Nineteenth Century Black and White US Statures: The Primary Sources of Vitamin D and their Relationship with Height

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Abstract

Vitamin D is vital in all vertebrates because it allows them to absorb more calcium from their diets, contributing to stronger skeletal systems and stature growth. Using a new source of 19th century US state prison records, this study contrasts the statures of comparable African-Americans and whites by the primary sources of vitamin D production: time exposed to solar radiation, skin pigmentation, and nativity. Greater insolation (vitamin D production) is documented here to be associated with taller black and white statures, and a considerable share of the stature differential by socioeconomic status was related to insolation.

JEL Code: I10, J01, J15, J16, N81.

Keywords: socioeconomic status, vitamin D, insolation, 19th century US statures.

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1. Introduction

Modern studies illustrate the beneficial role that vitamin D has on health outcomes,[1] and the pathways by which vitamin D influences health have come into focus. Vitamin D helps calcium absorption, facilitates bone formation, and stature growth; vitamin D also acts as an autoimmune regulator and may limit hyper proliferate cell growth, subsequently, the spread of cancer (Holick, 2004, p. 366). Unlike other vitamins and nutrients, the primary source of vitamin D is not dietary but is produced internally in the stratum corneum by the synthesis of sunlight and cholesterol. Vitamin D production is therefore related to the physical environment, indicating occupations are related to vitamin D production.[2] This paper uses a large source of 19th century US male prisoners to illustrate how stature variation was associated with the three most important sources of vitamin D production, which, in order of importance, are the amount of time exposed to sunlight, skin pigmentation, and nativity (Holick et al., 1981, p. 590).

Vitamin D is related to statures and statures are used to measure biological and economic conditions in both contemporary and historical studies. A populations' average

[1] Multiple cancers—including prostate, colorectal, breast, and ovarian—are linked to insufficient vitamin D. Other chronic diseases, such as multiple sclerosis and rheumatoid arthritis, have been tied to insufficient vitamin D consumption.

[2] Recognizing the incidence of rickets, in the 1930s, the US government advocated the supplementation of the US milk supply with vitamin D to promote stronger bone formation.

stature reflects the net cumulative balance between nutrition, disease exposure, work, and the physical environment. By considering average versus individual stature, genetic differences are mitigated, leaving only the influences of the economic and physical environments on stature. When diets or the physical environments improve, average stature increases and decreases when diets become less nutritious, disease environments deteriorate, or the physical environment places more stress on the body. Greater direct sunlight (insolation) produces more vitamin D, and vitamin D is related to adult terminal stature (Xiong et al, 2005, pp. 228, 230-231; X-ZLiu et al, 2003; Ginsburg et al 1998; Uitterlinden et al, 2004).[3] Hence, stature provides significant insights into understanding historical processes, especially in the 19th century US, where other measures for living standards are limited.

It is against this backdrop that this paper considers a sample of over 180,000 19th century black and white male inmates that covers from slavery, through Reconstruction, and the end of the 19th century.[4] Two issues are considered. First, because occupations represent time spent outdoors, what was the relationship between stature and insolation by occupation? Results presented here illustrate that workers who worked outdoors, such as farmers and laborers, were taller than workers who worked indoors, such as white-collar and skilled workers, indicating that taller statures were associated with exposure to

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[3] Insolation is an acronym for incident solar radiation, and is a measure for sunlight energy received for a given surface area at a given time. If w equals watts, m equals meters, and i equals insolation,

$$i = \frac{w}{m^2} = \frac{kwh}{m^2 \cdot day}.$$

[4] The total number of inmates recorded in the Texas prison between 1873 and 1922 is over 50,000. This includes nearly 8,000 observations of Mexicans, females, and Europeans not considered here.

direct sunlight. Second, after considering socioeconomic status, what were the primary sources of stature variation?[5] The majority of 19th century stature differentials by socioeconomic status were attributable to insolation and race, indicating that the primary source of vitamin D production were the amount of time spent outdoors, skin pigmentation, and nativity.

2. Vitamin D, Calcium, and 19th Century Black and White Statures

Any comparison between 19th century black and white statures must account for an ironic finding. Black and white statures have the ability to reach comparable average levels when brought to maturity under similar biological conditions (Eveleth and Tanner, 1966, Appendix. Tables 5, 29, and 44; Tanner, 1977, pp. 341-342; Margo and Steckel, 1982). However, 19th century black and white statures demonstrate that blacks were consistently shorter than whites, but we are less certain of the source for this difference (Margo and Steckel, 1982; Sünder, 2004; Carson, 2008). Moreover, any explanation must account for a robust geographical finding: Southern blacks were shorter than Southern whites, and Northern blacks were shorter than Northern whites (Margo and Steckel, 1992, p. 516). A common explanation for taller mulatto statures is that 19th century social and economic forces favored fairer complexions over lighter complexions, and lighter colored blacks benefited from these social and economic institutions (Margo and Steckel, 1982, p. 521; Bodenhorn, 1999, p. 983). An additional explanation for this

[5] Margo, Robert and Richard Steckel, "Heights of American Slaves," 519. Modern studies demonstrate that well-fed Americans of African descent reach approximately the same statures as Europeans and Americans of European descent; hence, variation in genetics may play minor roles in black-white stature differentials.

white stature advantage and why Southerners were taller than Northerners may be related to biology, especially its relation to geography (Carson, 2008, pp. 822-825). Calcium and vitamin D are two chemical elements required throughout life for healthy bone and teeth formation; however, their abundance are most critical during younger ages (Wardlaw, Hampl, and Divilestro, 2004, p. 394-396; Tortolani et al, 2002, p. 60). Calcium generally comes from dairy products, and vitamin D is typically not dietary but its primary source is the synthesis of cholesterol and sunlight in the epidermis' stratum granulosum (Holick, 2004, pp. 363-364; Nesby-O'dell, 2002, p. 187; Loomis, 1967, p. 501; Norman, 1998, p. 1108; Holick, 2007).

Vitamin D is vital in all vertebrates because it allows them to absorb more calcium from their diets and contributes to stronger skeletal systems (Jablonski, 2006, p. 62).[6] After the circulatory system contains sufficient amounts of vitamin D and to avoid vitamin D toxicity, vitamin D production is restricted within the stratum granulosum and residual vitamin D is broken down into inert matter (Holick et al, 1981, pp. 591-592; Jablonski, 2006, p. 62; Holick, 2001, p. 20; Holick, 2004, p. 363). This self-limiting vitamin D effect may account for some of the difference between how black and white statures were associated with insolation, because at North American latitudes whites are closer than blacks to the natural threshold where vitamin D production is curtailed (Carson, forthcoming). At the opposite extreme, insufficient vitamin D has been linked to rickets, osteomalasia, auto-immune diseases, and certain cancers (Holick, 2001, p. 28; Garland et al, 2006, pp. 252-256; Grant et al, 2003, p. 372).

Vitamin D production also depends on melanin (skin pigmentation) in the stratum corneum (Norman, 1998, p. 1108), and lighter colored 19th century blacks were

[6] There are few dietary sources of vitamin D.

consistently taller than darker pigmented blacks (Tanner, 1977; Steckel, 1979, pp. 374-376; Margo and Steckel, 1982, pp. 532-34, Table 6; Bodenhorn, 1999, 2002; Xiong et al, 2005, pp. 228, 231; Z Liu, 2003, p. 825). Higher melanin concentrations in the stratum corneum interferes with vitamin D's synthesis in the stratum granulosum, and darker pigmentation filters between 50 to 95 percent of the sunlight that reaches the stratum granulosum (Jablonski, 2006, p. 80-81; Kaidbey et al., 1979, pp. 249 and 253; Loomis, 1967, p. 502; Weisberg et al, 2004, p. 1703S; Holick, 2007, p. 270).[7] Therefore, a complete explanation to address the stature differential between whites and blacks may be related to biology and vitamin D production.

3. Data

Prison Data

The data used to study black and white statures is part of a large 19th century prison sample, and using 19th century statures is essential when considering the relationship between D produced from insolation, because the US fortified its food supply in the 1930s to reduce the incidence of rickets. All state prison repositories were contacted and available records were acquired and entered into a master data set. These prison records include Arizona, California, Colorado, Idaho, Illinois, Kansas, Kentucky, Missouri, New Mexico, Ohio, Oregon, Pennsylvania, Texas, and Washington (Table 1). Most blacks in the sample were imprisoned in the Deep South or Border States—Kentucky, Missouri, and Texas. Most whites in the sample were imprisoned in Missouri

[7] To address rickets in the US population, in the 1930s the federal government advocated fortification of the US milk supply with vitamin D (Holick, 2004, p. 1679S).

and Texas, but Northern whites were also from Illinois, Ohio, and Pennsylvania. The Far West is also represented in the sample.

Table 1, African-Americans and Whites in Nineteenth Century US State Penitentiaries

	Blacks		*Whites*	
Prison	N	Percent	N	Percent
Arizona	148	.25	1,579	1.27
California	433	.74	8,230	6.61
Colorado	921	1.57	7,021	5.63
Georgia	1,315	2.24	157	.13
Idaho	104	.18	2,074	1.66
Illinois	1,221	2.08	9,942	7.98
Kansas	977	1.66	4,082	3.28
Kentucky	6,243	10.62	6,650	5.34
Missouri	10,479	17.83	23,787	19.09
New Mexico	344	.59	1,998	1.60
Ohio	5,279	8.98	24,841	19.94
Oregon	61	.10	2,040	1.64
Pennsylvania	3,899	6.63	16,026	12.86
Texas	27,356	46.54	16,171	12.98
Total	58,780	100.00	124,598	100.00

Source: Data used to study black and white anthropometrics is a subset of a much larger 19^{th} century prison sample. All available records from American state repositories have been acquired and entered into a master file. These records include Arizona, California, Colorado, Idaho, Illinois, Kansas, Kentucky, Missouri, New Mexico, Ohio, Oregon, Pennsylvania, Texas, Utah, and Washington.

Notes: Stature is in centimeters. The occupation classification scheme is consistent with Ferrie (1997).

All historical height data have various biases, and prison and military records are the most common source of historical height records. One common shortfall for military samples is a truncation bias imposed by minimum stature requirements (Fogel et al, 1978, p. 85; Sokoloff and Vilaflor, 1982, p. 457, Figure 1). Prison records do not implicitly suffer from such a constraint and the subsequent truncation bias observed in military samples. However, prison records are not above scrutiny. The prison data may have selected many of the materially poorest individuals, although there are skilled and agricultural workers in the sample. While prison records are not random, the selectivity they represent have their own advantages in stature studies, such as being drawn from lower socioeconomic groups, those most vulnerable to economic change (Bogin, 1991, p. 288; Komlos and Baten, 2004, p. 199). For height as an indicator of biological variation, this kind of selection is preferable to that which marks many military records – minimum height requirements for service (Fogel, 1978, p. 85; Sokoloff and Vilaflor, 1982, p. 457, Figure 1).

There also is concern over entry requirements, and physical descriptions were recorded by prison enumerators at the time of incarceration as a means of identification, therefore, reflect pre-incarceration conditions. Between 1830 and 1920, prison officials routinely recorded the dates inmates were received, age, complexion, nativity, stature, pre-incarceration occupation, and crime. All records with complete age, stature, occupations and nativity were collected. There was great care recording inmate statures because accurate measurement had legal implications for identification in the event that inmates escaped and were later recaptured.[8] Arrests and prosecutions across states may

[8] Many inmate statures were recorded at quarter, eighth, and even sixteenth increments.

have resulted in various selection biases that may affect the results of this analysis. However, black and white stature variations within US prisons are consistent with other stature studies (Steckel, 1979; Margo and Steckel, 1982; Komlos, 1992; Komlos and Coclanis, 1997; Bodenhorn, 1999; Sünder, 2004). Because the purpose of this study is 19th century male black and white statures, females and immigrants are excluded from the analysis.

Inmate enumerators were quite thorough when recording inmate complexion and occupation. For example, enumerators recorded inmates' race in a complexion category, and African-Americans were recorded as black, light-black, dark-black, and various shades of mulatto (Komlos and Coclanis, 1997). Enumerators recorded white complexions as light, medium, dark, and fair. The white inmate complexion classification is further supported by European immigrant complexions, which were always of fair complexion and were also recorded as light, medium, and dark.[9] While mulatto inmates possessed genetic traits from both European and African ancestry, they were treated as blacks in the 19th century US and are grouped here with blacks when comparing whites to blacks.

Enumerators recorded a broad continuum of occupations and defined them narrowly, recording over 200 different occupations, which are classified here into four categories: merchants and high skilled workers are classified as white-collar workers; light manufacturing, craft workers, and carpenters are classified as skilled workers;

[9] I am currently collecting 19th century Irish prison records. Irish prison enumerators also used light, medium, dark, fresh and sallow to describe white prisoners in prisons from a traditionally white population. To date, no inmate in an Irish prison has been recorded with a complexion consistent with African heritage.

workers in the agricultural sector are classified as farmers; laborers and miners are classified as unskilled workers (Tanner, 1977, p. 346; Ladurie, 1979; Margo and Steckel, 1992; p. 520). Unfortunately, inmate enumerators did not distinguish between farm and common laborers. Since common laborers probably encountered less favorable biological conditions during childhood and adolescence, this potentially overestimates the biological benefits of being a common laborer and underestimates the advantages of being a farm laborer.

Because the youth height distribution is itself a function of the age distribution, a youth height index is constructed that standardizes for age to determine how statures were distributed and whether there were arbitrary truncation points imposed on inmate stature, either by law enforcement or state legislation. The age adjusted youth stature index is calculated by first calculating the average stature for each age group; each observation is then divided by the average stature for the relevant age group (Komlos, 1987, p. 899). Figure 1 demonstrates that black and white statures were distributed approximately normal and there is no evidence of age heaping or arbitrary truncation points.

Table 2, Nineteenth-Century Black and White U.S. State Penitentiary Age, Birth Decades, Occupations, and Nativity

	White				*Black*			
Ages	N	Percent	Mean	S.D.	N	Percent	Mean	S.D.
Teens	16.821	13.50	169.76	6.70	11,178	19.02	167.98	7.46
20s	63.876	51.27	171.97	6.52	31,711	53.95	171.10	6.88
30s	27.054	21.71	172.01	6.47	10,230	17.40	10,230	6.72
40s	10.947	8.79	171.90	6.51	3,779	6.43	170.73	6.80
50s	4,352	3.49	171.62	6.51	1,338	2.28	170.36	6.98
60s	1,315	1.07	171.25	6.73	452	.77	169.80	6.49
70s	233	.19	170.94	6.42	92	.16	169.03	5.91
Birth Decade								
1800s	906	.73	172.41	6.50	195	.33	169.42	6.27
1810s	2,467	1.98	172.52	6.56	647	1.10	169.81	6.96
1820s	4,202	3.37	172.45	6.80	848	1.44	169.29	7.02
1830s	7,994	6.42	171.79	6.66	1,517	2.58	170.20	6.86
1840s	14,539	13.27	171.46	6.52	4,521	7.69	170.22	6.88
1850s	25,075	20.12	171.31	6.69	9,866	16.78	170.71	7.13
1860s	25,368	20.36	171.70	6.54	11,687	19.88	170.87	7.22
1870s	22,206	17.82	171.66	6.52	13,520	23.00	170.52	7.05
1880s	12,847	10.31	171.74	6.50	10,277	17.48	170.25	6.99
1890s	6,594	5.29	171.96	6.52	5,259	8.95	170.32	6.96
1900s	400	.32	170.80	6.22	443	.75	169.41	7.30
Occupation								
White-Collar	13,780	11.06	171.33	6.37	2,346	3.99	1.69.77	6.75
Skilled	32,133	25.79	171.29	6.38	6,249	10.63	170.20	6.93
Farmer	16,563	13.29	173.19	6.44	5,931	10.09	171.79	6.85
Unskilled	55,927	44.89	171.56	6.66	42,998	73.15	170.42	7.09
No Occupation	6,195	4.97	170.98	7.14	2,346	3.99	169.34	7.88
Nativity								
Northeast	4,029	3.23	170.70	6.31	240	.41	169.52	6.51
Middle Atlantic	32,334	25.95	170.09	6.36	4,092	6.96	168.47	6.74
Great Lakes	32,629	26.19	171.88	6.42	3,501	5.96	170.18	6.97
Plains	17,838	14.32	171.94	6.38	7,772	13.22	169.27	6.84
Southeast	21,854	17.54	172.91	6.66	21,985	37.40	170.26	7.01
Southwest	10,173	8.16	173.63	6.81	20,726	35.26	171.67	7.10
Far West	5,741	4.61	170.65	6.59	464	.79	169.27	6.78

Source: See Table 1.

Notes: Stature is in centimeters. Youth age is between ages 15 and 22. The occupation classification scheme is consistent with Ferrie (1997); The following geographic classification scheme is consistent with Carlino and Sill (2000): New England= CT, ME, MA, NH, RI and VT; Middle Atlantic= DE, DC, MD, NJ, NY, and PA; Great Lakes= IL, IN, MI, OH, and WI; Plains= IA, KS, MN, MO, NE, ND, and SD; South East= AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA, and WV; South West= AZ, NM, OK, and TX; Far West= CA, CO, ID, MT, NV, OR, UT, WA, and WA. Stature difference is average white stature less average black stature.

Table 2 presents black and white inmates' age, birth decade, occupations, and nativity proportions. Although average statures are included, they are not reliable because of possible compositional effects, which are accounted for in the regression models that follow. Whites were a larger portion of the prison population than blacks; 68.03 percent of the US prison population was white. Blacks were less likely to be incarcerated during the early 19th century; however, with passage of the 13th amendment, slave owners no longer had claims on black labor, and free blacks who broke the law were turned over to state penal systems to exact their social debt. Age percentages demonstrate that black inmates were incarcerated at younger ages, while whites were incarcerated at older ages. Southern law evolved to favor plantation law, which generally allowed slave owners to recover slave labor on plantations while slaves were punished (Komlos and Coclanis, 1997, p. 436; Wahl, 1996, 1997; Friedman, 1993). Whites within 19th century US prisons were more likely than blacks to be white-collar, skilled workers, and farmers were less likely to be unskilled.

United States' Insolation

To account for the relationship between vitamin D and stature, a state-level measure is constructed that accounts for solar radiation. Insolation is the incoming direct sunlight that reaches the earth, its atmosphere, and surface objects. Insolation is also the primary source of vitamin D (Holick, 1991, p. 590; Holick, 2007, p. 270). Because of its distance from the equator, European insolation is lower than African insolation, and before their migration to North America, Europeans had to be more efficient in vitamin D production in low insolation latitudes. Before their forced migration to North America, Africans were exposed to considerable insolation, which was significantly greater than the insolation received by their progeny in the US. Because of its size, Africa has a large insolation variation, and because of its proximity to the equator, its average insolation is greater than the insolation received in the US. For example, from a random sample of western African sites, West Africa receives approximately 5.6 hours of direct insolation per day with a standard deviation of .53 hours; however, the US only receives 4.10 hours of direct sunlight per day with a standard deviation of .61 hours and the difference is significant at acceptable levels.[10]

Because US historical insolation is unavailable, a modern insolation index (1993-2003) is constructed, and monthly insolation values are measured from January through June. The insolation index measures statewide average insolation levels across each of

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[10] Western African sites include Ouagadougou, Burkina Faso; Yaoundé, Cameroon; Bangui, Central African Republic; Accra, Ghana; Gambia, Gambia; Conakry, Guinea; Liberia; Nouakchott, Mauritania; Niamey, Nigeria; Freetown, Sierra Leone; Dakar, Senegal.

the states based on the hours of direct sunlight per day at county centroids in each state.[11] Each state estimate was then determined by summing the average hours of direct sunlight for each county (at its centroid), weighted by the proportion of the county's total land area (in square miles) to the state's total land area (in square miles). While this index is a rough approximation for historical insolation, it provides sufficient detail to capture state latitudinal insolation variation and consequently, vitamin D production. Predictably, Southern states have greater insolation than Northern states. For example, Texas receives 1.43, or 29 percent, more hours of direct sunlight per day than New York. It is also difficult to interpret insolation's net direct effect on human health, because greater insolation reduces calories required to maintain body temperature and produces more vitamin D, but greater insolation also warms surface temperatures, which may have made disease environments less healthy from water-born diseases, especially in the South (Steckel, 1992, p. 501).

4. The Comparative Socioeconomic Effects of Demographics and Insolation on Black and White Stature

The timing and extent of a population's stature variation not only reflects the cumulative relationship between diet and disease, but also the distribution of wealth, population change, sectoral shifts in production, and migration (Steckel, 1994, p. 16; Lynch and Kaplan, 1997, pp. 305-308). Stature variation is also related to hours exposed

[11] Insolation is not the insolation in the county that surround's the state's centroid, but insolation in each county's geographic center. The range of state insolation values extends from Maine's minimum of 3.43 hours of direct sunlight to Arizona's maximum of 5.22 hours of direct sunlight per day.

to direct sunlight (Carson, 2008, p. 821-824), and in 19th century America, the bulk of the labor force worked in outdoor occupations (Rosenbloom, 2002, p. 88). To isolate the relationship between stature relative to the three main sources of vitamin D, we test how race, demographics, nativity, migration, and insolation were associated with 19th century statures by socioeconomic status. Because exposure to insolation is sensitive to occupations, individuals are partitioned into skilled, agriculture, and unskilled occupations. The stature of the ith individual is assumed to be related with age, birth period, nativity, migration status, and insolation. If vitamin D contributed to differences in 19th century stature, the hours of direct sunlight, skin pigmentation, and nativity will be related to individual statures.

$$Centimeter_i = \beta_0 + \beta_1 Race_i + \sum_{j=12}^{70s} \beta_j Age_{i,j} + \sum_{t=1800}^{1900} \beta_t Birth_{i,t} + \sum_{n=1}^{6} \beta_n Nativity_{i,n}$$

$$\sum_{n=1}^{6} + \beta_{Mig} Migrant_{i,Mig} + \sum_{d=1}^{4} \beta_d Migrant\ Direction_{i,d} + \beta_{Insol} Insolation_{i,Insol} +$$

$$B_{Insol^2} Insol^2_{i,Insol} + \varepsilon_i$$

Black and mulatto race dummy variables are included to account for how skin pigmentation was related with vitamin D and stature. Dummy variables are included for individual youth ages 14 through 22; adult age dummies are included for ten year age intervals from the 30s through the 70s. Birth decade dummies are in ten year intervals from 1800 through 1899. Nativity dummy variables are included for birth in Northeast, Middle Atlantic, Great Lakes, Southeast, Southwest, and Far West regions. A dummy variable accounts for migration status and directional migration dummy variables are included to account for North-South migrations.[12] If insolation was a driving force in stature growth, northward moves will have adverse stature effects, and southward moves will be associated with taller statures. Continuous insolation and insolation difference variables between receiving and sending location are added to account for insolation and vitamin D production.

Four models are presented. Model 1 considers workers in the three pooled occupations: skilled, farmers, and unskilled. Model 2 considers only how skilled workers' statures varied with observable characteristics. Models 3 and 4 do the same for farmers and unskilled workers

[12] North1 is an intermediate move from Southern to Central or Central to Northern states. North2 is a long distance move from Southern to Northern states. South1 is a move from a Northern to Central or Central to Southern state. South2 is a move from Northern to Southern states. Northern states include Maine, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Michigan, Wisconsin, Iowa, Minnesota, North Dakota, South Dakota, Wyoming, Montana, Idaho, Oregon, and Washington. Central states include Delaware, Maryland, Virginia, Wes Virginia, Kentucky, Indiana, Illinois, Missouri, Nebraska, Kansas, Colorado, Utah, Nevada, and California. Southern states include North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, Texas, New Mexico, and Arizona. The binary variable North1 is an intermediate move from Southern to Central or Central to Northern states. North2 is a long distance move from Southern to Northern states. South1 is a move from a Northern to Central or Central to Southern state. South2 is a move from Northern to Southern states.

Table 3, National Stature Models related to Demographics, Birth Period, Migration, and Insolation by Socioeconomic Status

	Total	*SE*	*Skilled*	*SE*	*Farmers*	*SE*	*Unskilled*	*SE*
Intercept	154.03***	2.32	149.26***	4.22	169.44***	4.57	150.79***	3.30
Race								
White	Reference		Reference		Reference		Reference	
Black	-2.16***	.242	-2.06***	.097	-2.07***	.126	-2.21***	.052
Mulatto	-1.51***	.065	-1.23***	.140	-1.53**	.205	-1.56***	.080
Ages								
14	-11.95***	.436	-10.01***	1.31	-9.03***	1.67	-12.34***	.467
15	-8.27***	.253	-8.31***	.744	-7.00***	.819	-8.46***	.284
16	-5.05***	.130	-4.43***	.407	-4.35***	.422	-5.34***	.144
17	-3.12***	.093	-3.00***	.215	-2.91***	.254	-3.25***	.113
18	-2.10***	.074	-2.00***	.172	-1.96***	.212	-2.22***	.090
19	-1.09***	.070	-.989***	.148	-.894***	.199	-1.20***	.086
20	-.458***	.070	-.621***	.145	-.146	.198	-.532***	.088
21	-.123*	.067	-.314**	.131	-.145	.185	-.116	.085
22	.012	.064	-.113	.123	-.511***	.184	.107	.082
20s	Reference		Reference		Reference		Reference	
30s	.058	.043	.117*	.071	-.197	.126	.015	.060
40s	-.306***	.061	.080	.098	-.758***	.161	-.451***	.090
50s	-.780***	.093	-.420***	.147	-1.50***	.230	-.850***	.142
60s	-1.40***	.162	-1.12***	.272	-2.01***	.329	-1.49***	.255
70s	-2.13***	.351	-1.38***	.578	-2.75***	.714	-2.57***	.552
Birth Decade								
1800s	1.44***	.198	1.06***	.312	1.88***	.427	1.20***	.316
1810s	1.38***	.125	1.06***	.207	1.93***	.323	1.26***	.177
1820s	.992***	.103	.789***	.173	1.44***	.267	.789***	.146
1830s	.267***	.078	.171	.125	.346	.212	.152	.113
1840s	-.140**	.057	.008	.097	-.073	.162	-.379***	.079
1850s	-.223***	.049	-.338***	.088	-.237	.146	-.211***	.064
1860s	Reference		Reference		Reference		Reference	
1870s	-.239***	.049	-.270***	.088	-.422***	.142	-.147**	.064
1880s	-.539***	.056	-.243**	.106	-.707***	.164	-.558***	.073
1890s	-.317***	.072	.218	.140	-.249	.191	-.490***	.094
1900s	.271	.238	-.541	.459	1.01	.559	.277	.311
Nativity								
Northeast	-1.37***	.131	-.753***	.208	-1.39***	.433	-1.44***	.191
Middle Atlantic	-1.73***	.093	-1.28***	.162	-1.99***	.241	-1.58***	.131
Great Lakes	.149**	.070	.369***	.124	-.200	.172	.138	.098
Plains	Reference		Reference		Reference		Reference	
Southeast	.895***	.058	.876***	.116	.755***	.160	.979***	.075
Southwest	2.80***	.110	2.78***	.225	1.87***	.304	2.77***	.141
Far West	-.441***	.135	.638***	.264	-.436	.369	-.827***	.174

Migration								
Migrant	.497***	.042	.508***	.074	-.124	.119	.603***	.058
Non-Migrant	Reference		Reference		Reference		Reference	
Migration Direction								
North-Short	-.901***	.060	-.673***	.107	-.599	.174	-1.02***	.079
North-Long	-.596***	.126	-.891***	.243	.372	.248	-1.02***	.183
South-Short	.359***	.054	.334***	.086	.188	.169	.469***	.077
South-Long	1.13***	.133	1.07***	.196	1.87**	.744	1.20***	.187
Insolation								
Insolation	8.61***	1.10	10.97***	2.02	2.65***	2.25	9.79***	1.55
Insolation^2	-1.02***	.132	-1.35***	.242	-.382***	.279	-1.12***	.184
N	183,378		54,508		22,494		106,376	
R^2	.0689		.0421		.0441		.0842	

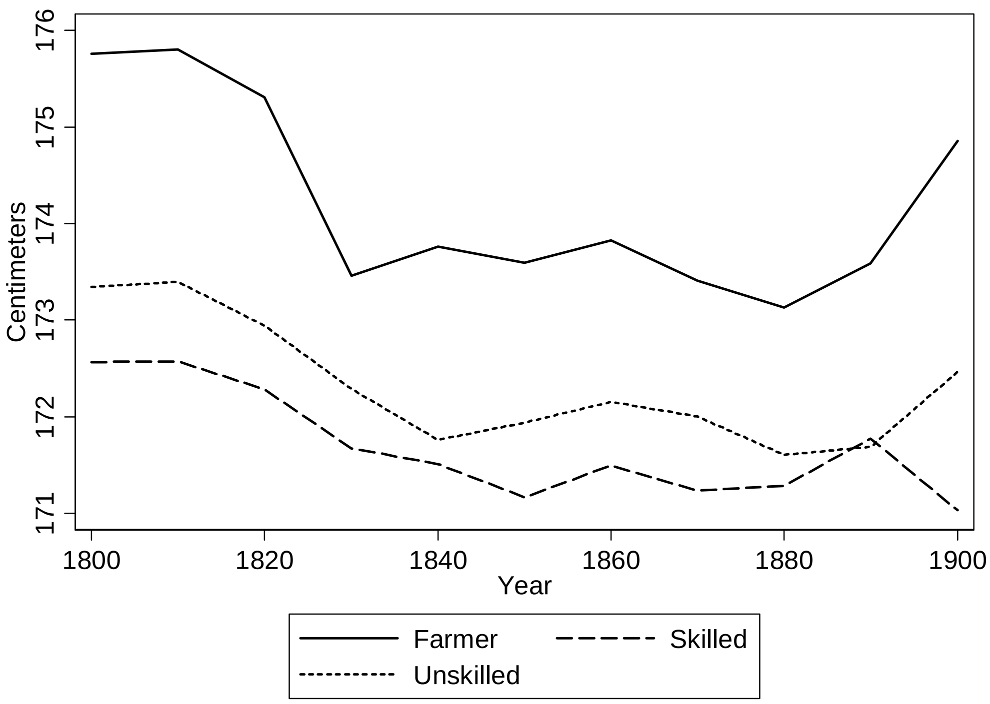
Source: See Table 1.

Notes: Because US historical insolation is unavailable, a modern insolation index (1993-2003) is constructed, and monthly insolation values are measured from January thru June. The insolation index measures the hours of direct sunlight per day at county centroids in each state and is weighted by a county's square miles relative to square miles in the state.[13] While this index is a rough approximation for historical insolation, it provides sufficient detail to capture state latitudinal insolation variation and consequently, vitamin D production. The US geographic classification scheme is consistent with Carlino and Sill (2000): New England= CT, ME, MA, NH, RI and VT; Middle Atlantic= DE, DC, MD, NJ, NY, and PA; Great Lakes= IL, IN, MI, OH, and WI; Plains= IA, KS, MN, MO, NE, ND, and SD; South East= AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA, and WV; South West= AZ, NM, OK, and TX; Far West= CA, CO, ID, MT, NV, OR, UT, WA, and WA. *** Significant at .01; **Significant at .05; *Significant at .10.

[13] Insolation is not the insolation in the county that surround's the state's centroid, but insolation in each county's geographic center. The range of state insolation values extends from Maine's minimum of 3.43 hours of direct sunlight to Arizona's maximum of 5.22 hours of direct sunlight per day.

Two general patterns emerge when comparing black and white stature variation by occupations. First, consistent with the stature-insolation hypothesis, individuals were taller in states that received—or moved to states that received—more insolation. For insolation levels equal to the average US insolation, an additional hour of insolation was associated with approximately one centimeter taller statures (Table 3, Model 1). Closely related with insolation are workers' occupations, which are also approximations for the number of hours exposed to solar radiation. Farmers, who spent more time outdoors, were taller than non-farmers, and farmers benefited from their close proximity to nutritious diets and mild disease environments. Workers in occupations with greater exposure to direct sunlight may have also been taller because they were exposed to more insolation as children and produced more vitamin D. Islam et al (2007, p. 383-388) demonstrate that children exposed to more direct sunlight produce more vitamin D, and if there was little movement away from parental occupations, 19th century occupations may be a good indicator for the occupational environment in which individuals came to maturity (Costa, 1993, p. 367; Margo and Steckel, 1992, p. 520).

Figure 1, Nineteenth Century Stature Variation by Occupations



Source: See Table 2.

Notes: To simplify graphs, insolation was not included in these models.

Overtime farmer statures decreased by more than the statures of workers in other occupations (Figure 1). Nineteenth century US agricultural commercialization separated producers from consumers, and while farmers worked in rural agricultural environments, the rise of Northeastern urban centers, such as New York City, Boston, and Philadelphia, placed disproportionate stress on rural farmers, who lived near urban centers (Carson, 2008b, pp. 367-368). Urbanization created other pathways by which the costs of agricultural commercialization accrued to farmers. The proliferation of industrialization, urbanization, and agricultural commercialization compromised the quality of dairy and meat production, and in this pre-refrigeration period, food spoilage increased as the distance between rural farms and urban centers increased (Craig, et al, 2004). For example, although Southeastern Pennsylvanians were in close physical proximity to leading dairy producing Bucks, Chester, and Lancaster counties, they were also closer to urbanized Philadelphia, and individuals from Southeast Pennsylvania reached shorter terminal statures than individuals from rural Pennsylvania environments (Carson, 2008b, pp. 363-368).

Second, it is striking the degree to which average white statures exceeded black statures, and whites were between two and three centimeters taller than blacks. This is even more significant since modern black and white statures are comparable when brought to maturity under similar biological conditions (Eveleth and Tanner, 1976; Tanner, 1977; Steckel, 1995, p. 1910; Barondess, Nelson and Schlaen, 1997, p. 968; Komlos and Baur, 2004, pp. 64, 69; Nelson et al., 1993, pp. 18-20; Godoy et al, 2005, pp. 472-473). Moreover, compositional effects can-not explain the white-black stature differential, which was due, in part, to whites' access to meat and better nutrition (Margo and Steckel, 1982, pp. 514-515, 517, and 519). Mulatto statures also support the stature-insolation hypothesis because mulattos, who have less melanin in their stratum corneum, were taller than darker complected blacks but shorter than lighter complected whites.

Third, statures also varied by nativity, and after controlling for insolation, Southerners reached the tallest statures (Carson, 2008a, pp. 822-823; Carson, 2008b, 2008b, pp. 364-365). Moreover, immigrants who located to the South were taller than those who immigrated to the North, and part of the Southern migration advantage was related to Southern agriculture. The 19th century opening of the New South to agriculture increased Southwestern agricultural productivity, which was higher than elsewhere in the

US (Higgs, 1977, p. 24; Margo and Steckel, 1982, p. 519; Komlos and Coclanis, 1997, p. 443). Before the Civil War, the South was self-sufficient in food production, and relatively high white wages may have been associated with taller Southern white statures (Fogel, 1994, pp. 89, 132-133). After the Civil war, Southern wages in the West South Central were in general lower than Midwest wages and were comparable to those in the Middle Atlantic region. Blacks from the Great Lakes were taller than blacks from the Northeast and Plains. The relative price of dairy and calcium were lowest in dairy producing regions, such as Great Lake states, but 19th century blacks were overwhelmingly native to the South.[14] Northeasterners, especially blacks, encountered adverse biological environments, and contemporary reports of rickets—a result of vitamin D deficiency—may have contributed to shorter Northeastern statures (Kiple and Kiple, 1977, p. 293-294; Tortolani et al, 2002, p. 62).[15] Therefore, as suggested by Holick (1981, p. 590), results presented here illustrate the primary sources of greater vitamin D production and statures were the number of hours exposed to sunlight, skin pigmentation, and nativity.

5. Explaining the Stature Advantage by Socioeconomic Status

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[14] Southern observers at the time reported that milk was fairly abundant in border states but in short supply in the Deep South (Kiple and King, 1981, p. 83).

[15] Stature is also related to air pollution, which interfered with the amount of insolation received (Holick, 1995; Tiwari and Puliyell, 2004, Agarwal et al, 2002), and Northerners near polluted industrial centers were shorter than rural Southerners who lived in less polluted in environments.

To more fully account for the source of stature differentials by socioeconomic status, a Blinder-Oaxaca decomposition is imposed on the occupation stature differential (Oaxaca, 1973). Farmers are first compared to skilled workers; farmers are then compared to unskilled workers; lastly, skilled workers are compared to unskilled workers. Let S_t and S_s represent worker statures in the tallest and shortest occupations, respectively; α_t and α_s are the autonomous stature components that accrue to workers in taller and shorter occupations; β_t and β_s are the returns associated with specific stature enhancing characteristics, such as age and nativity. X_t and X_s are the characteristic matrices for individuals in taller and shorter occupations, and taller statures are assumed to be the base structure.

$$\Delta S = S_t - S_s = (\alpha_t - \alpha_s) + (\beta_t - \beta_s)X_s + \beta_t(X_t - X_s)$$

The second right hand-side element is that component of the stature differential due to differences in stature returns, and since occupations are ordered according to stature rank, was likely positive for most characteristics. The third right-hand side element is the stature differential component due to characteristic differences and is also likely positive because farmers probably had characteristics associated with taller statures. Hence, if the biological advantage to workers in occupations with taller statures were due to superior biological conditions, the stature returns, β_t, will be larger than stature returns to short stature occupations, β_s.

Table 4, Nineteenth Century National Prison Stature Oaxaca Decomposition by Socioeconomic Status

	Oaxaca I		***Oaxaca II***	
Farmers-Skilled	$(\beta_f - \beta_s)\overline{X}_s$	$(\overline{X}_f - \overline{X}_s)\beta_f$	$(\beta_f - \beta_s)\overline{X}_f$	$(\overline{X}_f - \overline{X}_s)\beta_s$
Levels				
Sum	-74.19	-.172	-41.65	-.020
Total		-74.36		-41.67
Proportions				
Intercept	-.158		-.282	
Race	.017	.010	.053	.010
Ages	.574	.002	.846	.005
Birth	-.020	9.56^{-5}	-.096	-1.5^{-4}
Nativity	-.032	-.011	-.129	-.019
Migration	.021	-.001	-.073	.003
Insolation	.596	.002	.680	.002
Sum	.998	.002	.999	.001
Total		1		1
Farmers-Unskilled				
Levels				
Total	-120.82	.176	-63.97	.279
Sum		-120.65		-63.69
Proportions				
Intercept	-.129		-.243	
Race	-.010	-6.1^{-4}	-.020	-.001
Ages	.505	-2.4^{-4}	.707	.001
Birth	-.021	-6.4^{-4}	-.080	-4.9^{-4}
Nativity	.019	-.002	.018	-.004
Migration	.009	-2.7^{-4}	-.056	9.2^{-5}
Insolation	.628	.002	.678	.003
Sum	1.00	0	1.00	0
Total		1.00		1.00
Skilled-Unskilled				
Levels				
Total	-72.99	.459	-53.65	.235
Sum		-72.53		-53.42
Proportions				
Intercept	-.052		-.071	
Race	.088	-.007	.072	-.015
Ages	.628	-.004	.663	-.006
Birth	.021	5.7^{-4}	-.001	-8.4^{-4}
Nativity	.033	.008	.006	.012

Migration	-.004	-.001	-.011	-.001
Insolation	.293	-7.1^{4}	.346	.006
Sum	1.01	-.01	1.00	0
Total		1		1

Source: See Tables 1 and 3.

For each comparison, the majority of the occupational stature gap is associated with returns to age and insolation (Table 4); characteristics associated with stature remained noticeably insignificant. Stature by occupation illustrates farmers were, on average, taller and had greater stature returns with insolation than workers in other occupations; farmers also had larger stature returns associated with age. Race (skin pigmentation) explained a small share of the stature gap, and stature differentials due to nativity were smaller than exposure to insolation. Therefore, stature differentials by socioeconomic status support that a population's greatest source of 19th century stature gains through vitamin D were hours spent outdoors, skin pigmentation, and nativity (Holick, 1981, p. 590).

6. Conclusion

This study considers the three most important sources of a population's stature variation by vitamin D production, and illustrates that in each case, hours of direct sunlight was the primary source of 19th century stature variation. Farmers, who traditionally worked outdoors and were exposed to more direct sunlight, were taller than workers in other occupations. At North American latitudes, more melanin in their epidermises also prevented African-Americans from reaching taller statures. Nativity influenced stature, and workers native to the South were taller than workers located further north from the equator and the beneficial effects of direct solar radiation. Therefore, rather than only sociological processes and access to nutrition explaining a population's stature variation, part of 19th century stature variation was biologically based.

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