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The development of sizing systems for Taiwanese elementary- and high-school students

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Abstract

This study aims to develop sizing systems for Taiwanese elementary- and high-school students. A total of 7800 students' anthropometric data covering their ages from 6 to 18 years for both genders were used in this study. A two-stage cluster analysis was performed for the classification of figure types. The size charts were developed based on the morphological characteristics of each figure type. Twelve sizing systems were established systematically by age group (elementary-, junior high-school and senior high-school students), gender (male and female) and garment type (upper and lower garments). The coverage rate of the developed sizing systems was over 85%, and the number of sizing groups of each system was less than 36. In addition, an index of aggregate loss of fit was used to validate the size charts, and the results showed that all the developed size charts had a good fit. Moreover, the developed sizing systems were compared with the Korean Standards, and a similar trend was found.

Relevance to industry

The developed sizing systems were based on the most recent and complete anthropometric database in Taiwan. The proposed method can be used to develop sizing systems for different populations. The results obtained provide important references for the design and production of different clothing.

Keywords: Anthropometric data; Sizing system; Cluster analysis; Figure type; Student clothing

1. Introduction

A garment sizing system is essential for effective clothing design and production. A sizing system classifies a specific population into homogeneous subgroups based on some key body dimensions. Persons of the same subgroup have the same body shape characteristics, and share the same garment size.

With the difference in body dimensions and morphological characteristics, different body shapes can be generalized to a few figure types (Ray et al., 1995). Figure type plays a decisive role in a sizing system and contributes to the issue of fit. Emanuel et al. (1959) recommended the use of the difference in figure types as the classification of ready-to-wears, and developed a set of procedures to formulate standard sizes for all figure types. In early times, the classification of figure types was based on body weight and stature. Later on, anthropometric dimensions were applied for classification. Based on this method, a linear structure was found in many of the commonly used sizing systems, such as KS K 0050 and JIS L 4002. This type of sizing system has the advantages of easy grading and size labelling. But, the disadvantage is that the structural constraints in the linear system may result in a loose fit. Thus, some optimization methods have been proposed to generate a better fit sizing system, such as an integer programming approach (Tryfos, 1986) and a nonlinear programming approach (McCulloch et al., 1998).

For the development of sizing systems using optimization methods, the structure of the sizing systems tends to affect the predefined constraints and objectives. Tryfos

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(1986) indicated that the probability of purchase depended on the distance between the sizing system of a garment and the real size of an individual. In order to optimize the number of sizes so as to minimize the distance, an integer programming approach was applied to choose the optimal sizes. Later on, McCulloch et al. (1998) constructed a sizing system by using a nonlinear optimization approach to maximize the quality of fit. Recently, Gupta et al. (2006) used a linear programming approach to classify the size groups. Using the optimization method has the advantages of generating a sizing system with an optimal fit, but the irregular distribution of the optimal sizes may increase the complexity in grading and the cost of production.

Furthermore, data mining techniques such as cluster analysis (Moon and Nam, 2003), neural networks (She et al., 2002) and the decision tree approach (Hsu and Wang, 2005) have been applied to develop garment sizing systems. Cluster analysis was used as an exploratory data analysis tool for classification. A cluster which is typically grouped by the similarity of its members' body shape can be considered as a size category or a figure type. Moon and Nam (2003) used the *K*-means cluster analysis method to classify the lower body shapes of elderly women into fewer figure types, and then used the control dimension and size interval to establish a lower garment sizing system. The pitfall of the method is that it requires one to pre-assign the number of clusters to initialize the algorithm, and it is usually subjectively determined by experts. To overcome this disadvantage, a two-stage cluster analysis is proposed here to eliminate the requirement of subjective judgment and to improve the effectiveness of size classification.

About 29% of the world populations are children (under the age of 15 years) (Population Reference Bureau, 2006). For children's sizing systems, the related studies are rare because of its complexity and lack of up-to-date anthropometric data. Age and gender are the two important factors affecting children's body shape characteristics. Girls start to grow between the ages of 8 and 12 years and reach puberty about 2 years earlier than boys. During the growth period, there is a rapid change in body proportion, and the segmental relations of children have more variations than adults. This issue can be addressed if we include more body dimensions to describe figure types.

Among all the sizing systems for children, only a few were developed by classifying figure types. Many sizing systems for children were developed by referring to the adult's sizing systems. If we neglect the fact that children's figure types have much more variations than adults, there will be a fit problem. For example, using the drop value (the difference between chest girth and hip girth) is a popular method to classify figure types for adults, but it is not suitable for classifying figure types for children during the growing period, because the girth difference for children is not so obvious. Thus, it is necessary to consider the body's dimensional characteristics in each growing period to establish the corresponding sizing system. The objective of this study is to develop sizing systems for elementary- and high-school students by using a two-stage cluster analysis approach.

2. Method

2.1. Data preparation

Anthropometric data of 7800 Taiwanese elementary and high-school students (3960 males and 3840 females) from an anthropometric database were obtained (Wang et al., 2002). It is the most recent and complete anthropometric database in Taiwan. The age of the students ranged from 6 to 18 years. For the elementary-school (6–12 years), junior high-school (13–15 years) and senior high-school students (16–18 years), the samples in each of the three groups were 3958, 2594 and 1248, respectively.

Thirty-six anthropometric dimensions that are commonly used in clothing design were selected to establish the sizing systems. The definitions of the anthropometric dimension are the same as ISO 8559, except for waist girth. Waist girth was defined as the girth of the natural waistline between the top of the hip bones and the lower ribs in ISO 8559. But the location of the natural waistline may vary from person to person. Using the navel as the reference point can be an easy landmark to identify the waistline while taking the measurement. Thus, the waist girth was measured by taking the horizontal girth around the navel.

During anthropometric data measurements, three kinds of equipment were used, i.e. a 3D coordinate measurement probe, a digital caliper and a digital tape measure. The 3D coordinate measurement probe and the digital caliper were used to measure the linear dimensions, and the tape measure was used to measure the contour length and circumference. All equipments were calibrated with an accuracy level of up to 0.1 mm (Wang et al., 2002). The male subjects were asked to wear shorts and the female subjects were asked to wear leotards during measurement.

2.2. Factor analysis

Factor analysis is a multivariate statistical analysis method that examines the inter-relationships among a large number of variables and extracts the underlying factors. Here, factor analysis with varimax rotation was applied to obtain important factors for body shape representation. Using the factor scores extracted by factor analysis, cluster analysis was performed for the classification of body shape.

2.3. Cluster analysis

A two-stage cluster analysis which combines hierarchical and non-hierarchical methods was proposed to classify figure types. For the hierarchical approach, the Ward's minimum variance method was applied to identify the number of clusters. Subsequently, the non-hierarchical approach, i.e. the *K*-means cluster analysis, was then applied to group the homogeneous individuals into clusters. Each cluster here can be considered as a figure type.

2.4. Establishing the size systems

Considering the general practice in international standards, the use of control dimensions and size interval can help to effectively identify the parameters for developing sizing systems.

For the control dimensions, according to ISO/TC 133, stature should be taken as the principal variable for growing children. The other commonly used control dimensions include chest girth, waist girth and hip girth. Figs. 1–4 show the changing trend in vertical body dimensions, horizontal body dimensions and weight for subjects aged from 6 to 18 years. The vertical dimensions include stature, back waist length, arm length and waist height. The horizontal dimensions include chest girth, waist girth, hip girth and shoulder width. Both male and female students under the age of 13 years have rapid changes in both vertical and horizontal dimensions. Thus, it is necessary to develop a sizing system for students aged from 6 to 12 years using both vertical and horizontal dimensions as the control dimensions.

For male teenagers, the growth in vertical dimensions continues until the age of 16 years and the growth in horizontal dimensions continues until the age of 18 years (see Figs. 1 and 2). Male students over the age of 13 years have more obvious changes in the horizontal dimensions than in the vertical dimensions. For female teenagers, the growth in vertical dimensions becomes steady when they reach the age of 13–14 years, and there is still a slight

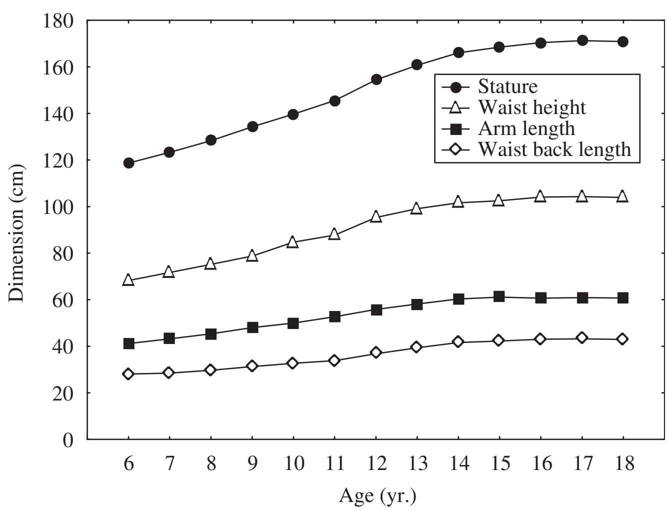

Fig. 1. The growth trend of the male students' vertical body dimensions.

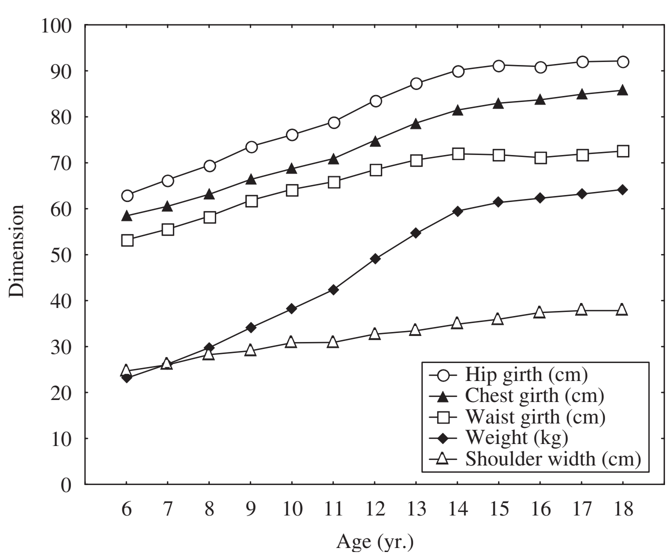

Fig. 2. The growth trend of the male students' horizontal body dimensions and weight.

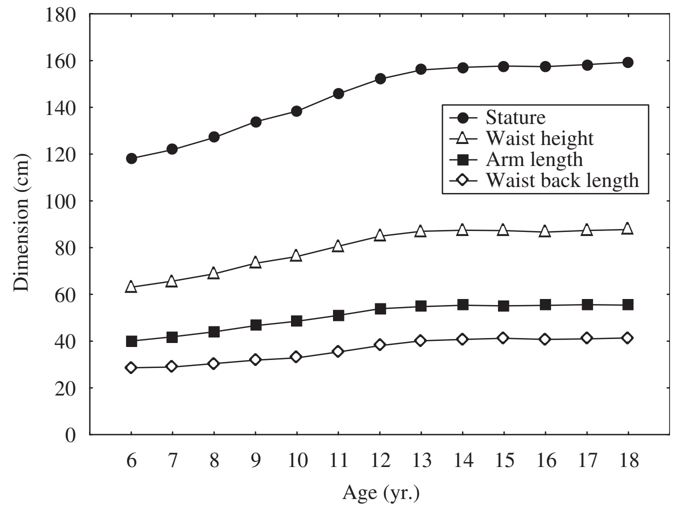

Fig. 3. The growth trend of the female students' vertical body dimensions.

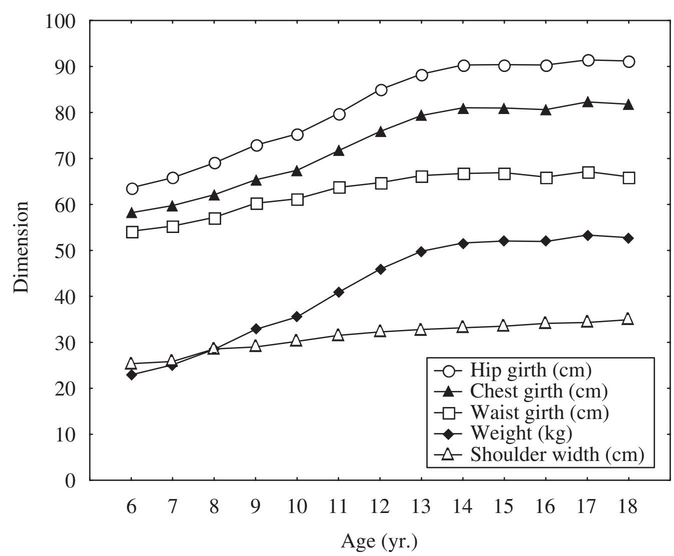

Fig. 4. The growth trend of the female students' horizontal body dimensions and weight.

development in horizontal dimensions until the age of 18 years (see Figs. 3 and 4). Therefore, the horizontal dimensions, such as chest girth, waist girth and hip girth, should be selected as the control dimensions for boys and girls over the age of 13 years while establishing their sizing systems.

For the size interval, a smaller interval with more size groups can provide a better fit, but it may also increase the production and inventory cost. In general, the size interval between 4 and 6 cm for girth dimension seems to be adequate for a wide range of adult garments (Eberle and Kilgus, 1996). The size interval for stature was from 5 to 10 cm in current sizing standards (e.g. ISO/TR 10652).

Control dimensions and size interval are the fundamental elements in a size chart. Moreover, some body dimensions (such as bust breadth and armscye) that are not critical measurements for garment sizing but are necessary for different garment design have been identified as reference dimensions. The reference dimensions were also included in the size chart for improving pattern making and fashion design.

3. Results

Since the same method was taken to obtain the sizing systems for elementary- and high-school students, the procedure of developing the sizing system for male elementary-school students (age 6–12 years) is presented here.

3.1. Identifying critical factors

Factor analysis was applied to extract critical factors from anthropometric dimensions. By using Kaiser's eigenvalue criterion, factors with eigenvalue greater than 1.0 were selected (Kaiser, 1960). Table 1 presents the results of factor analysis for the anthropometric dimensions of upper garments. Considering the factor loadings in each factor, the name of each factor can be identified. The variables with factor loading greater than 0.7 in Factor 1 were girth-related variables, including head girth, neck girth and chest girth. Thus, Factor 1 was named as girth factor. Similarly, Factor 2 was named as width factor and Factor 3 was named as height factor. Then, using factor scores of the three extracted factors as independent variables, a two-stage cluster analysis was performed for the classification of body shape. In addition, the body dimensions used for validation were selected based on the results of factor analysis.

3.2. Classifying figure types

From the results of the two-stage cluster analysis, three clusters were extracted. Fig. 5 illustrates the distribution of stature (x-axis) vs chest girth (y-axis) for all three clusters. The cluster with 776 samples was defined as M type. The cluster with 495 samples having short stature and small

Table 1
Results of factor analysis for upper garment sizing system

Dimensions	Factor 1	Factor 2	Factor 3
Weight	0.348	0.787[e]	0.422
Stature	0.188	0.522	0.804[e]
Head girth	0.746[e]	0.529	0.349
Neck girth	0.740[e]	0.555	0.331
Chest girth at scye	0.782[e]	0.524	0.254
Chest girth	0.903[e]	−0.139	0.251
Chest girth below bust	0.846[e]	0.348	0.230
Waist girth	0.746[e]	0.571	0.123
Abdominal girth	0.723[e]	0.522	0.334
Buttock girth	0.715[e]	0.534	0.404
Armscye girth	0.688	0.528	0.317
Biceps girth	0.755[e]	0.590	0.101
Elbow girth	0.742[e]	0.420	0.254
Wrist girth	0.799[e]	0.335	0.316
Hand girth	0.722[e]	0.259	0.458
Front waist length[a]	0.631	0.203	0.603
Neck to bust point length	0.637	0.454	0.484
Back waist length[b]	0.572	0.245	0.619
Arm length	0.591	0.252	0.723[e]
Sleeve inseam[c]	0.526	0.165	0.778[e]
Shoulder to elbow length	0.124	0.469	0.801[e]
Shoulder width	0.210	0.564	0.670
Biacromial breadth	0.346	0.821[e]	0.369
Chest breadth	0.340	0.801[e]	0.367
Bust breadth	0.288	0.785[e]	0.382
Interscye breadth[d]	0.668	0.412	0.328
Variance explained	10.327	6.798	5.734
Total proportion	0.397	0.261	0.221
Eigenvalue	19.634	1.779	1.603

[a]The distance from the neck shoulder point, over the nipple, then vertically straight to the front waist.
[b]The distance from the 7th cervical vertebra, following the contour of the spine column, to the waist.
[c]The distance from the axilla along the inside arm to the radial stylion.
[d]The distance across the back between the posterior auxilliary folds at the lower level of the armpit.
[e]Factor loadings >0.7.

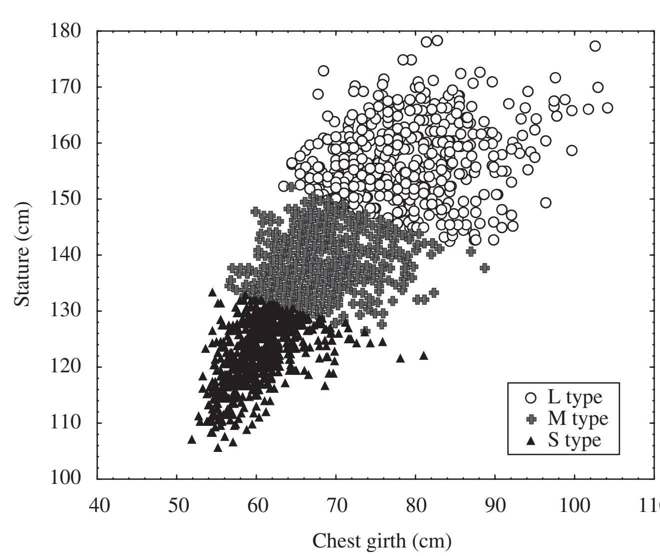

Fig. 5. The scatter plot of stature vs chest girth for the three figure types.

chest girth was defined as S type. Similarly, L type with 741 samples was identified with tall stature and large chest girth. From the analysis of variance results, significant differences ($p<0.01$) have been found among the 3 clusters in chest girth, waist girth, front waist length, arm length and shoulder width, as shown in Fig. 6.

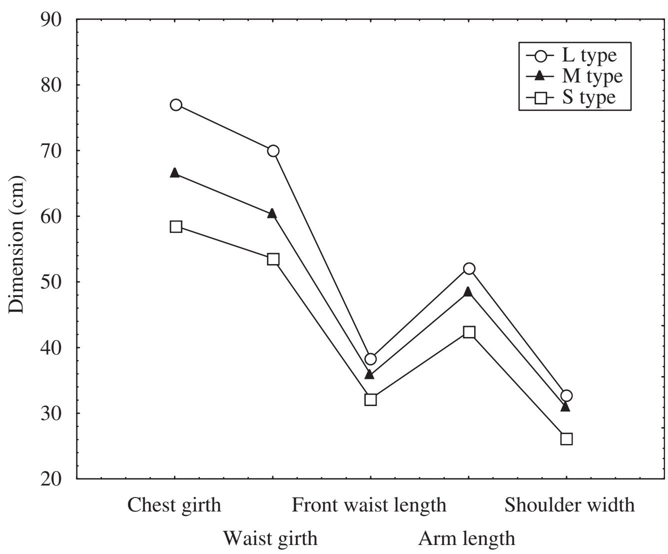

Fig. 6. The three figure types and the related anthropometric variables.

3.3. Establishing the sizing systems

Each figure type was classified into several size subgroups based on the control dimensions and size interval. According to ISO/TC 133, the control dimensions for the elementary-school students were stature, chest girth, waist girth and hip girth. Because students over the age of 13 years have more obvious changes in the horizontal dimensions than in the vertical dimensions, the control dimensions for the junior high-school and senior high school students were chest girth, waist girth and hip girth. The size interval for stature was 8 cm and for the other dimensions it was 4 cm. Except for the male junior high-school students, all the size intervals were specified as 6 cm due to the dramatic growth of the male students in this age group. Fig. 7 illustrates the sizing system for the male elementary-school students. For the upper garment, the size interval for chest girth was 4 cm and for stature it was 8 cm. The stature was used to further divide into 8 subgroups using an interval of 8 cm. As for chest girth, an interval of 4 cm was used for each division. For the lower garment, the size interval for hip girth was 4 cm and for stature it was 8 cm. Table 2 shows the size chart for elementary-school boys. Each size provides 26 reference dimensions for upper garments and 14 reference dimensions for lower garments. The percent population coverage for each size is also given.

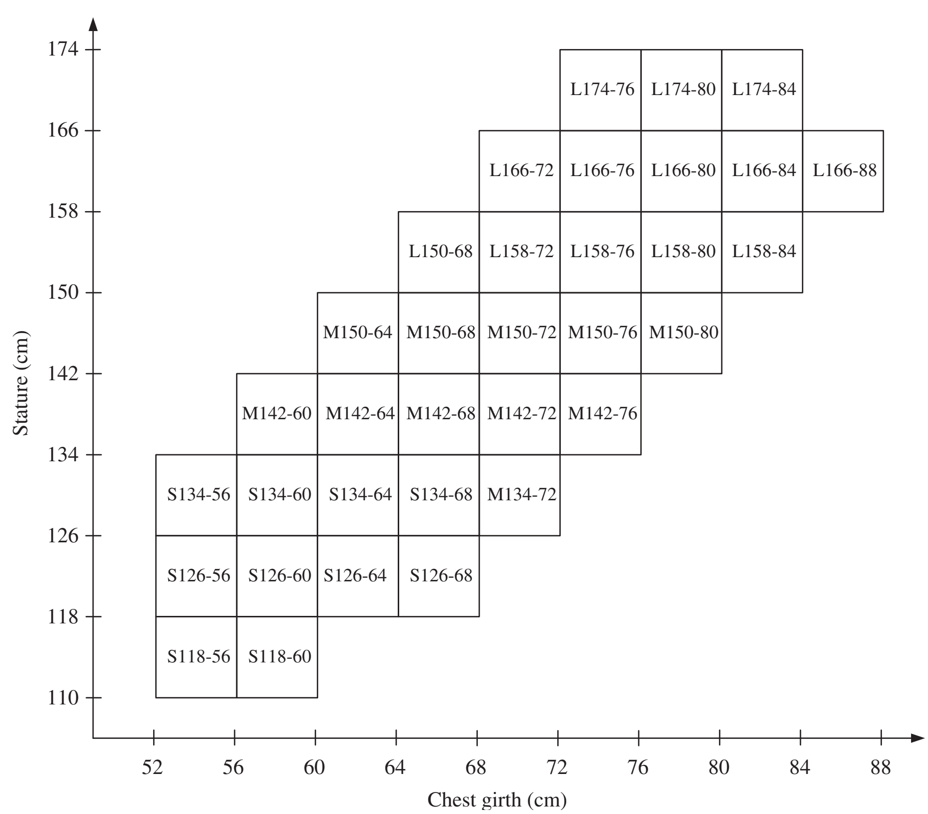

Fig. 7. The sizing system of the male elementary school students.

Table 2
The size chart of the male elementary school students

Category	Upper garment								
Size designation		S118-60	S126-64	S134-68	M142-72	M150-76	L158-80	L166-84	L174-84
Control dimensions	Stature (cm)	118	126	134	142	150	158	166	174
	Chest girth (cm)	60	64	68	72	76	80	84	84
Reference dimensions	*Girth measurements* (cm)								
	Head girth	51.8	52.5	53.1	54.0	54.2	55.2	55.6	56.7
	Neck girth	27.1	27.5	28.7	29.8	31.3	32.1	34.2	34.5
	Chest girth at scye	58.5	62.8	67.4	71.4	76.3	80.1	82.5	87.0
	Chest girth below bust	57.2	60.4	64.1	68.3	71.9	75.6	80.0	80.8
	Waist girth	53.2	56.4	62.6	67.4	71.8	73.8	78.3	75.8
	Abdominal girth	54.4	58.8	63.3	68.8	73.3	76.4	81.1	77.3
	Hip girth	62.5	67.4	73.0	78.4	83.6	87.2	92.5	93.9
	Armscye girth	26.9	28.3	30.6	33.4	35.4	37.6	40.9	41.0
	Biceps girth	17.9	19.3	21.2	22.6	24.0	25.0	26.6	25.3
	Elbow girth	24.9	27.2	29.6	31.5	33.6	36.4	39.2	39.0
	Wrist girth	13.0	13.5	14.4	14.9	15.5	16.2	16.8	16.3
	Hand girth	15.5	15.8	16.9	17.3	18.3	19.6	20.5	20.4
	Vertical and length measurements (cm)								
	Front waist length	31.7	33.8	36.0	37.9	40.1	41.7	41.9	44.2
	Neck to bust point length	16.2	17.5	19.2	20.6	21.9	22.9	23.6	24.8
	Back waist length	27.2	28.4	30.1	32.2	33.8	36.3	39.4	41.6
	Arm length	39.9	43.5	45.8	49.7	51.3	55.7	58.9	60.8
	Sleeve inseam	30.7	33.4	35.4	38.1	40.0	43.3	45.9	46.7
	Shoulder to elbow length	22.2	23.6	24.7	26.8	28.4	30.1	32.1	32.3
	Width measurements (cm)								
	Shoulder width	24.6	28.0	29.3	29.8	31.1	33.1	33.8	35.9
	Biacromial breadth	28.3	31.1	33.2	35.7	37.7	39.8	41.1	41.9
	Chest breadth	19.4	19.8	18.0	21.3	25.6	24.9	28.9	30.4
	Bust breadth	12.2	13.5	14.3	15.2	16.1	17.1	18.1	17.8
	Interscye breadth	24.0	25.3	26.9	28.5	30.6	32.1	33.3	34.7
	Weight (kg)	22.3	27.0	32.0	38.9	45.7	52.5	61.1	61.3
Percentage (%)		1.8	3.7	2.4	4.3	3.3	1.9	1.2	0.6

Category	Lower garment								
Size designation		S118-62	S126-70	S134-74	M142-78	M150-82	L158-86	L166-90	L174-90
Control dimensions	Stature (cm)	118	126	134	142	150	158	166	174
	Hip girth (cm)	62	70	74	78	82	86	90	90
Reference dimensions	*Girth measurements* (cm)								
	Waist girth	51.0	55.8	62.0	64.4	67.0	69.3	72.1	69.3
	Abdominal girth	53.8	58.9	66.5	68.2	75.2	74.0	77.9	75.4
	Thigh girth	35.4	40.7	43.0	46.9	48.8	51.8	53.7	53.5
	Knee girth	25.5	28.5	29.6	31.9	33.1	34.7	35.7	35.8
	Calf girth	24.4	26.8	28.6	30.7	32.5	35.1	36.2	35.6
	Ankle girth	16.5	18.4	19.3	20.4	21.5	23.0	23.1	23.1
	Vertical and length measurements (cm)								
	Waist height	66.3	71.9	74.9	81.8	88.0	94.7	99.6	102.3
	Waist to ankle length	60.4	65.1	67.9	74.4	79.0	85.2	90.0	92.8
	Body rise[a]	14.5	16.0	16.4	17.9	18.4	20.0	20.8	21.8
	Crotch height	47.1	51.0	53.6	58.8	63.6	68.8	73.3	75.2
	Waist to knee length	32.0	34.2	35.2	38.8	42.2	45.4	48.2	49.2
	Weight (kg)	20.8	27.0	32.1	37.0	42.6	49.1	55.5	53.9
Percentage (%)		2.8	2.5	3.5	6.4	2.4	3.5	1.4	0.6

[a]The vertical distance between the waistline and the crotch level.

Table 3
The summarized results of the 12 sizing systems

Gender	Male (3960)						Female (3840)					
Age (years)	6–12		13–15		16–18		6–12		13–15		16–18	
Category	U	L	U	L	U	L	U	L	U	L	U	L
Cover rate (%)	89.3	85.4	85.7	88.1	88.9	87.8	87.5	85.3	91.2	89.3	85.1	88.7
Size interval (cm)	4	4	6	6	4	4	4	4	4	4	4	4
Num. of sizes	34	36	25	25	20	20	33	32	25	25	20	20
Aggregate loss (cm)	5.23	6.05	6.72	6.57	6.18	6.84	5.54	6.22	6.14	6.91	6.48	6.53

U: upper garment; L: lower garment.

Size label is an important interface for customers to quickly locate the right garment size for further consideration. The size label used in this study followed the format of ISO 3636 and ISO 3637. For a size label of an upper garment, e.g. M134-72, it indicates that this size is suitable for the medium figure type with stature between 126 and 134 cm and chest girth between 69 and 72 cm. For the size label of a lower garment, the control dimensions were stature and hip girth. Table 3 presents the summarized results for the sizing systems of elementary- and high-school students. As we can see, the coverage of each of the sizing systems was over 85%. The number of sizing groups for all the developed sizing systems was between 20 and 36.

3.4. Validating the sizing systems

Regarding the performance in good fit, the index of aggregate loss was used for evaluating the developed sizing systems. The aggregate loss was defined as an average Euclidean distance from the actual body dimensions to the corresponding dimensions of the assigned size. A good sizing system should have a low aggregate loss (Ashdown, 1998). Gupta and Gangadhar (2004) proposed the criterion of a good fit by suggesting the benchmark value of $(n)^{1/2}$ inch, where n is the number of body dimensions used in the size chart. Based on the results of factor analysis and the critical dimensions in clothing design, we used chest girth, waist girth, front waist length and shoulder width from the size charts to calculate the aggregate loss for the upper garment, and waist girth, hip girth, waist-to-ankle length and crotch height to calculate the aggregate loss for the lower garment. Table 3 presents the obtained aggregate loss of the sizing systems in this study. For the upper garment, the aggregate loss of the three male age groups (from young to old) was 5.23, 6.72 and 6.18 cm, respectively, and the aggregate loss of the three female age groups was 5.54, 6.14 and 6.48 cm, respectively. For the lower garment, the aggregate loss of the three male age groups was 6.05, 6.57 and 6.84 cm, respectively, and the aggregate loss of the three female age groups was 6.22, 6.91 and 6.53 cm, respectively.

4. Discussion

An effective sizing system should satisfy three main criteria, i.e. fewer sizes, higher coverage of the population and better fit. Since these three criteria are in compromising conflict, it is almost impossible to have a perfect sizing system (McCulloch et al., 1998).

In fit issues, the aggregate loss was used to validate the sizing system. For the results displayed in Table 3, all of the aggregate loss values were slightly higher than the benchmark value, i.e. 5.08 cm ($4^{1/2} \times 2.54$ cm), and were also similar to the results reported by Gupta and Gangadhar (2004) (6.22 cm for the upper garment and 6.77 cm for the lower garment). Thus, the performance in good fit for the developed sizing systems is satisfactory.

Furthermore, the Korean sizing standards were adopted for comparing the differences between the two sizing systems. The KS (Korean Standards) K 0050 and KS K 0051 are the standards of sizing systems for male garments and female garments. These standards are specified for Koreans from ages 6 to 70 years, and are classified into 4 age groups (i.e. 6–10, 11–13, 14–17 and 18–70 years). For children in the age groups of 6–10 and 11–13 years, the stature range is from 105 to 175 cm, and they are classified into 15 stature groups using an interval of 5 cm. Further, each stature group is further divided into three garment sizes using the size interval of 4 cm for chest girth, except for the group of 105 cm. Hence, there are 43 garment sizes for children in the age group of 6–13 years.

Fig. 8 shows the size distribution of stature vs chest girth for the KS K 0050 (Korean boys, age 6–13 years) and the sizing system developed in this study (Taiwanese boys, age 6–12 years). It seems that both sizing systems are similar and have the same increasing trend. The total number of sizes in the Korean standards is more than that in this study, owing to the size interval in stature for the Korean standards being smaller.

Developing an effective sizing system is not only a statistical problem but also a marketing one (Beazley, 1998). The control and reference dimensions provided in Table 2 can be used to design and produce different kinds of school uniforms, such as blazers, skirts, pants, slacks, vests, shirts and blouses. Moreover, the percentage

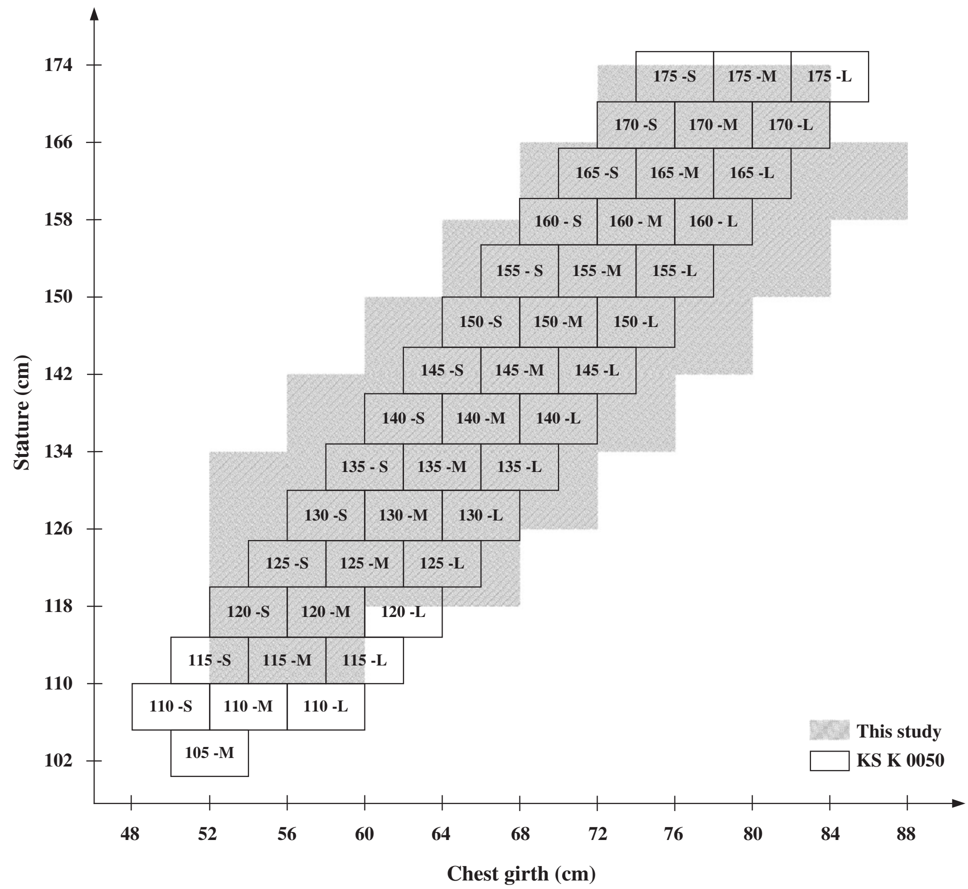

Fig. 8. The comparison of the KS K 0050 and the sizing system obtained in this study.

distribution information is very important for the manufacturers to estimate the customers' demands and make effective production planning about the quantity for different size groups. The size charts in here only provide the anthropometric dimensions of each size. Some additional steps are necessary to translate the anthropometric dimensions to garment dimensions for effective garment design and production.

5. Conclusion

This study proposed a two-stage cluster analysis approach to develop 12 sizing systems for the elementary-school, junior high-school and senior high-school students. These well-structured sizing systems have the advantages of a high coverage rate (over 85%) with few size groups (less than 36) and a good fit performance. The control and reference dimensions in the size chart can provide very useful information for the design and making of clothing for school students. Also, the percentage distribution information of each of the size groups can help the garment manufacturers to better understand the customer's body size and shape characteristics and to make effective production planning. Lastly, comparison with the Korean sizing standards demonstrated a similar trend between the two sizing systems.

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