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Discriminant function analysis versus morphognostic sex determination of 637 crania from the Poschiavo ossuary

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Summary

The paper presents a new discriminant function (DFA) for sex determination from cranial skeletal material specifically suitable for Swiss alpine populations. The formula was developed on a large cranial series (n=637) originating from an ossuary in Poschiavo Switzerland (16th–19th century AD). The accuracy of the new DFA was compared to other published DFA (Giles and Elliot 1963; Henke 1973; Kajanoja 1966; Brůžek and Velemínský 2006) whereas a validation of all formulae was made on skeletal material mainly from Switzerland, southern Germany and Austria (12 series; ca. 1400 individuals; 9th mil. BC–19th century AD). The new DFA proved accurate with a high degree of concordance with morphognostic sex determination (79%) compared to the other DFA (69%–83%). Considering also that with the Poschiavo DFA more individuals could be classified based on the small number of necessary measurements, the present DFA proved especially valuable. The high accuracy levels and the fact that few measurements are needed make the proposed DFA suitable for Swiss alpine populations, applicable to a large amount of individuals and less time-consuming.

Keywords: craniometrics, alpine population, ossuary, demography, Graubünden.

Introduction

In anthropology, as in archaeology or forensic science, sexing is a very important part of any study, as many further analysis and interpretations will be based on it. Until now, there have been two principal methods to determine sex: morphognostic and metric, while analysis of DNA for sex determination is primarily used within a medico-legal context. Within the metric analyses repertoire there is the possibility of developing discriminant functions. This is done by deriving one or more equations from relevant measurements and obtaining a value which will act as cut-off point between males and females. The choice of measurements depends on two major factors: the degree of sexual dimorphism they present, and the level of preservation. Thus, some discriminant function analyses (DFA) rely on few measurements (e.g. Henke 1973, with a maximum of 5 measurements) or are based on specific anatomical structures which tend to be better preserved (e.g. Gapert *et al.* 2009, DFA for the occipital condyle).

DFA for sex determination has been used on most parts of the skeleton with various degrees of success, varying between 60–90% (cranium: Gapert *et al.* 2009; Birkby 1966; Kajanoja 1966; Henke 1973; Ferembach *et al.* 1979; İşcan *et al.* 1995; Dayal *et al.* 2007; Franklin *et al.* 2005; mandibula: Calcagno 1981; Arnay de la Rosa *et al.* 2007; postcranium: Holland 1991; Marino 1995; Sacragi and Ikeda 1995; Dibbenardo and Taylor 1983), both for archaeological and forensic purposes. DFA can be used as a subsidiary method to morphognostic sex determination, but it has proved especially useful on isolated bones for which no standard visual method has been developed (Gapert *et al.* 2009; Marino 1995). Arnay de la Rosa (1997) even obtained more accurate sex determination results using metric analysis on a Canary Island population than with traditional visual methods.

The advantage of metric analysis and the reason why it became increasingly popular is the „objectivity" of the method (Dayal 2007; Calcagno 1981), making obtained data easily comparable to other studies. One major drawback however, often pointed out, is the fact that the results are highly influenced by the size, robusticity and sexual dimorphism of the population for which the DFA had been developed (Marino 1995; Birkby 1966; Cowal and Pastor 2007; Walker 2008). Thus, Henke (1973) proposed to adapt DFA to other populations by shifting the sectioning point and Konigsberg *et al.* (2009) underlines the importance of knowing the ancestry before applying metrics on any individual or population.

The aim of this paper is twofold: to develop a DFA applicable to Swiss alpine and subalpine populations and to apply it to cranial material from an Alpine ossuary in order to increase the amount of sexually determined individuals.

Material and Methods

The cranial material used originates from the ossuary of Poschiavo, Canton Graubünden, Switzerland. It consists of 637 excellently preserved crania kept in the oratorio of Santa Anna, 596 adults and 41 subadults. The ossuary itself dates to the beginning of the 20th century, but the cranial material was brought there from the church and the cemetery of Saint Vittore also situated in Poschiavo, and it is estimated that the skulls date to the 16th–19th century AD (Papageorgopoulou *et al.* 2011). Information about the individuals such as name, age, sex or kinship was not available.

Determination of the sex of the adult individuals using morphognostic diagnosis was based on the recommendations by Ferembach *et al.* 1979, 1980. Each individual was attributed a number between -2 and 2; -2 being extremely female and 2 being extremely male. Since the "recommendations" (Ferembach *et al.* 1979, 1980) give no clear limits between male, probable male, undetermined, probable female and female, the authors used the following system (Tab. 1). A series of standard cranial measurements described by Martin (1928) were taken (M1, M23, M45, M52, M55). To evaluate observer error of the cranial measurements, 65 crania were selected at random and measured twice, observer error was estimated following the procedure described by Gapert *et al.* 2009.

Value after Ferembach *et al.* (1979, 1980)	Classification
< -0.5	female, certain
-0.5 to -0.1	female, probable
-0.1 to +0.1	undetermined
+0.1 to +0.5	male, probable
> +0.5	male, certain

Tab. 1: Relation between calculated values after Ferembach *et al.* (1979, 1980) and final classification of sex into categories.

Sex determination based on the metrics of the crania was done by applying standard DFA to all the individuals. From the worthy overview of Sjøvold (1988; compare Rösing *et al.* 2007) we selected all those DFA which seem suitable to our material and to the availability of measurements (Tab. 2). The DFA recommended by Ferembach *et al.* 1980 (525, "formula 1"), based on the Terry collection, was not taken into account because it integrates the height of the processus mastoideus (M19a) which is also used for the morphognostic sex determination. To keep both approaches independent we excluded this special DFA. Furthermore we adopted the proposal of Brůžek and Velemínský (2006) which should be useful for medieval Slavonic people. Their nine formulas were arranged by us according to their percentage of correct classification at the reference series (Brůžek and Velemínský 2006, Tab. 7).

A DFA based on the Poschiavo was developed [1a, 2a]. Only individuals morphognostically sexed with confidence were taken into account (n=410; Tab. 3). The measurements used were M1 or M23, M45, M52 and M55, chosen for their high sexual dimorphism.

References	Reference population	N individuals (♂ / ♀)	Measurements used (Martin 1928)
Giles and Elliot 1963	Terry and Todd collection: USA, modern population	150 / 150	1, 8, 17, 19a, 40, 45, 48, 61
Henke 1973	Westerhus, Sweden, medieval population	48 / 44	1, 5, 8, 17, 23, 25, 45, 48
Kajanoja 1966	Finland, modern population	166 / 67	1, 5, 8, 17, 40, 45, 48, 54
Brůžek and Velemínský 2006	Czechia, 9-10th c. AD	128 / 82	1, 5, 8, 9, 12, 17, 40, 45, 47, 48, 51, 52
this paper	Switzerland, post-medieval population	221 / 187	1, 23, 45, 52, 55

Tab. 2: Standard DFA methods applied to Poschiavo and the twelve collected series.

	n	%	%
male, certain	221	37.1	50.8
male, probable	82	13.8	
female, certain	188	31.5	44.1
female, probable	75	12.6	
undetermined	30	5.0	5.0
total	596	100	100

Tab. 3: Morphognostic sex determination for the ossuary of Poschiavo.

[1a] x = (0.06062551 × M1) + (0.13443861 × M45) - (0.12356525 × M52) + (0.10816357 × m55) - 29.65908118

[2a] x = (0.02770114 × M23) + (0.11758105 × M45) - (0.12485032 × M52) + (0.10899042 × M55) - 31.04928909

From the 410 crania, 131 could not be taken into account due to missing measurements. Of these 131 crania, 130 were missing the M45. Therefore a second formula without M45 was developed in order to maximize the number of evaluable crania [1b, 2b].

[1b] x = (0.13105189 × M1) - (0.15242140 × M52) + (0.20503567 × m55) - 27.84870270

[2b] x = (0.05900227 × M23) - (0.15061273 × M52) + (0.16620376 × M55) - 33.37984367

The cutpoint for all formulas is zero, with x < 0 = female and x > 0 = male. The formula was tested on a broad spectrum of European populations (Tab. 4).

We want to prove the amount of successful classifications by the different DFA when applied to other series than those they had been developed for. Additional to the Poschiavo series we therefore collected published data of 12 series mainly from Switzerland, southern Germany and Austria, where morphognostic sex determination and measurements of the skull were available (Tab. 4). To avoid the problem of small numbers, the ossuaries of Buochs and Stans, both in the canton of Nidwalden, Switzerland, are taken as one series, as well as three mesolithic cemeteries (9th–6th millenium BC). All the selected DFA are applied to these populations, and the result is compared with the morphognostic sex determination.

Series	Date	Kind	Reference	Males	Females	Total
Buochs, Nidwalden, CH	17–18th c.	oss.	Schürch 1899	33	28	61
Stans, Nidwalden, CH	17–19th c.	oss.		23	14	37
Baden (region), D	16–18th c.	anat.	Mühlmann 1932	44	12	56
Canton Wallis, CH	11–18th c.	oss.	Pittard 1910	459	337	796
Westerhus, Sweden	13–14th c.	cem.	Gejvall 1960	63	67	130
Tomils, Graubünden, CH	11–15th c.	cem.	Papageorgopoulou 2008	134	121	255
Pottenbrunn, Austria	8–9th c.	cem.	Fabrizii-Reuer 2001	50	50	100
Eichstetten, D	6–7th c.	cem.	Hollack and Kunter 2001	91	107	198
Stetten, D	6–7th c.	cem.	Koniecka and Kunter 1999	45	46	91
Linz, Austria	4th c.	cem.	Wiltschke-Schrotta *et al.* 1991	18	18	36
Pully-Chamblandes, Wallis, CH	4th mil. BC	cem.	Schenk 1903 Moinat and Simon 1986	14	18	32
Sonderhausen (region), D	5th mil. BC	cem.	Bach 1978	46	50	96
Taforalt, Marocco	9–6th mil. BC	cem.	Ferembach 1962	95	74	139
Moita, Portugal			Ferembach 1974	62	64	126
Vlasac, Serbia			Nemeskéri *et al.* 1978	43	23	66

Tab. 4: Series taken from publications, where measurements from skull were published for individuals. In total 12 series with 2.250 individuals (1.221 males, 1.029 females). – kind (of collection); oss.: ossuary; cem.: archaeologically excavated cemetery; anat.: anatomical collection. Abbreviations for countries: CH Switzerland, D Germany.

	n	δ min.	δ max.	δ mean	TEM	rTEM	R
M1	65	-2 mm	4 mm	0.20 mm	0.770	0.445	0.997
M23	65	-15 mm	28 mm	0.28 mm	4.382	0.859	0.982
M45	47	-5 mm	36 mm	0.81 mm	3.836	2.934	0.964
M52	65	-1 mm	8 mm	0.48 mm	0.996	3.029	0.957
M55	65	-2 mm	26 mm	0.77 mm	2.478	5.108	0.938

Tab. 5: Observer error for crania measured twice (n=65). δ: difference between two measurements; TEM: technical error of measurement; rTEM: relative technical error of measurement; R coefficient of reliability; TEM, rTEM and R after Gapert *et al.* (2009).

Results

Table 3 shows the amount of sexed individuals for Poschiavo using morphognostic analysis only. Although less than 5% are left completely undetermined, only 69% of the individuals were sexed with confidence. Intra- as interobserver error at morphognostic sex determination was tested by examining some crania twice. There was no difference between intra- and interobserver error, so both categories were analysed together. From the 56 crania observed twice, 7 were classified differently (12.5%). The mean difference of the calculated value after Ferembach *et al.* (1979, 1980) between first and second observation was 0,011 with standard deviation of 0,440 (minimum –1.04, maximum 1.04, n = 56). Further analysis was based on the first observation.

Observer error of the cranial measurements used for DFA is documented in Tab. 5; the mean difference between first and second observations is lower than 1 mm, the relative technical error of measurement rTEM lies between 0.4 and 5.1%, the coefficient of reliability R was 0.94 at least (Tab. 5). The DFA [1a,b; 2a,b] combined with the morphognostic method resulted in 11% more individuals being classified with confidence, and only 2% of individuals remained indeterminate (Tab. 6).

	DFA: male	DFA: female	DFA: total
male, certain	187	30	217
male, probable	49	30	79
indet.	12	16	28
female, probable	21	53	74
female, certain	19	168	187
Total	**288**	**297**	**585**

Tab. 6: Comparison of morphognostic sex determination (detailed) with sex classification by the DFA for Poschiavo [1a,b; 2a,b].

Table 7 shows the degree of concordance obtained when selected DFA (Tab. 2) are applied to other published series. Giles and Elliot's formula exhibit 81% correctly identified individuals, Kajanoja's 83%, Henke's 78%, Brůžek and Velemínský 69% and the DFA based on Poschiavo's 79%. Besides the criterion of concordance with morphognostic sex determination it is worthy to compare how many individuals could be classified by the different DFA, which depends on the availability of the necessary measurements. As table 7 shows, the DFA after Henke (1973), Brůžek and Velemínský (2006) and d'Eyrames classify most of the individuals with a high amount of correct classifications, especially for Henke (1973) and d'Eyrames.

Discussion

Intra- and interobserver error of morphognostic sex determination for the ossuary of Poschiavo showed a mean difference very close to zero, which means that there was no directed bias. The standard deviation of 0.44 indicates, that the second observation is often close to the first one, but not identical. About 12.5% of all cases (n=56) would get another classification. This underlines the well known problems of morphognostic sex determination on skulls only and the worth of trying to validate it by DFA on metrics. Observer error and reliability of the cranial measurements used for DFA are comparable to other studies and lie within tolerable limits (Tab. 5; compare e.g. Gapert *et al.* 2009, Veroni *et al.* 2010).

Developing a DFA for the Poschiavo ossuary did improve the percentage of identified individuals. Using morphognostics only, 69% of the crania were identified with confidence, and about 5% were left as indeterminate. After adjoining the DFA [1, 2], 78% were identified with confidence and no indeterminate individuals were left. This illustrates the usefulness of DFA in improving morphognostic methods. The

combination of both DFA and standard methods however is not routinely done. Taking only DFA into account, results are comparable to those from previous studies (82% concordance).

Steyn and İşcan (1998) obtained up to 86% accuracy in a study on cranial measurements of South African whites. Dayal *et al.* (2008) also produced similar results (85% accuracy) on a modern black South African population. One has to take into account that in both cases strong sexual dimorphism within the populations was noted, which was not the case in Poschiavo. Although Calcagno (1981) suggested that no sexual dimorphism difference between populations could be as great as the size variation within each sex of a given population, the fact that the Poschiavo population did show little sexual dimorphism had an impact on the results. This can also be observed on other less sexually dimorphic populations. A study led by Arnay de la Rosa (2007) showed that a DFA on mandibles of a Canary Island population proved to be correct in only 70% to 75% of cases due to the gracile nature of the males and the robusticity of the females. The same applies to a study on a modern Japanese population İşcan *et al.* 1995), which showed a 74% rate of success due to the increasing robusticity of females.

Concerning the application of our DFA to other populations, results were very satisfactory. Many of the formulas published (see Sjøvold 1988 for a comprehensive list of published DFA) require measurements that are either rarely taken or impossible to take due to preservation issues. From the four formulas chosen (Giles and Elliot 1963, Kajanoja 1966, Henke 1973, Brůžek and Velemínský 2006), Henke proved to be the most successful for two reasons. Firstly, the measurements required could often be taken on a great number of individuals due to the flexibility of the formula, increasing the relevance of the results. Secondly, the results themselves were very satisfactory with an overall percentage of accuracy of 78% (span 67 to 86%). On the one instance where only 56% of the individuals were correctly identified (Linz) one can argue that the low amount of individuals (9) is to blame. The formula developed for the Poschiavo population proved to be comparable to Henke's DFA for most populations, and in some instances better (up to 92% accuracy).

Conclusions

Whenever possible, a combination of DFA and morphognostic methods for determining sex from crania is recommended. The high accuracy levels of the Poschiavo DFA and their validation on other reference collections demonstrated the suitability of this formula

Series	Giles and Elliot 1963	Kajanoja 1966	Henke 1973	Brůžek and Velemínský 2006	this paper [1a,b; 2a,b]
Poschiavo	334/455=73%	352/424=83%	442/559=79%	412/559=75%	457/557=82%
Buochs & Stans, Nidwalden, CH	73/98=74%	n.a.	76/98=78%	78/98=80%	72/98=73%
Baden (region), D	18/25=72%	18/24=81%	27/40=68%	31/39=79%	25/34=74%
Canton Wallis, CH	444/531=84%	424/501=85%	601/762=79%	556/780=71%	566/705=80%
Westerhus, Sweden	79/95=83%	69/85=81%	106/124=86%	76/127=60%	84/99=85%
Tomils, Graubünden, CH	97/114=85%	78/94=83%	129/165=78%	106/162=65%	107/138=76%
Pottenbrunn, Austria	25/32=78%	21/25=84%	35/44=80%	29/42=69%	29/38=76%
Eichstetten, D	4/4=100%	4/4=100%	7/9=78%	8/10=80%	12/13=92%
Stetten, D	10/21=48%	4/7=57%	25/40=63%	21/39=54%	21/36=58%
Linz, Austria	3/5=60%	2/4=50%	5/9=56%	3/8=38%	7/10=70%
Pully-Chamblandes, Wallis, CH	11/14=79%	9/10=90%	14/17=82%	11/18=61%	13/15=87%
Sonderhausen (region), D	55/60=92%	33/38=87%	55/72=76%	41/70=59%	58/64=91%
Taforalt, Marocco/Moita, Portugal/ Vlasac, Serbia	22/33=67%	7/12=58%	31/46=67%	27/45=60%	21/33=64%
All (without Poschiavo)	841/1032=81%	669/804=83%	1111/1426=78%	987/1438=69%	1015/1283=79%

Tab. 7: Comparison of sex determination by DFA with morphognostic sex determination. The columns follow the scheme: number of identically classified individuals/number of individuals = percentage of identically classified individuals. Percentages rounded. „n.a." not available, because necessary measurements are missing.

as of Henke (1973) for Swiss populations. The fact that few measurements are needed here makes the proposed DFA applicable to a great amount of individuals as well as less time-consuming.

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