STATISTICAL-MATHEMATICAL PROCESSING OF ANTHROPOMETRIC FOOT PARAMETERS AND ESTABLISHING SIMPLE AND MULTIPLE CORRELATIONS. PART 2: CORRELATIONS AMONG ANTHROPOMETRIC PARAMETERS OF THE FOOT

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STATISTICAL-MATHEMATICAL PROCESSING OF ANTHROPOMETRIC FOOT PARAMETERS AND ESTABLISHING SIMPLE AND MULTIPLE CORRELATIONS. PART 2: CORRELATIONS AMONG ANTHROPOMETRIC PARAMETERS OF THE FOOT

ABSTRACT. Footwear manufacturing based on suitable lasts and appropriate sizes is possible, using the results obtained from anthropometric measurements. The construction of the last, the establishment of dimensions required to meet the comfort requirements of a larger proportion of consumers, must be based on the knowledge and the most accurate characterization of the anatomical-morphological differences of the types of foot encountered within that population of consumers as well as the frequency of these types within the population. For this purpose, it is periodically necessary to perform anthropometric studies on the population differentiated according to certain criteria (gender, age, geographical region, etc.) in order to obtain information about the dimensional particularities of the average representative foot for that population, the anthropometric parameters distribution laws that characterize the representative average foot of the country's population in terms of size. In order to define the characteristic dimensions of the foot, one- and two-dimensional distributions of anthropometric parameters were used as well as a series of correlations that model the interdependence among the various parameters, with direct applicability in designing the last. Linear regression equations can be used in last design to determine the dependences between the geometric parameters of the last in close connection with the laws of variation of the anthropometric parameters of the foot. Multiple linear correlations have been established demonstrating that there are very high correlations between certain variables.

KEY WORDS: anthropometric parameters, foot, correlation

PRELUCRAREA STATISTICO-MATEMATICĂ A PARAMETRILOR ANTROPOMETRICI AI PICIORULUI ŞI STABILIREA CORELAŢIILOR SIMPLE ŞI MULTIPLE. PARTEA 2: CORELAŢII ÎNTRE PARAMETRII ANTROPOMETRICI AI PICIORULUI

REZUMAT. Realizarea de încălţăminte pe calapoade adecvate, într-un pontaj corespunzător, este posibilă, prin utilizarea rezultatelor obţinute prin măsurători antropometrice. Construcţia calapodului, stabilirea tipodimensiunilor necesare satisfacerii cerinţelor de confort a unei ponderi cât mai mari de consumatori, trebuie să aibă la bază cunoaşterea şi caracterizarea cât mai exactă a diferenţelor de ordin anatomo-morfologic a tipurilor de picior care se întâlnesc în cadrul acelei populaţii de consumatori precum şi a frecvenţei acestor tipuri în cadrul populaţiei. În acest scop, periodic, este necesară efectuarea unor studii antropometrice asupra populaţiei diferenţiate după anumite criterii (sex, vârstă, regiune geografică etc.) în scopul obţinerii unor informaţii privind particularităţile dimensionale ale piciorului mediu reprezentativ pentru acea populaţie, legile de distribuţie a parametrilor antropometrici ce caracterizează sub raport dimensional piciorul mediu reprezentativ al populaţiei ţării respective. În vederea definirii tipodimensiunilor caracteristice ale piciorului, s-au utilizat distribuţii uni şi bidimensionale ale parametrilor antropometrici precum şi o serie de corelaţii ce modelează interdependenţa dintre diverşi parametri, având aplicabilitate directă în proiectarea calapodului. Ecuaţiile de regresie de tip liniar pot fi folosite la proiectarea calapoadelor pentru stabilirea dependenţelor dintre parametrii geometrici ai calapodului în strânsă legătură cu legile de variaţie a parametrilor antropometrici ai piciorului. S-au stabilit corelaţii multiple de tip liniar care demonstrează că există corelaţii foarte ridicate între anumite variabile.

CUVINTE CHEIE: parametri antropometrici, picior, corelaţie

LE TRAITEMENT STATISTIQUE-MATHÉMATIQUE DES PARAMÈTRES ANTROPOMÉTRIQUES DU PIED ET LA DÉTERMINATION DES CORRÉLATIONS SIMPLES ET MULTIPLES. DEUXIÈME PARTIE: DES CORRÉLATIONS ENTRE LES PARAMÈTRES ANTROPOMÉTRIQUES DU PIED

RÉSUMÉ. La fabrication des chaussures à partir d'une forme et des dimensions appropriées est possible en utilisant les résultats obtenus par des mesures anthropométriques. La construction de la forme, l'établissement des tailles standard pour satisfaire les exigences de confort pour la majorité des consommateurs, doivent être fondés sur la connaissance et la caractérisation plus exacte des différences anatomiques et morphologiques des types du pied rencontrés chez cette population des consommateurs, ainsi que la fréquence de ces types au sein de la population. A cet effet, périodiquement, il est nécessaire de mener des études anthropométriques sur la population différenciée selon certains critères (sexe, âge, région géographique, etc.) afin d'obtenir des informations sur les particularités dimensionnelles du pied représentatif pour la population, les lois de distribution des paramètres anthropométriques qui caractérisent le pied moyen représentatif de la population du pays. Pour définir les tailles standard caractéristiques du pied, on a utilisé des distributions uni- et bidimensionnelles des paramètres anthropométriques ainsi qu'un certain nombre de corrélations qui déterminent l'interdépendance entre les différents paramètres, avec application directe dans la conception de la forme. Les équations de régression linéaire peuvent être utilisées pour concevoir les formes de chaussures et pour définir les dépendances entre les paramètres géométriques de la forme en étroite collaboration avec les lois de variation des paramètres anthropométriques du pied. Des corrélations multiples ont été établies, démontrant qu'il existe des corrélations très élevées entre certaines variables.

MOTS CLÉS : paramètres anthropométriques, pied, corrélation

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INTRODUCTION

It is periodically necessary to perform anthropometric studies on the population differentiated according to certain criteria (sex, age, geographical region, etc.) in order to obtain information about the dimensional particularities of the average representative foot for that population, the laws of distribution of anthropometric parameters that characterize the representative average foot of the population of the respective country. In order to define characteristic dimensions of the foot, one- and two-dimensional distributions of anthropometric parameters as well as a series of correlations that model the interdependence among various parameters, with direct applicability in designing the last. The correlation between two or more anthropometric parameters is the statistical interdependence between them. The correlation involves establishing a real connection between the studied parameters, connection that may be analyzed in terms of its direction, form and intensity. Correlations among the studied anthropometric parameters are useful in the design of lasts and footwear.

EXPERIMENTAL

Materials and Methods

Using the INFOOT USB system, made up of the 3D scanner and the dedicated MEASURE 2.8 software, as a result of foot shape scanning and placement of anatomical points on the surface of the scanned foot shape, values for a set of 20 anthropometric parameters, lengths, widths, girths and angles were determined (Table 1) [1].

Table 1: Anthropometric parameters of the foot

1.	Foot length	Lp	(mm)
2.	Ball girth circumference	Pd	(mm)
3.	Foot breadth	Id	(mm)
4.	Instep circumference	Pr	(mm)
5.	Heel breadth	Ic	(mm)
6.	Instep length	Lr	(mm)
7.	Toe height	Hd	(mm)
8.	Instep height	Hr	(mm)
9.	Toe 1 angle	Ud1	(°)
10.	Toe 5 angle	Ud5	(°)
11.	Toe 1 height	Hd1	(mm)
12.	Toe 5 height	Hd5	(mm)
13.	Height of navicular	Hn	(mm)
14.	Height of Sphyrion fibulare	Hsf	(mm)
15.	Height of Sphyrion	Hs	(mm)
16.	Height of the most lateral point of lateral malleolus	Hme	(mm)
17.	Height of the most medial point of medial malleolus	Hmi	(mm)
18.	Heel angle	Uc	(°)
19.	Heel girth	Pc	(mm)
20.	Ankle girth	Pg	(mm)

Anthropometric footprints obtained using the INFOOT USB system were statistically analyzed using the SPSS software package, which is a package dedicated to statistical data processing, making it easy to obtain the desired results quickly. Anthropometric data collected by 3D scanning of the left and right foot were grouped into four samples (South, East, Centre-West and Total) and then statistical indicators of characterization (arithmetic mean and standard deviation) and statistical indicators of variation (minimum and maximum value, amplitude and coefficient of variation) were calculated for each variational sequence of the 20 anthropometric parameters studied. Regressions and correlations

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were established between parameters of the analyzed samples: statistical dependencies, simple linear correlations, simple non-linear correlations, multiple linear correlations.

Subjects

Anthropometric studies were conducted on a sample of 300 male subjects from three geographic regions of Romania: Dobrogea, Oltenia and Muntenia - South (100 subjects), Moldavia and Bucovina - East (100 subjects) and Transylvania and Banat - Centre and West (100 subjects). Subjects with particular anthropometric features, including deformities and structural abnormalities of the foot, were excluded.

RESULTS AND DISCUSSIONS

Simple Correlations (between Two Variables) to Characterize the Interdependence of Anthropometric Parameters

The intensity of dependence between two random variables, namely the analyzed anthropometric parameters, is quantitatively expressed by the coefficient of correlation, r_{xy} [2, 3]:

$$r_{yx} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{nS_xS_y} \qquad (1)$$

where:

$(x_i - \bar{x})\ si\ (y_i - \bar{y})$ - deviations of particular values of variables from the average;

S_xS_y - mean squared deviations of variables;

n – selection volume.

Values of coefficients of correlation between the studied anthropometric parameters are presented in Table 2. Coefficient of variation r_{yx} varies in the range between -1 and +1 (Figure 1). If r_{yx} is in the range (0,1) then dependence between variables is direct and if r_{yx} is in the range (-1,0) then the connection between variables is reversed.

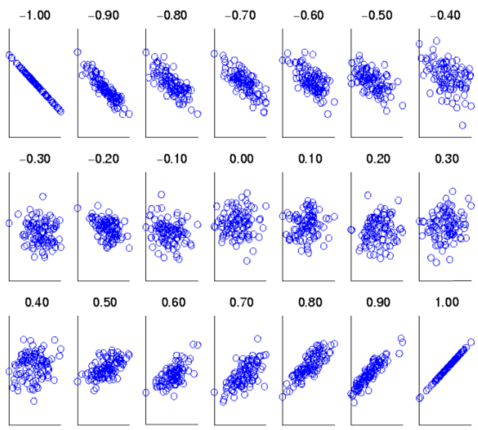

Figure 1. Graphic representation of correlations for r_{yx} from -1 to +1

Table 2: Matrix of values of coefficients of correlations between anthropometric parameters

	Lp	Pd	ld	Pr	lc	Lr	Hd	Hr	Ud1	Ud5	Hd1	Hd5	Hn	Hsf	Hs	Hme	Hmi	Uc	Pc	Pg
Lp	1.000																			
Pd	0.762	1.000																		
ld	0.651	0.966	1.000																	
Pr	0.529	0.827	0.745	1.000																
lc	0.506	0.622	0.608	0.590	1.000															
Lr	0.939	0.625	0.638	0.468	0.445	1.000														
Hd	0.866	0.507	0.492	0.455	0.454	0.813	1.000													
Hr	0.254	0.609	0.414	0.701	0.450	0.136	0.222	1.000												
Ud1	0.003	0.070	0.160	-0.033	0.017	0.023	-0.108	-0.168	1.000											
Ud5	0.009	0.297	0.329	0.266	0.089	-0.069	0.051	0.176	-0.061	1.000										
Hd1	0.254	0.440	0.315	0.493	0.462	0.203	0.280	0.633	-0.117	0.008	1.000									
Hd5	0.266	0.453	0.443	0.405	0.442	0.229	0.236	0.352	0.219	0.147	0.479	1.000								
Hn	-0.066	0.107	0.025	0.175	0.130	-0.141	0.048	0.431	-0.022	0.078	0.385	0.212	1.000							
Hsf	0.373	0.388	0.302	0.386	0.159	0.381	0.378	0.427	-0.154	0.088	0.310	0.062	0.303	1.000						
Hs	0.419	0.405	0.325	0.318	0.159	0.419	0.429	0.380	-0.152	0.042	0.203	-0.072	0.278	0.824	1.000					
Hme	0.458	0.438	0.358	0.403	0.210	0.453	0.445	0.426	-0.120	0.072	0.297	0.040	0.292	0.954	0.839	1.000				
Hmi	0.481	0.458	0.380	0.366	0.193	0.466	0.476	0.402	-0.140	0.077	0.209	-0.051	0.237	0.826	0.973	0.870	1.000			
Uc	0.124	0.041	0.091	0.023	-0.111	0.123	-0.070	-0.208	0.040	0.031	-0.193	-0.082	-0.184	0.128	0.006	0.111	0.028	1.000		
Pc	0.775	0.767	0.696	0.760	0.753	0.699	0.744	0.628	0.000	0.113	0.493	0.455	0.206	0.401	0.401	0.463	0.453	-0.137	1.000	
Pg	0.693	0.658	0.581	0.703	0.587	0.616	0.671	0.592	0.050	0.090	0.474	0.400	0.227	0.323	0.319	0.391	0.381	-0.172	0.897	1.000

Interpretation of coefficients of correlations:

r_{xy}=0.2-0.4 – Very low correlation - Orange

r_{xy}=0.4-0.7 – Low correlation - Green

r_{xy}=0.7-0.9 – High correlation - Blue

r_{xy}=0.9-1 – Very high correlation - Yellow

Linear correlations are described by the following regression equation [3-5]:

$$y=b0+b1*x \quad (2)$$

Where:

x – independent variable;

y – value of the dependent variable calculated by means of reaction equation;

b_1, b_0 – coefficients of the regression equation.

Simple linear regression equations were determined for the pairs of anthropometric parameters characterized by the coefficients of correlation higher than 0.7 (strong and very strong correlation) and are presented in Table 3, and for exemplification, the graphic form of these equations is represented in Figures 2-15.

Table 3: Linear regression equations

No.	Correlated variables y=f(x)	R^2	Coefficients of equation b_0	b_1
1.	Id=f(Pd)	0.934	-1.864	0.416
2.	Id=f(Pr)	0.555	32	0.284
3.	Lr=f(Lp)	0.882	0.446	0.715
4.	Pd= f(Lp)	0.437	82.25	0.668
5.	Pc=f(Lp)	0.600	91.06	0.957
6.	Hd=f(Lp)	0.749	20.09	0.556
7.	Pr=f(Pd)	0.683	19.51	0.933
8.	Pc=f(Pd)	0.587	102.5	0.936
9.	Hr=f(Pr)	0.491	2.343	0.166
10.	Pc=f(Pr)	0.577	130.6	0.822
11.	Ic=f(Pc)	0.567	6.148	0.183
12.	Hd=f(Pc)	0.553	34.45	0.387
13.	Pg=f(Pr)	0.494	90.80	0.710
14.	Pg=f(Pc)	0.804	-12.6	0.836

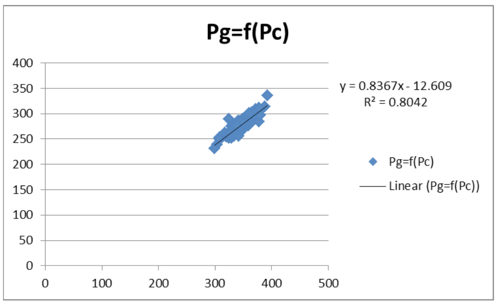

Figure 2. Graphic representation of the simple linear regression equation for correlated variables Pg and Pc

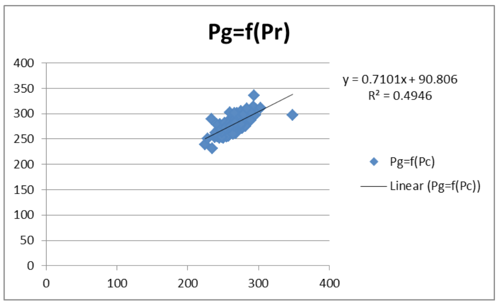

Figure 3. Graphic representation of the simple linear regression equation for correlated variables Pg and Pr

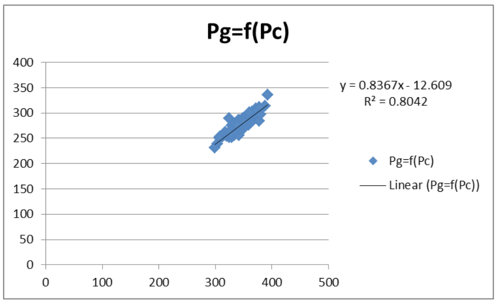

Figure 4. Graphic representation of the simple linear regression equation for correlated variables Hd and Pc

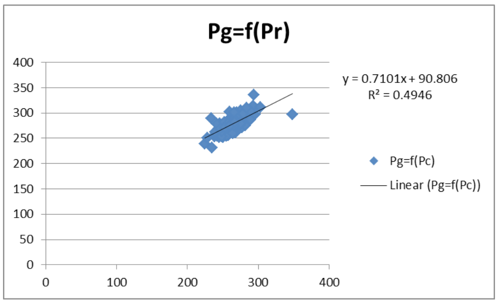

Figure 5. Graphic representation of the simple linear regression equation for correlated variables lc and Pc

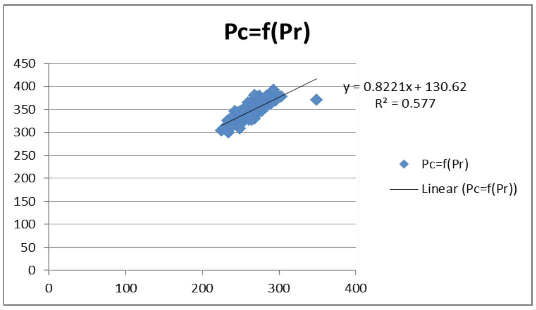

Figure 6. Graphic representation of the simple linear regression equation for correlated variables Pc and Pr

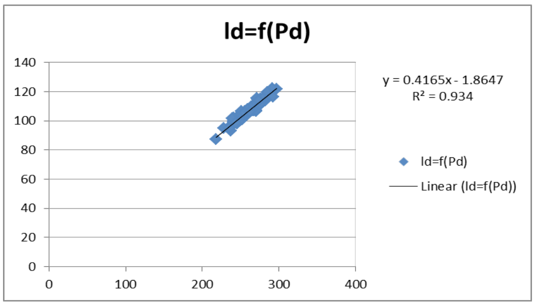

Figure 7. Graphic representation of the simple linear regression equation for correlated variables ld and Pd

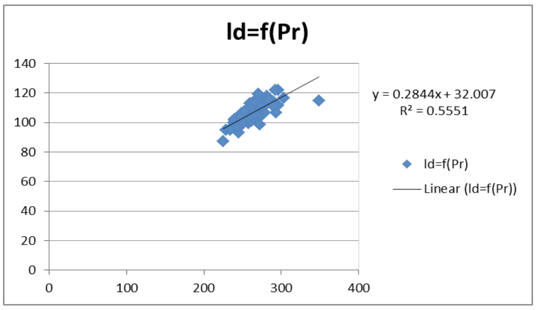

Figure 8. Graphic representation of the simple linear regression equation for correlated variables ld and Pr

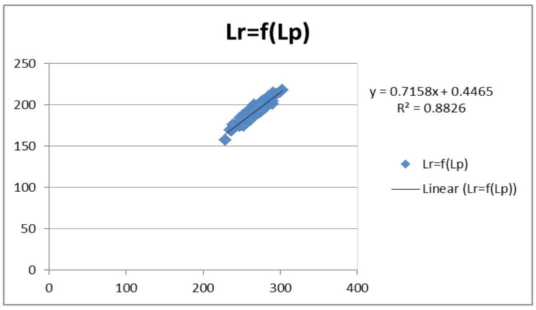

Figure 9. Graphic representation of the simple linear regression equation for correlated variables Lr and Lp

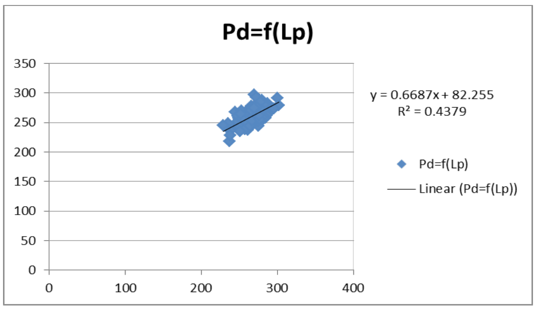

Figure 10. Graphic representation of the simple linear regression equation for correlated variables Pd and Lp

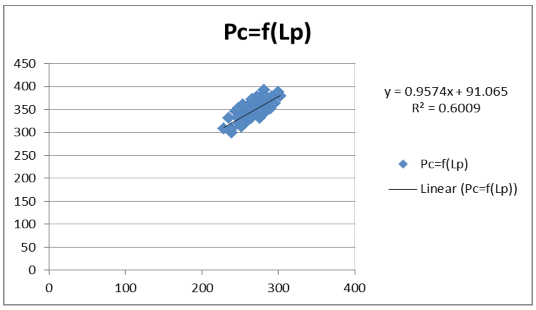

Figure 11. Graphic representation of the simple linear regression equation for correlated variables Pc and Lp

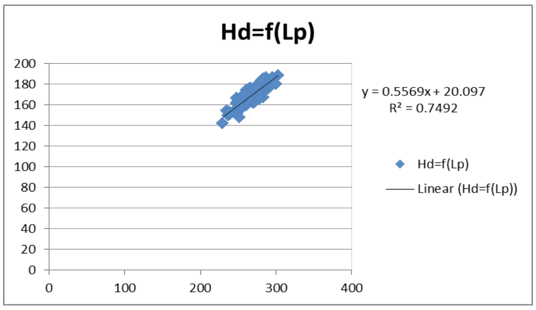

Figure 12. Graphic representation of the simple linear regression equation for correlated variables Hd and Lp

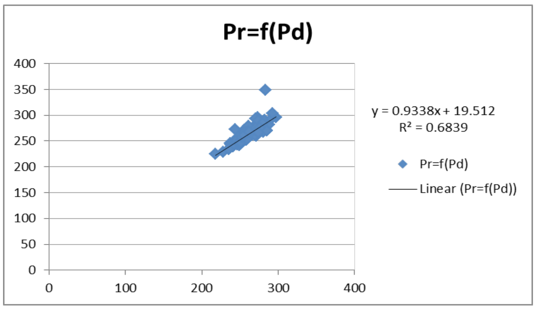

Figure 13. Graphic representation of the simple linear regression equation for correlated variables Pr and Pd

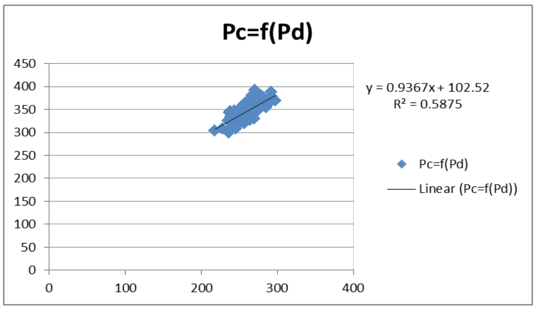

Figure 14. Graphic representation of the simple linear regression equation for correlated variables Pc and Pd

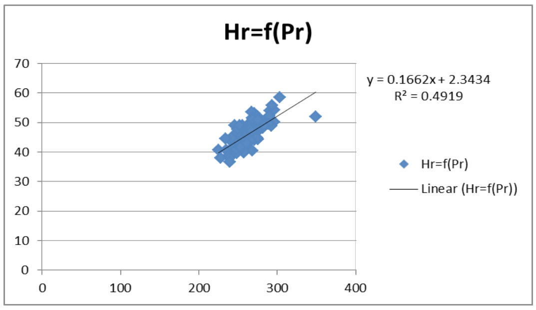

Figure 15. Graphic representation of the simple linear regression equation for correlated variables Hr and Pr

Multiple Correlations (among Three Variables) to Characterize the Interdependence of Anthropometric Parameters

Intensity of correlation among three variables is represented by the coefficient of multiple correlation R_{yx1x2} [2-4]:

$$R_{yx1x2} = \sqrt{\frac{r_{yx1}^2 + r_{yx2}^2 - 2r_{yx1}r_{yx2}r_{x1x2}}{1 - r_{x1x2}^2}} \quad (3)$$

Table 4 exemplifies the intensity among the following anthropometric parameters: Pr with Lp and Pd, ld with Lp and Pd, lc with Lp and Pd. There is a very high correlation of the ld variable with Lp and Pd, represented by the value of the coefficient of correlation R_{yx1x2}>0.9. In the case of the Pr variable depening on Lp and Pd and lc variable depending on Lp with Pd, correlations are high, 0.7<R_{yx1x2}<0.9.

Table 4: Values of simple and multiple coefficients of correlation

Anthropometric parameter	r_{yx1} Lp=x_1	r_{yx2} Pd=x_2	R_{yx1x2}
Pr= f(Lp, Pd)	0.602	0.765	0.832
ld=f(Lp, Pd)	0.545	0.928	0.915
lc= f(Lp, Pd)	0.654	0.755	0.789

CONCLUSIONS

➢ In order to characterize the dependence between two pairs of anthropometric parameters, the simple and multiple linear correlation was verified. For the simple correlation, coefficients of correlation r_{xy} were calculated, and the resulting values were compared with the values presented in the literature to characterize the type of correlation, namely:

- r_{xy}=0.2-0.4 – Very low correlation
- r_{xy}=0.4-0.7 – Low correlation
- r_{xy}=0.7-0.9 – High correlation
- r_{xy}=0.9-1 – Very high correlation

This analysis proved the existence of high and very high correlations, as follows:

- **Very high** correlations are obtained for the following groups of parameters: ld and Pd (r_{xy}=0.966), Lr and Lp (r_{xy}=0.939), Hme and Hsf (r_{xy}=0.954), Hmi and Hs (r_{xy}=0.973)
- **High** correlations are obtained for Lp and Pd (r_{xy}=0.762), Pr and Pd (r_{xy}=0.827), Pr and ld (r_{xy}=0.745), Hd and Lp (r_{xy}=0.866), Hr and Pr (r_{xy}=0.701), Pc and Lp (r_{xy}=0.775), Pc and Pd (r_{xy}=0.767), Pc and Pr (r_{xy}=0.760), Pc and lc (r_{xy}=0.753), Pc and Hd (r_{xy}=0.744), Pg and Pr (r_{xy}=0.703), Pg and Pc (r_{xy}=0.897).

➢ Simple linear regression equations were determined for the pairs of anthropometric parameters characterized by coefficients of correlation higher than 0.7 (strong and very strong correlations). Of all pairs tested, very strong linear dependences are found, described by the following relationships: ld=f(Pd), ld=f(Pr), Lr=f(Lp), Pd=f(Lp), Pc=f(Lp), Hd=f(Lp), Pr=f(Pd), Pc=f(Pd), Hr=f(Pr), Pc=f(Pr), lc=f(Pc), Hd=f(Pc), Pg=f(Pr). Linear regression equations (Y=f(x), Y=b0+b1*X) may be used in designing lasts to establish dependences among geometric parameters of the last in close connection with the laws of variation of anthropometric parameters of the foot.

➢ Establishing multiple linear correlations proved that there is a very high correlation of the ld variable (foot breadth) with Lp (foot length) and Pd (ball girth circumference) (ld=f(Lp, Pd), represented by the value of the coefficient of correlation R_{yx}1x2>0.9. In the case of variable Pr (instep circumference) depending on Lp (foot length) and Pd (ball girth circumference) (Pr=f(Lp, Pd) and lc variable (heel breadth) depending on Lp (foot length) and Pd (ball girth circumference) (lc=f(Lp, Pd)), correlations are high, 0.7<R_{yx}1x2<0.9.

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