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Hand anthropometry of Colombian Caribbean college students using software based method.

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Abstract

A hand anthropometric characterization was made in the Colombian Caribbean Coast out of a sample of 41 males and females from Universidad del Norte. The measurements were taken using a computer tool that was developed and validated with the traditional manual method. This research shows comparisons among the anthropometric parameters of different regions of the country and foreign countries. It also includes the estimation of the circumference of the fingers through a novel statistical approach. Results confirm the predicted diversity of the measurements within the country and abroad.

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1. Introduction

Anthropometry is the science that deals with the measurement of the dimensions of the body. Its data has multiple applications in ergonomics, commonly used for the design of products, workspaces, workstations, equipment, among others [1]. The anthropometry of the hand becomes an essential set of dimensions when considering the design and
production of all the elements interacting with the human being. The demand for professional hand tools ergonomically designed has had a vast growth [2] due to the persisting usage of hand tools in the performance of manual work and its consequences for misuse and incompatibility as upper-extremity musculoskeletal [3].

The greatest Colombian anthropometric study was summed up in 1995, ACOPLA 95 [4], but there aren’t studies concerning profoundly on hand measures. In [5] is taken as a case study 120 flower farms near Bogotá, were used as tools for measuring an anthropometer, anthropometric grid and measure tape, in the study the scarcity of this type of research is highlighted. Therefore the lack of this information in the country and significant differences between the female population of Bogotá and other locations. Not having a database that contains a hand anthropometric characterization, has led to a lack of compatibility between the work elements and the workers dimensions since most of the machinery, tools and personal protective equipment are imported from other countries. [4]. Ergonomically, the fact that the imported features come with the size and dimensions of the natives of the exporting country, can have negative consequences in terms of health, comfort, security and productivity.

The design and manufacturing process of different products, especially those for the disable population, don’t usually include the real needs of the consumer but focus on the objective of increasing profits and have a high sales rate [6]. Therefore, there is a part of the population who find difficulties when using these products[7]. This affects the entire population, but has the most negative effects in persons with special needs or advanced age.

In a previous study a software to measure the hand was developed, willing to generate a significant improvement in the measurement process. Following this purpose, the outcomes were positive: great accuracy and a reduction of time proportions in comparison to the traditional manual method [8]. A different field of application is the design of prosthesis for hand amputates. Accuracy is in this case essential. As well as the lower contact possible with the amputate part, especially when treating burns. These requirements will be fulfilled by using the software as the measurement method [9]. However, during the research it was found that there were statistical methods such as regression that could be used to reduce the error in some of the measurements and find estimated values for necessary measurements that are not available [10], which is the aim of this investigation.

2. Methodology.

2.1 Subjects.
This is a pilot study were a sample of 41 college students from Universidad del Norte were measured, aged between 16-55 years. With the purpose of see the pros and cons of the techniques proposed in the literature.

2.2 Hand dimensions.
The measures are described in table 1.

| Hand dimension | Definition |
|----------------|------------|
| 1 Fingertip to root digit 5 | Hand is extended and the palm is facing up. The distance along vertical the axis of digit 5, from the midpoint of the tip of this digit to the root of the hand. |
| 2 First joint to root digit 5 | Hand is extended and the palm is facing up; the distance along the vertical axis of digit 5, from the midpoint of the first joint of digit 5 to the root of the hand. |
| 3 Second joint to root digit 5 | Hand is extended and palm is facing up; the distance along the vertical axis of digit 5 from the midpoint of the joint of digit 5 to the root of the hand. |
| 4 | Fingertip to root digit 3 | Hand is extended and the palm is facing up; the distance along the vertical axis of digit 3, from the tip of digit 3 to the root of the hand. |
| 5 | First joint to root digit 3 | Hand is extended and the palm is facing up; the distance along the vertical axis of digit 3, from the midpoint of the first joint of digit 3 to the root of the hand. |
| 6 | Second joint to root digit 3 | Hand is extended and palm is facing up; the distance along the vertical axis of digit 3 from the midpoint of the joint of digit 3 to the root of the hand. |
| 7 | Breadth at tip digit 5 | Hand is extended and palm is facing down; the breadth at the tip of digit 5. |
| 8 | Breadth at first joint of digit 5 | Hand is extended and palm is facing down; the maximum breadth of the first joint of digit 5. |
| 9 | Breadth at second joint of digit 5 | Hand is extended and palm is facing down; the maximum breadth of the second joint of digit 5. |
| 10 | Breadth at tip digit 3 | Hand is extended and palm is facing down, the breadth at the tip of digit 3. |
| 11 | Breadth at first joint of digit 3 | Hand is extended and palm is facing down; the maximum breadth of the first joint of digit 3. |
| 12 | Breadth at second joint of digit 3 | Hand is extended and palm is facing down; the maximum breadth of the second joint of digit 3. |
| 13 | Maximum breadth of the hand | Hand is extended and palm is facing down; fingers are together while the thumb is held loosely against the hand. This dimension is measured horizontally at the widest section of the hand section of the hand. |
| 14 | Breadth of the Knuckles | Hand is extended and palm is facing down. This dimension is measured across the palm of the hand at the junction between the palm and the fingers, not including the thumb. The hand and fingers must be held flat, palm uppermost the hand. This dimension is measured horizontally at the widest section of the hand. |
| 15 | Length of hand | Hand is extended and palm is facing up. This dimension is measured from the wrist crease directly below the pad of muscle at the base of the thumb to the tip of the middle finger. The hand and fingers should be held straight and flat palm uppermost. |
| 16 | Palm length | Hand is extended and palm is facing up. This dimension is measured from the wrist crease directly below the pad of muscle at the base of the thumb to the root of the middle finger. |
| 17 | Third digit to base of the thumb | Hand is extended and palm is facing up; thumb is held away from the side of the hand with its axis about 45° to the long axis of the hand. The measurement is taken along the long axis the long axis of the hand from crotch 1 to dactylion. |
| 18 | Depth at tip digit 5 | Hand is extended and palm is facing down; the depth at the tip of digit 5. |
| 19 | Depth at first joint digit 5 | Hand is extended and palm facing is down; the maximum depth of the first joint of digit 5. |
| 20 | Depth at second joint digit 5 | Hand is extended and palm is facing down; the maximum depth of the second joint of digit 5. |
| 21 | Depth at tip digit 3 | Hand is extended and palm is facing down; the depth at the tip of digit 3. |
2.3 Procedure

All subjects were measured using only a portable computer, a camera and designed software. Two assistants were trained to carry out the measurement process.

The software was designed to use critic points of each one measure, but, using the line equation the software can interpolate more points that the measurer introduce. The algorithm is based on pixel counting without segmentation [12] and the photometry science and was developed in the image processing toolbox of Matlab©.

Anthropometric data was obtained from a set of 3 stages of each hand position; this set of stages was defined considering that it allows the collection of the 25 dimensions chosen. Of these, 17 were taken in the palm of the hand, 6 by putting the fingers parallel and horizontal to the camera and 2 with the fist perpendicular to the camera. The application was calibrated and validated in [8], but was expanded for the present work.

To obtain the greatest amount of information from the data, the software do all possible regressions and to see the respective $R^2$ of the data obtained from the measure procedure. This information can be used to reduce the time expended, the effort of the measurer, and in general the length of the experiment, because, less points can be are needed to obtain the same quantity of information[13].

3. Results

The study result of the normal measure process is showed in the table 2, the estimation of the circumference of the fingers is displayed in the table 3, and finally the all possible regression of the measures of the table 1 are illustrated in the figure 2.

| Table 2. Hand measures. |
|-------------------------|
| Hand dimension          | Standard deviation | Mean    | minimum | maximum | coefficient of variation |
| Fingertip to root digit 5 | 5,34               | 59,71   | 44,03   | 69,55   | 0,09                  |
| First joint to root digit 5 | 2,20               | 19,43   | 15,03   | 23,43   | 0,11                  |
| Second joint to root digit 5 | 3,67               | 36,63   | 26,15   | 44,07   | 0,10                  |
| Fingertip to root digit 3 | 6,35               | 79,84   | 67,28   | 89,83   | 0,08                  |
| First joint to root digit 3 | 3,83               | 28,70   | 21,70   | 35,58   | 0,13                  |
| Second joint to root digit 3 | 6,25               | 53,40   | 38,93   | 63,45   | 0,12                  |
| Breadth at tip digit 5   | 2,75               | 12,89   | 9,13    | 18,42   | 0,21                  |
As proposed by [14] and probed by [15], the circumference of the fingers can be predicted using its breadth and depth, through the Super-Ellipse mathematical model. The calculation of the Super-Ellipse model has a high complexity level. However, the equation (1) was proposed by [16] to facilitate the calculation process. This idea was adopted to estimate 6 measurements, as shown in table 3. For these the real number of measurement that the software offers is 31.

**Equation 1.** Super-Ellipse’s circumference estimation equation.

\[
C \approx \pi (a + b)[1 + \frac{3 (a - b)^2}{10 + \sqrt{4 - 3 (\frac{a - b}{a + b})^2}}]
\]

Where C is the estimated circumference, a is the semi-major axes and b is the semi-minor axes of the ellipse.
Table 3. Predicted circumferences.

| Hand dimension                        | breadth | depth | circumferences |
|---------------------------------------|---------|-------|----------------|
| Digit 5 fingertip circumference       | 12,89   | 13,69 | 83,53          |
| Digit 5 first joint circumference     | 15,97   | 11,07 | 85,10          |
| Digit 5 second joint circumference    | 14,41   | 10,28 | 77,72          |
| Digit 3 fingertip circumference       | 15,43   | 16,28 | 99,67          |
| Digit 3 first joint circumference     | 20,07   | 14,01 | 107,21         |
| Digit 3 second joint circumference    | 16,22   | 12,12 | 89,14          |

*All measures in millimeters.

4. Discussion

The mean and standard deviation for the Colombians long side other nationalities (measurements in mm). The studies around the world shown below, have at least some college students within the sample.

Table 4. Comparison of mean an SD between present study and others studies.

| Hand dimension                        | Colombian | Caribbean | Jordanian [11] | Vietnamese [17] |
|---------------------------------------|-----------|-----------|----------------|-----------------|
|                                       | n=41      | n=235     | n=71           |                 |
| Fingertip to root digit 5             | Mean      | SD        | Mean           | SD              |
| First joint to root digit 5           | 59,71     | 5,34      | 58,83          | 4,08            |
| Second joint to root digit 5          | 36,63     | 3,67      | 35,33          | 3,24            |
| Fingertip to root digit 3             | 79,84     | 6,35      | 78,14          | 5,62            |
| First joint to root digit 3           | 28,70     | 3,83      | 26,91          | 2,60            |
| Second joint to root digit 3          | 53,40     | 6,25      | 52,86          | 4,65            |
| Breadth at tip of digit 5             | 12,89     | 2,75      | 11,39          | 1,00            |
| Breadth at first joint of digit 5      | 15,97     | 2,22      | 14,45          | 1,06            |
| Breadth at second joint of digit 5     | 14,41     | 2,42      | 16,33          | 1,20            |
| Breadth at tip of digit 3             | 15,43     | 3,12      | 14,70          | 1,15            |
| Breadth at first joint of digit 3      | 20,07     | 3,80      | 16,72          | 1,02            |
| Breadth at second joint of digit 3     | 16,22     | 2,12      | 19,24          | 1,26            |
| Breath of the knuckles                | 84,48     | 8,50      | 98,99          | 8,65            |
| Maximum breadth of the hand            | 105,90    | 27,41     | 82,65          | 4,38            |
| Length of the hand                    | 177,13    | 28,20     | 181,02         | 8,90            |
| Third digit to base of the thumb      | 93,15     | 9,40      | 130,95         | 13,63           |
| Depth at tip digit 5                  | 13,69     | 2,64      | 11,47          | 1,03            |
| Depth at first joint digit 5           | 11,07     | 2,00      | 12,01          | 1,30            |
| Depth at second joint digit 5          | 10,28     | 1,99      | 14,63          | 1,23            |
| Depth at tip digit 3                  | 16,28     | 6,36      | 13,37          | 1,37            |
| Depth at first joint digit 3           | 14,01     | 2,81      | 13,92          | 1,04            |
| Depth at second joint digit 3          | 12,12     | 3,16      | 17,45          | 1,34            |
| Hand dimension                              | n= 80 | n= 50 |
|--------------------------------------------|-------|-------|
| Bangladesh [18]                            |       |       |
| Mean | SD    | Mean  | SD    |
| Fingertip to root digit 5                  | 55.00 | 3.79  | 54.90 | 3.68  |
| First joint to root digit 5                | 17.65 | 1.89  | 17.30 | 2.08  |
| Second joint to root digit 5               | 32.75 | 2.74  | 32.65 | 3.40  |
| Fingertip to root digit 3                  | 74.85 | 3.29  | 75.70 | 4.76  |
| First joint to root digit 3                | 25.00 | 2.79  | 26.50 | 2.89  |
| Second joint to root digit 3               | 48.30 | 4.27  | 50.10 | 3.78  |
| Breadth at tip of digit 5                  | 11.65 | 3.85  | 12.85 | 1.69  |
| Breadth at first joint of digit 5           | 13.45 | 1.08  | 14.15 | 1.25  |
| Breadth at second joint of digit 5          | 16.25 | 1.57  | 16.20 | 1.20  |
| Breadth at tip of digit 3                  | 14.05 | 1.00  | 14.95 | 1.27  |
| Breadth at first joint of digit 3           | 16.40 | 1.52  | 15.90 | 1.26  |
| Breadth at second joint of digit 3          | 18.85 | 1.81  | 18.80 | 1.10  |
| Breadth of the knuckles                     | 93.50 | 7.49  | 96.80 | 5.59  |
| Maximum breadth of the hand                | 77.00 | 5.85  | 81.15 | 4.47  |
| Length of the hand                         | 170.50| 9.35  | 178.65| 8.67  |
| Third digit to base of the thumb            | 129.50| 8.37  | 123.45| 16.77 |
| Depth at tip digit 5                       | 9.29  | 1.29  | 9.80  | 1.06  |
| Depth at first joint digit 5                | 10.60 | 1.82  | 11.90 | 1.11  |
| <Depth at second joint digit 5              | 13.60 | 1.69  | 17.25 | 1.49  |
| Depth at tip digit 3                       | 11.05 | 1.64  | 11.15 | 1.15  |
| Depth at first joint digit 3                | 12.80 | 1.79  | 13.50 | 0.95  |
| Depth at second joint digit 3               | 16.20 | 2.04  |       |       |

The contrasts shows that the present study hand have a lot differences between the measured hands of the present study and the hands over the world, Clarifying that the measures in this study are performed in the population of Universidad del Norte, whose participants has an age range between 16 and 55 years.

The population is also influenced by genetics, since the different ethnic groups located in Colombia have many anthropometric differences between them[4]. Furthermore, differences between genders were found, showing that females generally have smaller hands than males. This could explain that only one of the measures that were the same in the [5] study and the present study proves that there is no evidence to reject the hypothesis that the measurement entitled “Breadth at second joint of digit 3” is the same in both studies. Compared with ACOPLA95 [4]. this study only shares two measures, in which the t test showed that the differences are significant, which can be explained by the changes in the population over time, which adds value and promotes the realization of such studies in a continuous way. In comparison with the college student study in Nigeria[20] , study only have in common two measures, where both was significant different to the present study. In addition, the present study only have 1 similar measure (Fingertip to root digit 3) with Garrett’s study of the hand in USA [21] of six possible, this shows that when importing large amount of personal protective equipment from other countries, regardless of the size of the population, they present problems when being used by Colombians.
5. Conclusions

The hand measurements are very useful in improving the ergonomic design of tools, workstations, and aids for disable people, which are factors that influence the development of industrial activities and therefore the productivity of organizations. To date, there are few studies that collect measurements of the hand of Colombians, therefore, occurs need to know the dimensions of the hand by the wide variety of specialized tools, so taking measurements is necessary because workers regularly use their hands and require that the equipment is arranged according to their physical dimensions both to facilitate the task to prevent occupational hazards, or to facilitate inclusion into society of persons with disabilities.

The measure method represents an ideal contribution to Colombia, where a comparison of other countries have not developed technologies designed exclusively for anthropometric measurements. In addition, the country's institutions easily fulfill the requirements for an anthropometric study population, with the proposed tool.

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7. References

[1] R. S. Bridger, "Introduction to ergonomics," 1995.
[2] N. A. Snow, Newby, T.J., "Ergonomically designed jobaids.," Performance and Instruction Journal 28, 1984.
[3] G. Harilh and B. Dolsak, "Tool-handle design based on a digital human hand model," International Journal of Industrial Ergonomics, vol. 43, pp. 288-295, 2013.
[4] J. Estrada, "Parámetros antropométricos de la población laboral colombiana 1995 (acopla95)," Rev Fac Nac Salud Pública, vol. 15, pp. 112-9, 1998.
[5] R. G. García-Cáceres, S. Felknon, J. E. Córdoba, J. P. Caballero, and L. H. Barrero, "Hand anthropometry of the Colombian floriculture workers of the Bogota plateau," International Journal of Industrial Ergonomics, vol. 42, pp. 183-198, 3/2012.
[6] M. M. Soares, "Translating user needs into product design for the disabled: an ergonomic approach," Theoretical Issues in Ergonomics Science, vol. 13, pp. 92-120, 2012.
[7] K. Scott and A. Perez-Gracia, "Design of a prosthetic hand with remote actuation," in Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE, 2012, pp. 3056-3060.
[8] M. Massiris, M. Maestre-Meyer, R. Penabaena Niebles, and O. Oviedo-Trespalacios, "Convergent validity of an application for hand anthropometric measurement," in Biomedical and Health Informatics (BHI), 2014 IEEE-EMBS International Conference on, 2014, pp. 45-48.
[9] J. Highton, P. Davidson, and V. Markham, "A laser-aligned method for anthropometry of hands," Journal of biomechanics, vol. 36, pp. 1397-1400, 2003.
[10] H. You and T. Ryu, "Development of a hierarchical estimation method for anthropometric variables," International journal of industrial ergonomics, vol. 35, pp. 331-343, 2005.
[11] N. Mandahawi, S. Imrhan, S. Al-Shobaki, and B. Sarder, "Hand anthropometry survey for the Jordanian population," International Journal of Industrial Ergonomics, vol. 38, pp. 966-976, 11/2008.
[12] R. Ma, L. Liyuan, H. Weimin, and T. Qi, "On pixel count based crowd density estimation for visual surveillance," in Cybernetics and Intelligent Systems, 2004 IEEE Conference on, 2004, pp. 170-173 vol.1.
[13] K. N. Dewangan, C. Owary, and R. K. Datta, "Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region," International Journal of Industrial Ergonomics, vol. 38, pp. 90-100, 1/2008.
[14] J. Yao, Zhang, H., Zhang, H., Chen, Q., "R&D of a parameterized method for 3D virtual human body based on anthropometry," ed, 2008.
[15] A. Yu, K. L. Yick, S. P. Ng, and J. Yip, "2D and 3D anatomical analyses of hand dimensions for custom-made gloves," Applied Ergonomics, 2012.
[16] X. Zhang and P. L. Rosin, "Superellipses fitting to partial data," Pattern Recognition, vol. 36, pp. 743-752, 2003.
[17] S. N. Imrhan, Nguyen,M.,Nguyen,N.,"Hand anthropometry of Americans of Vietnamese origin.," International Journal of Industrial Ergonomics, vol. 12, pp. 281–287., 1993.
[18] S. N. Imrhan, Sarder,M.D.,Mandahawi,N.,2006. Hand anthropometry ina sample of Bangladesh males., "Imrhan,S.N.,Sarder,M.D.,Mandahawi,N.,2006. Hand anthropometry ina sample of Bangladesh males. Y FEMALES," presented at the Eighth Annual Industrial Engineering Research Conference, Clearwater,FL,pp.15–18., 2015.
[19] S. N. Imrhan, Contreras,M.G., "Hand anthropometry in a sampleof Mexicans in the US Mexico border region.," in XIX Annual Occupational Ergonomics and Safety Conference., Las Vegas, US., 2005, pp. 589–593.
[20] O. S. ISMAILA, "Anthropometric Data of Hand, Foot and Ear of University Students in Nigeria," *Leonardo Journal of Sciences ISSN 1583-0233*, 2009.

[21] J. W. Garrett, "The adult hand: some anthropometric and biomechanical considerations," *Human Factors*, vol. 13, pp. 117–131, 1971.