A Critical Review of the Methodology for the Study of Secular Change Using Skeletal Data

John Albanese

Secular changes or secular trends are non-genetic changes that occur over multiple generations in a population. The changes are not due to evolution because there are no corresponding changes in allele frequencies in the population. These changes typically correspond with changes in living conditions and are reflected in the population means for growth and development, and not necessarily in any one individual. The most studied secular change is change in stature or height. Improvements in living conditions have resulted in measurable increases or positive secular changes in stature from parents to children. The most obvious cases have been observed when comparing first generation immigrants to their children. Conversely, decreases or negative secular changes in mean population stature from parents to children have been documented when living conditions worsen due to natural disasters, wars, or prolonged economic hardships.

Several sources of data can be used for the study of secular change in stature and body size including historical stature data (Steckel 1994) such as recruitment records (for example, Floud 1994; Mokyr and Gráda 1994) and stature measurements collected on cross-sectional samples specifically for research on stature (for example, Brauer 1982; Tobias 1986). Skeletal data are underutilized yet potentially useful sources of information for the study of secular change in stature as well as body proportions. With a few exceptions (Angel 1976; Jantz 2001; Jantz and Meadows Jantz 2000; Meadows Jantz and Jantz 1999; Ousley and Jantz 1998; Tobias 1986; Tobias and Netscher 1977; Trotter and Gleser 1951) osteometric data have not been used extensively for this purpose. In all of these studies a similar methodology has been used to investigate secular change using skeletal data. The purpose of this paper is to critically review this methodology and underlying theoretical concepts using empirical data (femur length) from three reference collections: the Robert J. Terry Anatomical Collection, the Coimbra Identified Skeletal Collection and the Forensic Anthropology Data Bank. The primary focus will be to investigate the effects of the current standard approach of combining samples from different reference sources into racial groups for the study of secular change. Because of the similarities among the sources of data, close comparisons are made between the results from the current study and Meadows Jantz and Jantz (1999), and to a lesser extent with Trotter and Gleser (1951) and Angel (1976).

Investigation of Secular Change Using Osteometric Data

Long bone length data can be used to assess stature and secular change. Using in vivo stature measurements and long bone measurements, Trotter and Gleser (1951) demonstrate that trends derived from stature data and long bone data are synchronized. However, the more robust approach is to use long bone length data since the derived stature will result in additional sources of error inherent in stature estimation equations and correction for the effects of age (Tobias 1986; Trotter and Gleser 1951). Long bone data may be superior to historical stature data for the following reasons:

1) Changes in limb and body proportions can be investigated along with absolute changes in any given skeletal element (Angel 1976; Meadows Jantz and Jantz 1999). Although stature measurements have been collected for centuries as a biometric component of per-

sonal identification in North America and elsewhere (Steckel 1994), other anthropometric data are relatively scarce (a rare exception is Greiner and Gordon 1992).

2) The use of modern, calibrated equipment produces greater precision of measurement (Meadows Jantz and Jantz 1999).
3) Accuracy related to the rounding of stature measurements in historical records is not a source of error with skeletal data. Rounding to whole inches, feet or meters and certain ages (even number, multiples of five, numbers ending in zero) is common in many data sources, including some modern studies (Steckel 1994). Although this problem can be corrected statistically (Steckel 1994), rounding can still mask, or magnify, modest positive or negative changes in stature.
4) It is possible to test and control for intra-observer measurement error and inter-observer measurement error if more than one person collects data.
5) Sources of measurement error associated with age, posture, or even wearing shoes during measurement are not an issue with long bone length data (Brauer 1982; Trotter and Gleser 1951).

The effects of age must be controlled in any investigation of secular change involving living stature in a cross-sectional sample (Brauer 1982). For example, Tobias (1986) found that after correcting for the effects of age on a cross-sectional sample, a positive secular change of 17 mm over the first five decades of the 20th century was actually a negative secular change of 2 mm over the same period. Because the sample was cross-sectional, those individuals in the earliest birth cohorts were also the oldest and were affected most by age-related changes (compression of joints, posture, etc.). In an analysis of uncorrected data from a cross-sectional sample it is impossible to separate age effects on stature from secular change in stature (Trotter and Gleser 1951).

With both skeletal and documented stature data, sampling and defining the parameters of the population can be problematic. For example, some of the biases of historical military stature data are obvious: only males are included. Other possible biases in military samples are much more complex. The level of representativeness of the military sample of the population will vary over time depending on approaches to recruiting, changes in entrance requirements, variation in socio-cultural and economic motivation for volunteering, and the phasing in and out of mandatory service (Greiner and Gordon 1992). Similarly, skeletal reference collections and cemetery samples are not random samples of the populations from which they were drawn (Albanese 2003; Hunt and Albanese 2005). A further complication is that the acquisition and cataloguing of skeletons in reference collections usually occurs over a short period producing a collection with a relatively narrow range of years of birth. Excavations of specific cemeteries to form collections may result in similar biases. In several studies, samples from different sources have been combined to extend the range of years of birth that are covered by any one sample. For example, Angel (1976) used data from many sources to investigate secular change in the entire skeleton in American "Blacks" and "Whites" in two periods. The first period, referred to as Colonial-American Civil War (1675-1879), was composed of samples from over two dozen family plots or small burial grounds in over a dozen states including New Mexico, Texas, Montana, New York, Virginia and Maryland. The second period referred to as modern middle class (with years of death between 1950 and 1975), was composed of a small number of bequeathed individuals from the Terry Collection, and 163 forensic cases where death was accidental.

In a more recent study, Meadows Jantz and Jantz (1999) used skeletal data to investigate secular change in bone lengths and limb proportions using six long bones: humerus, radius, ulna, femur, tibia, and fibula. Following Angel's (1976) approach, they combined data from four different sources (in overlapping chronological order): the Huntington Collection, the Terry Collection, World War II Casualties, and the Forensic Anthropology Data Bank (FDB). The data from these sources were combined into two racial categories, "Black" and "White," covering a range of years of birth from 1800 to 1979. They found that secular change was significantly greater in males than females, and greater in the lower limb bones than the upper limb bones. Differences were greater in "Whites" than "Blacks" but not at a statistically significant level.

Regardless of whether skeletal or historical stature data are used, the approach to sample construction and defining the parameters of the population are critical and affect inferences of secular change. There are several methodological problems that can produce misleading results when samples from different sources, which may not represent the same population, are grouped into racial categories. Amalgamating these individuals into a single sample can confound interpretations of secular change because it is not clear if the different sources of data that are sampled represent the same population. There are several possible explanations or interpretations if secular change is observed in a combined sample. Apparent change through time can be caused by: 1) secular change due to improving or worsening conditions if the different samples represent the same population, 2) genetic variation in different populations that just happen to be from different time periods, 3) differences in living conditions between two different populations that are coincidently separate in time, and 4) any combination of the above.

In contrast to Angel (1976) and Meadows Jantz and Jantz (1999), Trotter and Gleser (1951) used a different approach. They investigated secular change using two samples in two periods: the Terry Collection (years of birth 1840-1909) and World War II casualties (1900-1924). Unlike later investigations of secular change, these authors did not combine the samples but instead compared the pattern in the different samples:

> no attempt has been made to delineate a continuous curve for either stature or bone length based on data from the Terry Collection and from military personnel... *the two groups are not comparable in many respects.* Nevertheless, the trends presented by separate curves for the two sources of data may be compared and are seen to differ [Trotter and Gleser 1951:437; emphasis added].

Combining samples from different sources can confound interpretations.

Dividing samples from reference collections by "race" can produce equally misleading results. Overwhelming evidence indicates that the biological race concept is not applicable to Homo sapiens and that racial categories are not useful research tools for the study of phenotypic or genotypic variation (Armelagos and Goodman 1998; Brown and Armelagos 2001; Cartmill 1998; Keita and Kittles 1997; Lieberman 2001; Relethford 2001, 2002; Templeton 1998). Classification into racial groups has varied depending on the number of categories in the racial scheme, and the social criteria used to segregate "races," which have also varied over time and space in both popular and academic circles (Armelagos and Goodman 1998; Keita and Kittles 1997): "individuals can change their race by getting on a plane and flying from New York to Salvador or Port-au-Prince... what changes is not their physical appearance but the folk taxonomies by which they are classified" (Fish 1999:198). In a recent meta-analysis of genetic, protein and enzyme variation within and between racial groups, Brown and Armelagos (2001) demonstrate that considering samples in racial categories does not control for genetic differences. Even studies whose aim was to "maximize the amount of variance accounted for by race" (for example Hartmann et al. 1994; Nei and Roychouldhury 1982; Ryman et al. 1983) found clear evidence supporting the negative conclusions regarding race and genetics established over 30 years ago by Livingstone (1962) and Lewontin (1972). Using a combination of genetic evidence and craniometric data, Relethford (1994, 2001, 2002) reaffirmed these conclusions: 1) there is much more intra-race variation than inter-race variation; 2) race accounts for only about 6-13% of genetic and craniometric variation; 3) there is no concordance of human (genetic and craniometric) variation with racial categories, continental origin or skin pigmentation.

In the context of any discussion regarding skeletal reference collections, it is important to consider that the terms "White," "Black," "Negroid," "Caucasoid," etc. were terms applied by the people who were collecting skeletons (or data) at the end of the 19th century and throughout the 20th century based on changing social criteria and *perceived* phenotypic criteria. The phenotypic traits are described as perceived because racial categories cram continuous variation into discrete categories. Using a more benign and less politically charged example, what measured stature can separate "short" people from "tall" people?

It is problematic to assume that there is consistency in the criteria used by physical anthropologists over a century to assign any given individual to a specific racial group. It cannot be assumed that the criteria used by Huntington to classify someone in 1895 are the same criteria used by Terry in 1935, or Trotter in 1955. Even within any one collection there are likely many inconsistencies in the criteria used for racial designation. Popular and academic concepts of race changed a great deal over the six and a half decades during which the Terry Collection was created. Racial designation is even more complex in the FDB because racial designation is based on self reporting on ante-mortem documents. For the Huntington collection, the nationality of European individuals was documented when known. After it was moved to the Smithsonian Institution, Hrdlička (1934) began differentiating between "Whites" born in the U.S.A. and recent European immigrants to the U.S.A.

When Terry was designating race, he was trying to categorize continuous human variation (e.g. Terry 1932); racial designation in the FDB was based on an individual's perceived place in a society; and racial designation in the Huntington Collection was ascribed by Hrdlička (but current researchers are not limited by his classifications). The racial terms used to describe individuals do not necessarily have the same social connotations in each collection or even within any one collection and it is not possible to reconstruct how any of the collectors may have used these terms when classifying any one individual. For the major American anatomical collections (including the Terry and Huntington Collections), St. Hoyme and Işcan (1989:61) describe the racial designation as "social or legal, not biological, assessments, based on local custom." Even if the same criteria for classification were used, skin colour is not a proxy for either genetic or skeletal variation (Relethford 2002).

Methodological problems associated with using racial categories for the study of secular change or human variation in general are illustrated in the following analysis. Quotation marks are used around racial terms when referring to the categorization of individuals in the various reference collections to draw attention to the point that these terms have different meanings in each of the sources of data and for different individuals within each source of data. Unless otherwise stated, the term population refers to the statistical definition of population and not its biological meaning. A biological population is a group of interbreeding individuals that is relatively isolated from other similar groups in a species (Molnar 2002), whereas statistically, "a population always means the totality of individual observations about which inferences are to be made, existing anywhere in the world or at least within a definitely specified sampling area in space and time" (Sokel and Rohlf 1973:7). The distinction between a biological and statistical population is made because there is overwhelming genetic and phenotypic evidence that racial groups do not represent biological populations.

Materials and Methods

Sources of Skeletal Data

There is some overlap among the sample sources used by Meadows Jantz and Jantz (1999), Angel (1976), Trotter and Gleser (1951) and in this investigation. The four inquiries draw data from the Terry Collection and all but the Trotter and Gleser study use data from the FDB. For this study, data were also collected from the Coimbra Collection, a cemetery reference collection from Portugal. See Table 1 for details regarding sample sizes used in the current study. Ousley and Jantz (1998) and Meadows Jantz and Jantz (1999) describe the FDB in some detail. The single largest contributor to the database is Lawrence Angel (n = 182 cases) and the data bank undoubtedly includes many of the individuals used by Angel (1976) in his investigation of secular change. The FDB has data from individuals from almost the entire U.S.A. with a bias towards southeastern, northeastern, and southwestern states.

The Terry Collection was collected by Robert J. Terry and Mildred Trotter at the medical school at Washington University in St. Louis, Missouri, from the end of the second decade of the 20th century until 1967. Collection practices were very different under Terry and Trotter. Terry's interest in normal human skeletal variation resulted in a large sample of individuals being included in the collection with no gross pathological conditions. After Terry's retirement in 1941, Trotter concentrated on including almost exclusively younger "White" females in order to balance the demographic profile of the collection. In the collection, years of birth range from 1828 to 1943 with the majority falling between 1850 and 1920 (see Hunt and Albanese 2005 for more information about the Terry Collection).

The Terry Collection was derived from anatomy school cadavers. Most were unclaimed bodies from various hospitals and institutions in St. Louis and the State of Missouri who did not have the means to pay for their own burial. This fact alone strongly suggests that most individuals in the collection were of low socio-economic status, at least at the time of death. Only a relatively small number who died after 1955, about 10% of the entire collection, were people who bequeathed their bodies for scientific research. Angel (1976) drew his sample (19 females and 6 males) for the study of secular change from this small segment of the Terry Collection in an effort to sample what he described as modern middle class Americans. More detailed data on place of birth are available for a series of 107 individuals in the Terry Collection who died between July, 1926, and March, 1928. Although some of the individuals in this sub-sample were European immigrants or born outside the state, the single most common birthplace is Missouri. Sixty percent of the sub-sample were born in Missouri or the semicircle of states to its south and east including Arkansas, Louisiana, Tennessee, Mississippi, Alabama, Georgia, and Kentucky.

The Coimbra Collection (n = 505), is curated at the Museum of Anthropology at the University of Coimbra, Coimbra, Portugal. This collection consists of individuals who died between 1904 and 1936 and who were excavated from the common burial ground at the Cemitério de Conchada in the city of Coimbra (see Cunha 1995; Rocha 1995 for more information about the collection). The type of burial is strong evidence of low socio-economic status, and the available information on cause of death and occupation confirm this assessment (Cunha 1995). Information regarding nativity is available for 501 of 505 individuals in the Coimbra Collection. The single most frequent place of birth is the District of Coimbra, and 68% of the individuals in the collection were born in the District of Coimbra or the surrounding districts that share a border with Coimbra including Aviero and Viseu to the north, Guarda and Castelo Branco to the east, and Leiria to the south.

These three samples have overlapping ranges of years of birth that cover a period from the third decade of the 19th century to the last decade of the 20th century. The range of years of birth sampled in my study roughly corresponds with previous research: 1841 to 1977. However, Meadows Jantz and Jantz (1999) use data from American World War II casualties from the Pacific Theater collected by Trotter during repatriation of the remains. The latter source is reflected in the large sample size (n > 460 for the femur) for "White" males for the 1910-1919 and 1920-1929 cohorts (Meadows Jantz and Jantz 1999: Table 1). A portion of these military data were originally used by Trotter and Gleser (1951) in their study of secular change.

A second difference exists between the earliest part of the range of years of birth. The Coimbra Collection was used in my study. The Huntington Collection was used by Meadows Jantz and Jantz and was amassed by George S. Huntington at the end of the 19th century and beginning of the 20th century at the College of Physicians and Surgeons, New York and transferred after his death to the Smithsonian Institution's National Museum of Natural History in 1927 (Hunt and Albanese 2005). The Huntington and Coimbra Collections are similar in class composition and temporal representation. The Huntingdon Collection is made up of people of lower socio-economic classes who immigrated from Europe at the end of the 19th century (Meadows Jantz and Jantz 1999:59) and

Table 1. *Composition of the samples from three sources by sex and "race" for each birth cohort.*

	Coimbra Collection[a]		Terry Collection[b]				Forensic Data Bank[b]				Total			
Birth Cohort	F	M	WF	WM	BF	BM	WF	WM	BF	BM	WF	WM	BF	BM
<1875	45	46	11	20	9	14					56	66	9	14
1875-1899	59	58	20	20	44	41	1	1	1		80	79	45	41
1900-1924	15	14	39	13	48	34	11	33	18	32	65	60	66	66
1925-1949			3	7	2	2	19	52	8	19	22	59	10	21
1950+							40	52	10	18	40	52	10	18
Total	119	118	73	60	103	91	71	138	37	69	263	316	140	160

[a]Using current social criteria in Portugal, all the individuals in the Coimbra Collection sample would be considered "White."
[b]"Race" was assigned at the time each individual was included in the collection.
Note: F = female, M = male, WF = "White" female, WM = "White" male, BF = "Black" female, BM = "Black" male.

the Coimbra Collection consists of Portuguese people of lower socio-economic classes who remained in Europe from about the same time period. There are, however, some obvious differences between these Collections. The Huntington Collection was derived from cadavers that were used for anatomical instruction, whereas the Coimbra Collection was excavated from a common burial ground. Neither collection is necessarily representative of Europeans (geopolitical or racially). Most importantly neither should be combined with "Whites" from the Terry Collection or the FDB for the study of secular change.

Data Collection and Sample Size

Although other researchers have used combinations of long bone lengths, cranial measurements and various indices, in this study only femur length data are used. If it can be demonstrated that there are methodological problems with combining samples from different sources into racial groups using femur length measurements, then *the same should be true regardless of which variable is used*. The goal of this paper is to highlight problems associated with sample construction and population parameters rather than to investigate secular change in any given variable.

Maximum femur length was collected by the author from both the Terry (n = 327) and from the Coimbra (n = 237) Collections, while data from the FDB (n = 317) were collected by different contributors to the FDB. The samples were divided into five 25-year birth cohorts in order to maximize the sample sizes within each cohort. The date of birth is not readily available for most of the individuals in the Terry and Coimbra Collections. Year of birth was calculated by subtracting the age at death from the year of death for each individual. Individuals whose year of death or age at death were in any way suspect where excluded from the analysis (see Hunt and Albanese 2005 for more information on assessing the accuracy of these data for the Terry Collection). Individuals were included in the FDB sample only if they were positively identified. For the samples from all three data sources, ages are between 18 and 80 years. Details on the composition of the three samples by sex and "race" (as described by the collectors) for each birth cohort are available in Table 1.

Intra-observer and Inter-Observer Measurement Error

Femur length data were re-collected for a subsample of 66 individuals from the Coimbra Collection (n = 13 males and 13 female) and the Terry Collection (n = 20 males and 20 females) to assess intra-observer measurement error. Percent intra-observer measurement error was calculated using the following equation:

$$\%\text{Intra-observer Error} = \frac{\text{Absolute Value (Measurement 1-Measurement 2}}{\text{Measurement 1}} \times 100$$

Percent intra-observer error was determined for each of the 66 individuals. Mean percent intra-observer measurement error is 0.06% with a range from 0 to 0.46%.

Some of the cases in the FDB (n = 135) are Terry Collection individuals who were born after 1898. Eight of these individuals from the FDB overlap with the intra-observer error sample collected by the author, and therefore, it is possible to assess the level of inter-observer measurement error. Following a similar approach used for the assessment of intra-observer error, the percent inter-observer error was calculated using the following equation:

$$\text{\%Intra-observer Error} = \frac{\text{Absolute Value (Measurement 1-FDB Measurement}}{\text{Measurement 1}} \text{x100}$$

As with the intra-observer error, the mean inter-observer measurement error is also 0.06%. The range of inter-observer error is 0 to 0.23%. Although the sample size for the assessment of inter-observer measurement is small, it follows a pattern similar to the intra-observer measurement error and suggests overall that the effect of these kinds of measurement errors is negligible. None of the individuals from the Terry Collection that are represented in the FDB and collected by this author were included in the FDB sample used in this study.

Statistical Approach

One-way analysis of variance (ANOVA) procedure was used in this study because post hoc tests can be used to assess significant differences between specific birth cohorts and sub-samples within each birth cohort. Statistical tests using one-way ANOVA were conducted in three separate phases using SPSS 9.0 for Windows (SPSS 1998). First, the samples from the three data sources (the Coimbra Collection, the Terry Collection and the FDB) were combined by previously defined "race" in order to look for significant differences in mean femur length over time separately for "Black" males, "White" males, "Black" females and "White" females. This first phase was an attempt to reproduce the previous approaches that have used skeletal data for the study of secular change (for example, Angel 1976; Meadows Jantz and Jantz 1999; Ousley and Jantz 1998). In the second phase of testing, data from each collection were analyzed separately in order to test for significant differences in mean femur length over time within each collection. For example, is there a significant secular change in femur length in Coimbra Collection males? In the third phase, birth cohort was held constant and variation within each cohort was compared in order to assess whether it is appropriate to divide the samples by "race." For example, are there significant differences in mean femur length among Terry Collection "Black" males, "White" males, "Black" females and "White" females, and Coimbra females and Coimbra males in the 1875-1899 cohort?

In all three phases Tukey's HSD (honestly significant difference) test was used *post hoc*. A number of different post hoc tests can be used with one-way ANOVA. Tukey's HSD test was selected for several reasons. First, as the name implies the test is neither too conservative (as with the Scheffe or Bonferroni tests) nor too liberal (as with the LST, least significant test) in assessing significant differences when compared to other post hoc tests. Second, Tukey's HSD is both a multiple comparison test (pairwise comparisons are made between means to identify significant differences) and a range test (similar means are grouped into homogeneous subsets). Thus, when birth cohort is held constant, it is possible to assess whether racial or other more relevant criteria should be used to define sub-samples, and it is possible to assess in which cohorts there are significant changes in long bone lengths. In Tables 2, 3, and 4, the significance values at the bottom of each column indicate that there are no significant differences between the sub-sample means listed in that column. These significance values should not be confused with the overall F and p values for the one-way ANOVA analysis.

Results

Phase I

The mean femur lengths for each sub-sample spanning five birth cohorts are presented graphically in Figure 1a. There seems to be a positive secular change in all four sub-samples, although it is slight in some cases. Separate one-way ANOVA tests for each sex and "race" sub-sample seem to suggest different patterns of change over time for each "race." For "White" females, the two birth cohorts before 1900 are significantly smaller than the three cohorts after 1900 ($F = 14.168$, $p <$

Table 2. *Homogeneous subsets (using Tukey HSD post hoc) of mean femur length for sex and "race" groups divided into five birth cohorts. All means are in mm.*

"White" Females				"Black" Females		
Cohort	**n**	**subset 1 (mean)**	**subset 2 (mean)**	**Cohort**	**n**	**subset 1 (mean)**
<1875	56	412		<1875	9	432
1875-1899	80	413		1875-1899	45	439
1900-1924	65		429	1900-1924	66	441
1925-1949	22		436	1925-1949	10	448
1950+	40		439	1950+	10	443
sig.		1.000	0.263	sig.		0.483
"White" Males				**"Black" Males**		
<1875	66	447		<1875	14	482
1875-1899	79	451		1875-1899	41	478
1900-1924	60		467	1900-1924	66	481
1925-1949	59		476	1925-1949	21	487
1950+	52		474	1950+	18	483
sig.		0.915	0.156	sig.		0.714

Table 3. *Homogeneous subsets (using Tukey HSD* post hoc*) of mean femur length for each sex in the 1900-1924 birth cohort. All means are in mm. Te = Terry Collection; FDB = Forensic Anthropology Data Bank.*

Females				Males			
Group	**n**	**subset 1 (mean)**	**subset 2 (mean)**	**Group**	**n**	**subset 1 (mean)**	**subset 2 (mean)**
Coimbra	15	407		Coimbra	14	450	
Te "White"	39		433	Te "White"	13	470	470
Te "Black"	48		439	Te "Black"	33		473
FDB "White"	11		445	FDB "White"	34		474
FDB"Black"	18		446	FDB "Black"	32		489
sig.		1.000	0.444	sig.		0.089	0.138

0.0001). Similarly, for "White" males, the two birth cohorts before 1900 are significantly smaller than the three cohorts after 1900 (F = 21.860, p < 0.0001). "Blacks" seem to follow a different pattern than "Whites." There is no significant change in mean femur length over time for "Black" females (F = 1.361, p = 0.251) or "Black" males (F = 0.493, p = 0.741). Homogeneous subsets for each sex and "race" sub-sample are presented in Table 2.

Phase II

The pattern of secular change is similar for each sex and "race" sub-sample *within* each source of data. There is no significant secular change in any of these sub-samples when examined separately. In Figure 2a, the means for "White" females in each birth cohort are plotted along with the means for "White" females separately by data source. The significant positive secular change in "White" females described above disappears when the sample is considered separately by data source. There are no significant changes in mean femur length in Coimbra Collection females (F = 0.052, p = 0.949), Terry Collection "White" females (F = 0.166, p = 0.919), or FDB "White" females (F = 0.481, p = 0.620). In Figure 2b, the means for "White" males in each birth cohort are plotted along with the means for "White" males separately by data source. As with the "White" females, the significant positive secular change in the combined sample of "White" males disappears when the samples are considered separately by data source. There are no significant changes in mean

Table 4. *Homogeneous subsets (using Tukey HSD* post hoc*) of mean femur length for four birth cohorts.**

<1875

Group	**n**	**subset 1 (mean)**	**subset 2 (mean)**	**subset 3 (mean)**	**subset 4 (mean)**
Co Fe	45	408			
Te "White" Fe	11	430	430		
Te "Black" Fe	9		432		
Co Ma	46		445	445	
Te "White" Ma	20			464	464
Te "Black" Ma	14				482
sig.		0.075	0.385	0.154	0.256

1875-1899

Group (mean)	**n (mean)**	**subset 1 (mean)**	**subset 2 (mean)**	**subset 3 (mean)**
Co Fe	59	407		
Te "White" Fe	20		429	
Te "Black" Fe	44		438	
Co Ma	58		442	
Te "White" Ma	20			463
Te "Black" Ma	41			478
sig.		1.000	0.197	0.109

1925-1949

Group	**n**	**subset 1**	**subset 2**
FDB "White" Fe	19	437	
FDB "Black" Fe	8	445	
FDB "White" Ma	52		476
FDB "Black" Ma	19		488
sig.		0.695	0.407

1950+

Group	**n**	**subset 1**	**subset 2**
FDB "White" Fe	40	439	
FDB "Black" Fe	10	443	
FDB "White" Ma	52		474
FDB "Black" Ma	18		483
sig.		0.958	0.608

*All means are in mm. Te = Terry Collection, Co = Coimbra Collection, Fe = female, Ma = Male

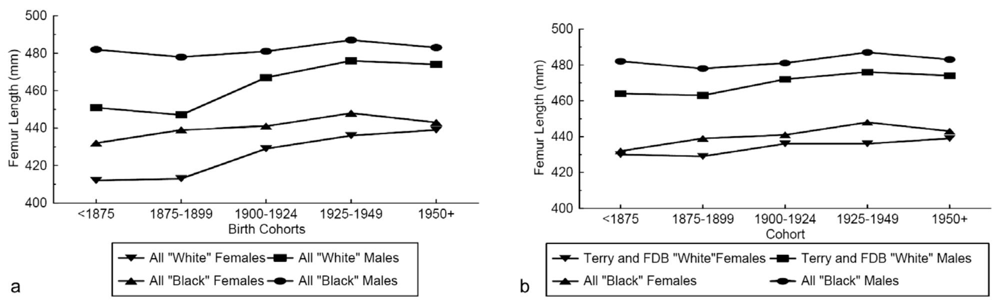

Figure 1. *Mean femur lengths for each sex and "race" group by birth cohort with Coimbra Collection data (a) and without Coimbra Collection data (b). See Table 1 for sample sizes.*

femur length in Coimbra Collection males (F = 1.040, p = 0.357), Terry Collection "White" males (F = 1.119, p = 0.349), or FDB "White" males (F = 0.144, p = 0.866). A similar breakdown by data source for "Black" females and males are plotted in Figure 2c and Figure 2d, respectively. The lack of significant differences in the combined sample is also seen when the samples are separated by data source. There are no significant secular changes in mean femur length of Terry Collection "Black" females (F = 0.587, p = 0.625) or males (F = 0.273, p = 0.844) nor are the changes significant for FDB "Black" females (F = 0.428, p = 0.655) or males (F = 0.381, p = 0.684).

Phase III

When birth cohort is held constant and the femur length means are compared, there are no significant differences between racial categories in any given birth cohort. Table 3 includes the homogeneous subsets of sub-samples for the 1900-1924 cohort in which all three sources of data overlap. The Coimbra females are significantly different from the "White" and "Black" females in the birth cohort (F = 7.198, p < 0.0001) and there are no significant differences between "Black" and "White" females from the Terry Collection or the FDB. The pattern is very similar for males. Coimbra males are significantly different from Terry Collection "Black" males, FDB "Black"

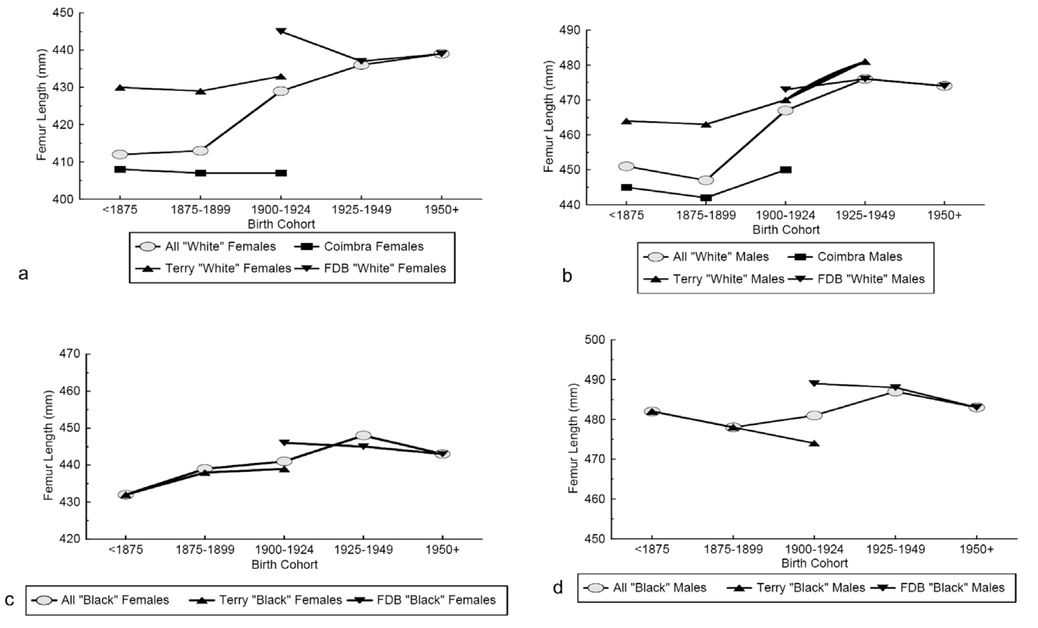

Figure 2. *Femur length means of samples combined by "race" and separately for each source of data: (a) "White" females, (b) "White" males, (c) "Black" females, (d) "Black" males. See Table 1 for sample sizes.*

males and FDB "White" males (F = 5.655, p < 0.0001), and there are no significant differences between "Blacks" and "Whites" from the Terry Collection or the FDB. Homogeneous subsets in Table 3 group Terry Collection "White" males with Coimbra Collection males and with all other males from the Terry Collection and the FDB. Stated another way, Terry Collection "White" males are not significantly different from Coimbra males nor from all other males from the Terry Collection and the Coimbra collection.

Results for the other four birth cohorts are presented in Table 4. The pattern is consistent for all birth cohorts except for the slight variation in the earliest cohort. In the earliest birth cohort, there are significant differences between Coimbra females and all other sex and "race" sub-samples except Terry Collection "White" females; Coimbra Collection males are significantly smaller than Terry Collection "Black" males but not Terry Collection "White" males (a pattern similar to the 1900-1924 cohort) (F = 32.235, p < 0.0001); and there are no significant differences between "Blacks" and "Whites" of either sex in the Terry Collection. In the 1875-1899 cohort, there are significant differences between Coimbra females and all other sex and "race" sub-samples; Coimbra Collection males are so small that they are not significantly different than Terry Collection females regardless of "race" (F = 53.951, p < 0.0001); and there are no significant differences between "Blacks" and "Whites" of either sex in the Terry Collection. In the two most recent birth cohorts (1925-1949 and 1950+), there are no significant differences between "Blacks and "Whites." Males from the Terry Collection and the FDB are grouped together regardless of "race" and the females from these two sources are grouped together regardless of "race."

Discussion

Despite the differences in the sources of data (Coimbra Collection instead of Huntington Collection and lack of World War II casualty data), the results from the first phase of analysis are similar to the results of Meadows Jantz and Jantz (1999: Figure 1d). Both studies show overall positive changes in "Blacks" and "Whites" of both sexes although they are not always large increases (as with “Black” males) or significant in the current study. The greatest similarities occur in the birth cohorts starting at 1900 in both studies except for “White” females in the Meadows Jantz and Jantz (1999) study. With the exception of these “White” females, both studies show increases in femur length beginning at about 1900 (Figure 1a). Larger 25-year cohorts in this study make it appear as if the increase is beginning earlier when the data are presented graphically (Figure 1a). Despite the lack of World War II casualty data, the pattern for “White” males over the entire range of years of birth included in this study closely resembles the pattern described by Meadows Jantz and Jantz (1999). A relatively flat or slightly negative trend changes suddenly into a large positive trend around 1900. By the fourth decade of the 20th century femur length levels off and then seems to decrease slightly.

The results from phase II of the statistical analysis clearly show that the significant positive secular change seen in “Whites” and the positive, but not significant, changes in “Blacks” are the result of combining samples that represent different groups with different mean femur lengths that are coincidently separated in time (Figure 2). It is a fair assumption that any significant positive secular change in the combined sample should also appear in each of the different sources of data when analyzed separately. For example, the significant positive change in “White” females over time should appear at least as a positive, if not significant, change when the data from the different data sources are analyzed separately. Figure 2a does not reflect this pattern. Although the femur length does increase slightly (3 mm) for the Terry Collection “White” females over the 85 years covered by the first three birth cohorts, the femur length in Coimbra Collection females decreases by 1 mm over a similar period and femur length of the FDB “White” females decreases by 6 mm from the 1900-1925 cohort to the most recent cohort. In all three sources of data, testing in phase II shows that slight negative and slight positive changes are not significant. The significant positive trend is clearly only an average that results from the combination of data that represent different populations rather than any real secular change in the combined sample. The pattern in Figures 2b and 2c and the lack of significance of change over time for any sub-sample within a data source suggest that a similar pattern exists for “White” males and “Black” females. The pattern for “Black” males in Figure 2d *appears* to be different. The two negative, though not significant, trends in the Terry Collection “Black” males and FDB “Black” males result in a false cyclical trend in mean femur length over time when the data from these two sources are combined. Not surprisingly, the flat lines for Terry Collection “White” and “Black” males mirror the results of Trotter and Gleser (1951) who also used samples from the Terry Collection.

As noted above, there is an increase in femur length around 1900 in all sub-samples described in this study and the Meadows Jantz and Jantz (1999) study except for their “White” female sample. After analyzing the sources of data separately, it is clear that in my study the increase in femur length occurs in all sex and “race” sub-samples because the 1900-1924 cohort is the transitional cohort where the main sources of data change from the Coimbra Collection and Terry Collection around the turn of the 19th century to the Terry Collection and the FDB at the beginning of the 20th century. Similarly, the shift in the source of data to almost exclusively the FDB in the 1925-1949 birth cohort, and exclusively the FDB in the most recent birth cohort, results in an apparent halt in the increase in femur length or even a slight decrease in femur length (Figure 1a). The same pattern is visible in three of four sub-samples in the Meadows Jantz and Jantz (1999) study, which suggests that the changes in the source of data are having a similar effect on their results. In the first cohort and then the fourth cohort of the 20th century, the source of data shifts as well. The shift in data source is different for males and females. For “White” and “Black” females, the data source shifts from the Terry Collection at the end of the 19th century to the Terry Collection and FDB in the first cohort of the 20th century, and then to FDB data exclusively in the fourth cohort of the 20th century. Although the source of data changes in the same cohorts for

"White" females, the cohorts likely follow a different pattern because of stochastic variation resulting from small sample sizes in the narrower 10-year cohorts used by Meadows Jantz and Jantz (1999). Their sample size for "White" females fluctuates from 4 to 25 for each birth cohort from 1840-49 to 1920-29.

For males, the data sources shift from the Terry Collection to the FDB and World War II casualties, which is obvious because of the sudden jump in sample size in the 1910-1919 and 1920-1929 cohorts for "White" males (Meadows Jantz and Jantz 1999: Table 1). The sample size for "Black" males does not increase substantially over this period because there are significantly fewer "Black" World War II casualties in the sample collected by Trotter and Gleser (1951:429) and used by Meadows Jantz and Jantz (1999). The sudden halt in the increase of femur length in the 1930-1939 cohort for "White" and "Black" males in the Meadows Jantz and Jantz (1999) study corresponds with a second major shift in their source of data from overwhelmingly World War II casualty data to exclusively FDB data. In all but one case ("White" females in the Meadows Jantz and Jantz [1999] study where sample size is very small) in both studies, the large increases and decreases in femur length, whether significant or not, correspond to changes in the sources of data. If Trotter and Gleser (1951) had also combined their data from the Terry Collection and World War II casualties, they would have found a similar sudden increase in femur length after 1900.

The first phase of analysis seems to suggest that there are different patterns in secular change for "Blacks" and "Whites." "White" males and females seem to show a significant secular change whereas, the apparent positive change in "Black" males and females is not significant. In Figure 1b, the Coimbra Collection individuals are excluded from the "White" male and female samples, and as a result, the change over time in "Whites" is very similar to the "Black" pattern. The apparent differences between "Black" and "White" females and "Black" and "White" males disappear in the earliest two cohorts (compare Figure 1a with Figure 1b). As with "Black" males, the difference in mean femur length over time for this combination of "White" males that excludes the Coimbra Collection sample is not significant ($F = 2.038$, $p = 0.091$). Similarly, the difference is not significant for "White" females ($F = 0.829$, $p = 0.509$). The combination of data that included the Coimbra Collection in the "White" sub-sample is statistically significant because the males and females in the Coimbra Collection are much smaller and coincidently have earlier average birth years. In several birth cohorts the Coimbra females are significantly shorter than both the Terry Collection females and the FDB females, and Coimbra males are significantly shorter than the Terry Collection and FDB males. In fact, Coimbra males are so small that they are consistently and significantly grouped with Terry Collection and FDB females (Table 4). Thus, the pattern of secular change may seem to be different for "Blacks" and "Whites" depending on which combinations of samples are used.

The different sources of data, therefore, make it impossible to interpret the cause of the greater secular change in "White" males. It could be a greater improvement in living conditions for "White" males, a sex difference in response to improved living conditions, or a statistical anomaly resulting from the inclusion of a large number of "White" males from different data sources. As Meadows Jantz and Jantz (1999) note, it is critical that males and females in a sample come from similar sources if sex differences in secular change are being investigated. However, it is absolutely essential that all the males and all the females combined into one sample from different data sources (FDB, Terry Collection, Coimbra Collection, Huntington Collection) represent the same geopolitical, socio-economic and biological population when investigating secular change.

Combining data from different populations will only produce confounded or misleading results. For example, an analysis that combines the Coimbra Collection sample with the Terry Collection "Whites" provides no basis for inferences about secular change in a "White" population. Aside from the possible genetic differences in the two populations represented in these two samples, the Coimbra and Terry Collections simply have too many micro and macro socio-economic and geopolitical differences. The Terry Collection (regardless of "race") and the Coimbra Collection are samples of two populations from Missouri (and surrounding states) and Coimbra (and surrounding districts), respectively, which have different biocultural histories. Their differences do not just result from differences in birth cohorts. Similarly, combining "Whites" from the Terry Collection (mostly Missouri and neighbouring states) with "Whites" from the Huntington Collection (mostly first generation European immigrants) who where born on average a couple of decades earlier does not reveal anything about secular change in a "White" population. It does, however, show that the poorer immigrants who were eventually included in the Huntington Collection are smaller than the poorer residents of Missouri and surrounding states who were eventually included in the Terry Collection.

The clear skeletal differences between the Coimbra and the Terry Collection, when birth cohort is held constant, do strongly suggest that these two samples should not be combined for the study of secular change. Similarly, the pattern in femur length in "Whites" and "Blacks" (Figure 1a and Figure 1b) with major changes occurring in cohorts that are transitional from one data source to the next suggest that the Terry Collection and the FDB may represent different populations. Furthermore, there are many other non-skeletal differences between these two sources of data that must be considered. The FDB is a selective sample of most of the U.S.A. whereas the Terry Collection is a selective sample of a cluster of about a half dozen states. Aside from socio-economic and geopolitical factors, complicated issues related to how the collections were amassed must also be considered. It has been stated by some authors (for example, Angel 1976; Ericksen 1982; Ousley and Jantz 1998) that the Terry Collection may not be representative of the greater American population because it was derived from a cadaver sample. The sources and magnitude of biases are actually much more complex. For example, changes in collecting practices by Trotter after Terry's retirement corrected some biases in the collection while increasing others (Hunt and Albanese 2005). These changes were due to Trotter's efforts to correct what she saw as a shortcoming in the collection, and a massive change in popular views of human dissection and anatomical instruction in the U.S.A. following the Second World War. The approach used by Terry (and then Trotter for the Terry Collection) for creating collections was very different than that used for the FDB (which also includes a very selective sampling of the Terry Collection). The specific biases of each source of data will have a different (though not necessarily negative) impact on different research questions depending on the relative importance of age, year of birth, and cause of death.

This study shows that controlling for "race" when constructing a sample or defining the parameters of a population only further confounds the analysis of secular change. There are methodological costs for using racial categories in this manner. As a methodological tool, the race concept is not a useful criterion for defining subsamples or populations for the study of secular change using reference collections. When the femur length data are presented graphically by "race," it seems as if "Black" males are consistently larger than "White" males and that "Black" females are consistently larger than "White" females in any given cohort. However, the results presented in Table 4 are very clear. In any given cohort, there are no significant differences between "Blacks" and "Whites" in the Terry Collection and the FDB, and there is no evidence from the femur length data to suggest that "Whites" and "Blacks" in the Terry and FDB collections should be analyzed separately. Males are consistently grouped together regardless of "race" and females are constantly grouped together regardless of "race." Furthermore, this approach is problematic for investigating the detrimental effects of racism. Combining samples by race in this manner reveals little about the effects of racism and related socioeconomic disparity on skeletal growth. It is not safe to assume that the same criteria to describe race were used by Huntington, Terry, Trotter or any of the self-reporting in the FDB. Thus, if the social criteria for classification in any given "race" have varied over time, then combining data from diverse sources that represent different populations where samples were segregated based on inconsistent social criteria reveals nothing about the impact of racism on living conditions and secular change.

The results of this study indicate that division of samples by "race" for the study of secular change in bone size is not methodologically sound, and that there is no evidence to suggest that males and females should be combined for an analysis of secular change. Beyond obvious sexual dimorphism, there is some evidence that males and females do react differently to changes in living conditions (Brauer 1982; Greulich 1951; Greulich et al 1953; Stini 1975, 1982; Stinson 1985; Tobias 1972, 1975). It is possible that these sex differences will appear in an analysis of secular change, although 25 year birth cohorts may be too broad to detect differences related to specific, acute incidents of improvement or worsening of conditions. However, one essential reason why males and females must be analyzed separately is that equal numbers of males and females are not always available for each birth cohort when using data from reference collections. Although not all males are larger than all females, males are significantly larger than females in femur length and many other variables. Differences in the proportion of males and females from cohort to cohort would result in what might appear to be secular change.

Conclusion

There are several benefits to using skeletal data for the study of secular change in stature and limb proportions. With skeletal data, different types of measurement error can be controlled or minimized and it is possible to investigate changes in absolute size, and body and limb proportions over time for both sexes. In this study, femur length data have been used for illustrative purposes; however, issues related to how samples are constructed for the study of secular change are relevant regardless of which variables are used. This study has shown that some caution must be exercised, and offers three major conclusions:

1) Combining data from different sources without confirming that the samples represent the same biocultural group can produce very misleading results. The focus in this study has been on skeletal data to highlight the differences between sources of data; however, other criteria must be considered before samples from different sources are combined. Socioeconomic and geopolitical criteria, and biases in the collection process when the data sources were amassed (which can amplify or minimize the effects of these criteria), must be considered before samples are combined for the study of secular change. Combining data from different sources without considering these factors will result in other sources of variation being attributed to secular change. However, for some research it is very advantageous to combine data from multiple sources. For example, the differences between the Coimbra Collection and the Terry Collection can actually be exploited to construct a reference sample to develop metric sex determination methods that can be applied successfully to both small and large individuals (Albanese 2001a, 2001b, 2002, 2003).
2) Dividing samples into racial groups does not control for differences between the sample sources. There is some evidence (documented nationality, place of birth, bequeathed versus not bequeathed, etc.) that the Terry Collection may not represent a single population, but there is no evidence that dividing samples from the same data source by "race" in any way controls for this possible lack of homogeneity. There are methodological problems with the use of the race concept to define samples for the study of human variation. Race is neither a biological concept that applies to humans nor a fixed social category. Variation through time in the social criteria used for racial designation raises problems even when investigating the effects of racism on secular change using reference skeletal collections.
3) It is essential that males and females be considered separately when investigating secular change for biological reasons and for reasons related to possible variation over time in the sex proportions in the study sample.

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John Albanese, Department of Sociology, Anthropology and Criminology, University of Windsor, Ontario