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The effect of living conditions on the stature of men and women: the case of south-eastern France (18th, 19th and 20th centuries)

Les effets des conditions sanitaires sur la stature des femmes et des hommes : le cas du sud-est français (XVIIIe, XIXe et XXe siècles)

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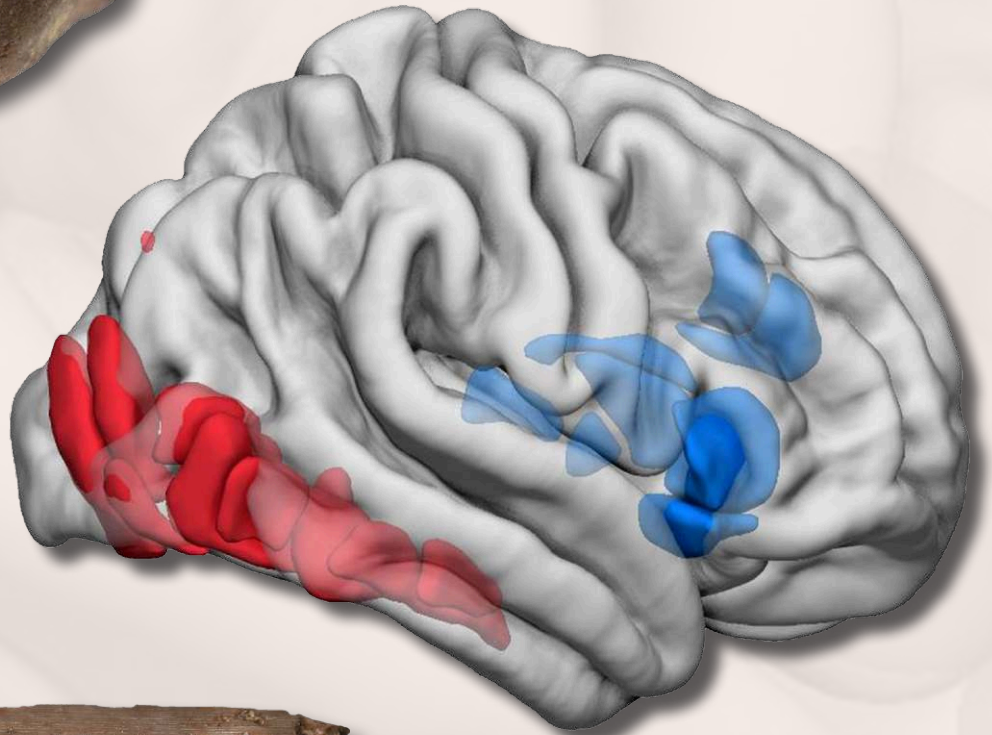
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Les effets des conditions sanitaires sur la stature des femmes et des hommes : le cas du sud-est français (XVIII^e, XIX^e et XX^e siècles)

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Abstract – In this paper we analyse the impact of different living conditions on the length of the femur, as a proxy for stature, of three Mediterranean samples with known historical contexts, and assess sex differentials in femur length changes. The first collection analysed is composed of 18th century plague victims who had suffered several previous starvation episodes. The second collection, from the 19th century, lived through comparatively better times. The third is from the 20th century, when living conditions were better than during the two previous centuries. We compared the femur lengths of females and males between the three collections using Mann-Whitney-Wilcoxon statistical tests. The median value of male femur lengths increased over time, as expected. However, the median values of the female sample decreased in the 19th century, while the differences between the 18th and the 20th centuries samples were not statistically significant. The samples from the 18th and 20th centuries are reliable sources, but for the 19th century collection, we have assumed a possible bias in the socio-economic representativeness of the female sample. While different trends in sexual dimorphism in stature have been observed in other studies, the non-significant difference between female femur length from the 18th and the 20th centuries is unexpected, given improvements in living conditions.

Keywords – bioarchaeology, stature, living conditions, gender inequalities, secular trends

Résumé – Dans cet article, nous analysons l'impact de différentes conditions de vie sur la longueur du fémur, considéré comme proxy de la stature, dans trois échantillons méditerranéens avec des contextes historiques connus, et nous évaluons si les longueurs fémorales des femmes et

des hommes suivaient les mêmes schémas. La première collection analysée est composée de victimes de la peste du XVIII^e siècle, qui ont subi plusieurs épisodes de famine avant la peste. La deuxième collection, du XIX^e siècle, a connu des temps meilleurs que la précédente. Enfin, la troisième collection date du XX^e siècle, quand les conditions de vie étaient meilleures qu'au cours des deux siècles précédents. Nous avons analysé les femmes et les hommes séparément, en comparant des mesures de chaque collection à l'aide d'un test de Mann-Whitney-Wilcoxon. La valeur médiane de la longueur du fémur masculin a augmenté au cours de ces siècles, comme attendu. Cependant, les valeurs médianes de l'échantillon féminin sont plus faibles au XIX^e siècle alors que les différences entre les échantillons des XVIII^e et XX^e siècles ne sont pas statistiquement significatives. Nous supposons que la collection du XIX^e siècle souffre d'un biais de représentativité pour la stature féminine. Au contraire, les échantillons des XVIII^e et XX^e siècles sont des sources fiables. Différentes tendances du dimorphisme sexuel de la stature ont été observées dans d'autres travaux, mais la différence non significative entre la longueur du fémur féminin au XVIII^e et au XX^e siècle n'est pas attendue, en raison de l'amélioration des conditions de vie.

Mots clés – bioarchéologie, stature, conditions sanitaires, inégalités de genre, tendance séculaire

Introduction

Anthropometry is an economic and demographic index of living conditions (Heyberger, 2015). It compares and identifies variations in stature with a view to detecting possible differences in access to basic survival resources

between groups or periods of time. Anthropometry can also be used to assess the impact of historical events, such as famine, war or colonisation, which affect access to assets and potentially exacerbate social differences.

Stature is partly determined by genetics but is also influenced by an individual's socio-economic environment and occupation and by climatic changes, among other factors (Subramanian et al., 2011; Tucker-Seeley and Subramanian, 2011; Koepke, 2016). It stands as an alternative to classic economic indices, such as *gross domestic product* (GDP) or salaries, as it can be used to assess how resources are distributed within a society (Heyberger, 2015). Stature analysis is applied to living or past populations using a range of data sources (measured stature, historical data or osteological analysis) and for different purposes. Among living populations, stature analysis can be applied on an individual or group level, with the aim of identifying individuals or groups who lack access to resources (WHO Expert Committee on Physical Status, 1995; Eiben et al., 2005; Araújo et al., 2016).

In the case of past populations, these studies can span long periods of time, while others can analyse differences in living conditions among the population within a single period. Vercellotti and co-authors (2011) evaluated stature and body shape differences between individuals from higher and lower social classes from an Italian mediaeval community (n=52). In this population, men from the two social classes presented more variability, while females had a more uniform stature. Koepke (2016) investigated changes in stature in Europe from the 8th century BC to the 18th century AD (n=18,000). She divided the continent into three main regions, central-western, north-eastern and Mediterranean, and evaluated how changes in stature were influenced by factors including climate change, dairy and meat consumption, urbanisation and population density, epidemics, wars, legislation and gender inequalities. She observed that stature in Europe increased over the centuries, with some periods of decrease. Dairy consumption was shown by the author to be associated with an increase in stature, while higher urbanisation rates were associated with a decrease in stature, especially in pre-modern times. Heyberger (2007) analysed changes in stature among 237,782 French conscripts born between 1780 and 1920 in four regions. The results for each region varied according to their political and economic situation during that period. For example, men from the least agriculturally productive area, Limousin, were smaller than in other regions; statures in the Brie region were more affected by the agricultural crisis of the 19th century and average stature increased in all regions in the early 20th century.

Heyberger (2015) presents many anthropometric studies of populations from the 19th and early 20th centuries where female stature appears to have been more sensitive to changes in living conditions than male stature. The author argues that these differences may be related to unequal access to nutrients or to a greater biological adaptivity of female individuals to crises. According to Heyberger (2015),

the lack of data on female statures in historical documents (many documents present conscript statures only), and the dearth of studies with compatible methodologies hinder a deeper understanding of these differences. When studying past populations, anthropological data are a very rich source of information. In the absence of written sources or lack of access to them, the skeleton may be the only remaining witness to a period of time, and the only available source of information on living conditions and resource sharing. Archaeo-anthropological studies are vital to gathering more information about female health conditions in the past and are sometimes the only source of information, since these conditions are under-represented in historical data (Batista-Goulart, 2021).

Some studies on 20th century populations have also observed that female statures did not increase similarly to male statures in the same population in times of improvement in living conditions. Conceição et al. (2012) compared the statures of females and males born from 1966 to 1980 in Portugal. While the stature of both sexes increased over time, male statures increased more. The authors did not mention whether the changes were statistically significant. Kuh et al. (1991) compared the statures of females and males born from 1900 until 1960 in the UK, observing that men born in 1958 were 7.12 cm taller than men born at the beginning of the century, while females born in 1958 were 3.08 cm taller than those born in 1900.

Koepke et al. (2018) compared trends in female and male stature in Switzerland from the 1770s to the 1930s, based on data gathered from historical records (passports, hospital and maternity registers and convicts). Female stature significantly increased earlier (1840-1860 birth cohorts) than male stature (1870-1890 birth cohorts), the latter having stagnated during most of the 19th century and increased at the end of the century. The authors consider that improvements related to industrialisation, such as increases in wages and GDP per capita and advances in child labour regulations, hygiene, nutritional education, social welfare and housing were contemporaneous with male stature increase. Yet female stature increased before these transformations, at the beginning of the industrialisation process, in the 1850s, when there were more options of paid work for women and when milk production and food security were on the increase. The authors consider that improvements in women's living conditions (which began earlier) contributed to the improvements in the health status of the next generation, both directly (during foetal development and infancy) and indirectly, "via the body conditions and health of future mothers" (Koepke et al., 2018:83).

Other studies have compared changes in sexual stature difference (SSD) and the potential correlation with different living conditions, cultural practices and access to resources. Gray and Wolfe (1980) analysed SSD in 216 societies to assess the possible influences of marriage practices, protein availability, the presence of milking herds, settlement size and climate. They conclude that both genetic and dietary factors have an influence on the degree of dimorphism.

Drawing on an ethnographic database, Holden and Mace (1999) evaluated a possible influence on SSD of the sexual division of labour, type of subsistence, polygyny (men having more than one wife) and nutrition. They observed that SSD was lower in societies where women contributed more to food production. Bocquet-Appel et al. (2008) evaluated sexual dimorphism in femur length, as a proxy for stature, together with other markers, to assess the impact of the agricultural transition on population health, based on data gathered at 22 archaeological sites in North America. They observed a decrease in SSD in times of resource scarcity.

Cámara (2015) analysed the impact of inter-generational and socio-economic status (SES) on SSD in 20th century Spain, using data gathered during health interviews (declared stature), with individuals born between 1910 and 1979. He observed that among upper-middle SES individuals SSD was lower among individuals having grown up during the Spanish Civil War (1936-1939). For the lower SES group, the lowest SSD occurred during the first decade of Franco's dictatorship, when the country suffered a famine caused by Franco's economic policy (Blanco, 2021). The author reported that male and female stature increased over time, but generally, male stature increased more than female stature (not mentioning whether this difference was significant). SSD differed between lower and upper-middle SES groups, being larger in the upper-middle classes.

Brennan and DeWitte (2022) evaluated SSD differences between three mediaeval samples having experienced different living conditions before and after Black Death (London, 1000-1200, 1200-1250 and 1350-1540.) They considered tibial, femoral, and lower-limb lengths as a proxy for stature, and analysed trends in SSD. They observed that while femur values changed significantly for both men and women between these periods, tibial lengths changed significantly solely in the male sample. SSD was higher in the later period, post-Black Death, when living conditions were better than in the earlier periods.

Considering the lack of studies on differential changes in female and male stature over time, our aim in this paper is (1) to assess the impact of different living conditions on femur length as a proxy for stature in three different historical periods and (2) to verify whether female and male samples follow the same patterns. To that end, we compared femur measurements for three samples from the French Mediterranean region of Provence through three centuries. The first sample, the *Capucins de Ferrières* osteoarchaeological collection (1720-1721) exhumed from the city of Martigues (figure 1), is made up of victims of the last severe plague epidemic to have occurred in France, the "Great Plague of Marseille" (1720-1722) (Tzortzis and Signoli, 2009). The second collection was exhumed from the *Îlot - Terminus* archaeological site, and comprises individuals who lived in the city of Antibes in the 19th century (Buchet and Séguy, 2003; Buchet et al., 2003; Séguy and Buchet, 2013). The third collection, the *Nice Bone Collection*, was put together during the 20th century in the city of Nice and is made up of skeletons of people who donated their bodies

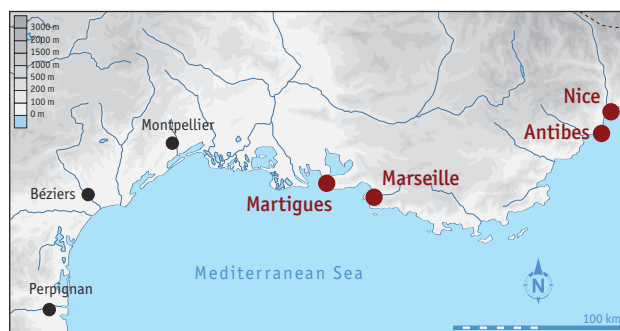


Figure 1. Location of Martigues, Marseille, Antibes and Nice / Localisation de Martigues, Marseille, Antibes et Nice

to science (Alunni et al., 2015; Quatrehomme et al., 2017). According to the historical documents available for these periods, living conditions improved throughout the 18th to 20th centuries in France.

Material and Methods

Samples

Martigues: Capucins de Ferrières

Surveys made during building works in Martigues identified skeletal remains near the *Capucins* monastery, the site of a temporary infirmary during the plague epidemic of 1720-1721. Following this discovery, an archaeological excavation was conducted by one of the authors. The skeletons were buried in five primary collective parallel trenches, of unequal size and with different body dispositions (Tzortzis and Signoli, 2009). This funerary ritual is not usual for this location and historical period and corroborates the hypothesis of a catastrophe context. The connection between this archaeological site and the plague epidemic was identified through abundant historical documents, the geographical location near a temporary infirmary, the unusual funerary arrangements, the estimated dating of grave goods (coins in particular) and by the presence of DNA of the plague bacillus, *Yersinia pestis*, in the dental pulp of some tested skeletons.

The *Capucins de Ferrières* osteoarchaeological collection, referred to here as the Martigues collection, is made up of 208 individuals, 86 non-adults (foetuses, infants, children and adolescents) and 122 adults. Among the 122 adult skeletons, 87 individuals were considered in this study: 31 females, 16 probable females, 24 males and 16 probable males. Females and probable females were grouped together, since they have similar femur length patterns, as were males and probable males (as detailed in the *Results* section). The sample was thus divided into two groups: 47 females and 40 males.

Research (Signoli et al., 2005; Séguy et al., 2007) on the plague epidemic in Martigues (1720-1721) has found that the age and sex structure of the plague victims were similar to those of the living population. The authors

therefore concluded that the plague victims are representative of the living population. The collection analysed is a subsample of plague victims from Martigues. In previous work (Batista-Goulart, 2021; Batista-Goulart et al., 2022), we also identified that the skeletons from this osteoarchaeological collection are representative of the plague victims from Martigues. We compared the age-class distribution of the Martigues plague victims, obtained via historical records, with the probable age-class distribution of the skeletons (adults only). To do so, we applied a Bayesian model (Séguy and Buchet, 2013), which considers the probability of each skeleton belonging to each age group. This model showed that the age-class distribution of the skeletons was the same as that of the plague victims from Martigues. Another advantage of this collection is that we are sure that these individuals lived under the same social rules

and faced the same environmental problems, since they all died over a short period of nine months. According to the list of plague victims made by the authorities during the epidemics, a few immigrants died from the plague in Martigues, corresponding to about 1% of the victims, but 72% of them came from nearby cities (less than 250 km from Martigues), as shown in figure 2.

Antibes: Ilôt-Terminus

The city of Antibes, 200 km east of Martigues, is also located on the French Mediterranean coast. We analysed an osteological collection from the city's modern cemetery, dating from the end of the 19th century, a period when living conditions in the south of France were better than in previous centuries.

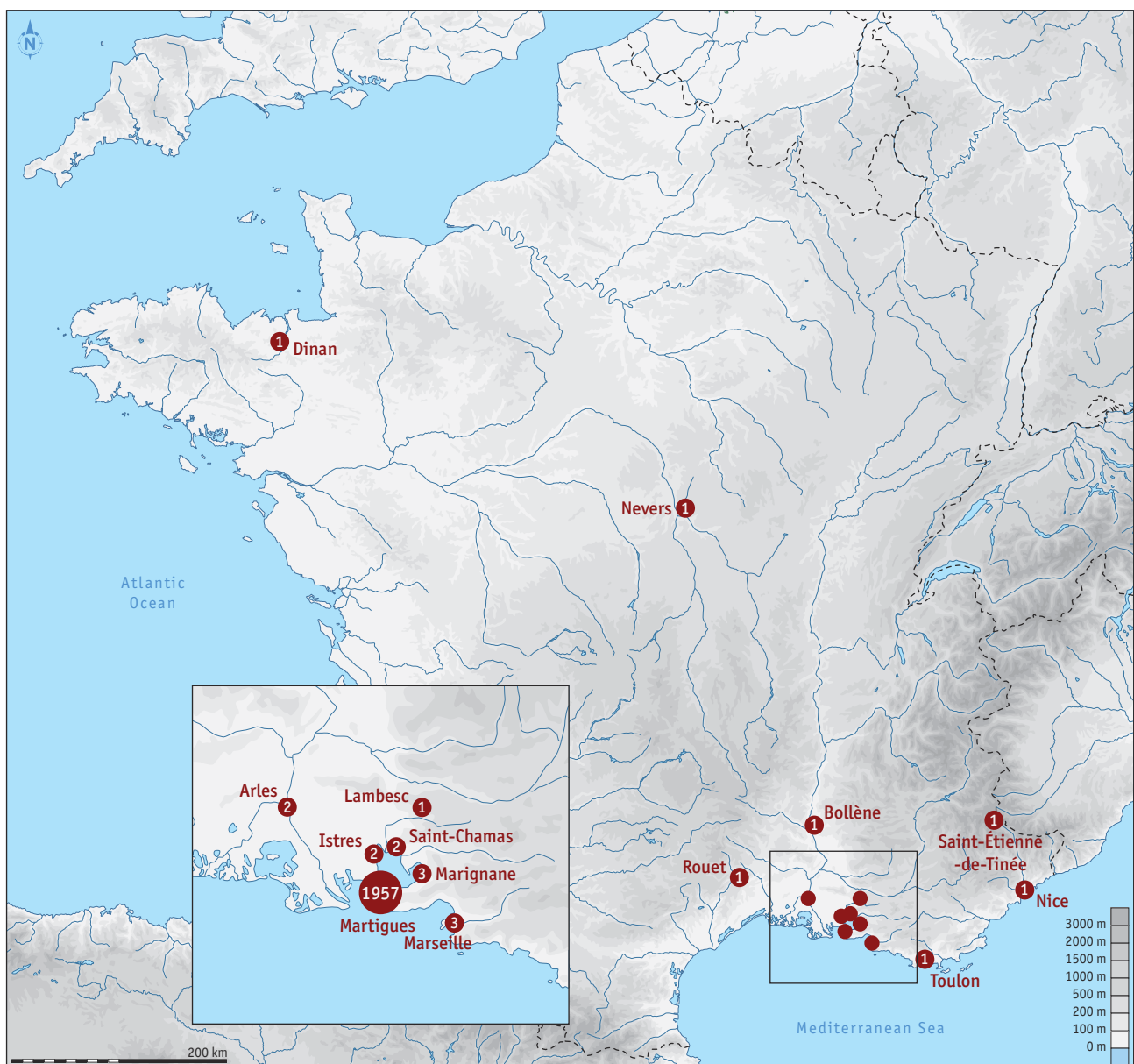


Figure 2. Original locations of plague victims other than Martigues / *Origine géographique des victimes de la peste de Martigues*

At the end of 19th century, the city had to transfer its public cemetery to a new location, to which families were asked to move the remains of their relatives. These transfers were made from 1897 to 1902. However, some remains dating from the later occupation of the cemetery (1877 to 1897) were never reclaimed by the families, and consequently not transferred. These remains remained in the primary location until 1998, when a rescue excavation was conducted prior to the construction a building on the old cemetery site (Buchet and Séguy, 1999).

The *Îlot-Terminus* osteoarchaeological collection, referred to here as the Antibes collection, is made up of these unclaimed bones and comprises 182 individuals, including 17 non-adults and 165 adults (Buchet and Séguy, 1999). After applying exclusion criteria (described in the *Methods* section), our sample comprised 26 skeletons: 5 females, 3 probable females, 14 males and 4 probable males. As with the Martigues collection, females were grouped together with probable females, and likewise males with probable males, making up a final sample of 8 females and 18 males.

This collection has three advantages. First, Antibes is in the same geographical area as Martigues and Nice. Secondly, it is chronologically intermediate between the two other samples, from 18th and 20th centuries. Thirdly, fewer crises occurred in the 19th than in the 18th century, and the period saw the start of several transformations in living conditions, as detailed in the *Discussion*. We wanted to investigate whether those transformations affected the stature of the individuals observed. Lastly, the cemetery is well-dated and had a short occupation sequence, making it possible to determine the historical period in which these individuals lived. However, the population of Antibes in the 19th century has some particular demographic features, including a substantial group of Italian workers (more women than men) employed in domestic service, agriculture and construction, and the presence of conscripts accounting for 10% to 20% of men aged 20 to 22 years (Buchet et al., 2003). We nevertheless decided to keep this sample in the study, despite its small size.

The Nice Bone Collection

This osteological collection, which is curated at the *Institut Universitaire d'Anthropologie Médico-Légale* in Nice, is made up of bones of adults who voluntarily donated their bodies to science. These individuals were born after 1920 and died between 1998 and 2008, most of them from 1999 to 2000. The collection is composed of full skeletons, skulls, coxae and long bones (Quatrehomme et al., 2017). We have access to their years of death and sex, but other information, such as birth location, cause of death, pathologies and socio-economic status, is not available for privacy reasons. For this study we analysed the femora of 64 individuals, 31 females and 33 males.

We added this collection to our study because of the geographical location of Nice, 215 km east of Martigues and

also on the Mediterranean coast, thus ensuring population homogeneity between the three samples. This collection is also relevant in view of the improvement in living conditions from the 18th to the 20th century. Living conditions were much better during the lifetime of these individuals in comparison with previous centuries, despite their having lived through World War II, in some cases during their developmental years. For this reason, we expected their stature, assessed via femur lengths, to be longer in comparison with the other two collections.

Methods

To evaluate the impact of living conditions on stature, the growth of the individuals must be fully complete, so that the result of the entire growing process may be observed. This is why our sample is composed entirely of adults, with fused femurs and coxae bones. Some skeletons were not considered in the analysis due to poor preservation, pathological conditions, traumas, the impossibility of estimating their sex (Martigues and Antibes collection) and the presence of prosthetic femurs (Nice collection).

In our analysis we considered anatomical femur length (Quatrehomme, 2015) rather than reconstructed stature, to avoid the errors resulting from mathematical methods for stature estimation (Pearson, 1899; Trotter and Gleser, 1958; Olivier et al., 1978; Ruff et al., 2012) and a possible inherent bias when methods built on 20th century reference populations are applied to pre-industrial populations (Formicola, 1993; Vercellotti et al., 2009, 2011; Ruff et al., 2012). As the use of an anatomical method (Fully, 1956; Raxter et al., 2006) to reconstruct stature would have eliminated numerous subjects due to poor skeletal preservation, we aimed to strike a balance between minimizing estimation errors and maximizing the sample size. In similar approaches, DeWitte and Slavin (2013) evaluated the impact of the Great Famine on a pre-Black Death sample through femur and tibia length variations; Vercellotti and co-authors (2011) considered skeletal height (defined as the total length of the bones constituting stature, without taking into account the soft tissue as proposed by the anatomical methods) rather than estimated stature; while Bocquet-Appel and collaborators (2008) also used femur length.

We chose the femur because it is the bone that best represents human stature (Quatrehomme, 2015). Moreover, analysing femur length avoids the impact of aging on stature. Our height is subject to changes (decrease) related to the aging process, yet these changes are mainly related to the degeneration of vertebrae and soft tissues. Decreases in femur length are not directly related to aging since they only occur in the event of fractures, but individuals with fractures were excluded from our sample. Analysing the femur is suitable for our study, since the effect of aging on stature is not a topic of interest in this analysis. We aim to compare growth peaks, which are well represented by femur lengths, and shed light on the influences of living conditions.

The femur measurements and sex estimations for the three collections¹ were carried out by the first author. To estimate sex, we followed the method proposed by Buikstra and Ubelaker (1994), using the coxal bone and the skull. We considered the mean anatomical length of right and left femora (measured with an osteological table). When one of them was not available, we considered just one measurement.

To evaluate whether variation in femoral length is significant between the collections observed, we applied a one-tailed Wilcoxon-Mann-Whitney test² (Wilcoxon, 1945; Mann and Whitney, 1947), a non-parametric test that assesses differences in medians. This test is more appropriate for our (small) sample size and its characteristics than the Student's *t*-test. Since the collections have different sex ratios, mixing males and females could have led to biased results. We therefore analysed them separately so that sex differences could be assessed by secular trends in femur lengths.

To validate the analysis of females and probable females and of males and probable males from the Martigues collection as two sex categories, we applied the Kruskal-Wallis rank sum test (Kruskall and Wallis, 1952), an extension of the Wilcoxon-Mann-Whitney test allowing the comparisons of more than two samples. The pairwise Wilcoxon-Mann-Whitney test was applied as a post-hoc analysis to identify which groups differed from each other. The same test could not be applied to the Antibes collection because there would be not enough observations in each category to perform a null-hypothesis test, as in the Kruskal-Wallis test. We would face the same problem when comparing collections. In addition, as the Nice collection was already divided into two sex categories, since the sex of the individuals was known, it was preferable for the purpose of comparison for all the collections to be divided into two sexes. We present a boxplot (see *Results* section) that shows the similarity between females and probable females and between males and probable males from the Antibes collection. When comparing the stature dispersion shown in the boxplot, grouping the sample into two sexes does not appear to be problematic.

Results

Descriptive statistics

Table 1 summarises the descriptive statistical results of our study, grouping the collections. For details, see the corresponding sections.

Martigues

As shown in tables 1 and 2, the median femur length of females is 41.10 cm, while for males it is 43.98 cm. Considering females and probable females and males

and probable males separately, the results are 41.10 cm, 41.25 cm, 44.35 cm and 43.73 cm respectively. The boxplot in figure 3 illustrates these data.

To increase the sample size and consider all females and all males in just two categories, we assessed whether the femur length variations between our four sexual categories differed significantly, using the Kruskal-Wallis test (*p*-value

Collection	Sex	n	Statistic	Value (cm)
Martigues	Females (all)	47	Minimum	36.90
			Median	41.10
			Maximum	45.45
			Standard deviation	1.99
	Males (all)	40	Minimum	37.60
			Median	43.98
			Maximum	50.10
			Standard deviation	2.22
Antibes	Females (all)	8	Minimum	36.70
			Median	39.95
			Maximum	41.20
			Standard deviation	1.54
	Males (all)	18	Minimum	41.40
			Median	44.95
			Maximum	49.30
			Standard deviation	2.40
Nice	Females (all)	31	Minimum	37.40
			Median	42.20
			Maximum	47.20
			Standard deviation	2.37
	Males (all)	33	Minimum	41.30
			Median	45.70
			Maximum	48.50
			Standard deviation	2.15

Table 1. Summary of femur length comparisons: measures of concentration and dispersion for each collection analysed / *Résumé de la comparaison de taille fémorale : mesures de concentration et de dispersion de chaque collection analysée*

Sex	n	Statistic	Value (cm)
Females (all)	47	Minimum	36.90
		Median	41.10
		Maximum	45.45
		Standard deviation	1.99
Males (all)	40	Minimum	37.60
		Median	43.98
		Maximum	50.10
		Standard deviation	2.22
Females (without probable females)	31	Minimum	36.90
		Median	41.10
		Maximum	42.17
		Standard deviation	2.03
Probable females	16	Minimum	36.90
		Median	41.25
		Maximum	43.85
		Standard deviation	1.99
Males (without probable males)	24	Minimum	37.60
		Median	44.35
		Maximum	50.10
		Standard deviation	2.46
Probable males	16	Minimum	40.05
		Median	43.73
		Maximum	47.45
		Standard deviation	1.88

Table 2. Femur length of Martigues collection: measures of concentration and dispersion for each sex / *Longueur fémorale de la collection de Martigues : mesures de concentration de dispersion pour chaque sexe*

1 For the Nice Bone Collection only femur measurements were made, since the sex of each individual was already known.
 2 All statistical tests were made in software R, in the RStudio environment.

<0.001). As observed, significant differences in femur length were observed between females and males, females and probable males, probable females and males, and probable females and probable males (table 3). However, there were no significant differences between females and probable females or between males and probable males. Consequently, we divided the sample into two sex categories: females (grouping females and probable females) and males (grouping males and probable males).

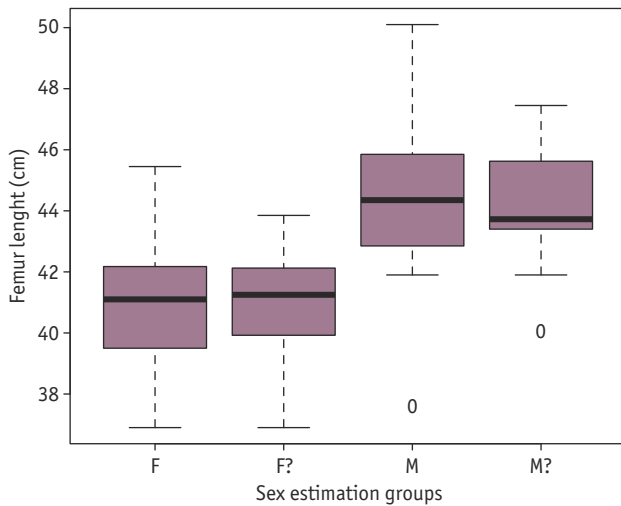


Figure 3. Femur length (cm) dispersion of the sex estimation groups in the Martigues collection: females (F), probable females (F?), males (M), probable males (M?) / *Dispersion des mesures de longueur fémorale de la collection de Martigues, en considérant les groupes de l'estimation de sexe : féminin (F), féminin probable (F ?), masculin (M), masculin probable (M ?)*

	Female	Probable female	Male
Probable female	0.74	–	–
Male	<.001	<.001	–
Probable male	<.001	<.001	0.75

Table 3. Martigues collection: results of the pairwise Wilcoxon-Mann-Whitney test (p-values), applied after the Kruskal-Wallis test, for femur length variation between the four sex categories / *Collection de Martigues : résultat du test Wilcoxon-Mann-Whitney par paires, appliqué après le test de Kruskal-Wallis, pour évaluer les variations de taille fémorale entre chaque groupe de l'estimation de sexe*

Antibes

Tables 1 and 4 show the descriptive statistics for the Antibes collection. The median female femur length in the Antibes collection is 39.66 cm, while the median male femur length is 44.95 cm. Table 4 and figure 4 illustrate the dispersion of femur length for the Antibes collection divided

into four sex groups: females, probable females, males and probable males. As explained in the *Methods* section, we were unable to perform a statistical test in this case. However, as we observe in the boxplot of figure 4, females and probable females are close to each other, as are males and probable males, and females and probable females are very dissimilar to both males and probable males. Consequently, we divided the Antibes sample into two sex categories, aiming to compare them with the other two samples.

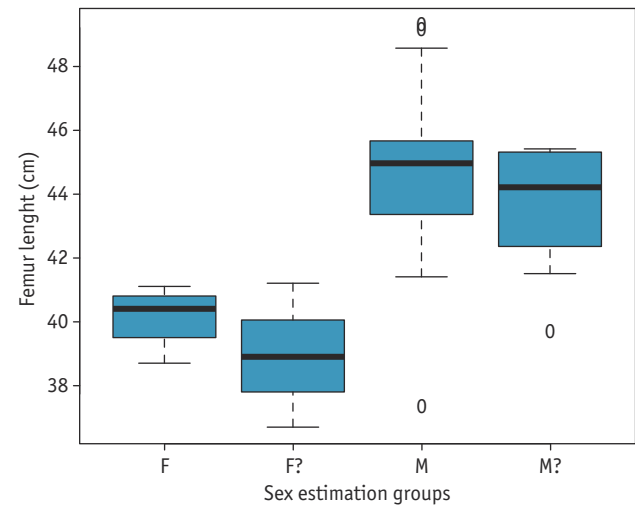


Figure 4. Femur length (cm) dispersion of the sex estimation groups in the Antibes collection: females (F), probable females (F?), males (M), probable males (M?) / *Dispersion des mesures de longueur fémorale de la collection d'Antibes, en considérant les groupes de l'estimation de sexe : féminin (F), féminin probable (F ?), masculin (M), masculin probable (M ?)*

Sex	n	Statistic	Value (cm)
Females (all)	8	Minimum	36.70
		Median	39.95
		Maximum	41.20
		Standard deviation	1.54
Males (all)	18	Minimum	41.40
		Median	44.95
		Maximum	49.30
		Standard deviation	2.40
Females (without probable females)	5	Minimum	38.70
		Median	40.40
		Maximum	41.10
		Standard deviation	0.99
Probable females	3	Minimum	36.70
		Median	38.90
		Maximum	41.20
		Standard deviation	2.25
Males (without probable males)	14	Minimum	41.40
		Median	44.95
		Maximum	49.30
		Standard deviation	2.53
Probable males	4	Minimum	41.50
		Median	44.20
		Maximum	45.40
		Standard deviation	1.84

Table 4. Femur length of Antibes collection: measures of concentration and dispersion for each sex / *Longueur fémorale de la collection d'Antibes : mesures de concentration de dispersion pour chaque sexe*

Nice

In the Nice collection, the median female femur length is 41.20 cm, while for males it is 45.70 cm, as shown in table 1. Because the sex of the individuals of this collection was known, we did not need to test whether the sample could be divided into two sex categories.

Changes in stature over time: comparison between the collections

As shown in figure 5 and table 5, the median male femur lengths changed as expected, increasing in the 19th century (Antibes collection), and again in the 20th century (Nice collection). To evaluate this trend, we used the Wilcoxon-Mann-Whitney test, comparing each pair of samples individually. According to the results, the Antibes male sample does not present a significant change in median femur length when compared with the other collections, but the medians differ significantly between Martigues and Nice (table 5). However, among the female samples, the median femur length for the Antibes collection (19th century) is significantly shorter than those of the other two groups, and the Nice collection (20th century) has the highest median femur length. However, the difference between median femur length in the Martigues collection and the Nice collection (female sample) is not significant if we consider the usual margin of error of 5%.

Sex	Compared samples	n	Median femur length (cm)	Results (p value)
Females	Martigues	47	41.10	0.035
	Antibes	8	39.95	
	Martigues	47	41.10	0.082
	Nice	31	41.62	
	Antibes	8	39.95	0.018
	Nice	31	41.62	
Males	Martigues	40	43.98	0.586
	Antibes	18	44.95	
	Martigues	40	43.98	0.057
	Nice	31	45.70	
	Antibes	18	44.95	0.204
	Nice	31	45.70	

Table 5. Results for femur length comparison between the three samples (separated sexes) / Résultat de la comparaison de taille fémorale entre les trois collections (sexes séparés)

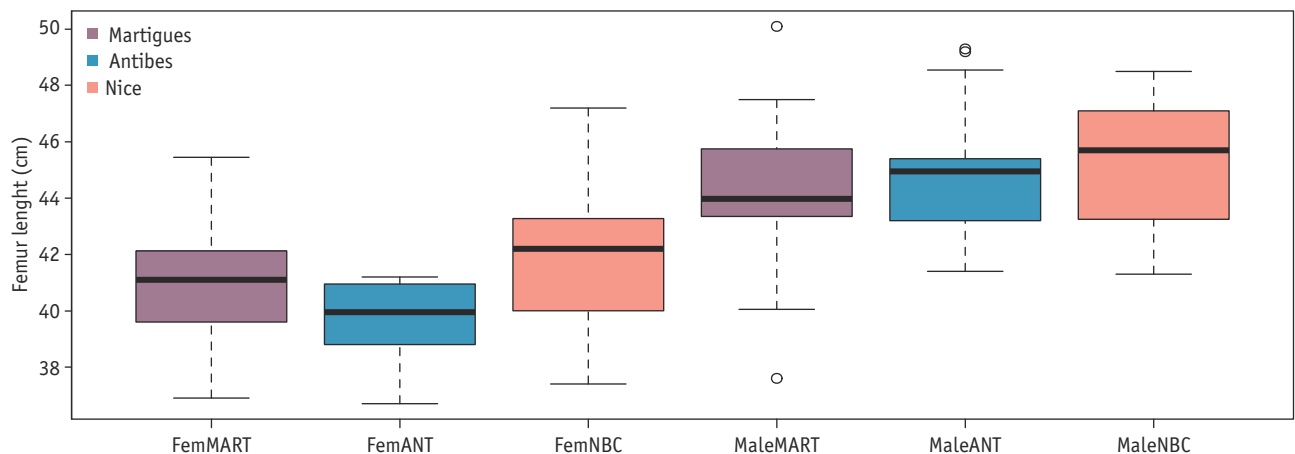


Figure 5. Femur length variation over time (separated sexes): females from the Martigues collection –18th century (FemMART), females from the Antibes collection – 19th century (FemANT), females from the Nice collection – 20th century (FemNBC), males from the Martigues collection (MaleMART), males from the Antibes collection (MaleANT), and males from the Nice collection (MaleNBC) / Variation de la longueur fémorale dans le temps (sexes séparés) : femmes de la collection de Martigues – XVIII^e siècle (FemMART), femmes de la collection d'Antibes – XIX^e siècle (FemAntNT), femmes de la collection de Nice – XX^e siècle (FemNBC), hommes de la collection de Martigues (MaleMART), hommes de la collection d'Antibes (MaleAntNT) et hommes de la collection de Nice (MaleNBC)

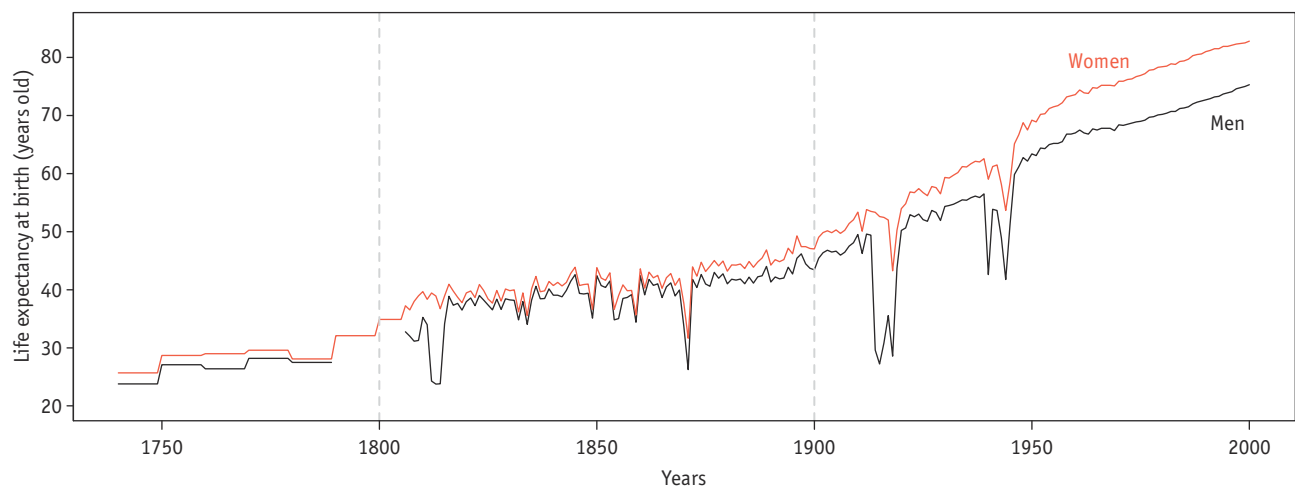


Figure 6. Life expectancy at birth in France, from 1740 to 2000 (adapted from Blayo 1975, Meslé and Vallin 1989 and Vallin and Meslé 2001 / *Espérance de vie à la naissance en France, de 1740 à 2000 (adapté de Blayo 1975, Meslé et Vallin 1989 et Vallin et Meslé 2001)*

Discussion

Living conditions during the three different historical periods

Historical demographers reconstructing French mortality data from 1740 onwards (Blayo, 1975; Meslé and Vallin, 1989; Vallin and Meslé, 2001) have observed a gradual increase in life expectancy at birth in France, with a decrease over certain periods. Sex differences in life expectancy also started to increase at the end of the 18th century, a trend that continued and intensified in the 20th century (figure 6). The data from 1740 until 1805 were reconstructed on a per-decade basis (Blayo, 1975). No data are available on male mortality from 1790 to 1805, as many deaths were not recorded during the French Revolution and Napoleonic wars (Blayo, 1975). The occasional decreases in life expectancy during the 19th and 20th centuries resulted primarily from wars and epidemics and are discussed in the respective sub-sections on each century, together with other examples of changes in living conditions.

From the end of the 19th century to the 1960s, life expectancy increased more substantially, this period being considered as the beginning of the health transition³ in France (Vallin and Meslé, 2004). This trend is characterised by changes in birth and mortality patterns, with a decline in deaths from infectious diseases (epidemics), maternal birth complications and malnutrition, which began to be replaced by degenerative diseases, such as cancers and cardiovascular problems (Omran, 1971). Vallin and Meslé (2004)

consider that three factors marked this transition in France. Firstly, epidemics were controlled by the public authorities, limiting the contamination of the population. Secondly, advances in agriculture and food distribution reduced famines and malnutrition, as did investments in drinking water and sewerage systems. Lastly, the transition was underpinned by medical progress, including immunisation, antibiotics and the establishment of social security systems.

17th and 18th centuries

Our main interest in this research, and our investigation of this collection made up of plague victims, is to identify the impact of crises that took place during the developmental phase of these individuals (from uterine life until approximately 18 or 20 years of age), i.e. events that occurred before the plague.

The Provençal diet was always more diverse than in other French regions. The main staples were bread, meat and wine, but the population also consumed pulses, fresh vegetables, fruits and nuts. In the 18th century, the main sources of proteins were meat (birds), fish and dairy products (Séguy, 2019). Agriculture and husbandry were practiced in Provence in the 17th and 18th centuries, but the quantities produced were not sufficient to feed the entire population. The region thus depended on food imports, particularly cereals, from neighbouring regions and countries (Séguy, 2019). Generally, this form of trade posed no problems, and the region was able to acquire the products needed by the population. However, during the period before the plague of 1720, several abnormal events occurred, resulting in food shortages. Climatic variations, such as the exceptionally cold winter of 1709 known as *Le Grand Hyver*, as well as epidemics and the wars waged by Louis XIV, caused years of food shortages and famines (Séguy, 2019).

³ It is not our goal in this paper to discuss the details, limitations and positive points in the models explaining the health transition (see Vallin and Meslé, 2004; Omran, 1971).

Previous studies have assessed the impacts of these crises on the population of Martigues (Signoli et al., 2005; Séguy et al., 2007, 2012; Séguy, 2016, 2019). Figure 7 shows the annual numbers of baptisms, marriages and burials from 1690 to 1725 (data source: Séguy, 2016). Mortality rates were high in 1694, 1698, 1705, 1709-1710 and 1720-1721, the latter period corresponding to the plague episode in which the individuals we analysed died. Many French regions experienced famine in 1692-1693, an extremely cold winter having affected agriculture (Lachiver, 1991). The impacts of this event were felt in Provence mainly in 1694 and the following years, as shown in figure 5. In 1698 and 1699, food production was affected by adverse weather events, including a very cold winter and rainstorms and flooding in summer, leading to famine. A few years later, in 1705, an epidemic, probably of whooping cough or measles, affected children aged from six months to six years of age (Séguy et al., 2012). In 1709-1710, much of Europe, including Provence, was affected by a bitterly cold winter that decimated harvests, while grain imports from other regions were undermined by the Spanish War of Succession (1701-1714).

The crises described in figure 7 should have affected the younger individuals in our sample during their developmental phase. However, other crises known to have affected Provence, France and Europe prior to 1690 may also have affected our sample. These include plague in Provence, from 1629 to 1630 and from 1649 to 1650 (Emmanuelli et al., 1991); the Franco-Spanish war, from 1635 to 1659; the war in the Mediterranean, when troops passed through Provence and revolts occurred in the region, from 1635 to 1640 (Emmanuelli, 1991); the Fronde civil wars, from 1648 to 1643, a series of extremely cold winters leading to famines, from 1660 to 1663, and a further outbreak of plague in 1663 (Lachiver, 1991; Le Roy Ladurie, 2015).

In a previous study we found no evidence of selective mortality during the crises of the 17th and 18th centuries that would have influenced the stature of men or women,

although this aspect calls for further investigation. Our analysis of the prevalence of stress markers among child victims of the plague in Martigues (linear enamel hypoplasia, *cribra orbitalia* and porotic hyperostosis of the cranial vault) (Batista-Goulart et al., 2023) demonstrated that stress markers were more numerous in children born closer to the years of famine than in other age groups. In the same paper, we compared the prevalence of stress markers among children from the Martigues collection with another sample from the nearby town of La Ciotat (18th century), which was not affected by the plague, studied by Perrin (2021). This burial site has more than one phase of occupation, one comprising children who died during the famines or other crises that affected Provence in the 17th and 18th centuries. A further phase of occupation consists of adults who faced those crises during childhood and survived to adulthood. We observed no significant difference in the prevalence of stress markers between Martigues and La Ciotat (children or adults), i.e., a similar prevalence of stress markers among children who survived the famines and children who died during these periods. Perrin did not study stature patterns in her work, which would have made for an interesting comparison.

19th century

Alfani and O'Gráda (2017) describe many starvation episodes that have affected Europe since the Middle Ages, but they do not refer to any episode in 19th century France. For the authors, the last famine in France occurred in 1788-1789, before the French Revolution, this being the last episode that could have affected the oldest individuals in the Antibes collection. According to Heyberger (2009), the last food crises in France occurred in the 19th century, in 1845-1847 and 1853-1857, and were related to high food prices. Though less serious than in previous centuries, food scarcity did not cease in the 19th century. However, there is a lack of research specifically on Provence.

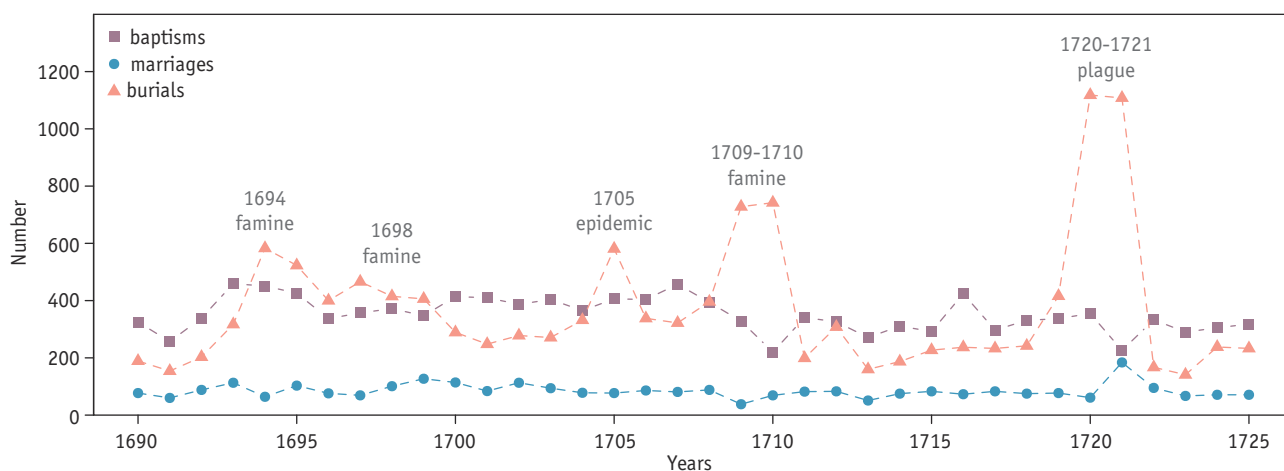


Figure 7. Demographic data representing baptisms, marriages and burials in Martigues from 1690 to 1725 (data source: Séguy, 2016) / Données démographiques représentatives des baptêmes, mariages et sépultures à Martigues de 1690 à 1725 (source des données : Séguy, 2016)

In the 19th century, life expectancy at birth in France increased from 37.25 years (females) and 32.77 years (males) in 1806, to 47.11 years (females) and 43.10 years (males) in 1899 (Meslé and Vallin, 1989), reflecting an improvement in living and health conditions. However, some episodes in the 19th century caused temporary decreases in life expectancy, including wars (the Napoleonic Wars from 1803 to 1815, the Crimean War in 1855, and the Franco-Prussian War in 1870) and epidemics (cholera in 1832, 1849 and 1854, influenza in 1834, and dysentery in 1859). Drawing on the same data as figure 6, figure 8 gives a clearer depiction of life expectancy in the 19th century.

Life expectancy for both sexes was similar during most of the 19th century, except at the beginning of the century, when male life expectancy was more affected by the Napoleonic Wars, and at the end of the century with the beginnings of the health transition. As shown in figure 7, female life expectancy was also affected by the wars of 1854 and 1870.

Since our goal is to compare living conditions between three centuries, it is important to observe their improvement relative to the 18th century, even with the difficulties faced in the 19th century. Life expectancy at birth was higher in the 19th century than in the previous century, except in 1812 to 1814.

20th century

Living conditions in Europe continued to improve during the 20th century. Life expectancy at birth in France was estimated to be 69.72 years (females) and 63.4 years (males) in 1950, and 82.5 years (females) and 75.0 years (males) in 1999 (INSEE, 2008). The number of deaths in the first year of life also decreased, as demonstrated in figure 9, which shows the decrease in infant mortality as measured by the ratio of numbers of deaths within the first year of life to total births in the same year (Vallin and

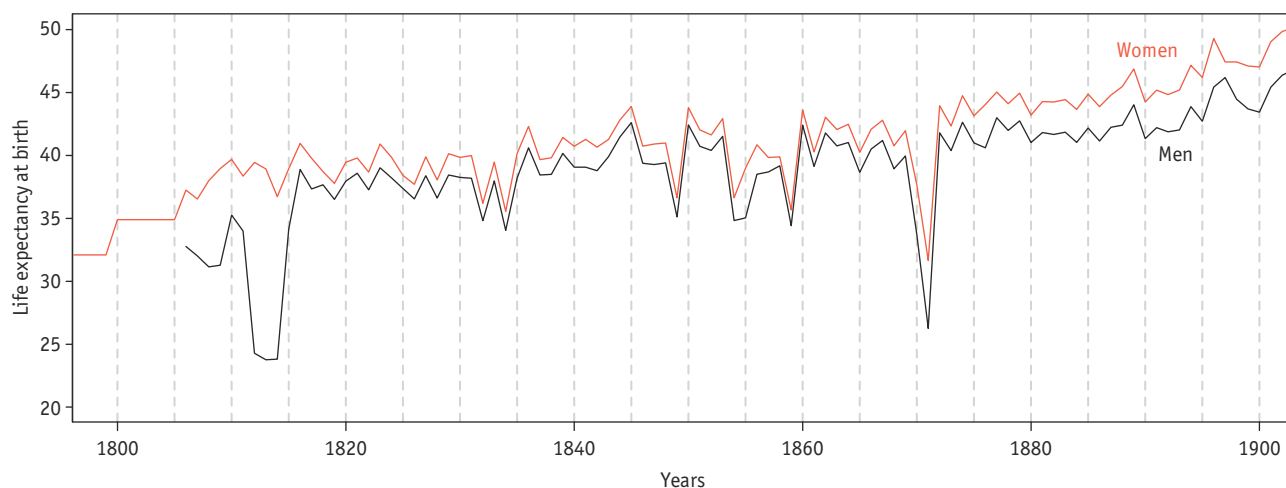


Figure 8. Life expectancy at birth during 19th century, in France (source: Meslé and Vallin, 1989; Vallin and Meslé, 2001) / *Espérance de vie à la naissance au XIX^e siècle, en France* (source : Meslé et Vallin, 1989; Vallin et Meslé, 2001)



Figure 9. Deaths in the first year of life divided by the number of births in the same year (source: Vallin and Meslé, 2001) / *Décès dans la première année de vie rapportés au nombre de naissances de la même année* (source : Vallin et Meslé, 2001)

Meslé, 2001)⁴. Despite the spikes during the two World Wars shown in figure 9, this indicator followed a general downward trend throughout the 20th century. Among other factors, this improvement resulted from advances in medicine, such as vaccines and antibiotics, and also from the development of the social security system in the second half of the 20th century.

Changes in male femur length over time in Provence

Male femur length changed much as expected considering the historical context, increasing over time, even though the data point to a statistically significant increase only when we compare the figures for Martigues (18th century) with those for Nice (20th century), i.e. the earliest and latest samples, respectively. This upward trend has also been observed in other studies, but these did not consider samples from the 18th century. For instance, Heyberger (2009) reports that male statures decreased slightly during the first half of the 19th century, but increased from 1850 to 1910. In that paper, the author presents data on the stature of conscripts from four French regions and for the whole country, but not for the south. Chamla (1964) compared changes in stature among French conscripts from 1880 to 1960, observing a general increase, but a short period of decrease in the decade following World War I (1920-1929). Since this period refers to the year of conscription rather than birth, the decrease observed in the 1920s may be related to poor living conditions during the war. Pineau (1993) also studied French conscript statures, demonstrating an increase of around ten centimetres from 1900 to 1990 (he did not include data from the 1920s). Arcaleni (2006) analysed Italian conscript statures from 1854 to 1980, and also observed an upward trend in stature, which the periods of deprivation during the two World Wars did not affect, according to the author.

Changes in female femur length over time in Provence

The changes in female femur length in the samples analysed were unexpected, considering the historical periods. First, the median femur length was significantly smaller in the 19th century collection (Antibes). Secondly, there was no significant difference in femur lengths between the Martigues (18th century) and Nice (20th century) samples, although the latter shows the largest stature. These results are surprising given the improvement in living conditions in France in the 19th and even more so in the 20th century.

Regarding the first observation, the statistical test applied (Wilcoxon-Mann-Whitney test) shows a significant difference between the Martigues and Antibes samples, median

stature being smaller in the latter. Since this statistical test is robust with respect to small and uneven sample sizes (Xia et al., 2018), this surprising result may be due to a biased sample, the Antibes collection (from the old cemetery) being composed of unclaimed skeletons that were not transferred to the new cemetery. It is likely to comprise a higher proportion of immigrants than the overall population (Buchet et al., 2003), or individuals whose families could not afford the reburial costs. Apart from the fact that individuals coming from outside of Provence may have experienced different living conditions, it may also include a socio-economic bias, which would explain the shorter stature of women, since there were more female migrants (see *Samples* section).

Concerning the second observation, as presented in the *Discussion*, living conditions improved in France between the 18th and 20th centuries. As such, one would expect a significant difference in the measurements for females in the 18th and 20th centuries these two samples, as observed in the male samples. These collections do not present a known sampling bias; both are from a known historical context, the years of death are known and the individuals died within a short period of time. The representativeness of the Martigues collection has been tested (Batista-Goulart, 2021; Batista-Goulart, et al, 2022) and the cause of death of the individuals is known (Tzortzis and Signoli, 2009).

Different patterns in stature changes between men and women

Multiple factors directly or indirectly influence the living conditions of a population and thus have an impact on an individual's stature. As we discussed in the introduction, there are many cases in which the patterns of change in female and male stature are not the same. But what we find surprising is the non-significant difference between the 18th and 20th centuries collections. The different patterns in stature changes between men and women can be ascribed to a range of factors. These include the influence of biological aspects (Stulp and Barrett, 2016), whereby men and women respond differently to an improvement in living conditions or to deprivation; the effect of gender discrimination, leading to unequal access to resources for women in the 20th century; and the impact of World War II, since the individuals in the Nice collection may have been in the developmental phase during a war, a possibility that would merit further study. Females and males were affected differently during World War II in France owing to the sexual division of labour in that period. Even the population not directly engaged in combat suffered the impact of the years of war: the examples in figures 6 and 9 show that deaths in the first year of life as well as female life expectancy at birth were affected by warfare. In future research, it would be interesting to investigate the effects of the two wars on female and male stature in France. It is possible that a difference may be due to a biological response to the lack of resources during wars, unequal access to resources, and/or a different mortality

4 Raw data is available for downloading, as part of the publication of Vallin and Meslé (2001). The proportion of deaths per birth was computed by us.

rate, which may have had an indirect effect on the stature of one sex or the other. Such a study would require a larger sample enabling a division into life cohorts (with sufficient observations in each cohort to conduct a statistical test). Koepke et al. (2018) analysed female and male stature changes in Switzerland during those periods, but Switzerland was neutral during the two World Wars and less affected than France, so the stature trends in the two countries may differ. Cámara (2014) showed that SSD in Spain was affected by the major events of the 20th century, particularly the Spanish Civil War and the subsequent dictatorship.

Conclusion

Since the incorporation of gender studies in academic research (Conkey and Spector, 1984; Dommasnes, 1992; Gilchrist, 1999; Sørensen, 2000), numerous works have focused on the female condition and contributions in past societies (Charpentier, 2010, 2019; Ginnaio, 2011; Hedenstierna-Jonson et al., 2017; Radini et al., 2019). But numerous gaps have yet to be filled, including differences in stature variations over time. In this respect, our work, within its scope, helps to further understanding of changes in female stature relative to male stature. The issue could be addressed on a larger scale to gain a firmer grasp of the underlying environmental and social causes.

In this paper, we studied female and male femur length changes as a proxy for stature. We observed that effects of changes in living conditions are traceable in the male samples. We conclude that, as expected, male femur lengths increased from the 18th to the 20th century, demonstrating the influence of improved living conditions on male stature. In an unexpected development, our data findings show a less emphatic increase in the femur length of women between the 18th and 20th centuries when compared to that of men, and a significant decline in female stature during the 19th century, possibly related to biases within the sample. The biological and social factors that may have affected female and male stature differently over time could be assessed in future research.

For female statures, the results for the 19th century (Antibes collection) call for further investigation, since our sample size was small. Another 19th century collection could be analysed to identify how female stature was affected by the changes that occurred during this period.

It would also be interesting in further research to use a 20th century Provence sample large enough to be divided into birth cohorts, which would make it possible to identify the effects of the two World Wars on secular stature trends and to assess their impacts in the south of France. To present living conditions in each century, we drew on standard indicators such as life expectancy at birth and death in the first year of life. But as discussed in the introduction, the advantage of stature studies is the possibility of going above and beyond standard indicators with a view to assessing how resources were distributed within a society. While we were unable to identify exactly why female and

male stature failed to follow the same patterns, we have confirmed that more aspects need to be explored if we are to fully understand how different groups benefit from improvements in living conditions and are affected by crises.

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