4-4-2017

An Examination of the Differential Effects of the Modern Epidemiological Transition on Cranial Morphology in the United States and Portugal

Katherine E. Weisensee
Department of Sociology and Anthropology, Clemson University, Clemson, SC, kweisen@clemson.edu

Richard L. Jantz
Department of Anthropology, University of Tennessee, Knoxville, TN

An Examination of the Differential Effects of the Modern Epidemiologic Transition on Cranial Morphology in the US and Portugal

Katherine E. Weisensee[1]* and Richard L. Jantz[2]

Secular Change in the US and Portugal

[1]Department of Sociology and Anthropology, Clemson University, Clemson, South Carolina.

[2]Department of Anthropology, University of Tennessee, Knoxville, Tennessee.

*Correspondence to: Katherine E. Weisensee, Department of Sociology and Anthropology, Clemson University, 132 Brackett Hall, Clemson, SC 29634-1356. E-mail: kweisen@clemson.edu.

KEY WORDS: CRANIOMETRICS, SECULAR CHANGE, PLASTICITY, GROWTH, DEMOGRAPHIC TRANSITION.

Abstract This research examines the pattern of secular change in the cranial morphology of two populations experiencing the epidemiological transition. The epidemiological transition is associated with decreased mortality rates in children, followed by declines in infant mortality, and subsequent increases in adult longevity. The two samples examined in this study come from U.S. and Portuguese individuals. The epidemiological transition occurs at different times in the U.S. and Portugal, with Portugal entering into the transition later than the U.S. The results of the study show that the U.S. and Portuguese samples experienced significant changes in cranial morphology during the approximately 150 years under study. In all of the samples the cranial base morphology changes significantly over time. However, the pattern of change in the U.S. and Portuguese samples varies in the other regions of the crania affected. The U.S. samples exhibit significant changes associated with the posterior cranial fossa. This region of the crania experiences the greatest growth during the fetal period and during the first year of life. Conversely, in the Portuguese sample the region of the cranium that shows the largest amount of change is in the face and lateral cranial base. This region of the cranium experiences the greatest amount of growth from 3-9 years. This differential pattern may reflect the differences in changing mortality patterns in the two countries. During the period under study the U.S. had already proceeded through the early stages of the epidemiological transition and improvements in the juvenile mortality and juvenile growth occurred previously. Subsequently, the U.S. experienced significant declines in infant mortality and the regions of the crania that exhibit the greatest changes occur in area with maximum growth velocity under one year. However, Portugal entered into the epidemiological transition later than the U.S. and therefore the greatest changes in growth occurred during the juvenile period, which is reflected in the adult

morphology in this group. This study demonstrates the utility of variation in growth patterns in different cranial regions to document changes in the demographic parameters in two different populations.

The environmental conditions of human populations have been radically altered over the past 200 years as the result of industrialization and urbanization. The pace and scale of change varies by location, but a general pattern corresponding to the epidemiological transition has been documented in populations around the world. The epidemiological transition is characterized by decreases in childhood and infant mortality and increases in adult longevity. Plasticity responses in a variety of phenotypic characteristics have been documented in human populations associated with the modern epidemiological transition. These include increases in stature, decreases in age at menarche, and changes in craniofacial morphology (Easterlin 2000; Fogel et al. 1983; Kouchi 2000; Jantz 2001; Meadows and Jantz 1995; Zellner et al. 1996). Although adult stature has been extensively studied with regard to the modern epidemiological transition, craniometrics allows for a more detailed investigation related to specific periods of growth.

Research into the epidemiological transition has been a central focus of demography for much of past 50 years and the shift from high mortality and fertility to low mortality and fertility has been documented in populations around the world (Coleman and Schofield 1986; Kirk 1996)). There is a great deal of variation in the rate and pattern of mortality change both between and within countries. However, some generalizations may be made across modernizing countries which led to the overall shift in demographic parameters. In general, the first group to experience a decline in mortality was children aged 1-14 years. These declines were often large and resulted, in large part, from the decline in deaths from infectious epidemics. Following the decline in childhood mortality, infant mortality went down although it was generally somewhat more resistant to change. Finally, adult survivorship increased slowly. These general trends suggest that decreased mortality of children and infants is the single largest initial contributor to increased survivorship of any group during the demographic transition (Schofield and Reher 1991:6).

The decrease in childhood mortality was not a linear decline across time (Riley 2001). Prior to large-scale urbanization in Europe and American, there was an overall decline in mortality, but as urban centers became more populated, mortality levels increased (Mercer 1990). As more people began to move into cities following industrialization at the end of the 18th century and first half of the 19th century, diseases and epidemics became more common. The epidemics associated with high population density, such as cholera and yellow fever, resulted in increased mortality rates especially among the young. Survivorship did not increase until public health initiatives and vaccination programs were successfully initiated in the second half of the 19th century. Juveniles (aged 5-14 years) were the first group affected by the decline in mortality, while infant mortality tended to be slower to respond to mortality declines; although over time infants also experienced a decline in mortality. Finally, adult longevity slowly increased from the beginning of the 20th century through the invention of more advanced medical procedures. This pattern of increased mortality followed by plummeting mortality levels has been observed in populations around the world experiencing intense urbanization (Fogel 2004).

The observed shift in demography results from changes in environmental factors that impact growth and development in populations, changes that can also be observed in morphological phenotypic responses. For example, previous studies examining changes in craniofacial morphology in Americans over the past 200 years documented significant trends related particularly to the narrowing of the face and cranial vault, increases in cranial vault height, cranial base length, and overall cranial length (Jantz and Meadows Jantz, 2000). The most significant changes observed in the American population occur in the cranial base and alterations of the pattern of growth in this region seem to play an important role in response to environmental changes that occurred. Significant changes have also been documented in a Portuguese sample (Weisensee and Jantz, 2010).

This study examines secular changes in the crania of American Black and White populations and Portuguese in order to compare the pattern, magnitude, and direction of change in populations experiencing broadly similar modern environments. The changes associated with modern environmental conditions include increase population size and urban density, changes in mortality and morbidity patterns, and access to modern health care. These conditions are unique in comparison to previous human history and the rapid pace of the changing environmental conditions has had profound effects on human biology. The collection methods and composition of the American and Portuguese samples are different. The American sample comes from several skeletal collections, both anatomic and forensic collection. The individuals sampled represent a broad geographical area of the U.S. that experienced differing rates of urbanization and large influxes of international immigration. The Portuguese sample contains individuals that died while living in Lisbon and represent the Lisbon population during a period of intensified urbanized and with relatively little international immigration. A similar pattern of change observed in both the American and Portuguese samples would suggest that the broadly defined modern environmental conditions have a similar affect regardless of these other factors related to local variability.

Materials and Methods

The samples from the American population come from two sources - the 19th century American individuals are from the Hamann-Todd and Terry anatomical collections, while individuals with later birth dates come from the Forensic Anthropology Database (FDB). The data includes both Black and White males and females. The Portuguese sample comes from the New Lisbon Skeletal Collection housed at the National Museum of Natural History in Lisbon, Portugal. The New Lisbon Collection contains individuals exhumed from one of Lisbon's three main cemeteries. The birth years represented in the samples range from 1802-1975. The demographic characteristics, including sex and year of birth, for all of the individuals included in the sample, are known from associated premortem records and were not estimated based on morphological features. The distribution of sample is seen in Table 1.

Fourteen interlandmark distances were used to explore secular changes in cranial morphology during the 19th and 20th centuries. The variables used in the analysis are shown in Table 2. The interlandmark distances for the Portuguese sample were derived from the three-dimensional landmarks. The interlandmark distances in the American samples were collected both from directly measured crania and derived from the digitized landmark data. There are a total of 1684 individuals included in the analysis. A canonical correlation procedure in the SAS 9.3 software (SAS Institute, Cary, NC) was used to derive a linear function of a set of variables for which year of birth is maximally correlated with the cranial measurements. This correlation analysis evaluates the relationship between a linear combination derived from craniometrics data and year of birth - the linear combinations are referred to as canonical variables. Previous studies of secular changes in Americans found that basion-bregma height had the highest correlation with year of birth; therefore this measure was also examined independently in all groups in a simple correlation analysis. In addition, a canonical discriminant analysis in the SAS 9.3 software (SAS Institute, Cary, NC) was used to examine variation across birth cohorts. For this analysis, the samples were divided into four 25-year birth cohorts in order to capture the common birth years among all the groups. Canonical discriminant analysis derives a linear combination of the craniometrics variables that provide maximal separation between the birth cohorts.

Results

Table 3 shows the results of the canonical correlation of year of birth with the cranial variables. For all of the groups, the canonical correlation and the univariate correlation with basion-bregma height is significant with year of birth, with the American samples showing larger correlation values. Table 4 provides the canonical structure matrix which shows the relative importance of each of the original cranial variables with year of birth and is derived from the canonical correlation analysis. Among the highest values for all the samples is an increase in basion-bregma height. For both American Whites and Portuguese individuals there is also an increase in basion-nasion height and basion-prosthion length. A decrease in bizygomatic breadth is noted across all of the samples with the exception of the Portuguese females. The American samples show an increase in occipital chord, while in the Portuguese sample there is little change in this dimension. Figure 1 shows a plot of the cranial canonical scores in relation to year of birth with a Lowess regression line fitted for all three groups (sexes pooled). There is a differing pattern of change among the groups with American Whites showing a steady increase in canonical scores across the 19th and 20th centuries. American Blacks show a slow rate of change until the early 20th century after which there is a sharp increase in the change. The Portuguese sample also show a moderate increase over time although the rate of change is not as dramatic as in the American samples. In the American White sample 50% of the variation in the cranial canonical score is explained by year of birth, 30% for the American Black sample, and in the Portuguese sample year of birth explains 10% of the variation. Figure 2 is a plot of the first and third canonical axes derived from the canonical discriminate analysis. The first and second axes separate the groups based on population differences, while the third axis has a strong temporal component. The first canonical axis explains 55% of the variation and the third canonical axis explains 15% of the variation. This plot shows that the first axis separates the groups by geography and ancestry. The third axis has a strong temporal component and clearly demonstrates that the two American populations are changing in similar ways over time. The Portuguese sample also shows a somewhat similar pattern of change, however not to the same magnitude as the American samples.

Discussion

The correlation between changes in cranial morphology and year of birth across diverse populations indicates the significant impact on human biology of modern environmental conditions. The Portuguese and American samples exhibit similar types of morphologic change, although at different rates, which suggest factors impacting patterns of growth and development are acting on these populations, even though Portugal's rate of modernization was slower compared to other Western countries. Previous research has shown that the crania of both Black and White Americans and also the Portuguese exhibit significant changes to the cranial base morphology during the 19th and 20th centuries (Wescott and Jantz 2005; Weisensee and Jantz 2011). The current study directly compares the two populations in order to assess the direction and magnitude of change. While the American and Portuguese samples both exhibit significant secular changes there are clear differences between the pace and scale of change in the different geographic locations.

In the American sample there is a corresponding decrease in cranial vault breadth with the increased cranial base height; however, this was not observed in the Portuguese sample. Kouchi (2000) examined secular changes in the cranium of the Japanese. Changes in the cranial base in the Japanese were similar to the American and Portuguese samples; however, in the Japanese there was a corresponding increase in cranial vault width. The relationship between increased cranial base height and cranial vault breadth are less clear in the Portuguese sample. Specifically, maximum cranial breadth slightly increases in females and slightly decreases in males. In the Portuguese sample the highest correlations with time are increased facial height (nasion-prosthion ht.) and vault height (basion-bregma ht.) in females and decreased bizygomatic breadth and basion-nasion length in males. Three-dimensional landmark analysis of the Portuguese showed that basion moves inferiorly over time in the sample resulting in the increases in basion related measurements with little change in either bregma or nasion (Weisensee and Jantz 2011). The facial region seems to be more impacted by secular changes than is observed in the American samples.

The pattern of change affecting different cranial regions among the three populations provides some insight into when during development the patterns of growth were most affected across the groups. For example, in the American samples the largest component of change occurs in the landmarks basion and lambda, specifically basion-bregma height and occipital chord length. According to Neubauer et al. (2009) this pattern of change in the posterior cranial fossa is typical of the growth during the fetal and perinatal growth up to about 1 year of age. In the Portuguese sample, while there is an increase in basion-bregma height associated with a more inferior location of basion, significant changes are also associated with the face and cranial base breadth, specifically biauricular breadth and nasion-prosthion height. This pattern of change is more typical of the changes in growth occuring from age 3 to 9 years (Neubauer et al. 2009). The later maturation of the lateral cranial base and face in comparison to the midline cranial base is also confirmed in longitudinal studies (Bastir et al. 2006; Bastir 2008). The variation in the regions of the crania related to secular change may be related to the differential improvements in mortality rates for different age groups in the United States and Portugal as each country experience the modern epidemiological transition at different times.

The modern epidemiological transition that occurs as populations around that world experience changes in mortality and fertility rates are the result of improved nutrition, declines in infectious diseases, and improvement in maternal survival, among others. Generally, the first group to experience improved survivorship during the modern epidemiological transition is childhood and, as populations undergo the transition, declines in childhood mortality rates occur first and most significantly. This is generally followed by declines in infant mortality with continued improvements in public health initiatives and later increases in adult longevity. The Portuguese entered the demographic transition later in comparison to the United States, so a large component of the observed changes impacted regions of the crania that experience the greatest growth during the juvenile period. However, in the United States improvements in juvenile mortality had occurred prior to the samples used in this study. Therefore, the period of growth in the American samples that were most impacted over the study period occurred during the fetal and perinatal period and the cranial region associated with posterior fossa experienced the greatest change in the American samples. As the Portuguese continued through the demographic transition and infants increasingly experienced less stress during the first year of life with corresponding lower mortality rate, perhaps changes similar to the American sample would be observed. During the modern epidemiological transition, one marker of decline in mortality is the first year that the infant mortality rate (IMR) falls below 100 infant deaths per 1,000 live births. The first country to achieve this marker is Sweden in 1895, in the U.S. in 1921, and in Portugal in 1950 (Abouharb and Kimball 2007; Kenny 2008). Additional skeletal samples with known demographic parameters could be useful for answering this question. Further support for this explanation comes from analysis of three-dimensional landmarks in this Portuguese sample that found secular changes in cranial shape were significantly associated with changes in childhood mortality in Portugal, but with no other demographic parameter (Weisensee 2008).

Bastir and Rosas (2006) found a significant correlation between growth trajectories in the lateral cranial base and the face. In the Portuguese sample the differential direction of change observed in females and males with regard to cranial base breadth results in a correspondingly similar direction of change in facial breadth measurements. The lateral cranial base matures later in comparison to the midline cranial base, therefore the facial regions covary with the lateral cranial base (Bastir et al. 2006). This same correspondence is observed in the American White sample; however the American Black sample does not follow the expected pattern. This may be related to the trajectory of the secular changes in the three groups shown in Figure 2. This figure shows that the American White sample follows a more or less linear pattern of change over time; however the American Black sample shows slow and intermittent change before the turn of the century and a more linear pattern after 1900. Today, the American Black population continues to exhibit greater mortality rates across all demographic parameters in comparison to the American White population and this pattern was even more exaggerated in the mid to late-19th century. American Blacks were and are subjected to differential access to healthcare, inadequate nutrition, and other markers of socioeconomic status. It is not surprising that changes in patterns of growth are not as clearly interpreted in the American Black sample.

In conclusion, all of the samples that are representative of populations experiencing the modern epidemiological transition show significant changes in cranial morphology across the time period sampled. In all three groups, there are significant changes to the cranial base morphology that show a significant secular trend. However, the corresponding regions of the crania that are most strongly associated with a secular trend indicate that the period of growth that is most affected by the changes in the environmental conditions varies across the three groups. In the American samples the posterior cranial fossa which experiences the greatest growth before 1 year of age, changes most significantly over time. This pattern is most apparent in the American White sample which experienced the greatest improvements in infant mortality during the time period under study. If infants born during this period experienced lower morbidity and better nutrition, they would also show more optimal growth during this period of development. In the Portuguese sample, there are still significant changes in the cranial base, but these changes are more closely linked to changes in the face. Face growth and growth in the lateral cranial base occurs during the juvenile period from age 3-9 years. As Portugal entered the modern epidemiological transition later than the United States, the first demographic parameter to show improvement was childhood mortality and only later did infant mortality improve. The changes in the environments in the two countries, at different stages of the modern demographic transition, which affect different growth periods, are associated with different patterns of change in cranial morphology.

Received 21 October 2015; revision accepted for publication 9 February 2016.

Works Cited

Abouharb, M. R., and A. L. Kimball. 2007. A new dataset on infant mortality rates, 1816–2002. *J. Peace Res*. 44:743–754.

Bastir, M., A. Rosas, and P. O'Higgins. 2006. Craniofacial levels and the morphological maturation of the human skull. *J. Anat*. 209:637–654.

Bastir, M. 2008. A systems-model for the morphological analysis of integration and modularity in human craniofacial evolution. *J. Anthropol. Sci*. 86:37–58.

Easterlin, R. A. 2000. The worldwide standard of living since 1800. *J. Econ. Perspect*. 14:7–26.

Fogel, R. W., S. L. Engerman, R. Floud et al. 1983. Secular changes in American and British stature and nutrition. *J. Interdiscipl. Hist*. 14:445–481.

Fogel, R. 2004. *The Escape from Hunger and Premature Death, 1700–2100*. Cambridge: Cambridge University Press.

Jantz, R. L., and L. Meadows Jantz. 2000. Secular change in craniofacial morphology. *Am. J. Hum. Biol.* 12:327–338.

Jantz, R. L. 2001. Cranial change in Americans: 1850–1975. *J. Forensic. Sci.* 46:784–787.

Kenny, C. 2008. A century of the infant mortality revolution. Available from charleskenny.blogs.com/weblog/files/histinf.pdf.

Kirk, D. 1996. Demographic transition theory. *Popul. Stud*. 50:361–387.

Kouchi, M. 2000. Brachycephalization in Japan has ceased. *Am. J. Phys. Anthropol*. 112:339–347.

Meadows, L., and R. L. Jantz. 1995. Allometric secular change in the long bones from the 1800s to the present. *J. Forensic Sci*. 40:762–767.

Mercer A. 1990. *Disease, Mortality and Population in Transition: Epidemiological-Demographic Change in England since the Eighteenth Century as Part of a Global Phenomenon*. Leicester: Leicester University Press.

Moore-Jansen, P. H., S. D. Ousley, and R. L. Jantz. 1994. Data Collection Procedures for Forensic Skeletal Material. Report of Investigations No. 48. Department of Anthropology, University of Tennessee.

Neubauer, S., P. Gunz, and J. J. Hublin. 2009. The pattern of endocranial ontogenetic shape changes in humans. *J. Anat*. 215:240–255.

SAS 9.3 for Windows. Version 9.3. Cary, NC: SAS Institute.

Schofield, R., A. Bideau, and D. S. Reher. 1991. *The Decline of Mortality in Europe*. Oxford: Oxford University Press.

Weisensee K. 2008. *Plasticity and Population Structure: Exploring Secular Trends in the Three-Dimensional Cranial Morphology of the Modern Portuguese*. Unpublished dissertation, Department of Anthropology, University of Tennessee.

Weisensee, K. E., and R. L. Jantz. 2011. Secular changes in craniofacial morphology of the Portuguese using geometric morphometrics. *Am. J. Phys. Anthropol*. 145:548–559.

Wescott, D. J., and R. L. Jantz. 2005. "Assessing craniofacial secular change in American blacks and whites using geometric morphometry." In *Modern Morphometrics in Physical Anthropology*, D. E. Slice, ed. New York: Kluwer: Academic/Plenum Publishers. 231–245.

Zellner, K., K. Kromeyer, and U. Jaeger. 1996. Growth studies in Jena, Germany: Historical background and secular changes in stature and weight in children 7–14 years. *Am. J. Hum. Biol*. 8:371–382.

Tables and Figures

Table 1. Sample size and range of birth years by ancestry and sex.

Sample	N	Range of Birth Years
American Black females	215	1802-1975
American Black males	263	1801-1975
American White females	317	1830-1975
American White males	463	1812-1975
Portuguese females	232	1822-1955
Portuguese males	230	1830-1957

Table 2. Interlandmark distances and definition (Moore-Jansen et al 1994).

Interlandmark Distances	Abbreviation	Definition
Maximum cranial length	GOL	Distance between glabella and opisthocranion in the midsagittal plane.
Cranial base length	BNL	Direct distance between nasion to basion.
Basion-bregma height	BBH	Direct distance between basion to bregma
Max. cranial breadth	XCB	Maximum width of the skull perpendicular to midsagittal plane wherever it is located, with the exception of the inferior temporal lines and the area immediately surrounding them.
Bizygomatic breadth	ZYB	Direct distance between the most lateral points on the zygomatic arches.
Biauricular breadth	AUB	Least exterior breadth across the roots of the zygomatic processes, wherever found.

Basion prosthion length	BPL	Direct distance from basion to prosthion.
Upper facial height	UFH	Direct distance from nasion to prosthion.
Nasial height	NLH	Direct distance from nasion to the midpoint of a line connecting the lowest points of the inferior margin of the nasal notches.
Nasial breadth	NLB	Maximum breadth of the nasal aperature.
Biorbital breadth	EKB	Direct distance between right and left ectoconchion
Frontal chord	FRC	Direct distance from nasion to bregma taken in the midsagittal plane
Parietal chord	PAC	Direct distance from bregma to lambda taken in the midsagittal plane
Occipital chord	OCC	Direct distance from lambda to opisthion taken in the midsagittal plane

Table 3. Canonical correlation of cranial variables and basion-bregma height with year of birth.

	Canonical Correlation	p	Pearson r BBH	p
Black Females	0.5174	<0.0001	0.3413	<0.0001
Black Males	0.5753	<0.0001	0.3198	<0.0001
White Females	0.6786	<0.0001	0.4579	<0.0001
White Males	0.7096	<0.0001	0.4806	<0.0001
Portuguese Females	0.3353	0.0217	0.1365	0.0378
Portuguese Males	0.3328	0.0247	0.137	0.0379

Table 4. Canonical structure coefficicents.

Cranial Measurement	Black Females	Black Males	White Females	White Males	Portuguese Females	Portuguese Males
GOL	-0.0469	-0.064	0.3141	0.4135	0.001	0.0293
BNL	0.4402	0.3393	0.5851	0.6407	0.1551	0.3716
BBH	0.6147	0.5173	0.7101	0.7398	0.3633	0.3089
XCB	-0.2446	-0.3076	-0.3228	-0.2527	0.0508	-0.0968
ZYB	-0.3000	-0.1776	-0.3012	-0.2461	0.242	-0.4119
AUB	0.0532	0.0525	-0.0796	-0.0341	0.2463	-0.1347
BPL	0.1762	0.1416	0.388	0.285	0.3103	0.3408
UFH	0.0547	0.1086	0.0973	0.1051	0.7493	0.2429
NLH	0.1288	0.195	0.0974	0.0358	0.153	0.3128
NLB	0.0335	-0.1145	-0.1283	0.0068	-0.2104	-0.1404
EKB	-0.3088	-0.0999	-0.2666	-0.0172	0.0658	-0.1189
FRC	0.3111	0.1547	0.4062	0.3716	-0.0211	0.0187
PAC	-0.3053	-0.4564	-0.1416	-0.1456	-0.068	-0.0211
OCC	0.459	0.5472	0.5131	0.7203	0.0851	-0.1181

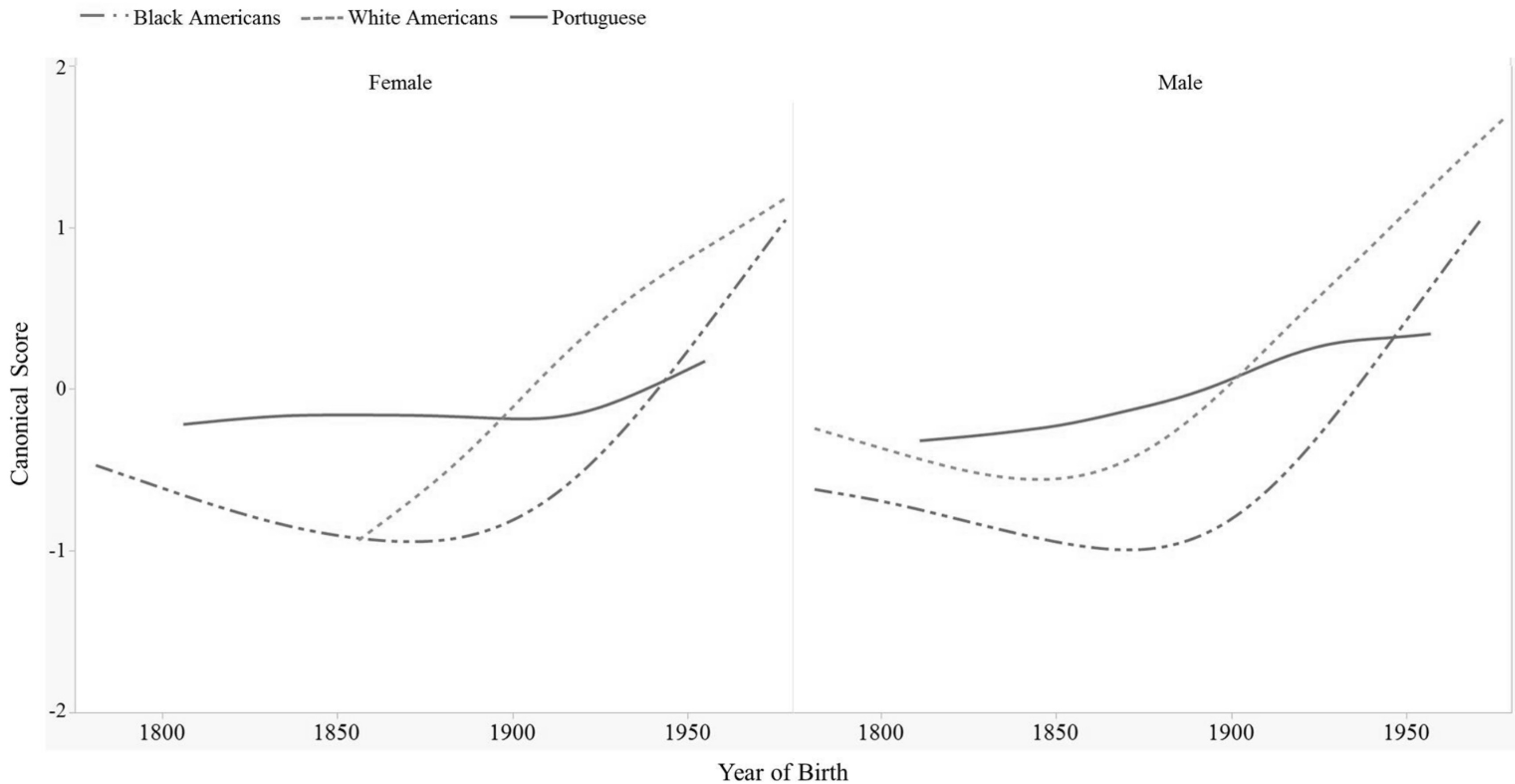

Figure 1. Smoothed plot of canonical score with year of birth for American Blacks, Whites, and Portuguese by sex.

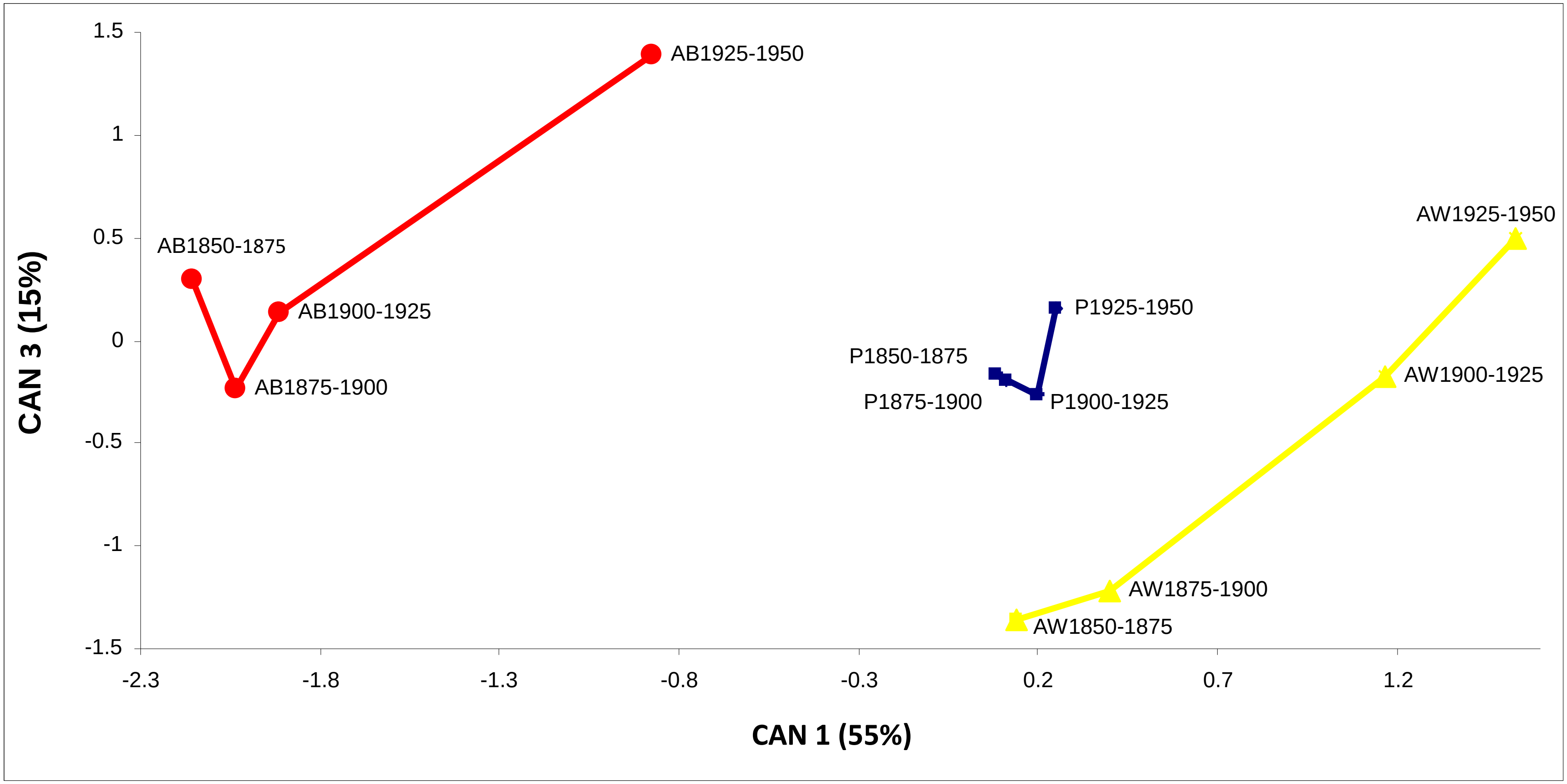

Figure 2. First and third canonical axes in 25-year birth cohorts in American Blacks (AB), American Whites (AW), and Portuguese (P).