

RESEARCH ARTICLE

Imbalanced Sex Ratios in Sex Estimation Using Probabilistic Sex Diagnosis (Diagnose Sexuelle Probabiliste [DSP]): Implications for Paleodemographic Interpretations

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ABSTRACT

This study investigates biases in sex estimation using the DSP (Diagnose Sexuelle Probabiliste—Probabilistic Sex Diagnosis) method in bioarchaeological contexts. The aim is to assess whether this method overperforms in estimating one of the sexes and to explore the implications for palaeodemographic interpretations. A meta-analysis was conducted using data from 32 archaeological and current populations ($n = 2303$), spanning prehistoric to modern times. DSP-based sex estimations were compared with results from medical analytical, genetic, and alternative osteological methods. In the DSP reference data, morphological variability was analyzed through principal component analysis of pelvic measurements, and classification methods were evaluated using both linear discriminant analysis and random forest modeling. Findings reveal a consistent overestimation of female representation in sex ratios when using DSP, particularly in prehistoric and contemporary populations. This bias is linked to population-level differences in sexual dimorphism, especially in the IIMT and SPU pelvic dimensions. The proportion of indeterminate individuals—most often male—varied by population, with European samples showing more male indeterminates and North American samples showing more female indeterminates. The study confirms a systematic sex classification bias within DSP applications, driven by both statistical and morphological factors. These distortions can mislead interpretations of population structures, funerary practices, and mortality patterns. Corrective approaches, such as redistributing indeterminate individuals or calculating confidence intervals for sex ratios, are proposed. Further research into population-specific dimorphism and complementary methods is recommended to improve reliability in sex estimation for population-based studies.

†Jaroslav Brůžek passed away (on 23 July 2025) before the publication of the manuscript.

1 | Introduction

The biological profiling of individuals often presents a challenge for biological anthropologists, due to the incompleteness of skeletal remains and the need to select appropriate methods. Palaeodemographic analyses can be further complicated by the presence of individuals remaining undetermined. Such analyses include the study of the proportions of females and males (Boldsen et al. 2022) commonly quantified using the sex ratio $((N_{\text{males}}/N_{\text{females}}) \times 100)$. This ratio is then compared to a theoretical expected value, corresponding to the average sex ratio of sexually reproducing organisms (100; Darwin 1874).

In humans, the average sex ratio at birth is around 105 due to higher female fetal mortality (Orzack et al. 2015). It exhibits significant geographical variations (Hesketh and Xing 2006; Renkonen et al. 1962) and fluctuates with age, as mortality rates differ between females and males across age groups (Austad and Fischer 2016; Case and Paxson 2005; Wang et al. 2012). Analyzing these variations allows for a better understanding of the impacts of natalist policies, migrations, environmental changes, epidemics, and conflicts on populations (Curtis and Roosen 2017; Hollingshaus et al. 2019; Li et al. 2011; Pedersen 1991).

In archaeology, the sex ratio is used to study the funeral recruitment of a given site. It can help identify preferential selections that may reflect social organizations (Vincenti et al. 2024), conditions for accessing a funerary space (Fernández-Crespo and de-la-Rúa 2016), or events leading to abnormal mortality rates for one sex (Franklin 2012).

One of the commonly used methods for estimating sex is DSP—"Diagnose Sexuelle Probabiliste" or Probabilistic Sexual Diagnosis (Brůžek et al. 2017; Murail et al. 2005), a primary sex diagnostic method (Santos 2021) validated and recommended for studies of large funeral assemblages (Galovičová 2024). DSP is a population nonspecific, well-defined, user-friendly, robust, and reliable technique for sexing the innominate in forensic anthropology (Klaes 2020) and bioarchaeology (Jerković et al. 2018).

The use of a dataset obtained through a method of sex estimation for paleodemographic analysis is relevant only if the probabilities of estimating the sexes of females and males are equal. More than 50 years ago, Kenneth M. Weiss highlighted the existence of a systematic bias favoring males in the estimation of sex for adult skeletons in preindustrial populations (Weiss 1972). This bias arises from the use of secondary sexual characteristics (robustness/gracility) more pronounced in males than in females and without considering intrapopulation variability. The inaccuracies introduced represent a major source of error in paleodemographic reconstructions (Walker et al. 1988).

Although DSP is not meant to estimate population parameters, its results are often generalized to characterize populations. Drawing on data collected from the research project WomenSOFar (Goude 2023), which included sex estimations using DSP and genetics, we noted a tendency for more males

than females among the individuals remaining indeterminate. The aim of this study is to confirm and analyze this bias. We also seek to determine whether it results from the statistical processing of DSP or whether it reflects a biological phenomenon that makes one sex more easily identifiable. Additionally, we aim to estimate the implications of this bias for population-level inferences.

2 | Materials and Methods

2.1 | Theoretical and Methodological Background of DSP

DSP is based on the existence of pelvic sexual dimorphism resulting from the adaptations unique to females and males for bipedal locomotion, gestation, and parturition (Dunsworth 2020; Ruff 1998; Schultz 1949; Wood and Chamberlain 1986). These morphofunctional distinctions are accepted as common to all human populations (Brůžek et al. 2005; Haas et al. 1994) and present in early anatomically modern humans (Hager 1989; Marchal 2003). DSP was validated on 309 coxal bones from females and 314 coxal bones from males from American and European populations (Murail et al. 2005). The software was further refined in a second version (Brůžek et al. 2017).

DSP employs combinations of 10 dimensions of the coxal bone, listed in order of discriminant potential (Murail et al. 2005):

1. PUM (M14)—Acetabulo-symphyseal pubic length (Brauer 1988)
2. SPU—Cotylo-pubic width (Gaillard 1960)
3. DCOX (M1)—Coxal length (Brauer 1988)
4. IIMT (M15.1)—Greater sciatic notch height (Brauer 1988)
5. ISMM—Ischium post-acetabular length (Schulter-Ellis et al. 1983)
6. SCOX (M12)—Iliac or coxal breadth (Brauer 1988)
7. SS—Spino-sciatic length (Gaillard 1960)
8. SA—Spino-auricular length (Gaillard 1960)
9. SIS (M14.1)—Cotylo-sciatic breadth (Brauer 1988)
10. VEAC (M22)—Vertical acetabular diameter (Brauer 1988)

To estimate the sex of an unknown individual, DSP uses a linear discriminant analysis (LDA) model learned on a reference sample of 2040 ossa coxa, originating from 10 population samples distributed across several continents. The posterior classification is performed according to a 0.95 probability threshold, increasing the reliability of the method but producing a variable number of individuals for whom sex remains indeterminate.

2.2 | Study Samples and Data Collection

We conducted a meta-analysis based on studies that applied DSP and another sex estimation method (genetics, morphoscopy, secondary sexual diagnosis, and medical data). They consist of

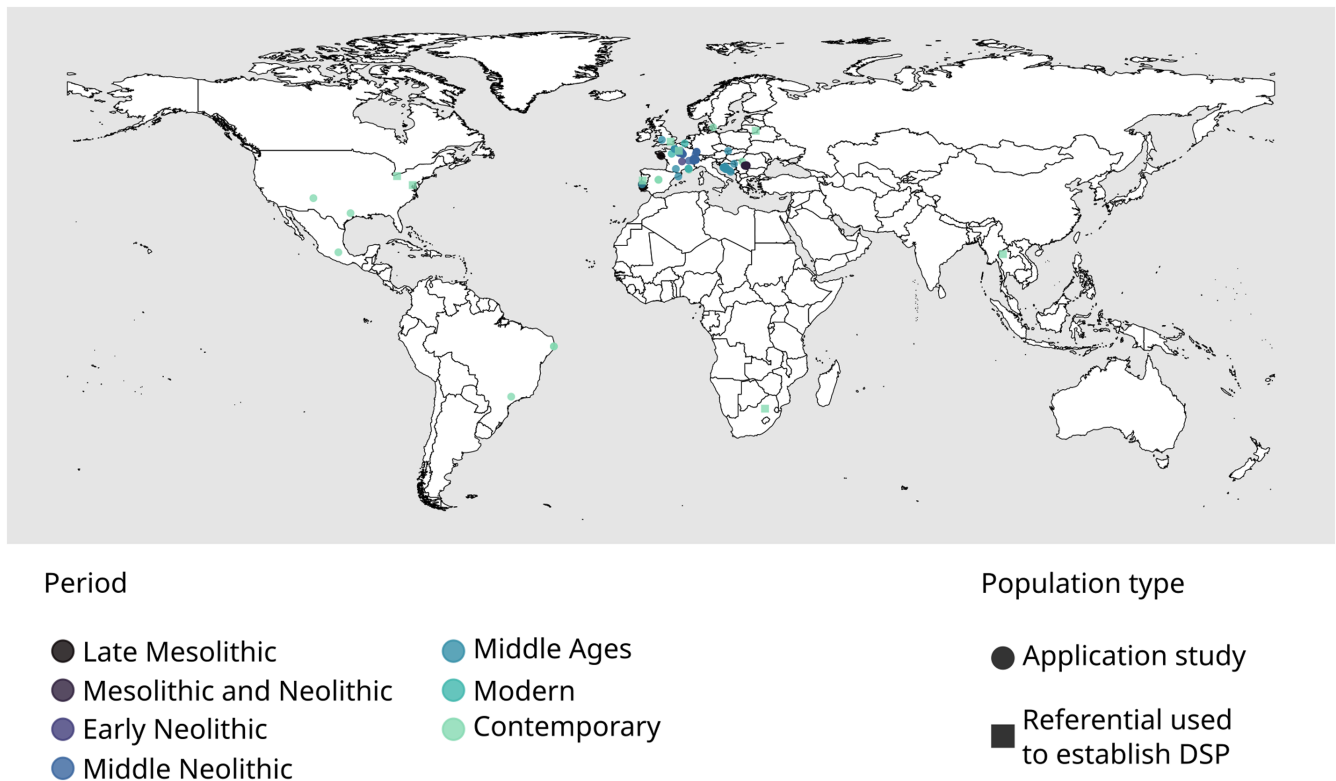


FIGURE 1 | Geographical origin and dating of the datasets used to conduct the meta-analysis and of the populations used to develop the DSP. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

either application studies in archaeological contexts or validation studies testing the accuracy of DSP.

Application studies include 23 archaeological assemblages from the Mesolithic to the Modern Period in Europe, encompassing 908 individuals. In particular, we relied on datasets collected as part of the projects ANCESTRA and INTERACT, which included DNA-based sex estimations for prehistoric French populations (Blaizot 2005; Féliu et al. 2017; Lefranc et al. 2018, 2015; Le Roy 2015; Saintot 2015).

Validation studies were mainly conducted on contemporary samples obtained in a medical context or on modern identified collections. They encompass 1395 individuals from American and European countries.

In total, data from 2303 individuals were collected, distributed across 32 datasets (Figure 1 and Table 1). These populations were defined either directly in the previous studies (Blaizot 2005; De Almeida et al. 2020; Féliu et al. 2017; Galovičová 2024; Jerković et al. 2018; Lefranc et al. 2018, 2015; Le Roy 2015; Lesciotto and Klaes 2024; Lopes et al. 2024; Machado et al. 2018; Mestekova et al. 2015; Murail et al. 2005; Saintot 2015; Sánchez-Mejorada et al. 2011; San-Millán et al. 2024; Stan et al. 2024) or in consultation with the authors (Villotte et al. 2024) to create groups that were geographically and chronologically consistent. For two studies (Lesciotto and Klaes 2024; San-Millán et al. 2024), the authors carried out analyses by laterality or by observer: we chose to keep only the observations corresponding to the right side and the first observer to avoid duplications.

These 32 samples constitute the test set used to assess the impact of using DSP to draw inferences at the population level. Subsequently, we used the DSP reference sample to search for morphological characteristics which may explain why, in certain populations, more males than females remain indeterminate.

2.3 | Computation of Sex Ratios

To assess the impact of DSP on population-level studies, we calculated two sex ratios for each sample:

- I. The sex ratio obtained from DSP sex estimates, thus considering only the subset of individuals whose sex could be estimated by the method;
- II. The sex ratio obtained on the whole sample, using another sex estimation method that avoided having indeterminate individuals.

After looking at the difference between these two sex ratio estimates, we used binomial tests to compare each sex ratio to a situation of equilibrium in order to verify whether the inference drawn using DSP was consistent with that made when all sexes are known.

2.4 | Exploration of DSP Reference Dataset

Subsequently, we used the DSP reference sample to search for morphological characteristics that may explain why, in certain populations, more males than females remain indeterminate.

TABLE 1 | List of populations used in the analysis.

Country	Datation	Study type	Total individuals	DSP N F	DSP N M	DSP N I	Other method N F	Other method N M	Refs.
France	Early Neolithic	Application study	16	14	2	0	11	5	Saintot (2015)
France	Late Mesolithic	Application study	7	3	2	2	3	4	Villotte et al. (2024)
Portugal	Late Mesolithic	Application study	27	13	4	10	10	18	Villotte et al. (2024)
Serbia and Romania	Mesolithic and Neolithic	Application study	33	6	15	12	15	18	Villotte et al. (2024)
Czech Republic	Middle Ages	Application study	197	48	110	39	84	113	Galovičová (2024)
Eastern Adriatic	Middle Ages	Application study	57	14	22	21	31	25	Jerković et al. (2018)
England	Middle Ages	Application study	57	32	18	7	35	22	Villotte et al. (2024)
France	Middle Ages	Application study	15	5	9	1	5	10	Villotte et al. (2024)
France	Middle Ages	Application study	30	12	15	3	15	15	Villotte et al. (2024)
France	Middle Ages	Application study	46	22	20	4	23	23	Villotte et al. (2024)
France	Middle Ages	Application study	23	13	6	4	13	10	Villotte et al. (2024)
France	Middle Ages	Application study	41	12	26	3	22	30	Villotte et al. (2024)
Spain	Middle Ages	Application study	7	3	0	4	3	4	Villotte et al. (2024)
France	Middle Neolithic	Application study	7	1	6	0	1	6	Lefranc et al. (2015)
France	Middle Neolithic	Application study	11	4	5	2	3	8	Blaizot (2005)
France	Middle Neolithic	Application study	12	8	2	2	9	3	Lefranc et al. (2018)
France	Middle Neolithic	Application study	4	3	0	1	3	1	Féliu et al. (2017)
France	Middle Neolithic	Application study	25	11	14	1	10	15	Le Roy (2015)
France	Middle Neolithic	Application study	39	17	13	9	22	17	Villotte et al. (2024)
Switzerland	Middle Neolithic	Application study	48	26	16	6	26	22	Villotte et al. (2024)
Belgium	Modern	Application study	35	17	16	2	17	18	Villotte et al. (2024)
France	Modern	Application study	121	33	62	26	41	80	Thèves et al. (2016)
France	Modern	Application study	50	15	25	10	21	28	Villotte et al. (2024)
England (London)	Contemporary	Referential DSP	116	—	—	—	65	51	Murail et al. (2005)

(Continues)

TABLE 1 | (Continued)

Country	Datation	Study type	Total individuals	DSP N F	DSP N M	DSP N I	Other method N F	Other method N M	Refs.
France (Paris)	Contemporary	Referential DSP	80	—	—	—	31	49	Murail et al. (2005)
Lithuania (Vilnius)	Contemporary	Referential DSP	111	—	—	—	57	54	Murail et al. (2005)
Portugal (Coimbra)	Contemporary	Referential DSP	62	—	—	—	31	31	Murail et al. (2005)
South Africa (Johannesburg-A)	Contemporary	Referential DSP	57	—	—	—	28	29	Murail et al. (2005)
South Africa (Johannesburg-S)	Contemporary	Referential DSP	56	—	—	—	29	27	Murail et al. (2005)
South Africa (Johannesburg-Z)	Contemporary	Referential DSP	157	—	—	—	78	79	Murail et al. (2005)
Thailand (Chiang-Mai)	Contemporary	Referential DSP	101	—	—	—	48	53	Murail et al. (2005)
United States (Cleveland-AA)	Contemporary	Referential DSP	57	—	—	—	29	28	Murail et al. (2005)
United States (Cleveland-EA)	Contemporary	Referential DSP	56	—	—	—	28	28	Murail et al. (2005)
United States (Washington-AA)	Contemporary	Referential DSP	108	—	—	—	55	53	Murail et al. (2005)
United States (Washington-EA)	Contemporary	Referential DSP	100	—	—	—	51	49	Murail et al. (2005)
Brazil	Contemporary	Application study	103	51	45	7	50	53	Machado et al. (2018)
Brazil	Contemporary	Application study	301	124	128	49	136	165	De Almeida et al. (2020)
Brazil	Contemporary	Application study	128	46	45	38	50	78	Lopes et al. (2024)
Denmark	Contemporary	Application study	116	65	44	7	67	49	Rodriguez Paz et al. (2019)
France	Contemporary	Application study	106	53	48	5	54	52	Mestekova et al. (2015)
Mexico	Contemporary	Application study	250	116	107	27	118	132	Sánchez-Mejorada et al. (2011)
Romania	Contemporary	Application study	80	35	22	23	40	40	Stan et al. (2024)
Spain	Contemporary	Application study	137	66	59	12	65	72	San-Millán et al. (2024)
United States	Contemporary	Application study	174	59	92	23	82	92	Lesciotto and Klales (2024)

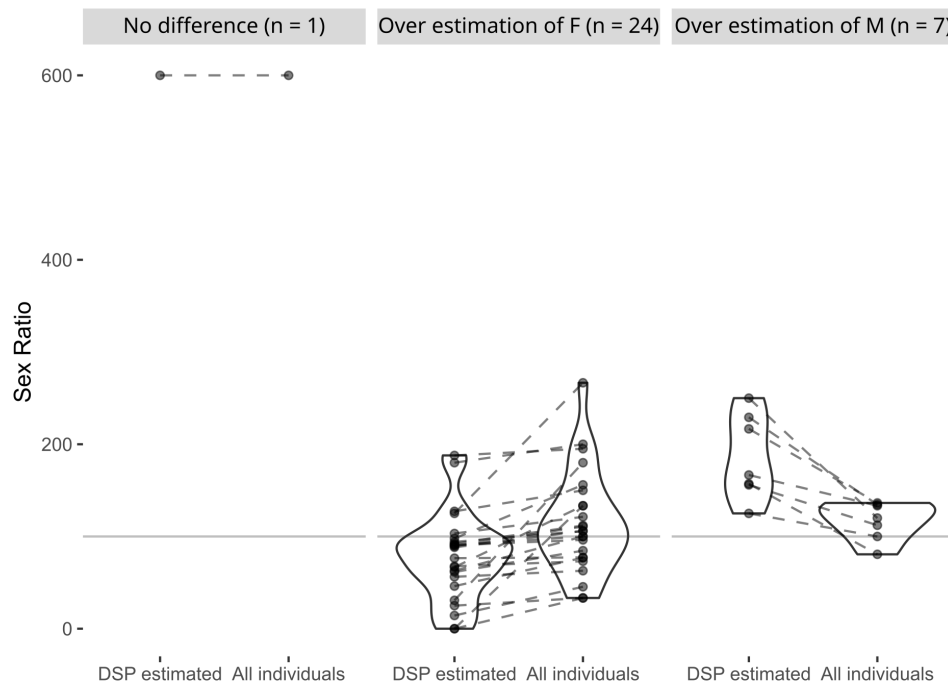


FIGURE 2 | Impact of using raw DSP results versus using overall population data on the calculation of the sex ratio. Populations are grouped according to whether the use of estimates based on the DSP produces a sex ratio that is comparable or overestimates the proportion of one of the sexes compared to the sex ratio of the entire population. The lines connect the sex ratios derived from the DSP and those derived from the entire population for the same dataset.

To rule out the hypothesis that a statistical artifact specifically related to LDA is responsible for DSP's generally higher ability to estimate the sex of females, we trained a random forest model (Breiman 2001), computed the proportions of females and males remaining indeterminate, and compared them to those obtained with the original version of DSP. Then, we explored the variability of the expression of sexual dimorphism across the 12 population samples using a principal component analysis (PCA) and analyses of variance.

3 | Results

3.1 | Sex Ratio Imbalances in DSP Applications

The use of estimations based on DSP led, in comparison to the data after estimations of the sexes of all individuals, to an overestimation of the proportion of females in 24 of 32 cases (75.00%), an overestimation of the proportion of males in 7 of 32 cases (21.87%), and no alteration of the sex ratio in one case (3.13%). Taking a strict value of 100 as an indicator of equilibrium, the interpretation of the sex ratio obtained by DSP differs from the interpretation after estimation of all individuals in 12 out of 32 cases (37.50%; Figure 2). Using a binomial test to verify the compatibility of the samples with natural populations, two populations (6.25%) show a shift in the interpretation, depending on whether only DSP is applied, or if the indeterminate individuals are assigned a sex by another method (Table 2).

The overestimation of the female component appears to be predominant for the prehistoric (9/11, 81.82%) and contemporary

(8/9, 88.89%) periods. For medieval and modern periods, the situation seems more balanced, with 7 out of 12 cases (58.33%) of overestimation of the female component.

3.2 | Effect of Classification Method Choice

On the DSP reference dataset, we examined the imbalances between females and males classified as undetermined (Table 3). Imbalances in indeterminates occur, with Coimbra, Paris, and London having a higher proportion of male-indeterminate individuals; Cleveland-AA, Washington-AA, and Washington-EA having more female-indeterminate individuals; and the other populations with a balance of the sexes among indeterminates.

To test the hypothesis of a statistical artifact, we replaced the LDA with a random forest model. The result shows the same trends as the linear analysis (Table 3). The imbalances in the indeterminates are not statistical artifacts but reflect morphological differences between populations.

3.3 | Population Variability Within the DSP Reference Dataset

To characterize the morphological differences within the DSP reference population, we created three new groups:

- The “IndetM” group, consisting of European populations where the indeterminate individuals are predominantly male (Coimbra, London, and Paris);

TABLE 2 | Impact of using the DSP-determined sample compared to the sample after estimating the sex of previously indeterminate individuals. Effects are estimated by comparing obtained sex ratios and by using binomial test against equilibrium situations.

Country	Datation	Sex ratio DSP	Sex ratio DSP + other method	Effect of using only DSP	p binomial test DSP	p binomial test DSP + other
Brazil	Contemporary	88.24	106.00	Overestimation of %F	1.00	1.00
Brazil	Contemporary	103.23	121.32	Overestimation of %F	1.00	1.00
Brazil	Contemporary	97.83	156.00	Overestimation of %F	1.00	1.00
Denmark	Contemporary	67.69	73.13	Overestimation of %F	1.00	1.00
France	Contemporary	90.57	96.30	Overestimation of %F	1.00	1.00
Mexico	Contemporary	92.24	111.86	Overestimation of %F	1.00	0.53
Romania	Contemporary	62.86	100.00	Overestimation of %F	1.00	1.00
Spain	Contemporary	89.39	110.77	Overestimation of %F	1.00	1.00
France	Early Neolithic	14.29	45.45	Overestimation of %F	0.29	1.00
France	Late Mesolithic	66.67	133.33	Overestimation of %F	1.00	1.00
Portugal	Late Mesolithic	30.77	180.00	Overestimation of %F	1.00	1.00
Serbia and Romania	Mesolithic and Neolithic	250.00	120.00	Overestimation of %M	1.00	1.00
Czech Republic	Middle Ages	229.17	134.52	Overestimation of %M	1.00	1.00
Eastern Adriatic	Middle Ages	157.14	80.65	Overestimation of %M	0.13	1.00
England	Middle Ages	56.25	62.86	Overestimation of %F	1.00	1.00
France	Middle Ages	180.00	200.00	Overestimation of %F	2.86E-05	1.00
France	Middle Ages	125.00	100.00	Overestimation of %M	0.12	0.02
France	Middle Ages	90.91	100.00	Overestimation of %F	1.00	1.00
France	Middle Ages	46.15	76.92	Overestimation of %F	1.00	1.00
France	Middle Ages	216.67	136.36	Overestimation of %M	1.00	1.00
Spain	Middle Ages	0.00	133.33	Overestimation of %F	1.00	1.00

(Continues)

TABLE 2 | (Continued)

Country	Datation	Sex ratio DSP	Sex ratio DSP + other method	Effect of using only DSP	<i>p</i> binomial test DSP	<i>p</i> binomial test DSP + other
France	Middle Neolithic	600.00	600.00	No difference	1.00	1.00
France	Middle Neolithic	125.00	266.67	Overestimation of %F	1.00	1.00
France	Middle Neolithic	25.00	33.33	Overestimation of %F	1.00	1.00
France	Middle Neolithic	0.00	33.33	Overestimation of %F	1.00	1.00
France	Middle Neolithic	127.27	150.00	Overestimation of %F	1.00	1.00
France	Middle Neolithic	76.47	77.27	Overestimation of %F	1.00	1.00
Switzerland	Middle Neolithic	61.54	84.62	Overestimation of %F	1.00	1.00
United States	Contemporary	155.93	112.20	Overestimation of %M	1.00	1.00
Belgium	Modern	94.12	105.88	Overestimation of %F	1.00	1.00
France	Modern	187.88	195.12	Overestimation of %F	1.00	1.00
France	Modern	166.67	133.33	Overestimation of %M	1.00	1.00

Note: Statistically significant differences between sex ratios and in binomial tests are in bold.

- The “IndetF” group, consisting of North American populations where the indeterminate individuals are predominantly female (Cleveland-AA, Washington-AA, and Washington-EA);
- The “Balanced” group, consisting of populations where the proportions of indeterminate male and female individuals are comparable (all other populations).

We then performed a PCA on the coxal bone measurements (Figure 3). We observed a gradient which is associated with the three population groups:

- IndetF show lower values on Axis 2 (lower IIMT and higher SPU values) and higher values on Axis 1 (higher PUM and SA values).
- IndetM show higher values on Axis 2 (higher IIMT and lower SPU values) and lower values on Axis 1 (lower PUM and SA values).

For IndetM, IIMT values are generally higher for males (Figure 4). The interaction Sex*Group is significant (ANOVA *p*-value <0.01), which is not the case for geographically more stable variables (ANOVA *p*-value >0.05). The SPU variable, as shown in Figure 4, also exhibits a population effect (ANOVA *p*-value = 0.02), with higher values for females in IndetF.

The “zone of uncertainty” (overlap area of female and male values) that prevents a reliable sex estimation (Galeta and Brůžek 2020) corresponds to the space between the two boxplots in the “Balanced” group. In the “IndetF” group, because SPU values are higher and IIMT values are lower, more females are pushed into this zone, leading to an increase in the proportion of female indeterminate individuals. Conversely, in the “IndetM” group, more males are pushed into this zone due to generally higher IIMT values and lower SPU values.

3.4 | Effect of Available Variables

We also examined the proportions of females and males classified as indeterminate based on the available variables. This approach simulates the effect of preservation while testing the impact of removing variables identified as having different dimorphic potentials across populations. The importance of the estimation discrepancies between sexes, and, more marginally, the direction of the imbalances, depends on the variables used (Table 4). Thus, it is impossible to predict the imbalance in indeterminate individuals across archaeological populations because (1) the measurable variables depend on preservation factors that are difficult to predict and (2) each combination of variables will have its own effect on the proportions of males and females remaining indeterminate.

TABLE 3 | Comparison of the proportions of female and male classified as indeterminate within the reference populations of the DSP based on the application of linear discriminant analysis or random forest analysis.

	Linear discriminant analysis			Random forest model			Sample composition		
	%IndetF	%IndetM	%IndetTotal	%IndetF	%IndetM	%IndetTotal	NF	NM	NTotal
Chang-Mai	2.08	7.84	5.05	2.08	8.82	5.56	96	102	198
Cleveland-AA	17.54	5.36	11.5	21.05	7.14	14.16	57	56	113
Cleveland-EA	8.93	7.14	8.04	3.57	3.57	3.57	56	56	112
Coimbra	3.85	20.59	11.21	3.08	18.63	9.91	130	102	232
Johannesburg-A	5.36	5.36	5.36	5.36	5.36	5.36	56	56	112
Johannesburg-S	15.52	15.38	15.45	5.17	11.54	8.18	58	52	110
Johannesburg-Z	13.73	9.8	11.76	13.07	14.38	13.73	153	153	306
London	6.45	19.35	12.9	12.9	16.13	14.52	31	31	62
Paris	1.61	19.39	12.5	6.45	11.22	9.38	62	98	160
Vilnius	5.36	3.7	4.55	12.5	1.85	7.27	112	108	220
Washington-AA	11.82	4.72	8.33	12.73	2.83	7.87	110	106	216
Washington-EA	16.67	6.19	11.56	16.67	8.25	12.56	102	97	199

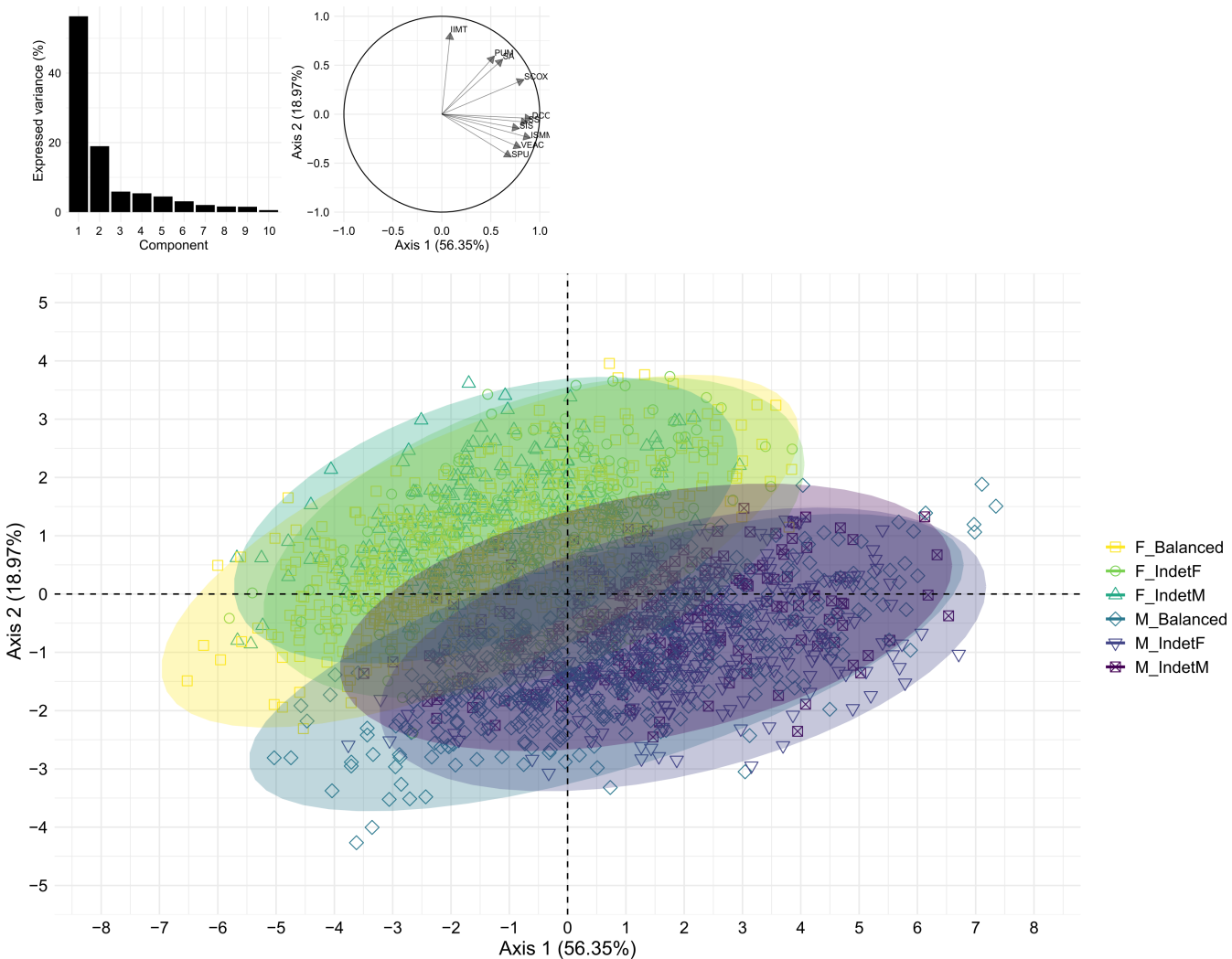


FIGURE 3 | PCA on the values of DSP measurements in populations used as references for the method, with distinction of groups based on whether the proportions of female or male classified as indeterminate are imbalanced. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/oa.70143)]

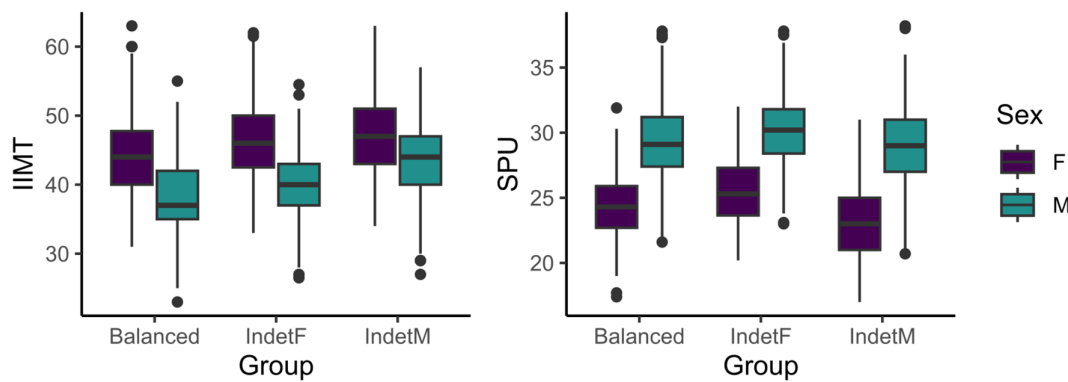


FIGURE 4 | Boxplots representing the dispersion of IIMT and SPU values by sex across populations with higher proportions of indeterminate female, higher proportions of indeterminate male, and balanced proportions of female and male classified as indeterminate. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/oa.70143)]

4 | Discussion

DSP is a reliable method for estimating sex from the metric characteristics of the coxal bone. Applied to a series, it is often used to conduct paleodemographic analyses. However, there is a tendency for the DSP to be left as indeterminate a greater proportion of males over females. This bias leads to overestimations of the proportion of females and possible misinterpretation of population data.

Within the dataset used as the reference for DSP, there are morphological differences between populations, which may help explain this bias. The IIMT measure is less dimorphic in populations with more indeterminate males, and the SPU measure is less dimorphic in populations with more indeterminate females. Thus, the discriminative potential of coxal measurements is not equivalent between populations. Interpopulation differences are never sufficient to surpass sex differences, but they may push more individuals of a given sex into the uncertainty zone. This results in an a priori inequality in estimating the sex of individuals, predominantly affecting males, and causing an artificial increase in the proportion of females in population studies.

Some authors have reported higher inter- and intra-observer error for the measurements IIMT and SPU and consider excluding them from sex estimation using the DSP method (e.g., Braun et al. 2023; Lesciotto and Kiales 2024). However, the information contained in those dimensions are strong enough to warrant their use (Kuchař et al. 2024).

Our study also shows that the interpretation may change dependent on the decision-making method (raw interpretation and statistical testing). The sex ratio is very sensitive to sample size, and for small populations, changing the sex of a single individual can be enough to alter the population-level interpretation. Therefore, we recommend always using a statistical approach to compare against an equilibrium situation to aid decision-making in paleodemographic analysis.

Our analysis is based solely on the results of applying DSP using the threshold value of 0.95 for posterior probability. When multiple methods are used to estimate biological sex and their results do not agree, the outcomes of all applied methods should be

presented; however, the final estimate is based on the observer's personal experience and overall impression of the remains, or preference is given to methods utilizing pelvic traits or measurements (Lesciotto and Kiales 2024). A subjective approach still prevails over the exact interpretation of posterior probability.

4.1 | Limitations of the Study

Population-based variations in sexual dimorphism related to genetics and environmental parameters such as development, diet, and physical activity (Sorrentino et al. 2025) should be considered in order to explain the observed phenomena. Bone preservation also plays an important role, especially because the coxal bone is highly sensitive to diagenetic degradation (Mays 1992; Waldron 1987). The imbalances in the indeterminates thus depend on both the dimorphism of the population and the variables used for classification. Hence, it is impossible to predict these inequalities in advance and to directly apply a correction within the method. Whereas in the current state of our studies we cannot develop a correction in the statistical processing of the DSP, we propose two solutions for presenting population results: The extension of the principle of conformity developed for the study of mortality (Sellier 1996) and the creation of intervals encompassing the actual sex ratio. Because these propositions for mitigating the biases intrinsic to statistical classifications are only theoretical, we present and elaborate on them in the [Supporting Information](#).

Due to the meta-analysis approach, which is subject to uneven documentation of the datasets, we were unable to test the effect of bone representation and therefore of feasible measurements of sex ratio imbalances in indeterminate individuals. It is therefore possible that the observed effects are accentuated or attenuated by preservation without being possible for us to identify it.

The proportions of females and males remaining indeterminate seem to show geographical and chronological trends: There is an overestimation of the proportion of females in the majority of prehistoric and contemporary populations. For Medieval and Modern populations, the situation is more balanced. The lack of exhaustive data within the meta-analysis prevents us from determining whether this phenomenon is related to population

TABLE 4 | Comparison of the proportions of female and male classified as indeterminate within the reference populations of the DSP based on the variables used. The discriminant potentials, which are used to define the best and worst variables, correspond to the order of the variables as presented above.

	All possible variables										10 variables										8 best variables									
	%IndetF					%IndetM					NF					%IndetF					%IndetM					%IndetF				
	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot
Chang-Mai	2.08	7.84	5.05	96	102	198	2.33	8	5.38	86	100	186	2.33	8	5.38	86	100	186	2.33	8	5.38	86	100	186	2.33	8	5.38	86	100	186
Cleveland-AA	17.54	5.36	11.5	57	56	113	14	5.77	9.8	50	52	102	14	5.77	9.8	50	52	102	14	5.77	9.8	50	52	102	14	5.77	9.8	50	52	102
Cleveland-EA	8.93	7.14	8.04	56	56	112	8.33	4.35	6.38	48	46	94	8.16	4.35	6.32	49	46	95	8.16	4.35	6.32	49	46	95	8.16	4.35	6.32	49	46	95
Coimbra	3.85	20.59	11.21	130	102	232	3.7	18.82	10.36	108	85	193	3.67	18.82	10.31	109	85	194	3.67	18.82	10.31	109	85	194	3.67	18.82	10.31	109	85	194
Johannesburg-A	5.36	5.36	5.36	56	56	112	6.82	6	6.38	44	50	94	6	6	6	50	50	100	6	6	6	50	50	100	6	6	6	50	50	100
Johannesburg-S	15.52	15.38	15.45	58	52	110	14.55	14.58	14.56	55	48	103	14.55	14.58	14.56	55	48	103	14.55	14.58	14.56	55	48	103	14.55	14.58	14.56	55	48	103
Johannesburg-Z	13.73	9.8	11.76	153	153	306	13.01	10.14	11.56	146	148	294	12.33	10.14	11.22	146	148	294	12.33	10.14	11.22	146	148	294	12.33	10.14	11.22	146	148	294
London	6.45	19.35	12.9	31	31	62	7.14	20.83	13.46	28	24	52	7.14	20.83	13.46	28	24	52	7.14	20.83	13.46	28	24	52	7.14	20.83	13.46	28	24	52
Paris	1.61	19.39	12.5	62	98	160	1.82	15.48	10.07	55	84	139	1.79	15.29	9.93	56	85	141	1.79	15.29	9.93	56	85	141	1.79	15.29	9.93	56	85	141
Vilnius	5.36	3.7	4.55	112	108	220	5.41	3.77	4.61	111	106	217	5.36	3.77	4.59	112	106	218	5.36	3.77	4.59	112	106	218	5.36	3.77	4.59	112	106	218
Washington-AA	11.82	4.72	8.33	110	106	216	11.21	5.1	8.29	107	98	205	12.04	4.95	8.61	108	101	209	12.04	4.95	8.61	108	101	209	12.04	4.95	8.61	108	101	209
Washington-EA	16.67	6.19	11.56	102	97	199	17.58	6.25	11.76	91	96	187	15.79	6.25	10.99	95	96	191	15.79	6.25	10.99	95	96	191	15.79	6.25	10.99	95	96	191

	4 best variables										4 worst variables										4 worst variables									
	%IndetF					%IndetM					NF					%IndetF					%IndetM					%IndetF				
	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot	%IndetF	%IndetM	%IndetTot	NF	NM	NTot
Chang-Mai	6.74	10.78	8.9	89	102	191	34.04	89	62.37	94	100	194	34.04	89	62.37	94	100	194	34.04	89	62.37	94	100	194	34.04	89	62.37	94	100	194
Cleveland-AA	21.15	5.36	12.96	52	56	108	66.67	52.73	59.82	57	55	112	66.67	52.73	59.82	57	55	112	66.67	52.73	59.82	57	55	112	66.67	52.73	59.82	57	55	112
Cleveland-EA	13.21	5.77	9.52	53	52	105	50	64.81	57.55	52	54	106	50	64.81	57.55	52	54	106	50	64.81	57.55	52	54	106	50	64.81	57.55	52	54	106
Coimbra	7.63	21.11	13.46	118	90	208	37.5	77.45	55.22	128	102	230	37.5	77.45	55.22	128	102	230	37.5	77.45	55.22	128	102	230	37.5	77.45	55.22	128	102	230
Johannesburg-A	7.55	12.96	10.28	53	54	107	65.31	52.73	58.65	49	55	104	65.31	52.73	58.65	49	55	104	65.31	52.73	58.65	49	55	104	65.31	52.73	58.65	49	55	104
Johannesburg-S	21.05	17.31	19.27	57	52	109	43.1	72.92	56.6	58	48	106	43.1	72.92	56.6	58	48	106	43.1	72.92	56.6	58	48	106	43.1	72.92	56.6	58	48	106
Johannesburg-Z	14.29	16.67	15.49	147	150	297	62.5	71.9	67.21	152	153	305	62.5	71.9	67.21	152	153	305	62.5	71.9	67.21	152	153	305	62.5	71.9	67.21	152	153	305
London	3.45	35.71	19.3	29	28	57	70.97	66.67	68.85	31	30	61	70.97	66.67	68.85	31	30	61	70.97	66.67	68.85	31	30	61	70.97	66.67	68.85	31	30	61
Paris	8.77	21.74	16.78	57	92	149	67.21	47.42	55.06	61	97	158	67.21	47.42	55.06	61	97	158	67.21	47.42	55.06	61	97	158	67.21	47.42	55.06	61	97	158
Vilnius	8.04	6.48	7.27	112	108	220	76.58	42.99	60.09	111	107	218	76.58	42.99	60.09	111	107	218	76.58	42.99	60.09	111	107	218	76.58	42.99	60.09	111	107	218
Washington-AA	16.67	4.85	10.9	108	103	211	63.3	46.08	54.98	109	102	211	63.3	46.08	54.98	109	102	211	63.3	46.08	54.98	109	102	211	63.3	46.08	54.98	109	102	211
Washington-EA	19.59	12.37	15.98	97	97	194	65.98	36.46	51.3	97	96	193	65.98	36.46	51.3	97	96	193	65.98	36.46	51.3	97	96	193	65.98	36.46	51.3	97	96	193

biology or bone conservation. We encourage further studies that test variations in pelvic sexual dimorphism expression across geographical and chronological scales.

Indeed, in the populations used as a reference for DSP, a geographical effect also appears to be present. Populations having more male-indeterminate individuals are exclusively European, whereas those with more female-indeterminate individuals are all North American. This finding is echoed in the meta-analysis: The only contemporary population with a higher proportion of females in the indeterminate category is from the United States, whereas contemporary populations with more male indeterminates are from the rest of the American continent and Europe. The small samples of populations per period, the unknown effect of bone preservation, and our geographical coverage call to caution when drawing inferences about temporal and geographical variations in sexual dimorphism.

Lastly, we were unable to test intra-individual variability, particularly the possible effect of asymmetries and their consequences on estimates of individuals' sex.

5 | Conclusion

DSP is a reliable method for estimating the sex of an individual. However, there is no a priori equality in estimating whether an individual is male or female. This phenomenon leads, in the vast majority of cases, to an increase in the proportion of females in population studies.

Although this effect is recurrent in archaeological samples, it is not constant, which makes it impossible to develop a corrective factor within the method itself due to the unpredictable effect of bone preservation. We therefore recommend using complementary methods whenever possible, such as secondary sexual diagnosis (Santos 2021), morphoscopic methods (Brůžek 2002), DNA analysis (Skoglund et al. 2012), or proteomics (Parker et al. 2019), to minimize the number of indeterminate individuals. We also propose applying corrections like the principle of conformity or the calculation of intervals. The use of statistical tests to create comparisons with theoretical equilibrium samples can also reduce the risk of misinterpretation, especially when studying small sample sizes.

Our results suggest but do not conclusively identify geographical or chronological constants indicating population-based variations in expressions of pelvic sexual dimorphism. We encourage further studies on these points to refine these characterizations, allowing for a better understanding of the effects of genetic, life-course, and environmental variables on the expression of sexual dimorphism and their implications for methods of estimating an individual's sex.

Finally, the a priori inequality likely exists in other biological identification methods. We encourage further exploration of its effects when applying them to population-based reasoning. For multivariate methods, we recommend specifying the individual weight of the variables to identify possible over- or under-performances of the method depending on skeletal representation. If reference samples are of geographically and

chronologically diverse origins, discussing the interaction of these parameters with the measurements and population imbalances within the reference datasets is crucial to avoid misinterpretation of general variability.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** A first case of DSP2 results on a given population sample. **Table S2:** A second case of DSP2 results on a given population sample.