0.0	±0.0	1.4	±2.7	100.0	±0.0	0.0	±0.0	0.0	±0.0
Desk height													
	Total	17.9	±4.5	0.4	±0.7	81.8	±4.6	65.7	±5.6	0.4	±0.7	33.9	±5.6
J1	B	0.0	±0.0	0.0	±0.0	100.0	±0.0	0.0	±0.0	0.0	±0.0	100.0	±0.0
	G	6.7	±8.9	0.0	±0.0	93.3	±8.9	6.7	±8.9	0.0	±0.0	93.3	±8.9
J2	B	8.6	±9.3	0.0	±0.0	91.4	±9.3	51.4	±16.6	0.0	±0.0	48.6	±16.6
	G	20.6	±13.6	0.0	±0.0	79.4	±13.6	52.9	±16.8	0.0	±0.0	47.1	±16.8
H	B	37.5	±11.2	1.4	±2.7	61.1	±11.3	98.6	±2.7	1.4	±2.7	0.0	±0.0
	G	13.9	±8.0	0.0	±0.0	86.1	±8.0	98.6	±2.7	0.0	±0.0	1.4	±2.7
Underneath desk height													
	Total	78.8	±4.8	5.8	±2.8	15.3	±4.3	89.8	±3.6	5.1	±2.6	5.1	±2.6
J1	B	74.2	±15.4	6.5	±8.6	19.4	±13.9	80.6	±13.9	0.0	±0.0	19.4	±13.9
	G	80.0	±14.3	0.0	±0.0	20.0	±14.3	80.0	±14.3	0.0	±0.0	20.0	±14.3
J2	B	62.9	±16.0	5.7	±7.7	31.4	±15.4	88.6	±10.5	5.7	±7.7	5.7	±7.7
	G	64.7	±16.1	5.9	±7.9	29.4	±15.3	100.0	±0.0	0.0	±0.0	0.0	±0.0
H	B	79.2	±9.4	13.9	±8.0	6.9	±5.9	86.1	±8.0	13.9	±8.0	0.0	±0.0
	G	94.4	±5.3	0.0	±0.0	5.6	±5.3	98.6	±2.7	0.0	±0.0	1.4	±2.7

above dimensions indicating that they could possibly be attributed to design principles and not simply differences among body dimensions. High percentages of mismatch for those dimensions were also reported for primary school children (groups J1 and J2 of the present study) from another Greek district (70–100% for seat height, 50–100% for seat depth and 70–100% for desk height) (Panagiotopoulou et al., 2004). In regard to the results for desk height, seat height and seat depth, the present design criteria order much different dimensions than that defined as appropriate from the present study.

The equations that were used to examine the match between school furniture and anthropometric dimensions can be problematic in the sense that they are sometimes based on contradictory criteria originating from theory that has not necessarily been confirmed with research. In the present study, the equations were determined based on either the prevailing or the more frequent viewpoints of other researchers. However, for the understanding of match results, it is necessary that all opinions should be evaluated.

The design of school furniture dimensions should have the seat height as the starting point (Cho, 1994; Molenbroek et al., 2003). The high frequency of above maxAL cases (71.5%) indicates that most children sit on higher seats and as a result they are not able to split their body weight appropriately by supporting their feet on the floor. This lack of foot support may increase tissue pressure on the posterior area of the knees (Milanese and Grimmer, 2004). Indeed, 39.3% of the maxAL cases (28.1% of the total) used seats that were at least 3 cm higher. The frequency of higher chairs was 60% for a Dutch population of 4–12 years old (Molenbroek et al., 2003) and 81–91% for American children aged 6–12 years (Parcells et al., 1999).

With regard to seat height, both below minAL or above maxAL cases could lead to discomfort since deviations greater than 5 cm have been associated with pathological postural behaviors (Bendix and Bloch, 1986; Bendix et al., 1988; Knight and Noyes, 1999; Oxford, 1969; Pheasant, 1991). Below minAL cases (1%) are not considered as harmful since most researchers believe that seats should be lower than popliteal height so that any pressure under thighs is avoided (Dul and Weerdmeester, 1998; Oxford, 1969; Parcells et al., 1999; Sanders and McCormick, 1993; Shih et al., 1966). Other studies proposed that it is easier for a tall person to be adapted into a low seat than for a short person to be adapted into a high seat (Evans et al., 1988; Karvonen et al., 1962; Keegan, 1953; Molenbroek and Ramaekers, 1996; Orborne, 1996; Pheasant, 1991).

Although the percentage of above maxAL cases in seat depth was low (12.4%), it represents the fact that this is larger than popliteal-buttock length and as a result, thighs may be compressed and blood circulation may be prohibited (Milanese and Grimmer, 2004). Furthermore, the misuse of backrest has been suggested to cause kyphotic postures (Hira, 1980; Khalil et al., 1993; Knight and Noyes, 1999; Orborne, 1996; Pheasant, 1991). At ages corresponding to primary school (6–12 years), above maxAL cases for seat depth were 25% (for seat depth of 34 cm), while in Parcells' research (Parcells et al., 1999) 15% (for seat depth of 39 cm). The percentage of below minAL that are <5 cm (~10% of our sample) can be interpreted as potential for discomfort, instability and leg hanging.

Seat width was narrower for 9.5% of the children, which may cause discomfort, unsteadiness and mobility constraint (Evans et al., 1988; Helander, 1997; Khalil et al., 1993; Occhipinti et al., 1993; Orborne, 1996; Sanders and McCormick, 1993). This was especially true for children in group H and particularly for girls. Above maxAL cases (33.2%) are not considered as inappropriate because they more affect esthetics and space economy.

Backrest height was above maxAL for 19.7% of the children, meaning that the backrest was higher than their scapula, restricting arm mobility (Evans et al., 1988; Orborne, 1996; Shih et al., 1966). The backrest height was appropriate for children of group H, less appropriate for group J2 and inappropriate for 50% of children in group J1. Below minAL cases (3%) are less harmful, yet are still related with discomfort and uneasiness.

Higher than maxAL desks (81.8%) imply that most children are required to flex their shoulders more than 25° and abduct them more than 20° in order to support their elbows on the desk (Karvonen et al., 1962; Milanese and Grimmer, 2004; Parcells et al., 1999; Sanders and McCormick, 1993). Although Mandal proposed very high desks (Mandal, 1981, 1982, 1984), such desks also required high seats, footrest and inclined desks (Bendix and Hagberg, 1984; Mandal, 1976), conditions that do not exist in Greek schools. For that reason, above maxAL cases were considered harmful only when they were over 5 cm. By calculating the exact deviations from the maximum accepted limits, it was estimated that deviations were greater than 5 cm for 40.5% and exceeded 8 cm for 20.4% of the total sample. These deviations correspond to the distance that children must raise their elbows in order to place them on the desk. The above percentages are higher than the percentage of 12.2% calculated by Parcells et al. (1999) for desks 69.3 cm high (the desks used by children of the same age in Greek schools are 60 and 66 cm).

Underneath desk height was below minAL for 5.8% of children revealing that there were cases of students, whose thighs were in contact with the desk, thus disabling any movement of the legs (Dul and Weerdmeester, 1998; Evans et al., 1988; Parcells et al., 1999; Sanders and McCormick, 1993). Boys from group H confronted that problem, while no girls from that group were considered below minAL. Thus, even among children of the same age, boys need more space between desk and seat. Above maxAL cases (15.3%) just allow more desk clearance even for leg crossing (Corlett and Clark, 1995; Helander, 1997).

4.2. Allocation of sizes according to the assumed situation

The three current sizes are much more satisfactory than the single size that was used in Greek schools until 1996. This was also confirmed by Panagiotopoulou et al. (2004), who reported a decrease in mismatch frequency when the present chairs and desks were compared to the old furniture. However, school principals are not adequately informed for the allocation of the sizes whereas, in some schools, furniture is not replaced for years resulting in an unbounded variety of sizes. In Japan, Hibaru and Watanabe (1994) established that although there were furniture sizes appropriate for every child, their allocation per grades constrained them to use smaller or bigger desks and chairs. Thus, the potentiality of giving children the chance to choose from all existing sizes, could improve match percentages. This was confirmed especially for children from groups J2 and H for whom the match percentages in desk height were significantly improved in Situation 2. Seat depth and width match were slightly improved (from 38.7% to 43.1% and from 57.3% to 62.0%, respectively), while those dimensions are the same for sizes 1 and 2 that groups J1 and J2 use. Likewise, backrest match was not considerably improved (from 77.7% to 83.9%).

5. Conclusions

The examination of match between school furniture dimensions and children's anthropometry revealed a substantial frequency of mismatch especially for desk height, seat height and seat depth. Deviations from the defined accepted limits varied among groups and between genders signifying their special requirements and their different potential problems. Assuming that children could use the most appropriate from the three available sizes, the estimated match was remarkably improved only for desk and seat height and mostly in group H. Nevertheless, this improvement cannot be ignored, since it confirms the necessity for a larger variety of sizes within the same grade. Therefore, yet with the existing design criteria, the identification of individual anthropometric requirements among children of the same age could be a useful tool for the arrangement of the issue of school furniture design and allocation.

The present study focused on the suitability of school furniture to the anthropometric characteristics of Greek children using equations modified in accordance with principles proposed by the literature. For the design of school furniture that will have the potential to fit any target population, reliable equations that originate from experimental research are needed. With these equations as a starting point, researchers should gather national anthropometric data attempting to design furniture that would fulfill bodily expectations of students, thereby promoting anatomical postures, comfort and consequently health.

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