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The Structure of Body Measurements for the Determination of Shoe Sizing for Young Croatian Men

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A B S T R A C T

The determination and promotion of the system of shoe sizing requires accurate knowledge of morphological properties of the foot and lower leg of the tested population. Similarly it is necessary to establish the occurrence and regional distribution of definite sizes in the tested population. Possible regional differences in morphological properties must not be ignored because it has been established by means of anthropological measuring that both foot dimensions and foot shapes differ between populations and within the same population. This has been proven by the investigation of body measures, carried out for the purpose of establishing a system of footwear sizes, which was executed on a randomly selected sample of 4,268 healthy and normally developed males aged 18–22. The investigation was carried out in 1993 on five locations each of which representing a definite region of the Republic of Croatia: Jastrebarsko (central), Koprivnica (northwestern), Pula (southwestern), Sinj (southern) and Požega (northeastern). The measuring instrument was 31 foot and lower-leg sizes according to the existing ISO standards for footwear. Interregional differences are significant in all body measures. The role and the contribution of individual measures to these differences has been established by means of discriminatory analysis with regions as a priori defined samples. In order to constitute a convenient and purposeful standard for the footwear size system it is necessary to work out a database with referent values for the same system.

Key words: *anthropometry, foot, dimensions, shoe fit*

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Introduction

By means of anthropometric measuring it has been established that foot dimensions and shapes differ between populations and within each particular population[1]. The results of anthropometric measurings provide an insight into the occurrence and regional distribution of certain sizes in the investigated population. By analyzing feet properties their build and their types have been established and thus a recommendation of referent values in the system of footwear sizing for a particular population can be made.

Within the human species the variations of foot shape and proportion may seem to be relatively small but some differences are noticed in the pattern of toe lengths (digital patterning), the height of the arch and instep (dorsum), the relationship between foot lengths and ball and heel width, the shape of the heel and the angles and shape of the toes. Variations in these and other parameters suggest that one shape will not represent the human foot closely enough to satisfy the comfort of fit requirements. Thus the examination of the pattern and degree of foot variation has significant implications in the domain of ergonomics[2].

The investigations carried out in the American army point that the differences in body size between subpopulations making up the army are so extensive that the designed material systems based on collective statistics for the military population are completely inadequate for some subpopulations[3,4].

An effective way of designing well-fitting products is to analyze human body forms and to classify them into several groups[5].

The results of the investigation of the anthropometric status of Croatian recruits executed with the aim of determining the body dimensions needed for working out a proposition of a clothing size system point to interregional differences in all investigated body measurements. Significant differences have been established not only in the body size but also in its build, especially between the northeastern and the western regions of Croatia[6].

These data point to the importance of considering the distribution of anthropometric variables within each subpopulation in the army with the goal of making it easier to establish which subpopulations contain more extreme distributions and which dimensions are specific for a certain population. These facts point to the necessity of carrying out anthropometric measuring in each particular military population as well as to the necessity of collecting data obtained from anthropometric measurements carried out for the needs of the army[3,4].

A systematic analysis of foot shape variations is indispensable in order to identify the causes of misfit and to establish an objective method of modifying the shoe cast to fit different shapes[7].

The results of a study covering a group of 390 Israeli infantry recruits show that three shoe widths for each shoe length were necessary to adequately accommodate the recruit population¢s foot anatomy[8].

The comfort of shoes seems to affect the fatigue, the injury outcome and the performance of each person. Therefore it is important to identify the factors that affect the footwear comfort[9].

The fit of the shoe and the amount of pressure the foot is exposed to at its plantar and dorsal surfaces are additional factors that may influence the long-term overloading and damage of the foot[10].

The essential requirements for comfort of fit are often neglected. For a shoe to be comfortable, the internal shape must closely approximate the shape of the foot,

which suggests that accurate knowledge of foot shape and dimensions is a fundamental pre-requisite for determining the shoe comfort. That is why it is necessary to work out the referent values concerning foot dimensions and proportions of each particular population[11,12].

Materials and Methods

The investigation was carried out in 1993 at five locations each of which representing a region of the Republic of Croatia: Jastrebarsko (C), Koprivnica (NW), Pula (SW), Sinj (S) and Požega (NE). 4,268 healthy and normally developed males aged 18–22 were randomly selected. Jastrebarsko was represented by 620 examinees who were on the average 19.88 years old (±0.957); Koprivnica by 1,200 examinees 19.74 years old (±0.727); Pula by 1,221 examinees 19.77 years old (±0.988); Sinj by 618 examinees 19.91 years old (±1.248) and Požega by 609 examinees 19.46 years old (±0.992). Most examinees were between 20 and 21 (respectively 1,684 and 1,707) years old, which, according to 1991 census, represents about 5% of Republic of Croatia¢s male population of the same age.

Considering that the investigation is part of a more widely defined project, the anthropometric variables were chosen and their measurements performed in accordance with the methodology offered by International Biological Program (IBP)[13], International standards for garment construction and anthropometric surveys – Body dimensions[14], International standards for shoe sizes[15]. Thus the anthropometric list encompassed 130 measurements taken on each examinee. They can be divided into four functional groups: the group of measurements for assessing the morphological status, the group of measurements for clothes, the group of measurements for footwear and the group of measurements for ergonomy. Measurers were trained and taught to follow the measuring protocol.

The object of this work is a group of measures for shoe sizing i.e. of anthropometric measures used for determining the dimensions of shoes and the size system of shoes encompassing 31 (sizes) variables shown in Table 1 (descriptively and in code). All variables have been measured according to ISO 8559 and ISO 9407. 14 variables have been taken from plantograms.

In accordance with the subject of this work (the structure of body measures for determining shoe sizing), the statistical data processing and analysis were carried out on 33 chosen anthropometric variables (Table 1) by means of univariate and multivariate methods. Since the emphasis is on structural distinctions, the variables have been described by standardized values. The assumed regional differences *a priori* defined by investigated locations (Jastrebarsko, Koprivnica, Pula, Sinj and Požega), were tested by multivariate analysis of variance, whereas the position of each region within the variables was evaluated by discriminant analysis. It is important to emphasize that the observed variables are multivariate normally distributed which lends legitimacy to the applied methods. All statistical analyses were carried out by means of program package data analysis SPSS for Windows Release 9.0.

Results and Discussion

The differences between variables according to place of investigation i.e. according to regions of the Republic of Croatia are represented on Figures 1 to 3, by mean standardized values in such a way that the differences can be read from the scale with units expressed by standard deviations.

The assumption of equality of centroids in Croatia can be rejected with a

TABLE 1
LIST OF FOOT MEASURES AND VARIANCE ANALYSIS RESULTS

Code	Variables	Sum of squares	df	Mean square	F	p
V01	Height (cm)	2215.0	4	43.22	51.3	<0.001
V02	Body mass (kg)	1604.2	4	92.57	17.3	<0.001
V03	Knee girth (cm)	142.8	4	4.39	32.5	<0.001
V04	Under knee girth (cm)	66.4	4	4.53	14.7	<0.001
V05	Right leg girth (cm)	114.6	4	6.41	17.9	<0.001
V06	Leg minimum girth (cm)	114.5	4	2.03	56.5	<0.001
V07	Ankle girth (cm)	712.5	4	2.07	344.1	<0.001
V08	Heel girth (cm)	183.3	4	2.59	70.7	<0.001
V09	Instep maximum girth (cm)	2766.5	4	2.28	1213.6	<0.001
V10	Instep girth (cm)	147.7	4	1.46	101.0	<0.001
V11	Ball of foot girth (cm)	76.2	4	1.65	46.2	<0.001
V12	Outer right ankle height (cm)	45.1	4	0.35	129.7	<0.001
V13	Foot maximum height (cm)	92.5	4	0.42	222.0	<0.001
V14	Instep height (cm)	32.9	4	0.30	109.7	<0.001
V15	Big-toe joint height (cm)	8.5	4	0.06	132.4	<0.001
V16	Big-toe distalfalang height (cm)	1.1	4	0.05	22.2	<0.001
V17	Maximum foot breadth (cm)	25.6	4	0.33	78.2	<0.001
V18	Heel maximum breadth (cm)	1.0	4	0.17	6.1	<0.001
V19	Foot length (cm)	49.3	4	1.56	31.5	<0.001
V20	Left foot lenght (cm)	34.7	4	1.53	22.6	<0.001
V21	Left sole length (cm)	56.4	4	1.48	38.1	<0.001
V22	Left sole maximum toe part (cm)	1.6	4	0.28	5.6	<0.001
V23	Maximum left foot part (cm)	2.9	4	0.17	17.1	<0.001
V24	Left heel symmetral (cm)	0.5	4	0.04	12.8	<0.001
V25	Left big-toe angle (°)	214.5	4	19.92	10.8	<0.001
V26	Left little-toe angle (°)	631.0	4	17.06	37.0	<0.001
V27	Right foot length (cm)	42.2	4	1.49	28.3	<0.001
V28	Right sole length (cm)	54.6	4	1.46	37.4	<0.001
V29	Right sole maximum toe part (cm)	1.9	4	0.29	6.5	<0.001
V30	Maximum right foot part (cm)	10.5	4	0.20	53.8	<0.001
V31	Right heel symmetral (cm)	0.3	4	0.04	7.4	<0.001
V32	Right big-toe angle (°)	176.2	4	21.34	8.3	<0.001
V33	Right little-toe angle (°)	1926.6	4	16.40	117.5	<0.001

high certainty ($p<0.001$) on the grounds of the results obtained by multivariate variance analysis in the area constituted by 31 variables for determining shoe sizing. Thus it is possible to verify the corresponding hypotheses by univariate analysis of variance, variable by variable. As it is evident from Table 1, Croatian regions differ in all dimensions (variables) for determining shoe sizing.

The role and contribution of individual variables to the established differ-

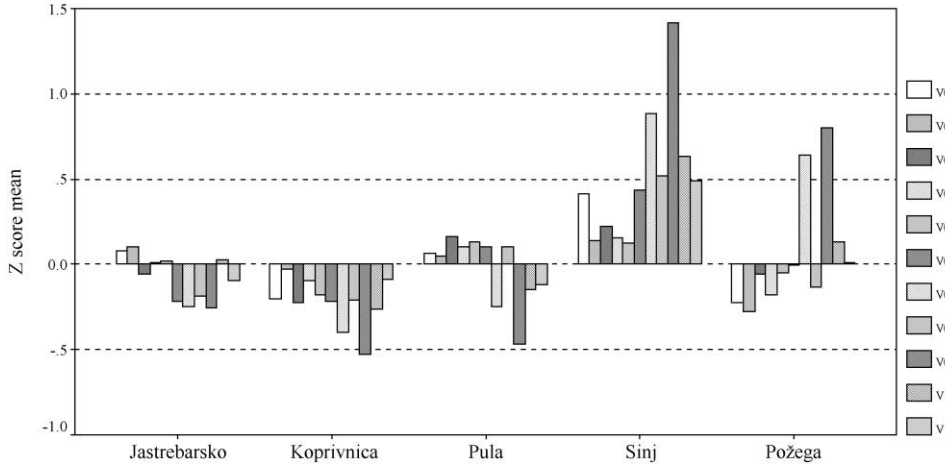

Fig. 1. Mean of standardized values of body measures V1 to V11 in terms of survey locations.

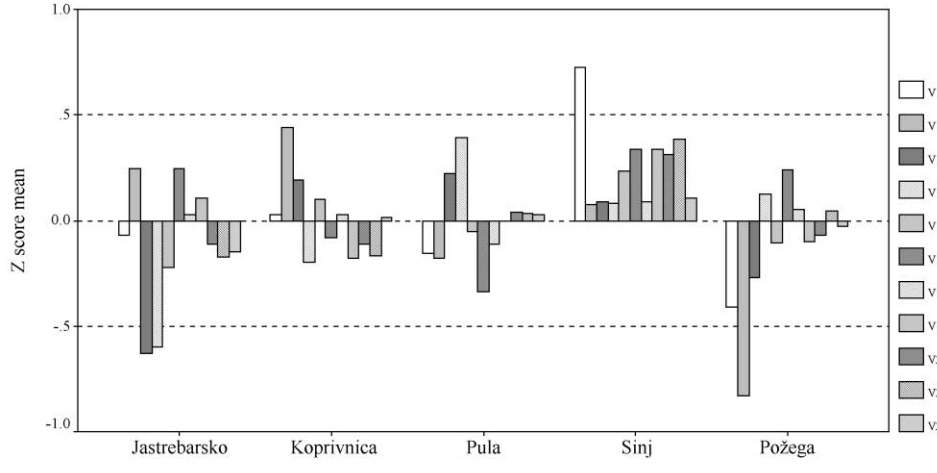

Fig. 2. Mean of standardized values of body measures V12 to V22 in terms of survey locations.

ences between regions can be explained on the basis of performed discriminative analysis with regions as *a priori* defined samples. The five groups i.e. five regions can be represented in four-dimensional discriminative space all of which being significant for discriminating the groups. The first discriminant function explains 72%, the second 17.7%, the third 5.6% and the fourth the remaining 4.7% of total variance (Tables 2 and 3).

The contents of individual discriminative function can be recognized on the grounds of their correlation with the starting variables i.e. with the original body measures for determining shoe sizing. Table 4 presents those correlations

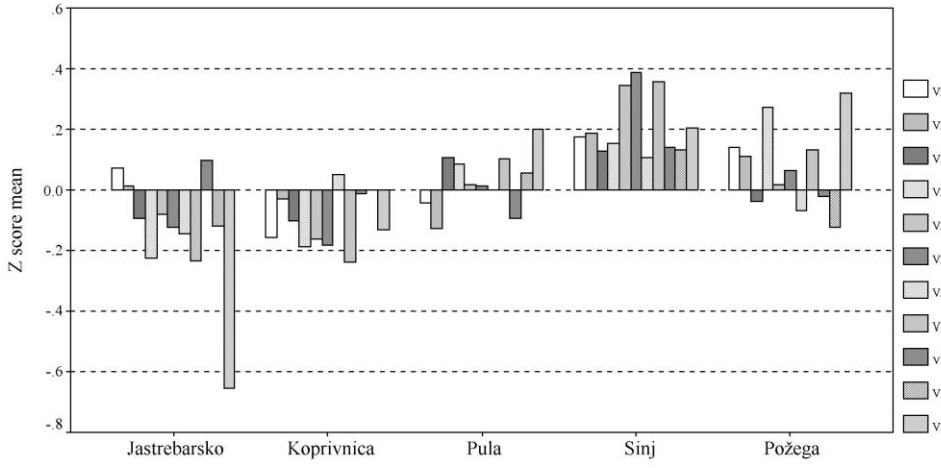

Fig. 3. Mean of standardized values of body measures V23 to V33 in terms of survey locations.

TABLE 2
EIGENVALUES

Function	Eigenvalue	% of Variance	Cumulative %	Canonical correl.
1	3.881	72.0	72.0	0.892
2	0.953	17.7	89.7	0.699
3	0.301	5.6	95.3	0.481
4	0.252	4.7	100.0	0.449

TABLE 3
WILKS' LAMBDA (Λ)

Test of functions	Wilks' Λ	χ^2	df	p
1–4	0.064	11645.5	132	<0.001
2–4	0.314	4914.5	96	<0.001
3–4	0.614	2071.3	62	<0.001
4	0.798	955.5	30	<0.001

arranged according to their absolute value.

The two afore-mentioned analyses (multivariate analysis of variance and discriminant analysis) point to considerable differences in the foot build of recruits from Jastrebarsko, Koprivnica and Pula on the one hand and Sinj and Požega on the other. The first and foremost discriminatory function is primarily defined by the instep maximum (V09) and ankle (V07) girth. Both variables are considerably higher in recruits from Sinj and Požega. The second discriminatory function is defined by the height of big-toe joint (V15) as well as the angle of the right and left little-toe (V33, V26). These variables are significantly lower in recruits from Jastrebarsko and Koprivnica. Larger foot width, which also participates in the second discriminatory variable, is significantly lower in recruits from Pula in comparison with the rest of recruits (Figures 1–3).

The similarity of examinees from Jastrebarsko, Koprivnica and Pula, on the one hand, and those from Sinj and Požega, on the other, is shown by the classification results (Table 5) as well as by the position in the discriminatory area constituted by the first two discriminatory functions (Figure 4). Namely, a larger number of examinees changed group only within these two groups of gravity

TABLE 4
POOLED WITHIN-GROUPS CORRELATIONS BETWEEN DISCRIMINATING VARIABLES AND STANDARDIZED CANONICAL DISCRIMINANT FUNCTIONS (STRUCTURE MATRIX)

Code[a]	Function[b]			
	1	2	3	4
V09	**0.532**	–0.070	0.230	0.279
V07	**0.286**	0.031	0.047	0.113
V24	**0.050**	–0.046	0.035	–0.015
V15	0.029	**0.350**	0.028	0.125
V33	0.079	**0.293**	0.101	–0.053
V17	0.102	**–0.185**	–0.022	–0.030
V26	0.068	**0.126**	–0.064	0.031
V31	0.022	**–0.066**	0.034	0.046
V18	0.023	**–0.052**	0.041	–0.048
V13	–0.130	–0.259	**0.501**	0.109
V12	0.061	–0.102	**0.479**	0.335
V14	–0.042	0.223	**0.403**	–0.010
V16	0.018	0.015	**0.253**	–0.005
V11	0.084	–0.026	**0.187**	0.140
V29	0.004	0.026	**0.133**	0.002
V32	0.001	0.039	**0.118**	0.092
V22	0.010	0.043	**0.101**	0.016
V01	0.040	–0.010	0.081	**0.398**
V08	0.069	0.080	0.177	**0.358**
V19	0.046	–0.034	0.029	**0.281**
V03	0.032	0.085	–0.020	**0.277**
V06	0.074	0.103	0.106	**0.268**
V10	0.137	–0.053	0.076	**0.260**
V04	0.000	0.023	0.045	**0.224**
V05	0.016	0.053	–0.057	**0.220**
V02	–0.017	–0.033	0.082	**0.218**
V30	0.083	0.121	0.030	**0.193**
V27	0.063	0.033	0.063	**0.190**
V20	0.043	0.040	0.110	**0.190**
V28	0.077	0.047	0.069	**0.185**
V21	0.073	0.064	0.095	**0.183**
V25	0.015	0.066	0.020	**0.139**
V23	0.055	–0.017	–0.079	**0.089**

[a] Variables ordered by absolute size of correlation within function

[b] Bold font style denote largest absolute correlation between variable and any disriminant function

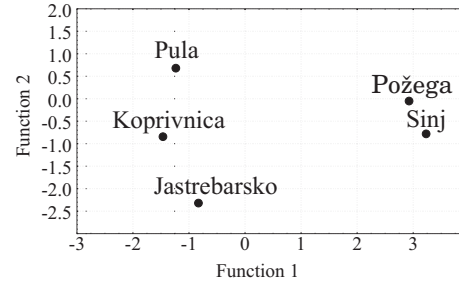

Fig 4. Positions of regions at the level of the first and second discriminative function.

centers. Thus, for instance, 19.1% of recruits from Jastrebarsko are similar to the recruits from Koprivnica while only an insignificant number is similar to the recruits from Sinj and Požega. The number of recruits from Sinj and Požega that traded places with each other is larger than the number of those who traded places with other gravity centers.

All these facts point to the robust foot build of the recruits from Sinj and Požega compared to that of the recruits from Jastrebarsko, Koprivnica and Pula. The differences are indicative enough and emphasize the need of working out specific casts for each of the two groups.

These results are important for the assessment of the biological variability of the body and feet of young males and therefore they can be applied in military and civilian footwear industry. Namely, the results can be directly employed in the selection of key dimensions necessary for the design and manufacture of footwear. Comfortable, anatomically shaped shoes can affect the fitness of the general population as well as of those liable for military service. The benefits of determining systems of footwear sizes for the general population as well as for target populations such as the Croatian army are multiple:

TABLE 5
CLASSIFICATION RESULTS[a]

	Region	Predicted group membership					
		Jastrebarsko	Koprivnica	Pula	Sinj	Požega	Total
Count	Jastrebarsko	466	118	24	8	3	619
	Koprivnica	94	866	234	3	3	1200
	Pula	26	157	1031	0	6	1220
	Sinj	9	14	12	485	98	618
	Požega	3	3	19	77	507	609
%	Jastrebarsko	75.3	19.1	3.9	1.3	0.5	100.0
	Koprivnica	7.8	72.2	19.5	0.3	0.3	100.0
	Pula	2.1	12.9	84.5	0.0	0.5	100.0
	Sinj	1.5	2.3	1.9	78.5	15.9	100.0
	Požega	0.5	0.5	3.1	12.6	83.3	100.0

[a] 78.6% of original grouped cases correctly classified

– footwear made according to well-defined body measures is more comfortable and better looking;
– it offers a convenient choice of sizes;
– it facilitates the communication between shoe manufacturers and consumers;
– in large systems, such as the army and the police, the stocks can be reduced or efficiently optimized which leads to financial savings.

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STRUKTURA TJELESNIH MJERA ZA ODREĐIVANJE SUSTAVA VELIČINA ZA OBUĆU MLADIH MUŠKARACA HRVATSKE

S A Ž E T A K

Određivanje i unapređivanje sustava veličina za obuću zahtijeva upoznavanje morfoloških obilježja stopala i potkoljenice ispitivane populacije. Isto tako, potrebno je ustanoviti pojavnost i regionalnu distribuciju određenih veličina u ispitivanoj populaciji. Pri tome se ne smiju zanemariti moguće regionalne (interpopulacijske) razlike u morfološkim obilježjima zbog toga jer je antropometrijskim mjerenjima utvrđeno da se dimenzije i oblici stopala razlikuju između i unutar populacija. Pokazuje to i provedeno istraživanje tjelesnih mjera za određivanje sustava veličina za obuću na slučajno odabranom uzorku 4268 zdravih i normalno razvijenih muškaraca u dobi od 18 do 22 godine. Istraživanje je provedeno na pet lokacija 1993. godine od kojih svaka predstavlja određenu regiju Republike Hrvatske: Jastrebarsko središnju, Koprivnica sjeverozapadnu, Pula jugozapadnu, Sinj južnu i Požega sjeveroistočnu. Kao mjerni instrument odabrana je 31 mjera stopala i potkoljenice prema važećim ISO standardima za obuću. Međuregionalne razlike značajne su u svim tjelesnim mjerama. Uloga i doprinos pojedinih mjera tim razlikama utvrđena je diskriminacijskom analizom s regijama kao a priori definiranim uzorcima. Za uspostavu prikladnog i svrhovitog standarda sustava veličina za obuću potrebno je izraditi bazu podataka sa referentnim vrijednostima sustava veličina za obuću.