Hand Shape Modeling for the Mexican Population

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Abstract. Anthropometric characteristics should be considered in the hand tools, workstations, and product design to diminish the risk of work-related musculoskeletal disorders. Even though univariate approaches disadvantages when used in multivariate analysis, most designs are based on the traditional percentile anthropometric data. This study obtained hand models through the univariate percentile values (1–99%) and two multivariate approaches: Principal Components Analysis (PCA) and Archetypal Analysis (AA) based on four hand dimensions. Fourteen hand models were obtained by the PCA, while three, five, and nine archetypal analysis *k*-value were selected after a root sum of squares analysis for $k = 1,\ldots, 12$ archetypes. Results suggest that AA models could provide higher accommodation levels, followed by PCA models and percentile values.

Keywords: Anthropometry · Percentiles · Principal Components Analysis · Archetypal analysis

1 Introduction

Poor anthropometric design can lead the individual user to assume awkward postures that can reduce their capacity at work and increase the risk for work-related musculoskeletal disorders [1, 2]. It is well known that most anthropometric workstation and hand tools designs are based on univariate anthropometric data [3]. It has also been demonstrated that the use of percentiles can be inappropriate since percentile values are not additive unless they are equal to 50% [4–6]. Several studies in the literature have investigated representative human models for different populations and anatomical regions across the world by using multivariate approaches such as Principal Components Analysis (PCA) and Archetypal Analysis (AA) [5, 7–9]. These study authors found no evidence of research that has analyzed human/hand models in the Mexican/northwestern Mexican population.

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The primary aim of this study is to model the dominant hand dimensions of the current northwestern Mexican male population. The study's second goal is to provide useful dominant hand models of the northwestern Mexican population that can be applied in the ergonomic design of workstations, hand tools, and products.

2 Materials and Methods

2.1 Anthropometric Data: Participants and Data Collection

To obtain the anthropometric information a total of 2,613 males were randomly selected for the survey. Subjects included healthy university professors, graduate and postgraduate students, and industrial workers between 18 and 61 years-old, who resided in northwestern Mexico at the time of the survey. Four hand measurements were taken from the dominant hand (Table 1).

Hand length, palm length, and palm width were taken with a caliper with a 1 mm accuracy; values were registered in centimeters. Grip diameter was measured with a plastic cone and the value measured was registered in millimeters.

Table 1. Anthropometric dimensions

Anthropometric dimension	Description	Measurement unit
Hand Length	Length of the dominant hand between the stylion landmark of the wrist and the tip of the middle finger	cm
Palm length	The length of the dominant hand between the landmarks of metacarpal 2 and metacarpal 5	cm
Palm width	Width of the palm measure below the knuckles, excluding the thumb	cm
Handgrip diameter	The maximum circumference of the circle drawn by the index finger and thumb of the dominant hand	mm

2.2 Data Analysis

Percentiles 1, 5, 10, 25, 50, 75, 90, 95, and 99 were calculated on each dimension. The mean, standard deviation, maximum and minimum values were also calculated.

The anthropometric dimension values were standardized using the normal distribution. Then, two boundary methods were considered in this study, Principal Components Analysis (PCA) and Archetypal Analysis (AA).

A 99% sphere was adjusted to the data. A total of 14 theoretical boundary cases were identified on the sphere contour. From the theoretical boundary cases the real boundary subjects were identified by selecting the closest subject to the boundary case point within the ellipsoid, based on the Euclidean distance. The PCA was performed using Matlab 2020a.

AA was performed using the Anthropometry Package developed by Vinue in RStudio [10]. AA assumes that there are several "pure" individuals who are on the "edges" of the data, and all other individuals are considered a mixture of these pure types. The analysis was performed for k = 1,…, 11 archetypes. The best k-value was determined by a graphical analysis of the root sum squared values (RSS). The real boundary cases were defined by the nearest neighbors to the archetypes, based on the Euclidean distance.

The percentile corresponding to each anthropometric dimension value was obtained, based on the complete database.

3 Results

The univariate percentile values, mean, standard deviation, and minimum and maximum values are presented in Table 2.

Table 2. Male percentiles, mean and standard deviation

AD	Percentile									Mean	SD	Min	Max
	1	5	10	25	50	75	90	95	99				
Hand length	16.8	17.4	17.7	18.3	18.8	19.4	19.9	20.2	20.8	18.81	0.85	15.50	22.00
Palm length	9.4	9.8	10.1	10.4	10.7	11.1	11.5	11.7	12.1	10.75	0.60	8.20	13.30
Palm width	7.6	8	8.2	8.4	8.7	9.1	9.4	9.6	10.04	8.77	0.50	7.00	10.70
Handgrip diameter	39	42	43	45	48	51	53	54	57	47.93	3.84	36.00	60.00

Table 3 shows the PCA scores for the four-hand anthropometric dimensions. The first three PCs were used to define the body models, as the first three components accounted for 95.19% of the total variance [11]. PC1, which was positive and accounted for 60.95% of the total variation, predicted the overall hand size. PC2, accounting for 19.24% of the variation, contrasted the dimensions correlated with hand length and handgrip diameter, and those correlated with palm length and palm width. PC3, accounting for 15.01% of the variation, contrasted the measurements of hand length and palm length with the rest of the dimensions.

Table 4 show the percentile values for the 14 boundary cases obtained by PCA. It can be assumed that models 1 and 3 are similar to the 99 a 1 percentile models, respectively.

In the case of AA results, Fig. 1 shows the RSS for the archetypal models obtained for k = 2,…, 11. It can be seen three inflection points at k = 3, k = 5, and k = 9. Percentile values for AA are shown in Tables 5, 6, and 7. The AA results obtained for k = 3 indicates that model 2 and 3 are the most similar to 1 and 99 percentile models,

Table 3. PCA scores for the hand dimensions

AD	PC1	PC2	PC3	PC4
Hand length	0.5880	−0.0996	−0.2508	0.7626
Palm length	0.5479	0.0043	−0.5724	−0.6101
Palm width	0.3996	0.7975	0.4485	−0.0564
Hand grip diameter	0.4410	−0.5951	0.6390	−0.2077
% Explained variance	60.95	19.24	15.01	4.81
Cumulative %	60.95	80.19	95.19	100.00

Table 4. Percentile values for the boundary cases obtained by PCA

AD	Model													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hand length	>99	49	<1	54	20	59	8	68	40	40	8	72	20	49
Palm length	>99	72	<1	18	10	77	5	77	60	60	22	90	72	92
Palm width	95	98	3	3	75	13	6	75	86	53	18	95	13	37
Hand grip diameter	99	10	2	86	91	6	22	98	40	22	15	71	61	10

whereas models 3 and 5 are the closest to the percentile models in the k = 5 AA. For the AA when k = 9, the most extreme models are archetypes 5 and 6 for the k = 9 analysis, similar to the 1 and 99 percentile models.

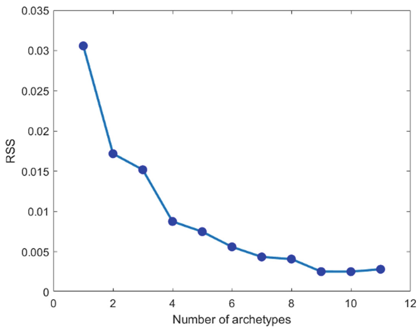

Fig. 1. RSS for the k = 1,.., 11 archetypes

Table 5. Percentile values for the boundary cases obtained by AA, k = 3

AD	Model		
	1	2	3
Hand length	49	1	99
Palm length	72	<1	100
Palm width	100	1	86
Hand grip diameter	10	10	100

Table 6. Percentile values for the boundary cases obtained by AA, k = 5

AD	Model				
	1	2	3	4	5
Hand length	68	82	<1	20	99
Palm length	92	46	<1	28	98
Palm width	100	75	13	1	97
Hand grip diameter	6	100	4	31	97

Table 7. Percentile values for the boundary cases obtained by AA, k = 9

AD	Model								
	1	2	3	4	5	6	7	8	9
Hand length	12	95	6	99	98	<1	4	75	40
Palm length	2	96	33	100	77	<1	2	53	100
Palm width	23	93	100	86	100	2	18	<1	75
Hand grip diameter	61	2	10	100	94	<1	100	61	71

4 Conclusions

Hand models were obtained by univariate and multivariate approaches. Although hand models for the northwestern Mexican male population obtained by multivariate accommodation methodologies (i.e., AA and PCA) can be used in workstations design due to their similar univariate percentiles, AA models could provide a higher accommodation level.

The models presented in this study can be used to develop hand tools and design workstations for 99% of the northwestern Mexican male population. The different models can also be used to create hand tools and personal protective equipment sizes. Despite the utility of these models, they can be improved by considering additional hand descriptors.

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