Comparison of cranial sex determination by discriminant analysis and logistic regression

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Abstract

Various methods have been proposed for estimating dimorphism. The objective of this study was to compare sex determination results from cranial measurements using discriminant analysis or logistic regression. The study sample comprised 130 individuals (70 males) of known sex, age, and cause of death from San José cemetery in Granada (Spain). Measurements of 19 neurocranial dimensions and 11 splanchnocranial dimensions were subjected to discriminant analysis and logistic regression, and the percentages of correct classification were compared between the sex functions obtained with each method. The discriminant capacity of the selected variables was evaluated with a cross–validation procedure. The percentage accuracy with discriminant analysis was 78.2% for the neurocranium (82.4% in females and 74.6% in males) and 73.7% for the splanchnocranium (79.6% in females and 68.8% in males). These percentages were higher with logistic regression analysis: 85.7% for the neurocranium (in both sexes) and 94.1% for the splanchnocranium (100% in females and 91.7% in males).

Keywords: neurocranium; splanchnocranium; sex determination; discriminant function analysis; logistic regression; sexual dimorphism

Introduction

Sex determination is the cornerstone for establishing a biological profile of human remains (Rogers, 2005). Traditional studies based on morphological characteristics encounter some difficulties, because many features depend on the observer, the nutritional status, occupation, and/or origin (Devang et al., 2015). Anthropometric methods are more reliable for sexing when adequate reference data (formulae) are available for the study population.

A complete description of logistic regression is provided by Albanese (2003), who suggests useful approaches for evaluating the fit of a logistic model to the data. Logistic regression differs from discriminant function analysis because it does not require a normal distribution of independent variables and is less sensitive to strong correlations among predictor variables (Press and Wilson, 1978; Albanese, 2003; Pohar et al., 2004; Acharya et al., 2011). Logistic regression is more flexible in its assumptions and delivers a better performance, even when the assumptions of discriminant function analysis are met (Albanese, 2003; Acharya et al., 2011).

Nevertheless, logistic regression is only rarely used in physical anthropology or forensic medicine for sex assessment from measurements, and discriminant function analysis has been applied by most authors. Thus, numerous authors employed the latter method to estimate the sex of individuals using craniometric variables, including bizygomatic width, basion-bregam height, nasal height and width, facial length and width, and/or maxillary-alveolar length and width (Cunha and Van Vark, 1991; Song, 1992; Steyn, and Iscan, 1998; Rosique et al., 2004; Franklin et al., 2005; Deshmukh and Devershi, 2006; Kemkes and Göbel, 2006; González et al., 2009). The percentage of correct sex allocation obtained by these authors ranged between **72.15 and 96.7%**.

Logistic regression can be used as an alternative option when predictor variables do not have equal variance-covariance matrices. Logistic regression functions developed for sex determination correctly classified 74.5% of individuals studied by Casas et al. (2009), who considered 5 dental variables and 88% of those studied by Walker (2008), who studied a series of cranial variables In a study to determine sex from the teeth of adults, Acharya et al. (2011) reported 91% sex allocation accuracy using logistic regression and only 62.9% accuracy using discriminant analysis, concluding that the former was superior for dental sex assessment.

The purpose of the present study was to compare the accuracy of sex identification from cranial measurements between two statistical approaches: discriminant analysis and logistic regression.

Material and methods

This study included adult skeletons of known sex, age, and cause of death from the San José collection, kept in the Physical Anthropology Laboratory of the University of Granada and derived from the municipal cemetery of Granada city (Southern Spain)**.**

The study sample comprised skulls from 130 Mediterranean individuals (70 males and 60 females) who died in Granada during the 20^{th} century. The mean age was 69 years (range, 22-93 years). Because of the advanced age of many of these individuals and the resulting alterations in the mandibular region (from tooth losses and consequent alveolar resorption) and frequent presence of disease, measurements of this region were not considered in the present study. For the same reason, it was not possible to measure BPL, UFH, and MAL variables (see Table 1 for abbreviations) in all of the individuals studied. Measurements were taken with a digital caliper (accuracy of 0.01 mm) by the same examiner (A.A-A.) and repeated after a 15–day interval to test the intra-observer error, considered a sufficient time interval to ensure that the second assessment was not influenced by learning acquired at the first examination (Viciano et al., 2013). A second observer used the same caliper to measure the same dimensions in 30 randomly selected individuals in order to assess the inter-observer error. Table 1 displays the cranial measurements taken, following Martin and Kunsmann (1988).

(Insert Table 1)

SPSS 15.0 (IBM, Chicago, IL) was used for the data analyses. Data were expressed as means with standard deviations, and the normality of their distribution was assessed using the one-sample Kolmogorov–Smirnov test. The intraclass correlation coefficient (ICC) was used to evaluate the intra- and inter-observer agreement, estimating the mean of correlations between all possible pairs of observations. The ICC classification (range 0–1) proposed by Fleiss (1986) was adopted. Repeated–measures analysis of variance (ANOVA) was performed to assess the statistical significance of the variability between pairs of measurements.

A *t*–test was used to compare data between the sexes and evaluate the homogeneity of variance (*F*–test). Dimensions showing no significant differences between sexes were excluded from subsequent statistical models. The effectiveness of the cranial dimensions for sex determination was first determined by discriminant function analysis, using a stepwise procedure to select the variables with the highest discriminant capacity. An M-Box test was performed to determine whether the covariance matrices were homogeneous. A cross–validation procedure re-calculated the discriminant function analysis, sequentially and randomly selecting one of the samples and averaging the results across all cross–validation values. Next, logistic regression analysis was separately performed to identify the most useful sex discrimination functions. Equations were calculated for pairs of measurements (considering all dimensions) in order to maximize the applicability of the technique for archaeological and forensic cases in which the cranium is incomplete or poorly preserved. The –2 log likelihood was calculated to assess the fit of logistic regression models to the data (lower –2 log statistic = better fit). Discriminant analysis function and logistic regression were separately performed for the neurocranial and splanchnocranial variables.

Results

The data for males and females were separately checked with the Kolmogorov–Smirnov test, which showed that all dimensions were normally distributed (*t*–test, $P > 0.05$**)**. The ICC results (ICC ≥ 0.75; $p > 0.05$) demonstrated that the measurements were generally highly reproducible, with an elevated precision and accuracy (Fleiss, 1986).

Table 3 reports the mean values recorded for all dimensions. Student's t-test results revealed statistically significant differences ($P < 0.05$) between the sexes in 6 of the 11 splanchnocranial dimensions and in 12 of the 19 neurocranial dimensions (Table 2).

(Insert Table 2)

Table 3 lists the coefficients, the classification functions for neurocranium and splanchnocranium, the *F* and Wilks' lambda values, and the discriminant functions with corresponding sectioning points. The M-Box test showed homogeneous covariance matrices ($P > 0.05$). The discriminant analysis yielded six functions for the neurocranium and only one for the splanchnocranium. Discriminant analysis selected

BBH, MCL, LIA, TSA, and ABH (see Table 3) for the neurocranium and BizB for the splanchnocranium as having the greatest discriminant power. Females and males could be readily differentiated, and the centroids markedly differed between the sexes.

(Insert Table 3)

The reliability (classification accuracy) values obtained for these functions are given in Table 4. The cross–validation procedure showed a mean reliability of 78.2% (82.4% in females and 74.6% in males) for the neurocranium and 73.7% (79.6% in females and 68.8% in males) for the splanchnocranium (Table 4). Univariate discriminant analysis of BBH (function 2), MCL (function 3), LIA (function 4), TSA (function 5), and ABH (function 6) revealed that the sexual dimorphism was highest for the BBH and lowest for the LIA (Table 4). The highest percentage sex classification accuracy was obtained with the BBH dimension.

(Insert Table 4)

Table 5 exhibits the logistic regression coefficients for each function. Five functions were obtained for the neurocranium and one for the splanchnocranium. Logistic regression selected MCL, BBH, TSA, and LIA for the neurocranium and BizB for the splanchnocranium. With this model, the percentage classification accuracy was 85.7% (in both sexes) for the neurocranium and 94.1% (100% in females and 91.7% in males) for the splanchnocranium (Table 5). In the case of the neurocranium, the same percentage of correct classification (85.7%) was obtained for the males tan for the females; however, in the case of the splanchnocranium, this percentage was higher for the females (100%) than for the males (91.7%) (Table 6).

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(Insert Table 5)

(Insert Table 6)

Univariate logistic regression results for MCL (Function 2), BBH (function 3), TSA (function 4), and LIA (function 5) showed the highest sexual dimorphism for BBH and the lowest for LIA (Table 5). Table 6 displays the data on the classification accuracy of these functions. In the paired logistic regression analyses, BBH was selected for all neurocranial functions, while BizB was the most frequent (79.5-94.1%) among splanchnocranial functions (Table 7). Both methods selected MCL, BBH, TSA, and LIA for the neurocranium and BizB for the splanchnocranium, although the percentages of correct classification differed between the statistical approaches.

(Insert Table 7)

Discussion

In this study of 130 adult skeletons, significant differences were found between the crania of females and males, in agreement with previous reports (Paiva and Segre, 2003; Kemkes and Göbel, 2006).

Most of the dimensions were selected by both discriminant analysis and logistic regression and can be considered useful for sex determination. The majority of these were previously identified as key variables by different authors, including: MCL by

Song (1992), Steyn and Iscan (1998), Fernández (2007), and Zabando et al. (2009); BBH by Krenzer (2005) and Franklin et al. (2005); and BizB by Giles and Elliot (1963), Song (1992), Steyn and Iscan (1998), Rosique et al. (2005), and Zabando et al. (2009).

In the discriminant analysis, the percentage sex classification accuracy was higher for neurocranial than splanchnocranial measurements. This may reflect a higher effectiveness when five dimensions are considered (BBH, MCL, LIA, TSA, ABH) rather than only one (BizB). In contrast, the percentage classification accuracy was higher for the splanchnocranium in the logistic regression analysis and would be the optimal region for sex determination using this approach.

The percentages of correct sex classification obtained with discriminant analysis slightly differed from those published by other authors using this statistical method. Thus, percentages of 85.6-89.7% were reported by Hanihara (1958) in a study of 9 cranial variables in a Japanese population and percentages of 80-86% by Steyn & Iscan (1998) in an examination of 91 South African skulls. Sanjai et al. (2007) used logistic regression in a study of 101 Thailandese skulls and obtained a percentage accuracy of 88.8%. The small variations among studies may be attributable to differences in sample size or in the origin of the samples.

The percentages of correct classification were higher for females than for males with both methods and in both cranial regions. All of the selected variables would have greater discriminant power in females than males. In general, it has been reported that males are more affected by diseases, malnutrition, and climatic events (Suazo et al., 2008), and Pucciarelli et al. (1990) demonstrated that growth patterns were more strongly influenced by environmental conditions in males than in females. However, these gender differences may vary among populations.

BBH and BizB proved to be the most useful sex determination variables in both analyses. In the paired logistic regression and univariate discriminant analysis, they achieved the highest classification percentages and were the most frequently repeated variables, and they showed the greatest weight when the multivariate function was applied. These were found to be the best cranial variables for sex determination by various authors, including Giles and Elliot (1963), Song (1992), Steyn and Iscan (1998), Krenzer (2005), Franklin et al. (2005), Rosique et al. (2005), and Zabando et al. (2009).

The percentage correct classification was higher with logistic regression than with discriminant analysis. Logistic regression appears to be a useful method for sex determination from cranial measurements in the absence of other bones with identifiable sex–specific characteristics (Albanese, 2003; Sangvichien, 2007).

Conclusions

The findings of this study indicate that logistic regression is the most useful method to determine sex from cranial measurements. In this Mediterranean population, the BBH and BizB offered the greatest discriminant power for sex determination. According to the logistic regression results, the optimal cranial region for sex determination is the splanchnocranium. This approach is of particular interest to anthropologists, because it can be used to determine the sex of skeletons when only part of the cranium is preserved.

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