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Anthropometric characterisation of palm and finger shapes to complement current glove-sizing systems

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Abstract

Hand length and width have traditionally been considered key metrics for glove-sizing systems. Morphological differences in palm and finger shapes should also be considered for more accurate glove fitting.

In this paper, finger and palm lengths of the five hand digits of 139 subjects from a Mediterranean population were measured. Hierarchical clusters and analysis of variance were applied to identify morphological differences. Three palm shapes and three finger shapes were identified, depending on the predominance of the dimensions of the peripheral digits. It is recommended that at least three different shapes, which combine some of the most frequent cross combinations of palm and hand shapes, should be considered to complement traditional glove sizes. These results provide new insights into improving the fitting of current glove-sizing systems and, consequently, glove safety and efficiency.

Relevance to industry

This work classifies palm and hand shapes from metacarpal and digit lengths to improve the fitting of current glove-sizing systems and, therefore, glove safety and efficiency.

Keywords: hand shape; glove design; hand characterisation

Abbreviations

Fi	Finger (i = 1 for thumb, i = 2 for index, i = 3 for middle, i = 4 for ring, i = 5 for little)
HB	Hand breadth
HL	Hand length
HS	Hand shape
MC	Metacarpal
PS	Palm shape
rat	ratio

1. Introduction

Anthropometric data are the basis of the ergonomic design used in size systems and are therefore used extensively in the development of products and equipment such as clothes, helmets and other wearable products, as well as for furniture and work equipment (Cakit et al., 2014; Carneiro et al., 2017; García-Cáceres et al., 2012; Jee et al., 2016; Liu et al., 2018, 2016; Mououdi et al., 2018; Pang et al., 2018; Park and Langseth-Schmidt, 2016; Skals et al., 2016; Verwulgen et al., 2018; Zheng et al., 2007). Products that fit subjects' anthropometric dimensions better are more comfortable and lead to enhanced performance (Barker et al., 2017; Carneiro et al., 2017; García-Cáceres et al., 2012; Pang et al., 2018).

Gloves are key instruments for workers' safety and, while providing hand protection, they should allow an accurate and comfortable interaction with the environment. Thus, studying the factors that affect the way gloves adapt to users' hands is essential to achieve optimised fitting and performance.

The effect of some glove design features has been studied in depth, such as the material used (Krzeminska and Irzmanska, 2013; Sawyer and Bennett, 2006) or their thickness (Bensel, 1993; Kinoshita, 1999; Muralidhar et al., 1999; Rice et al., 2015; Wimer et al., 2010). The conclusions indicate that these features affect user dexterity, strength and, consequently, performance. Another essential glove design feature that affects performance is their fitting to hand dimensions (Zschernack and Stack, 2010). However, only two general hand dimensions are usually considered in glove sizing. Kwon et al. (2009) identified hand length and hand circumference as the key dimensions for glove-sizing systems. Lee et al. (2015) used these two dimensions in their proposal to improve the coverage rate of a glove-sizing system. In fact manufacturers typically use one or at most two dimensions among hand length, hand circumference and hand breadth (Lee et al., 2015), where hand length and breadth are the most usual dimensions employed as relevant metrics for designing gloves (Jee and Yun, 2016).

Even when only these few general dimensions are used, they are employed merely as ratios of two of them, e.g. the hand breadth (HB) to hand length (HL) ratio. This is the case of European standard EN 420:2003+A1:2009 (CEN, 2009), which establishes six glove sizes from six hand sizes that have, in turn, been defined from a fixed ratio between hand circumference (closely related to HB) and HL. In other words, although sizes are based on two different hand measures, the various proportions between them have not even been considered.

However, the HB/HL ratio is not constant from one person to another and has been used to characterise different hand shapes and to establish hand typologies in order to compare several populations (Chandra et al., 2013; Jee et al., 2016). Clerke et al. (2005) employed a three-level ratio to classify hands into long, average and square-shaped hands. Different studies, which have focused on hand grip strength (Clerke et al., 2005; Fallahi and Jadidian, 2011), used the HB/HL ratio as an influential factor on strength, among other dimensions such as finger length or the finger length to hand length ratio.

Some authors have also pointed out that, apart from HB and HL, other dimensions like finger length should be considered to achieve better glove fitting. Jee and collaborators (Jee et al., 2016; Jee and Yun, 2016) were critical about the standard "one size fits all" approach that is currently used, and defended the need for more diversity in sizing options for the design of hand tools. They measured more than 20 hand dimensions in the Korean population, including hand lengths, breadths and circumferences at various levels (palm and digits). They then used factor and cluster analyses to analyse hand shape types. With the factor analysis, these authors concluded that the three main factors explaining the variability (78%) in dimensions are hand breadth, palm length and finger length. From the cluster analysis, they proposed a four-type hand classification, and analysed their frequency of appearance both globally and by gender. The four shapes identified are: wide hand and short fingers; short palm with above average fingers; long palm and fingers; narrow hand and short fingers. The groups were confirmed by ANOVA. Hsiao et al. (2015) measured 14 relevant glove design dimensions (lengths and breadths of hand, palm, thumb and fingers) in a study conducted to enhance the fit of glove sizes for fire fighters. They also used principal component and cluster analyses to analyse hand shape types. The principal component analysis showed two main factors that explained 76% of the variance: overall hand size and the breadth to length ratio for both hand and fingers. The cluster analysis led them to propose a seven-size glove system after considering two different breadth proportions (normal and wide hands) for central sizes. These hand shape classifications consider the lengths of palms and the lengths of fingers, together with hand breadth, which can be useful for designing hand tools and glove-sizing systems.

All these studies provide indications to select important dimensions to fit gloves both in length and width. However, the definition of glove measures does not usually consider the relative lengths or proportions of the fingers, which are a key factor in the grip function (Rincón Becerra and García Acosta, 2015). In fact, for the same total hand length (used as a reference for identifying sizes of gloves) some variability in finger lengths also exists (McLain, 2010). This variability may affect the fitting of gloves to each fingertip, which has not yet been considered and could be useful, particularly for defining glove-sizing systems.

In addition, and with a certain parallelism to gloves and hands, the length of toes and metatarsal bones has also been studied in depth to help adapt shoes to feet. It is well known that feet have been traditionally classified into five types based on the profile of the toes (whole foot length for each toe): Egyptian, Greek, Germanic, Celtic and Roman. Furthermore, as regards the metatarsal profile, feet are classified into index minus, index plus and index plus minus, depending on the relative dimension of the first metatarsal and the other metatarsal bones, which provides three profiles (Barrôco et al., 2011). In short, the profiles of toes and metatarsals are key measures for adapting shoes to feet.

After bearing these ideas in mind, we hypothesised that the study of the profiles of fingers and metacarpals could benefit the adaptation of gloves in the same way as the profiles of toes and metatarsals do in adapting shoes. That is to say, determining patterns based on morphological differences in metacarpal and finger shapes would optimise the accuracy of glove-fitting, which would go beyond establishing a sizing system based on the dimensions and general proportions between palm and finger lengths. Therefore, current glove-sizing systems could be complemented by analysing whether different shape groups exist according to variability in the proportions of palms and fingers, similarly to the classifications established for foot shapes. Previous studies (Hsiao et al., 2015; Jee et al., 2016; Jee and Yun, 2016) consider variability in hand length/width proportions in order to enrich glove-sizing systems but, to our knowledge, length profiles of the palm and total hand have not previously been considered.

Therefore, the main objective of this paper is to analyse the variability in the lengths of metacarpals and fingers to determine whether different profiles for palm and fingers can be identified, in order to provide suitable data with which to complement current glove-sizing systems and improve fit. To achieve this, clustering techniques are used to analyse the proportions of the lengths of the metacarpals (palm) and the fingers of the right hand in order to determine the existence of different profile patterns in both palm shape and total hand length (finger length) shape.

2. Material and Methods

2.1. Participants and settings

One hundred and thirty-nine healthy adults (69 females, 70 males) with no deformities or disability in their hands were voluntarily enrolled in this study. They were randomly recruited from University staff, and received no economic reward for participating. The experiment was approved by the University Ethics Committee, and the participants gave their written consent. Their ages ranged from 18 to 68 years (females: m = 34.3; SD = 11.87; males: m = 36.7; SD = 11.21). All the participants came from four provinces in the NE Mediterranean region of Spain. The sample was representative in terms of stature and weight (mean±SD: females 162.2±6.5 cm and 62±10.08 kg; males: 173.69±7.16 cm and 76.7±11.08 kg).

Hand dimensions were measured from photographs, taken with the subject's hand laid on a sheet of calibrated grid paper, which were then post-processed with the AutoCAD© software to adjust the scale and to perform measurements. The adjustments of the camera parameters and the post-processing method were carried out in the same way as in a previous study by the same authors (Vergara et al., 2018) . The optical camera zoom was set to maximum and the distance to the hand was adjusted to frame exactly the hand. In a previous pilot study, these parameters were found to minimise distortion due to the perspective. The subjects stood and placed their hands on the gridded paper, with their fingers extended and the back of the hand as close to the paper as possible, while adopting a comfortable posture for their body and arms (Figure 1).

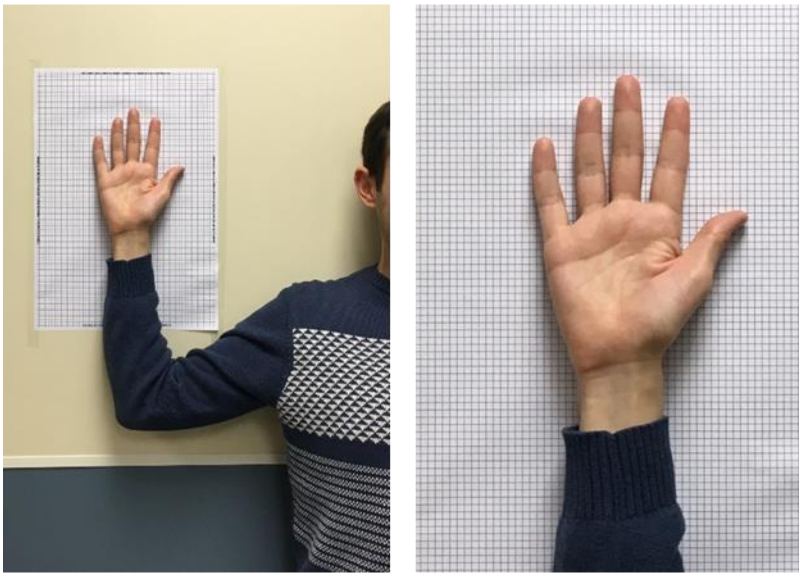

Figure 1. The subject’s posture while the photographs were taken.

2.2. *Hand anthropometric dimensions*

The right hand was chosen as being representative in the present study because previous studies have pointed out that there are barely any differences between right and left hand dimensions (Mandahawi et al., 2008). Metacarpal (MCi) and finger (Fi) lengths were measured for each digit (with *i* = 1 for thumbs; 2 for index fingers; 3 for middle fingers; 4 for ring fingers and 5 for little fingers) from the palmar side (Figure 2). The wrist limit was palpated with the wrist in a flexed position on the palmar aspect and a landmark was drawn on the skin. Creases at the base of the digits were used as landmarks to limit MC lengths from the wrist landmark, as creases have been considered the most useful glove-fitting landmark. The exact position of the wrist crease for each digit was selected as follows. For the middle finger (MC3): from the centre of the finger crease following the finger direction, for the thumb and little finger (MC1, MC5): from the centre of the finger crease following approximately the external contour of the metacarpals observed in the photograph, and for the rest of the fingers (MC2, MC4): from the centre of the finger crease to a point equidistant from the adjacent marks.

Photographs were scaled and processed to obtain the 10 dimensions.

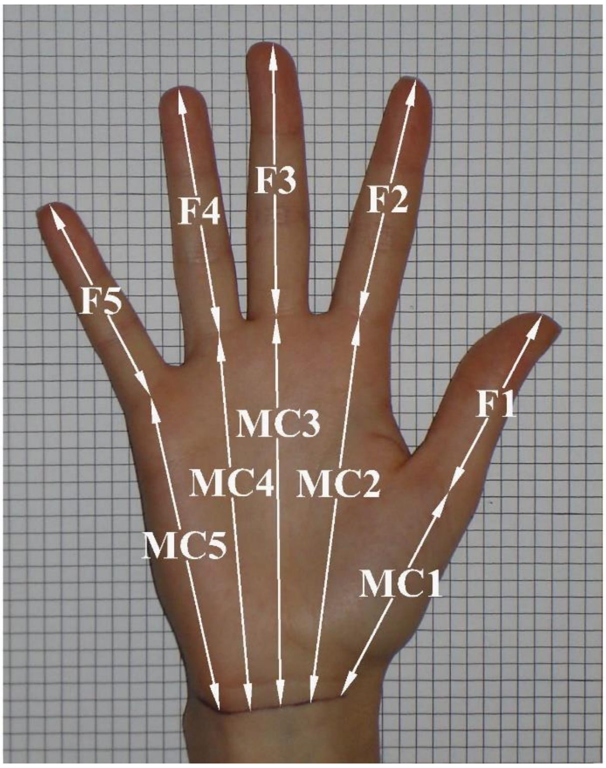

Figure 2. Hand anthropometric lengths measured.

The total hand lengths for each digit (length from the wrist crease to the end of each digit, namely HLi) were computed as the sum of their respective metacarpal and finger lengths from the previously collected dimensions (HLi = MCi + Fi).

In order to analyse and describe the profile patterns for longitudinal palm and total hand shape, the ratios between the different lengths were calculated using the middle finger length as a reference. Firstly, for the metacarpal lengths, the MC ratios were calculated in relation to MC3 (ratios were named MCrat_i = MCi / MC3, for i = 1 to 5, except for i = 3). In the same way, the hand length ratios were calculated in relation to HL3 (ratios were named HLrat_i = HLi / HL3, for i = 1 to 5, except for i = 3).

2.3. *Statistical analysis*

To verify the existence of **longitudinal palm shape** (hereafter, palm shape) patterns, a hierarchical cluster analysis was applied to classify the subjects with the five MCi variables in order to obtain homogeneous groups of subjects. For the hierarchical cluster, the linkage criterion was the *average linkage within group* and the distance criterion was the *Pearson correlation*, because the aim of this study was to determine relative proportions (patterns) in dimensions, rather than similarity in absolute dimensions. A descriptive analysis was performed for the results corresponding to 2, 3 and 4 groups (from the dendrogram) in order to select the number of groups that provided the solution with the most homogenous groups. The descriptive analysis consisted in box-plots and ANOVAs (with Bonferroni coefficient in the *post hoc* when the Levene test showed critical levels >0.05, otherwise the Games-Howell coefficient) to check for differences between groups in the four ratio variables. For the selected solution, groups are described in terms of the calculated ratios (the MCrat_i variables) and results of the four ANOVAs presented.

The same analyses (cluster analysis, description of groups and ANOVA) were performed to obtain the **total longitudinal hand shape** (hereafter, total hand shape) using their corresponding variables (HLi and HLrat_i).

After selecting the groups for each shape, an analysis of the cross combination of both groups of shapes was performed. Firstly, the frequencies for each combination of groups were computed both globally and by gender. Chi-squared (χ^2) tests were applied to their corresponding crosstabs (palm shape groups × hand length groups, and groups × gender) to test for independency. Afterwards, a detailed analysis of the more frequent (with a frequency of >5%) combinations of shapes was run to check for differences in hand dimensions between groups and their (possible) different glove sizing applicabilities, as suggested by the standard (CEN, 2009). A descriptive analysis of MCi and HLi is presented first. Kruskal-Wallis and ANOVA tests were applied to each dimension (HLi and MCi) to test the similarity of their distributions and means, respectively, between the more frequently combined groups of shapes. Each subject was assigned a glove size using HL3 as his/her total hand length, and considering the hand lengths suggested by the standard (CEN, 2009). The frequency of each group per glove size is presented, and a χ^2 test was applied to check for the different distributions of the groups of shapes among the sizes set out in the standard (CEN, 2009).

3. Results

For **palm shape**, the best solution obtained from the hierarchical cluster analysis was the one with three groups. Figure 3 shows the box-plots of the MCrat_i ratios for the 3-groups solution. The ANOVA for the 2-groups solution yielded significant differences ($p<0.05$) between groups in all the ratios (MCrat_i). The 3-groups solution yielded significant differences ($p<0.05$) for the mean of all the ratios between all the pairs of groups, except between groups 2 and 3 for the index and ring fingers ratios. The 4-groups solution split the PS3 group (of the 3-groups solution) and yielded significant differences only for the index finger (MCrat_2) in the split groups. Thus, this last split did not provide enough differences to be considered.

For the solution selected, the first palm shape group (group PS1) gave ratios above the mean for the thumb and index finger, and ratios lower than the mean for the ring and little fingers; i.e. palm shape followed a “decreasing pattern” compared to the mean, which is referred to henceforth as the *Thumb-index predominant* palm shape. The second group (group PS2) gave ratio values close to the mean for all the fingers, and is referred to henceforth as the *Average* palm shape. The third group (group PS3) displayed the opposite behaviour to PS1: ratios were lower than the mean for thumbs, and higher for little fingers, i.e. the palm followed an “increasing pattern”. Such a pattern is referred to henceforth as the *Little predominant* palm shape. Note that the names ‘*Finger predominant*’ do not represent the finger being longer than the other fingers, but the fact that its length ratio went over the mean compared to middle fingers.

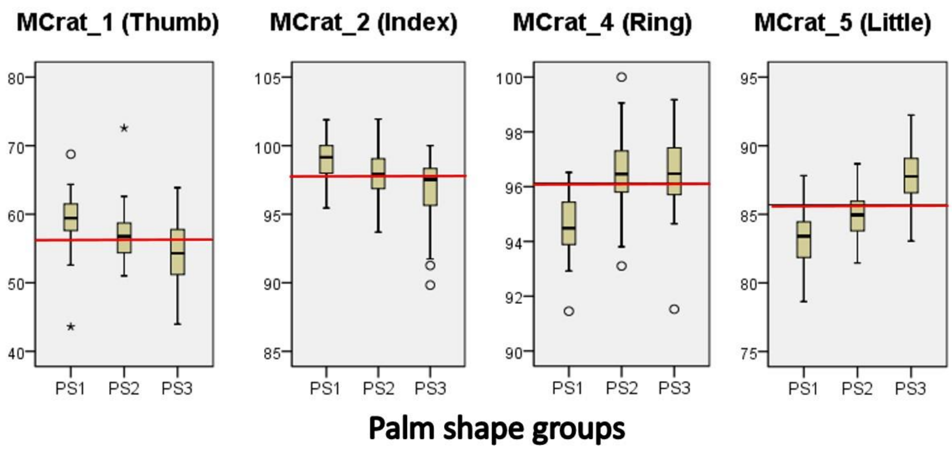

Figure 3. Box plots of the ratios (in percentage) of metacarpal lengths (MCrat_i) after separating the three groups identified in the cluster analysis. Boxes represent median and interquartile range (25 and 75 percentiles) and whiskers are drawn as 1.5 times the interquartile range. Dots and stars are outliers. Red horizontal lines represent the mean values of all the subjects.

Similarly to palm shape, the clearest solution for **fingers shape** (total hand shape) was that with 3 groups. Figure 4 shows the box plots of the HLrat_i ratios for the 3-groups solution. The ANOVAs for the 2-groups solution yielded significant differences ($p<0.05$) between groups in all the ratios (HLrat_i). The ANOVAs for the 3-groups solution indicated significant differences ($p<0.05$) for the mean of all the ratios between all pairs of groups, except for the index finger ratios, for which no significant difference was found between the 2- and 3-groups. The 4-groups solution was formed by splitting group HS2 and yielded significant differences only for the index finger (HLrat_2) in the split groups; this last split therefore did not provide enough differences to be considered. For the solution selected, the first hand shape group (group HS1) obtained ratios higher than the mean for thumbs and index fingers, and lower ratios than the mean for ring and little fingers; i.e. it was a *Thumb-index predominant* hand shape. The mean values of the second group (HS2) were around the mean; i.e. it was an *Average* hand shape. Finally, group HS3 obtained ratio values below the mean for thumbs, and higher ratio values than the mean for ring and little fingers; i.e. it was a *Ring-little predominant* hand shape.

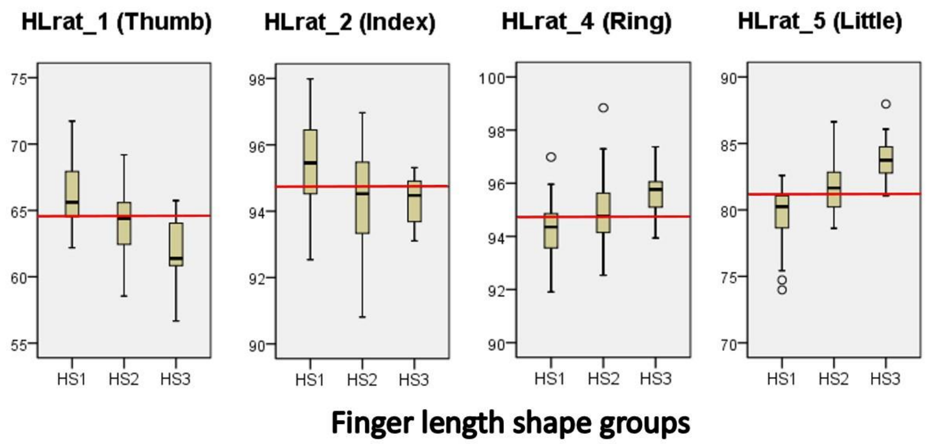

Figure 4. Box plots of the ratios (in percentages) of total hand lengths (HLrat_i) after separating the three groups identified in the cluster analysis. Boxes represent median and interquartile range (25 and 75 percentiles) and whiskers are drawn as 1.5 times the interquartile range. Dots and stars are outliers. Red horizontal lines represent the global mean values for all the subjects.

These groups for palm and hand shapes led to nine possible cross combinations, whose frequency of appearance is shown in Figure 5, together with a photograph of one of the hands in each combination of groups. The combinations with a frequency over 5% of the whole sample are highlighted. We can observe a tendency of not only the palm and hand to follow similar patterns, but also of combining palm shapes with patterns that follow slightly smaller predominant shapes than in the case of hand shapes (combinations PS2 with HS1, and PS3 with HS2, were even more frequent). This dependency was corroborated by the results of the χ^2 applied to the 3×3 crosstab ($p<0.001$).

		Palm shape			
		PS1. Thumb-index predominant	PS2. Average	PS3. Little predominant	TOTAL (N)
Hand shape	HS1. Thumb-index predominant	 N=27 (19.4%)	 N=19 (13.7%)	 N=7 (5%)	53
	HS2. Average	 N=5 (3.6%)	 N=31 (22.3%)	 N=33 (23.7%)	69
	HS3. Ring-little predominant	N=0	 N=1 (0.7%)	 N=16 (11.5%)	17
	TOTAL (N)	32	51	56	139

Figure 5. Frequency (N) of the appearance of the nine cross combinations of palm and hand shapes. Percentages of the total sample.

Figure 6 shows the frequency of these nine cross combinations of shapes as a percentage per gender. The *Little predominant* cases, in palms and hands, seemed more frequent for males, while the other cross combinations followed similar patterns for both genders. This slight dependency was corroborated by the χ^2 results: when applied to the 9×2 crosstab, it was not significant (p=0.067), but when applied independently to each group, both the 3×2 crosstabs presented significant differences (p=0.038 for PS, p=0.047 for HL).

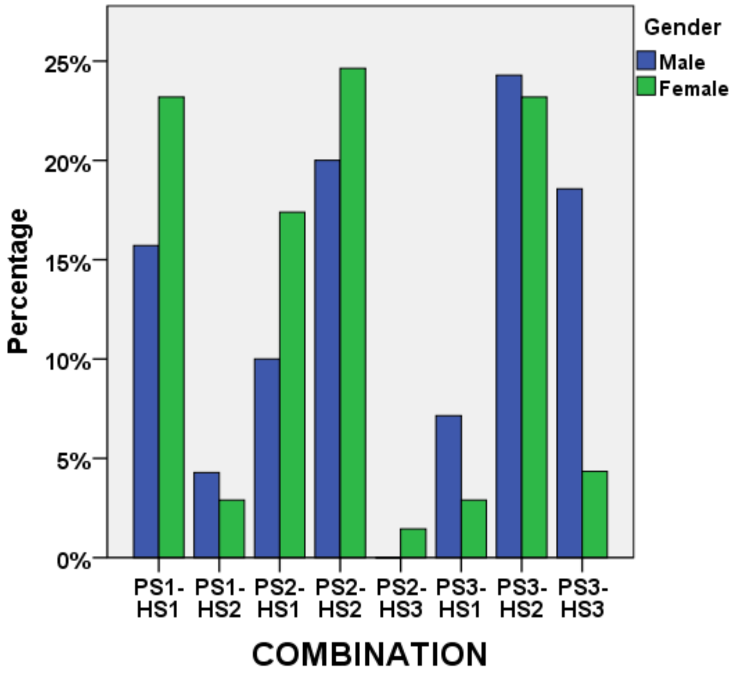

Figure 6. Frequency of the combinations of shapes per gender, as percentages per gender.

Table 1 shows the descriptive statistics (mean and standard deviations) for the MCi and HLi dimensions for the five most frequent cross combinations of shapes (those shaded in Figure 5). Note that the mean values for index and middle fingers are similar, which indicates that the different profiles do not depend on hand sizes, and that the biggest differences appear clearly in the peripheral digits, with the difference being bigger than 1 cm in one case. The ANOVA results confirmed that the differences in the mean values were significant ($p<0.01$) only for MC1, MC5 and HL5. The Kruskal-Wallis results indicated differences in the distributions of the same dimensions. Figure 7 shows the histograms of HL3 for all the most frequent cross combinations of shapes, with vertical lines representing the six reference hand dimensions for the glove sizes indicated in the standard (CEN, 2009). Table 2 provides the dimensions in which the paired differences obtained in the *post hoc* analyses for both tests are significant (after applying the appropriate correction for the p value). Figure 8 shows the histograms of these dimensions for these cross combinations. Note that the thumb and little finger dimensions follow different patterns across groups, especially for cross combinations PS1-HS1 and PS3-HS3, as expected.

	PS1-HS1	PS2-HS1	PS2-HS2	PS3-HS2	PS3-HS3
MC1	64.5 (6.15)	64.5 (7.13)	62.0 (4.66)	61.2 (7.07)	58.0 (6.31)
MC2	108.5 (8.43)	108.4 (6.07)	108.1 (7.81)	108.1 (8.13)	108.3 (6.67)
MC3	109.4 (8.30)	110.5 (6.86)	110.8 (7.44)	111.5 (7.72)	111.4 (6.21)
MC4	103.4 (7.79)	106.67 (6.39)	106.9 (6.75)	107.6 (7 31)	108.3 (5.79)
MC5	91.0 (7.61)	94.1 (5.17)	93.9 (6.71)	97.3 (7.17)	99.2 (5.68)
HL1	125.4 (9.30)	125.3 (10.00)	122.0 (9.81)	123.0 (9.35)	120.2 (9.92)
HL2	180.2 (11.64)	180.6 (10.69)	180.7 (13.34)	180.4 (11.98)	182.7 (9.73)
HL3	188.5 (11.85)	189.5 (11.15)	191.3 (12.26)	191. 5 (11.52)	193.1 (10.21)
HL4	177.0 (11.93)	179.3 (10.29)	181.6 (11.76)	181.9 (10.20)	185.6 (9.89)
HL5	149.2 (11.42)	152.4 (9.69)	155.6 (11.63)	157.2 (10.38)	162.8 (10.74)

Table 1. Mean and standard deviations m (SD) in mm of metacarpal and hand lengths for the five most frequent combinations of shapes.

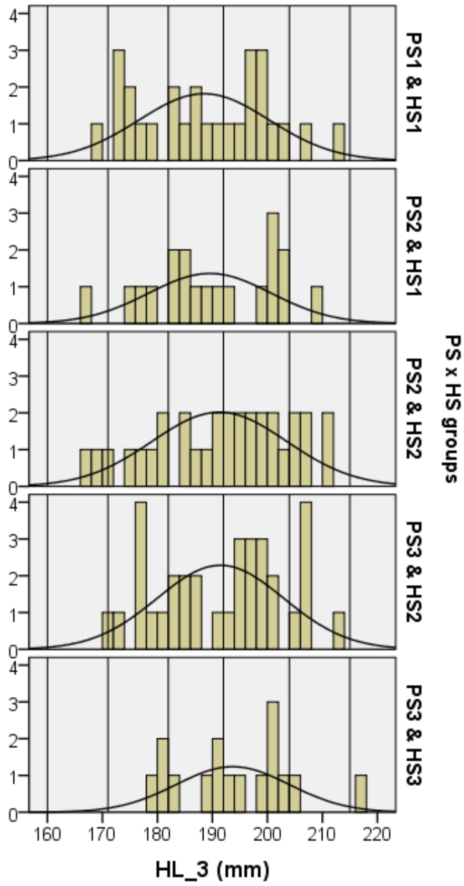

Figure 7. Histograms of HL3 for the most frequent combinations of groups. Vertical lines correspond to the six hand sizes suggested by the standard (CEN, 2009).

	PS3-HS2	PS3-HS3
PS1-HS1	MC5	MC1, MC5, HL5
PS2-HS1		MC1, HL5*

Table 2. Dimensions for which the paired differences were significant ($p<0.05$) in both tests: ANOVA and Kruskal Wallis. * Significant differences appeared only in the ANOVA test.

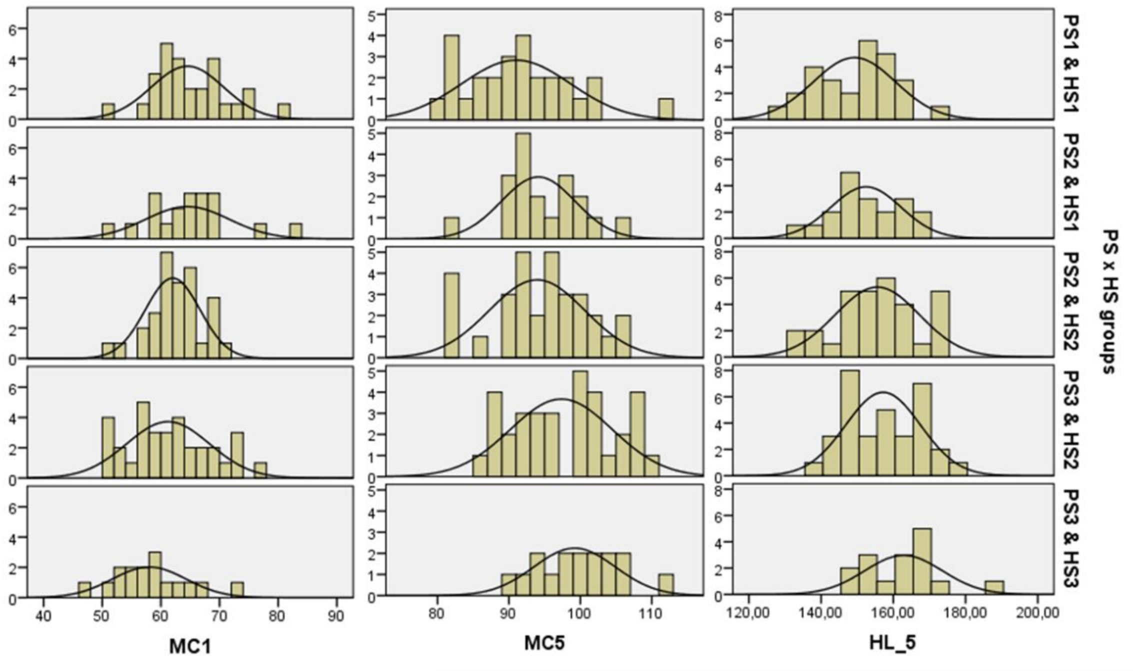

Figure 8. Histograms of the hand dimensions that presented significant differences between the most frequent combinations of shapes.

Table 3 presents the cross frequencies of the most frequent combinations of palm and hand shape groups for each glove size indicated in the standard. The χ^2 test presents no significant difference in the distribution of shapes per group. Note that no hand corresponds to the first size set out in the standard.

Size	PS1 & HS1	PS2 & HS1	PS2 & HS2	PS3 & HS2	PS3 & HS3	TOTAL N (%)
#1	0	0	0	0	0	0 (0%)
#2	41.18	11.76	29.41	17.65	0.00	17 (13.5%)
#3	17.65	20.59	17.65	32.35	11.76	34 (27.0%)
#4	21.05	10.53	28.95	23.68	15.79	38 (30.1%)
#5	15.63	18.75	21.88	28.13	15.63	32 (25.4%)
#6	20.00	0.00	40.00	20.00	20.00	5 (4.0%)

Table 3. Frequency (percentages) of the palm-hand shape combinations per hand size set out in the standard.

4. Discussion

Wearing gloves may limit the range of movements of different hand joints and require greater muscle activity to produce movements within the available range. In addition, when their fit is not good some hand postures may become impossible and the capability to exert the maximum force is reduced even more (Kovacs et al., 2002). Consider, for example, that the length of the glove thumb is too short (which may occur in current glove-sizing systems that do not consider different proportions in finger lengths), and the material is not extremely flexible. In this case, the thumb will not be able to oppose the rest of the fingers correctly, and its main function will be disabled. In this incorrect fitting, apart from comfort, important hand performance capabilities will be considerably affected (Dianat et al., 2012) and could be prevented by a correct fitting (Wells et al., 2010). Therefore, fitting gloves to hand dimensions is an essential design feature to provide a comfortable interaction between gloves and the environment and, thus, confer greater safety and efficiency upon gloves while they are in use.

Despite this, current glove-sizing systems are based mainly on only two global hand dimensions: hand length and hand breadth, or circumference (Kwon et al., 2009; Lee et al., 2015; McLain, 2010). There are no standards that define glove sizes in detail, and so manufacturers usually define their sizing systems with the hand length and estimations employed for the other dimensions with fixed proportions (McLain, 2010; Rincón Becerra and García Acosta, 2015; Robinette and Annis, 1986); as a result, gloves have a fixed profile for the fingers.

Some studies have shown that the proportions between different parts of the hand (e.g. maximum palm and finger lengths, or hand breadth) are not constant and this could be used to classify hand typologies, which may be specific for different populations (Chandra et al., 2013; Clerke et al., 2005; Jee et al., 2016). Taking such hand typologies into consideration in sizing systems could help improve glove fitting and, consequently, workers' safety and comfort. Some previous attempts to consider variability in hand proportions in order to improve glove-sizing have been made. Hsiao et al. (2015) considered variability in hand length/width proportions and they proposed a glove classification for hands that are, for example, 'wide hand and short fingers' or 'narrow hand and short fingers'. Different studies conducted by Jee et al. (Jee et al., 2016; Jee and Yun, 2016) considered variability in hand lengths, breadths and circumferences, concluding that the important dimensions that should be used to design sizing systems are hand breadth, palm length and finger lengths.

All these works use different statistical clustering analyses of many hand dimensions of different types, including dimensions that are quite different in size (lengths, breadths, etc.). Dimensions of the same type are expected to be more correlated between them than with other types of dimensions (e.g. length of digit 2 is expected to be more correlated with length of digit 3 than with its breadth or with its circumference). The fitting of gloves should consider both fitting in lengths (glove is not too short or too long) and in breadths (glove is not too wide or too narrow). The results of these works point out what dimensions are more appropriate to this two-dimensional fitting and provide indications for it. However, for the same size of the middle finger, there is variability in the dimensions of the other fingers (McLain, 2010). When the dimensions of the fingers of a glove are determined from the total length of the hand, this variability is not considered and only one or two fingers (usually index and middle) fit properly, while the gloves are too long on the other fingers (White, 1980). Some tasks require a good fit for all fingers in order to prevent loss of dexterity, which may be reduced even for very thin gloves such as those made of latex, when wearing gloves that are either too small or too large (Drabek et al., 2009). For such gloves, the tips should provide a good fit for all fingers, and so the study of this variability could improve glove fitting in terms of length.

Our study was aimed at analysing this variability to complement the sizes proposed in previous works by including different profiles for metacarpals and fingers in gloves. We have examined the existence of hand typologies for the palm and finger (total hand) length profiles, in order to enhance the fitting of sizing systems. Both the palm and fingers profiles are the two critical points for fitting gloves longitudinally to each digit and are the main factors in the variability of hand dimensions (Jee et al., 2016; Jee and Yun, 2016).

With the help of statistical tools (hierarchical cluster analysis) applied to the metacarpal (palm) lengths of the five digits and to the hand lengths of the five digits (lengths from the wrist to the tip of each digit), three different typologies of the shapes for palms, and three others for fingers (total hand shapes), were identified. It was thus confirmed that hand shapes presented different profiles in both palms and hands, depending on the relative dimensions of each finger.

The three shapes for palms, and the three for total hands, were characterised by the predominance (higher length ratio) of the thumbs (and index) or little fingers. The three groups were named *Thumb-index predominant, Average* and *Ring-Little predominant* shapes. These groups are in accordance with evidence described in the literature about the bad fitting of gloves for the peripheral digits when the middle finger has a good fit (White, 1980). The *Thumb-index predominant* shapes showed higher length ratios for the index fingers and thumbs than the global mean, and ones that were lower than the mean for little fingers. The *Average* shapes gave values of length ratios that came close to the mean for all fingers. The *Little predominant* shapes had lower length ratios than the mean for the index fingers and thumbs, and ones that were higher than the mean for the little fingers. The *Ring-little predominant* hand shapes were the least frequent, while the *Little predominant* palm shapes were the most frequent. This means that, although both shapes are related (palm lengths form part of total hand finger lengths), they are somewhat independent (McLain, 2010). Cross tabulation of frequencies for two hand dimensions is commonly used to select the most frequent combinations of dimensions to propose sizing systems (Kwon et al., 2009). The combined classification of these groups led to nine cross combinations of palm and hand shapes, five of which were identified as the most frequent ones. It should be pointed out that for more than 50% of hands, the palm and total hand shapes followed the same pattern (*Thumb-index predominant*, *Average* or *Little predominant*). Besides, in more than 40% of the hands, the palm followed a pattern that displayed more predominance for the little finger than for the whole hand.

Another main result is that shapes were independent of the total hand size, i.e. no significant differences were found for the length of the middle finger across the groups. Traditional methods for sizing gloves (Robinette and Annis, 1986) use models of the hand with fixed proportions in their dimension obtained from one or two general anthropometric dimensions (length, circumference and width), and assign the size in accordance with this general dimension. Recent proposals for sizing systems use more sophisticated methods such as multivariate analysis and ellipsoids to define the boundaries of sizes (Högberg et al., 2015; Kouchi et al., 2005) and already take into account different proportions between the main dimensions identified (usually two or three, corresponding to length and width or circumference). However, for each size, a fixed proportion is used for the relative length of fingers. Therefore, these methods still fail to apply different proportions of finger lengths, which in this work have been found to be independent of total hand length.

Despite the independence of the shape of fingers from total hand length, differences in length between combinations were observed in peripheral fingers. Thus, for both metacarpal length and total hand length, the differences between combinations were more evident for thumbs and little fingers. For these latter, the difference in the mean dimension between two combinations (*Little predominant* in both lengths versus *Thumb-index predominant* in both lengths) was bigger than 1 cm. This difference is high enough to generate poor contact at the tips of the fingers of the glove and affect manual dexterity (Dianat et al., 2012; Drabek et al., 2009).

Five combinations of shapes were present with a frequency above 5% of the sample, and so these should be the ones implemented in glove-sizing systems to obtain better fitting results.

However, in order not to make the implementation of a sizing system with wide diversity excessively difficult (Kwon et al., 2009), and by considering the differences in absolute palm length values (with a maximum difference of 8 mm) smaller than in total hand length (more than 1 cm), the number of shapes to be implemented could be reduced to three. Another fact to which more attention should be paid regarding the shape of fingers is that for the fingers to reach the end of the glove fingers, these latter should be slightly short, so that when the glove is placed on the hand, although the bases of the fingers are not in contact with the glove, the tips will be (White, 1980). Therefore, the three glove-sizing shapes proposed would result from combining some of the groups of the most frequent combinations of shapes: a *Thumb-index predominant* glove would result from considering the HS1-PS1 and HS1-PS2 cross combinations of shapes; an *Average* glove could result from combining HS2-PS2 and HS2-PS3; and a *Ring-little predominant* glove would result from the HS3-PS3 cross combination.

These three profiles should be available for each glove size defined by the standard (CEN, 2009), as significant differences between combinations have not yet been identified based on hand size. However, as the sample used herein was not chosen in a stratified manner, and the sample size is limited, the distribution of hand lengths for each glove size was not homogeneous and, as expected, the percentage of subjects assigned an extreme size (size #1 and #6) was quite low (0% and 4%, respectively). Therefore, the recommendation of making the three profiles available for all sizes, including extreme ones, should be tested in a study with a larger sample stratified by size. This wider study should also serve to confirm the groups obtained in this work. Furthermore, these specific results regarding percentages of hand sizes are valid for the population that was measured, namely the Spanish population. Populations from other countries/races could present different length ratios and various frequencies per shape.

Finally, we have to point out that the number of participants in this work is limited (139), but large enough to show the need to adjust glove-sizing systems, as significant differences in palm and hand profiles have been identified and some differences are bigger than 1 cm. Although the exact sizing proposed should be checked in a wider study, the detection of these differences that can affect the fitting of gloves is already a novelty. The US Army hand data (Greiner, 1991) includes the dimensions needed for a large sample, but the available data is limited to global statistics (mean, dispersion and correlation coefficients) that are not enough to test our results.

Conclusions

Three palm shape typologies and three others for total hand were observed depending on the predominance in the dimension of the peripheral digits. These profiles led to nine independent combinations of palm and hand shapes, of which five appeared more frequently. In more than 50% of hands, palms and hands followed the same pattern, but palms followed a different pattern to hands in more than 40% of cases (with more predominance in the dimensions of little fingers).

From the frequency of each combination of shapes and the absolute differences found between their dimensions, at least three different shapes are recommended for consideration in order to complement traditional glove sizes: *Thumb-index predominant*, *Average* and *Ring-little predominant*.

Although the size of the study sample was limited, the differences observed in palm and hand profiles show the existence of different hand shapes that may affect the fitting of gloves. These results provide clues as to how to improve current glove-sizing systems, and thus increase their fitting and their performance.

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