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Using a Multivariate Accommodation Model to Study Anthropometric Differences between Ethnic Groups in Ecuador

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Abstract

In this paper we use MAM to study the anthropometric differences of ethnic groups in Ecuador. The objective of this paper is to build anthropometric descriptors for men and women from groups of mestizos and indigenous inhabitants of the highlands of Ecuador and determine whether these descriptors are different for each population. We use ten anthropometric measurements from data obtained from men and women self-identified as mestizos (639) and Indigenous (99) of the Central Sierra region of Ecuador. We carried out a principal components analysis and from these factors we built anthropometric descriptors for each individual population and the combined population. We also evaluate the level of adjustment and then we compared MAM to traditional modeling. The results show that there are differences in body configurations for different populations. For these case study we found that the MAM performs better than traditional modeling, however when we analyzed the percentage of people excluded in each population we found that there are biases in coverage.

Keywords. Anthropometry, ergonomics, multivariate accommodation models, ethnic groups, Ecuador

Uso de un Modelo de Alojamiento Multivariado para estudiar las Diferencias Antropométricas entre Grupos Étnicos en Ecuador

Resumen

En este trabajo se utiliza MAM para estudiar las diferencias antropométricas de grupos étnicos en Ecuador. El objetivo de este trabajo es construir descriptores antropométricos para hombres y mujeres de los grupos de mestizos e indígenas del altiplano del Ecuador y determinar si estos descriptores son diferentes para cada población. Utilizamos diez mediciones antropométricas de datos obtenidos de hombres y mujeres auto identificados como mestizos (639) e Indígenas (99) de la región Sierra Centro del Ecuador. Se realizó un análisis de componentes principales y de estos factores construimos descriptores antropométricos para cada población individual y la población combinada. También evaluamos el nivel de ajuste y luego comparamos MAM con el modelado tradicional. Los resultados muestran que hay diferencias en configuraciones de cuerpo para las diferentes poblaciones. Para estos caso de estudio, se encontró que el MAM se comporta mejor que el modelado tradicional, sin embargo, cuando analizamos el porcentaje de las personas excluidas en cada población encontramos que existen sesgos en la cobertura.

Palabras Clave. Antropometría, ergonomía, modelos de acomodación multivariante, grupos étnicos, Ecuador

Introduction

It has been shown, that for the successfully ergonomic design, it is necessary that the anthropometric data used represent the characteristics of potential users [8]. Because many anthropometric variables vary from one population to another, when looking for an appropriate ergonomic design it is important that we use anthropometric data of the specific population for which the design is being sought. Although many countries have developed design guidelines that ensure the development of safe and comfortable workplaces, in Ecuador such guidelines are just beginning to gain importance [8, 12], this

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despite that the Constitution of the Republic of Ecuador, in paragraph 5 of Article 326 states: "Everyone has the right to develop their work in a suitable work environment that ensures the health, integrity, safety, health and welfare of the worker" (Constitución del Ecuador, 2008). However, this is not possible with workstations that are not designed for the people who will use them.

Traditionally, ergonomists have used anthropometric tables with the percentiles 5% and 95% to accommodate the middle 90% of the population on each variable independently. The human dimensions are multivariate in nature, with different strengths of correlation, thus the boundaries determine by this approach, which can be though as multidimensional cube, can result in accommodation models that at times are anatomically impossible. This results in a loss of accommodation, with the corresponding increase in risks and costs. [14, 18].

More and more, the use of anthropometrics tables for accommodation purposes are being replaced by the use of Multivariate Accommodation Models (MAM) [10]. These models, albeit less simple than the use of tables, are much better suited in providing more realistic anthropometric models, which result in better designs or accommodations. MAM uses Principal Component Analysis (PCA) to reduce the dimensionality of the model., This allows us to find a small understandable set of descriptors of human dimensions. Additionally, we can find accommodation ellipsoids with fewer dimensions that in most cases will fit better than traditional modeling. In many cases it is possible to identify and map different body configurations in the ellipsoids of accommodation, thus obtaining better models for design purposes [28].

The Constitution of the Republic of Ecuador also established that Ecuador is a "multicultural and multiethnic" state, given that ethnic diversity has always been an important factor affecting anthropometric data and the scope of their applications, are important the anthropometric research to populations data mixed with ethnic and gender information as it currently cannot be found isolated populations of these groups but rather as mixture of all together.

Methodology

Objective

The aim of this work is to use MAM (Multivariate Accommodation Models) to build anthropometric descriptors for men and women from two Ecuadorian ethnic groups Mestizos and Native Ecuadorians from the Central Sierra (highland), and study whether these descriptors are sufficiently different for each population so as to have a critical impact in accommodation issues.

Subjects and Anthropometric Measures

For this study, we used 10 anthropometric measurements that were collected from men and women between 18 and 65 years of ager; 639 mestizos and 99 native americans. Table 1 shows the gender and ethnic distribution in the sample.

	Gender		
Ethnic group	Female	Male	Total
Mestizo	311	328	639
Native-american	52	47	99
Total	363	375	738

Table 1: Sample Size

The data was collected in the provinces of Pichincha, Tungurahua, Chimborazo and Imbabura, since these provinces have the highest percentage of self-identified persons as Mestizo or Native Ecuadorians Indigenous (represented approximately 90% of the population in that region). For more details on these data see the study by [8]. For our analysis the variable Sitting Height Normal was excluded due to its very high correlation (0.89) with Sitting Height Erect. Table 2 gives the 9 measures and their definitions used in this study.

Principal Components Analysis

The PCA was done on the standardized variables. As a first step the correlation matrix of all the variables was examined. As mentioned above, we found, with no surprise, that Sitting Height Erect and Sitting Height Normal where very highly correlated. We decided to drop the variable Sitting Height Normal for the rest of the study.

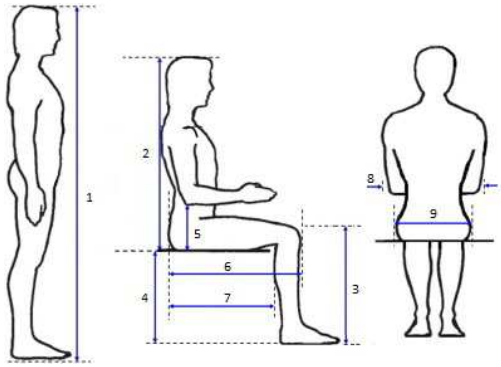

Figure 1: Anthropometric measurements, adapted from [6]

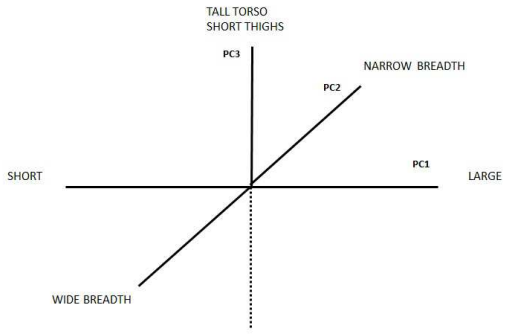

Figure 2: Anthropometric descriptors of the first 3 PCs for the mestizo males population

Measurement	Definition
1 Height	Distance vertical from the level of the patella to the floor (seated).
2 Sitting height erect	Distance vertical from the superior level of the head to the seat surface. With erect back (seated).
3 Knee Height	Distance vertical from the level of the patella to the floor (seated).
4 Popliteal height	Distance vertical from the floor to the popliteal measure with bend knees at 90 degrees (seated).
5 Elbow rest height	Distance vertical from the underside of elbow to seat surface with the arm at right angle (seated).
6 Buttock knee length	Horizontal distance from back of buttocks to knee cap (seated).
7 Buttock popliteal length	Horizontal distance from posterior buttocks to popliteal angle (seated).
8 Elbow to elbow breadth	Horizontal distance from posterior aspect of left elbow to posterior aspect of right elbow. (elbows flexed at right angle (seated).
9 Hip breadth	Horizontal distance of the hips (seated).

Table 2: Anthropometric measurements adapted from [13]

The analysis of the individual subpopulations will be presented firsts, follow by that of the combined population.

PCA for mestizo males

The PC loads and amount of variability accounted for by the first five standardized PCs for the male population is shown on Table 3.

Based on the results of the PCA we built the following anthropometric descriptors. PC1 has important loads in variables that contribute to tallness, while PC2 load on elbow to elbow breadth and hip breadth which seems to describe body breadth. PC3 loads heavily in sitting height erect and elbow rest height characteristics of a short torso; in addition PC3 presents positive loads on buttock knee length and long buttock popliteal length, descriptors of a body with long thighs.

Figure 2 illustrates the anthropometric descriptions of the first three PCs for the mestizo male population

PCA for mestizo females

The results of the PCA for the first five standardized PCs for the female population are shown on Table 4.

A similar analysis to the one done on males shows that with 5 PCs we have accounted for 80% of the variation. As before PC1 describes tallness. PC2 loads heavily on both breadth measures so it seems that PC2 measures breadth, while PC3 loads positively knee height and popliteal height and also loads negatively in buttock knee length and buttock popliteal length seems to describe short thighs and long legs.

When we compare the analysis of the male and female populations we see that the descriptors of PC1 and PC2 are very similar. The case of PC3 is particular in as much we cannot give this component a similar interpretation in both case.

The Figure 3 illustrates the anthropometric descriptions of the first three PCs for the female population.

PCA for indigenous males

The PC loads and amount of variability accounted for by the first five standardized PCs for the male population is shown on Table .

Looking at the results of the PCA we built anthropometric descriptors. The PC1 loads heavily negatively on the variables knee height and popliteal height that gives us information about a person with short legs, while the PC2 loads on the variables buttock knee length and buttock popliteal length characteristics of a body of long thighs. PC3 has high correlation with variables height, sitting height erect and hip breadth that seems to describe a small and narrow torso.

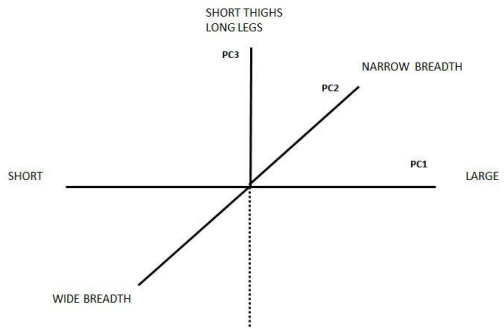

Figure 3: Anthropometric descriptors of the first 3 PCs for the mestizo female population.

Dimension	PC1	PC2	PC3	PC4	PC5
Height	-0.443	0.075	-0.312	0.344	-0.131
Sitting height erect	-0.356	-0.156	-0.531	0.142	-0.052
Knee height	-0.432	0.275	0.080	-0.414	-0.031
Popliteal height	-0.405	0.298	-0.023	-0.514	-0.059
Elbow rest height	-0.050	-0.445	-0.484	-0.192	0.481
Buttock knee lenght	-0.366	0.008	0.224	0.553	-0.195
Buttock poplietal lenght	-0.333	0.058	0.392	0.151	0.699
Elbow to elbow breadth	-0.194	-0.544	0.208	-0.239	-0.459
Hip breadth	-0.201	-0.555	0.363	-0.062	0.084
Standard deviation	1.56	1.22	1.11	1.03	0.90
Proportion of variance	0.27	0.17	0.14	0.12	0.09
Cumulative proportion	0.27	0.44	0.57	0.69	0.78

Table 3: PC loads and variability for the first five PCs (mestizos males)

Dimension	PC1	PC2	PC3	PC4	PC5
Height	0.427	-0.216	0.050	-0.414	0.168
Sitting keight erect	0.421	0.024	0.209	-0.312	0.437
Knee height	0.276	-0.068	0.570	0.273	0.205
Popliteal height	0.247	-0.100	0.518	0.172	-0.663
Elbow rest height	0.156	0.505	-0.043	-0.589	-0.342
Buttock knee lenght	0.380	-0.289	-0.451	0.188	-0.113
Buttock poplietal lenght	0.431	-0.280	-0.361	0.077	-0.206
Elbow to elbow breadth	0.273	0.536	-0.116	0.213	-0.176
Hip breadth	0.271	0.483	-0.106	0.441	0.311
Standard deviation	1.62	1.24	1.16	0.95	0.88
Proportion of variance	0.29	0.17	0.15	0.10	0.09
Cumulative proportion	0.29	0.46	0.61	0.71	0.80

Table 4: PC loads and variability for the first five PCs (Mestizo females)

Dimension	PC1	PC2	PC3	PC4	PC5
Height	0.174	-0.300	-0.377	0.490	0.006
Sitting height erect	-0.242	-0.285	-0.474	0.027	0.217
Knee height	-0.586	0.153	-0.150	0.269	-0.026
Popliteal height	-0.611	0.204	-0.138	0.106	-0.153
Elbow rest height	0.289	0.195	-0.291	0.308	0.574
Buttock knee lenght	0.210	0.561	-0.298	0.153	-0.200
Buttock poplietal lenght	0.084	0.417	0.372	0.499	-0.114
Elbow to elbow breadth	0.192	-0.336	-0.150	0.278	-0.697
Hip breadth	0.152	0.352	-0.507	-0.480	-0.248
Standard deviation	1.42	1.30	1.14	1.01	0.93
Proportion of variance	0.23	0.19	0.15	0.11	0.10
Cumulative proportion	0.23	0.41	0.56	0.67	0.77

Table 5: PC loads and variability for the first five PCs (indigenous males)

It is important to note that the PC1 is a descriptor of tallness in all locations except for this population; the Figure 4 illustrates the anthropometric descriptions of the first three PCs for the indigenous male population.

PCA for indigenous females

The loads corresponding to the 5 PC's and its variability explained is shown on Table . Note that 5 components capture 84% of the variability.

In this case PC1 also loads on variables that contribute to the tallness. PC2 loads significantly in knee height and popliteal height and strongly negatively on the buttock knee length and buttock popliteal length variables that describe a body of small thighs and long legs, while PC3 loads on hip breadth and elbow rest height features of a short torso and wide breadth.

PCA for the combine population

After analyzing the individual populations we proceeded to carry a similar analysis on the combine population. The results of the PCA are shown on Table .

With 5 PCs we have accounted for 82% of the variation.

Dimension	PC1	PC2	PC3	PC4	PC5
Height	-0.416	0.016	-0.386	0.016	-0.360
Sitting height erect	-0.300	0.168	0.283	-0.143	-0.646
Knee height	-0.217	0.618	-0.008	0.177	0.207
Popliteal height	-0.231	0.626	0.005	0.054	0.134
Elbow rest height	-0.258	-0.236	-0.409	0.459	-0.282
Buttock knee lenght	-0.494	-0.258	0.249	0.137	0.316
Buttock poplietal lenght	-0.488	-0.267	0.279	0.094	0.307
Elbow to elbow breadth	0.246	0.059	-0.129	0.737	0.084
Hip breadth	0.164	0.015	0.669	0.405	-0.335
Standard deviation	1.64	1.40	1.06	0.99	0.92
Proportion of variance	0.30	0.22	0.13	0.11	0.10
Cumulative proportion	0.30	0.52	0.64	0.75	0.84

Table 6: PC loads and variability for the first five PCs (indigenous females)

Dimension	PC1	PC2	PC3	PC4	PC5
Height	-0.450	0.113	-0.147	0.234	-0.302
Sitting Height erect	-0.424	0.031	-0.006	0.296	-0.306
Knee height	-0.400	0.144	0.440	-0.051	0.176
Popliteal height	-0.356	0.142	0.540	-0.051	0.352
Elbow rest height	-0.012	-0.439	-0.086	0.764	0.437
Buttock knee lenght	-0.366	0.021	-0.526	-0.189	0.052
Buttock poplietal lenght	-0.361	0.002	-0.419	-0.248	0.447
Elbow to elbow breadth	-0.254	-0.540	0.156	-0.078	-0.491
Hip Breadth	-0.056	-0.678	0.096	-0.407	0.158
Standard deviation	1.82	1.17	1.03	1.00	0.83
Proportion of Variance	0.37	0.15	0.12	0.11	0.08
Cumulative Proportion	0.37	0.52	0.64	0.75	0.83

Table 7: PC loads and variability for the first five PCs (Combine)

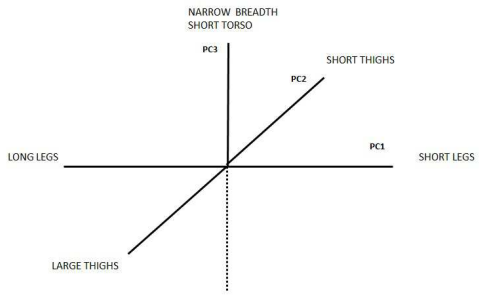

Figure 4: Anthropometric descriptors of the first 3 PCs for the indigenous male population

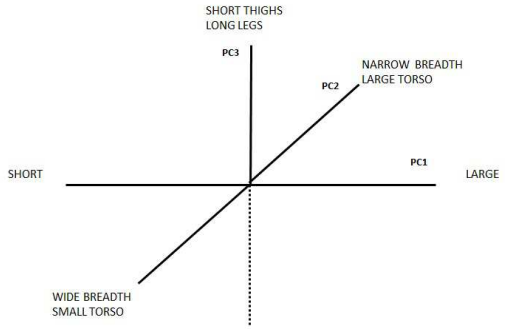

Figure 5: Anthropometric descriptors of the first 3 PCs for the indigenous female population

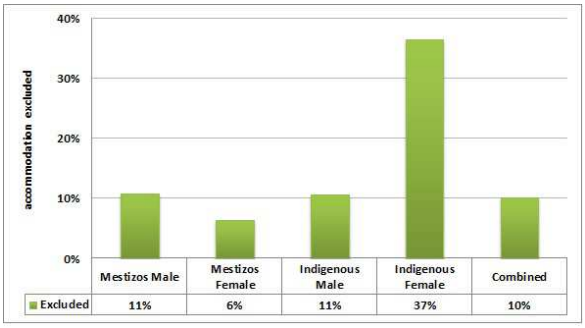

Figure 6: BIAS in MAM combined population coverage.

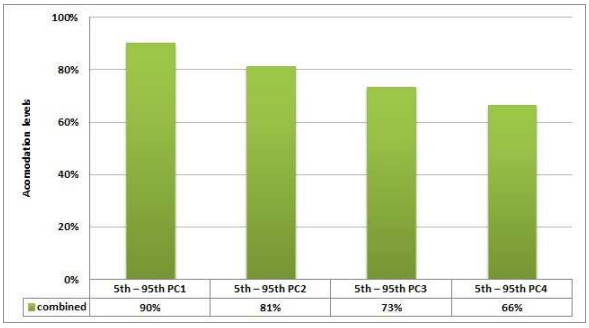

Figure 7: Sequential reduction in accommodation levels using progressive cuboids in the combine population.

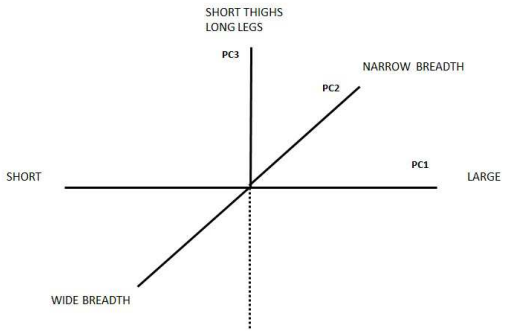

Figure 8: Anthropometric descriptors for the first three PCs (combine population).

PC1 is still a descriptor of Tallness. However one must be aware that the directions are opposite in some cases to the individual populations. PC2 is very similar to PC2 of the mestizo male population. Similarly we can observe that the PC3 is similar to PC3 of mestizo female population.

This combine analysis seems to confirm that in very few instances a mixture of two populations may be adequately analyzed, for the purpose of interpretability, as a single population. The fact that loads on the PCs of the combine population seem to be dissimilar (signs) to those on the individual population hints to the possibility that coverage of the accommodation ellipsoid, although correct, might exclude disproportionally individuals from one of the populations. We can also note that the descriptors represent the largest populations excluding the representation of minorities or small populations.

When the mix of the population is complex even MAM does not work very well, and it is important to consider the bias in coverage, Figure 6, shows that there is a marked bias in the coverage of the population of indigenous women.

In Figure 7, below, we illustrate de reduction of accommodation when using cuboids as oppose to ellipsoids in the first four PC

For illustration purposes we include Figure 8, which contains the corresponding anthropometric descriptors for the combined population

Conclusions and Future Work

We have built anthropometric descriptors for each population and we have found that different configurations according to gender and ethnicity, these descriptors can be used to build stations suitable for these groups, since as has been demonstrated using the MAM carries higher levels of accommodation

In the combined analysis we have found that the descriptors represent the largest populations excluding the representation of minorities or small populations, we have also found bias in the coverage of the ellipsoids of accommodation. It seems important to study when empirical ellipsoids for the combined populations do not have the desired coverage and also when they show bias towards one of the subpopulations.

It is important that Ecuador counts with anthropometric descriptors for each ethnic group, as has been observed [12] there are significant differences between anthropometric dimensions of each group and gender. It is recommended the study be extended to cover such ethnic groups from the coast like cholos, mestizos, montubios and afroecuatorianos. Also it is important to have larger samples for this groups and more anthropometric variables.

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