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The relationship between height and neighborhood context across racial/ethnic groups: A multi-level analysis of the 1999–2004 U.S. National Health and Nutrition Examination Survey

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ABSTRACT

While a growing literature has documented a link between neighborhood context and health outcomes, little is known about the relationship between neighborhood characteristics and height. Using individual data from the 1999-2004 U.S. National Health and Nutrition Examination Survey merged with tract-level data from the U.S. Census, we investigate several neighborhood characteristics, including neighborhood socioeconomic status (NSES), education index of concentration at the extremes (ICE), and population density, as potential predictors of height. Employing a series of two-level random intercept models, we find a one standard deviation increase in NSES to be associated with a 0.6–1.4 cm height advantage for white and foreign-born Mexican-American females and for U.S. born Mexican-American males, net of individual-level controls. Similarly, a 10 point increase in neighborhood education ICE was associated with 0.23–0.32 cm greater height for white and foreign-born Mexican-American females and U.S. born Mexican-American males. Population density was nominally negatively associated with height for foreign-born Mexican-American females. Our findings reveal that lower physical stature for some ethnic and gender groups is clustered within neighborhoods of low SES and education, suggesting that contextual factors may play a role in influencing height above individual-level attributes.

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1. Introduction

Correlated with a number of health outcomes over the life course, height is a useful marker for health, with the average population height generally increasing during times of prosperity and contracting during times of economic adversity (Batty et al., 2009; Davey Smith et al., 2000). While height is primarily determined by genetics at the individual level, this influence tends to be unimportant at the population level as long as the racial/ethnic (henceforth ethnic) composition of the population examined is accounted for (Fogel, 1994; McEvoy and Visscher, 2009; Tanner, 1986). Accordingly, differences in height across populations reflect differences in health and longevity.

Studies from industrialized countries suggest that there has been an overall increase in height over time, resulting from gradual changes in environmental conditions (Komlos and Lauderdale, 2007b). These changes include factors that had previously blocked full expression of biological potential, such as infectious diseases, inadequate nutrition, poverty (Tanner, 1992), and food availability and access

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(Floud, 1994; Sunder and Woitek, 2005; Woitek, 2003; Komlos, 1988) sustained during the periods of biological growth (Batty et al., 2009; Finch and Beck, 2011; Peck and Lundberg, 1995; Silventoinen et al., 1999; Singh-Manoux et al., 2010).

Yet, the attainment of biological well-being of Americans, as measured by height, lags behind other economically advanced countries despite the U.S. being among the richest nations in the world (Fredriks et al., 2000; Komlos, 2010; Sunder, 2003). Given the U.S.' relative affluence and economic prosperity, the incongruity between the strong positive association between socioeconomic status and height and Americans' shorter stature compared to citizens of other developed countries is striking.

In developed societies where caloric and protein intake is rarely limited by income, height reflects less the economic output of a community and more of its political, social choices, and lifestyles that influence overall health during childhood development. For example, this has been explored in the context of nutritional intake and obesity (Do et al., 2007; Salois, 2012). Consequently, social and structural factors, including neighborhood context, may contribute to the height attainment of individuals.

Growing evidence indicates a connection between the social and physical environments and individual health, independent of individual-level socioeconomic conditions (Kawachi and Berkman, 2003; Pickett and Pearl, 2001; Robert, 1999; Yen and Syme, 1999). Accordingly, uneven spatial distribution of goods and services, which is much greater in the U.S. than in Europe, may play a role in the relative height disadvantage of Americans (Komlos and Baur, 2004). Hence, a multi-level perspective may provide more insights into the sources of differences in height.

With few exceptions, investigation into how neighborhoods may influence height is virtually non-existent (Komlos and Lauderdale, 2007a; Yoo, 2012). Komlos and Lauderdale's study (2007a) is one of the few that examined the relationship between neighborhood (Zip Code Tabulation Area) conditions and height. After adjusting for individual income and education, little evidence was found to support an association between local economic conditions, as measured by median income, unemployment rate, and poverty rate, and height for either men or women. However, their study relied on a convenience sample of white individuals collected from shopping centers and business areas in the U.S. Hence, more investigations into the possible relationships between neighborhood context and height are warranted before any conclusive inferences can be drawn.

We investigate potential linkages between neighborhood context, specifically neighborhood SES (NSES), educational index concentration of extremes (ICE), and population density level, and whether these contextual factors are associated with height.

2. Neighborhood socioeconomic status, health, and height

Neighborhood socioeconomic level (e.g., poverty, disadvantage index) is commonly used as a measure to capture aspects of the social and structural environment not routinely measured in survey research. In particular, the socioeconomic characteristics of a neighborhood, also referred to as neighborhood SES, could influence diet through the quantity and quality of supermarkets and restaurants in the area, which, in turn, may determine access to nutritious foods; the availability and affordability of fresh produce; and the ease of transportation to grocery stores or healthy food options (Block et al., 2004; Diez-Roux et al., 1999; French et al., 2001; Macintyre, 2007; Moore and Diez Roux, 2006; Morland et al., 2002; Shohaimi et al., 2004).

Since stature is a good proxy for nutritional attainment among children and youths, access to fruits and vegetables that contribute to a healthy diet may not only be associated with positive health outcomes throughout the life-course but also may influence attained height. Thus, residents of poor neighborhoods may face obstacles to engage in a healthy diet, potentially incurring a permanent deficit in early life nutrition that may arrest the full development of their stature.

2.1. Urbanity, health, and height

Theory is ambiguous on the direction of the relationship between urbanity and health. On the one hand, more rural and less densely populated areas may benefit from lower environmental pollution, slower transmission of contagious diseases, and lower levels of stressors usually associated with city-life. On the other hand, more rural areas are characterized by poorer, less educated populations and fewer resources, including less access to health-care facilities.

While urban areas may have positive aspects such as decreased travel burden to health services compared to non-urban areas (Probst et al., 2007), conditions in urban areas have been called to question concerning its affects on the healthy development of individuals and communities. The health disadvantage of U.S. urban residents relative to non-urban residents has been described as the "urban health penalty" (Greenberg, 1991). Compared to non-urban areas, cities tend to have higher particulate pollution, higher income inequality, more hazardous waste landfills, and higher levels of noise pollution (Galea et al., 2005); all of these characteristics have been linked to a number of adverse health outcomes (Blakely et al., 2002; Passchier-Vermeer and Passchier, 2000; Shima et al., 2002; Vrijheid, 2000).

Poorer living conditions and higher exposure to communicable diseases in more densely populated areas were sources for the height disadvantage of urban residents in the early-industrial period compared to their rural counterparts (Margo and Steckel, 1982; Steckel, 1995). Recent empirical evidence suggests that attributes associated with low population density may still be relevant to height. Komlos and Lauderdale (2007a) found among white men that an increase in population density by a factor of 10 corresponded to a height decrease of 1.4 cm, independent of individual income and education. While the direction of the relationship was the same, no significant association was found for white women.

Table 1
Descriptive statistics (proportion and mean) for individual-level characteristics by ethnicity and gender in NHANES 1999–2004.

	White		Black		US Born Mexican-American		Foreign Born Mexican-American	
	Female	Male	Female	Male	Female	Male	Female	Male
N	1538	1256	750	641	337	250	595	565
Mean height (cm)	164.57 (6.16)	178.48 (6.98)	163.48 (6.41)	177.77 (6.98)	159.84 (6.19)	172.85 (7.31)	156.41 (5.89)	168.22 (6.84)
Mean age	33.91 (8.61)	35.41 (8.80)	34.62 (9.05)	34.76 (9.25)	33.35 (9.63)	34.35 (9.28)	33.19 (8.51)	34.19 (8.72)
Ratio of family income to the federal poverty level (PIR)								
PIR < 1	13.20	10.27	30.53	22.78	19.29	11.60	41.01	32.04
1 ≤ PIR < 2	16.19	15.53	27.33	24.96	26.41	25.20	36.97	39.82
2 ≤ PIR < 3	15.47	15.05	16.13	17.47	16.62	23.20	12.10	16.28
3 ≤ PIR < 4	14.50	16.08	9.60	12.64	16.32	14.40	5.21	6.02
4 ≤ PIR < 5	13.59	13.06	5.20	8.58	6.53	10.00	2.69	2.83
PIR ≥ 5	27.05	30.02	11.20	13.57	14.84	15.60	2.02	3.01
Employment status								
Employed	71.00	86.78	67.47	74.88	68.55	86.00	50.42	92.74
Unemployed	2.21	3.74	3.20	4.52	2.37	2.80	1.18	1.95
Not in the labor force	26.79	9.47	29.33	20.59	29.08	11.20	48.40	5.31
Education level								
Not a high school graduate	9.95	10.91	26.40	28.86	25.52	25.60	66.72	70.27
High school graduate	23.67	28.18	26.53	28.86	28.19	32.40	17.14	17.17
Some college	32.96	31.77	34.67	30.89	36.80	28.80	12.94	9.20
College graduate	33.42	29.14	12.40	11.39	9.50	13.20	3.19	3.36
Region								
Northeast	21.39	21.10	20.00	19.03	0.30	1.20	2.52	1.95
Midwest	25.36	25.48	22.40	22.62	6.23	9.20	9.24	10.44
South	33.22	32.48	52.27	50.39	30.86	34.00	33.11	36.46
West	20.03	20.94	5.33	7.96	62.61	55.60	55.13	51.15
Urbanity								
Large central metropolitan	23.86	27.31	52.67	51.95	46.59	48.80	61.51	57.70
Other metropolitan	63.66	58.84	43.46	43.89	41.25	37.20	35.30	38.05
Non-metropolitan	12.48	13.85	3.87	4.06	12.16	14.00	3.19	4.25

Note: Standard deviations in parenthesis.

2.2. Research questions

This study uses a nationally representative sample to investigate the link between neighborhood context and height, beyond that of individual-level characteristics. Further, we examine whether and to what extent the relationship between neighborhood-level context and height may differ by ethnicity.

Our specific research questions are: (1) Is neighborhood socioeconomic status (NSES), education Index Concentration of Extremes (ICE), or population density associated with adult height, net of individual-level characteristics? (2) Do these associations vary by ethnicity?

3. Methods

3.1. Data

This study utilizes individual-level data from the U.S. 1999–2004 National Health and Nutrition Examination Survey (NHANES) merged with tract-level data from the U.S. Census.[1] The survey oversampled blacks and Mexican-Americans, and persons aged 60 and over, and is a nationally representative, annual, cross-sectional sample of the civilian non-institutionalized population of the U.S. We used census tracts as neighborhood proxies throughout our analyses. Tract-level factors were derived from the 1990 and 2000 Decennial Census and linked to individual respondents in the sample via census tract identifiers. Neighborhood conditions for 2001–2004 were estimated by linearly extrapolating the 1990–2000 rate of change. These geo-coded identifiers reflect respondents' tract of residence at the time of the at-home interview. For analyses, our sample included those with non-missing information on tract of residence, reported ethnicity and nativity as U.S. born white, black, Mexican-American, or foreign-born Mexican-American, were between the ages of 20 and 50 years, and had full information on all covariates. The final sample comprised 2712 men and 3220 women.

All analyses were performed using SAS v9.2 at the National Center for Health Statistics' secure Research Data Center in Hyattsville, Maryland.

3.2. Individual-level measures

Our dependent variable is height, measured in centimeter.[2] Our individual-level independent variables

[1] Public use NHANES can be accessed at: http://www.cdc.gov/nchs/nhanes.htm. Tract-level Census measures were developed by RAND as part of the Center for Health and Health Disparities (CPHHD) Data Core Series: rand.org.

[2] Height was measured by trained clinicians in a mobile examination center or at a respondent's home during a physical examination.

Table 2
Regional mean height by ethnicity and gender in NHANES 1999–2004.

	White		Black		US born Mexican-American		Foreign born Mexican-American	
	Female	Male	Female	Male	Female	Male	Female	Male
Region								
Northeast	163.52 (6.03)	177.66 (6.92)	163.51 (6.52)	177.59 (7.14)	–	–	–	–
Midwest	164.72 (6.52)	178.49 (7.33)	163.94 (6.35)	177.07(7.19)	158.60 (4.57)	174.56 (6.05)	156.37 (5.81)	169.58 (7.19)
South	164.50 (5.99)	178.47 (6.86)	163.11 (6.44)	177.92 (6.82)	159.09 (6.58)	170.92 (6.93)	156.56 (5.26)	167.47 (7.12)
West	165.61 (5.96)	179.31 (6.71)	165.08 (5.71)	179.20 (7.03)	160.37 (6.07)	173.90 (7.48)	156.60 (6.10)	168.62 (6.51)
Urbanity								
Large central metropolitan	165.35 (6.17)	178.86 (6.86)	163.86 (6.25)	177.84 (7.27)	159.60 (5.85)	172.92 (6.62)	156.17 (6.01)	167.77 (6.67)
Other metropolitan	164.39 (6.12)	178.38 (6.95)	163.03 (6.57)	177.72 (6.71)	160.05 (6.43)	173.14 (7.83)	156.69 (5.72)	168.56 (6.92)
Non-metropolitan	163.97 (6.28)	178.14 (7.30)	163.41 (6.48)	177.37 (6.31)	160.01 (6.72)	171.81 (8.24)	157.84 (5.13)	171.17 (7.75)

Note: (–) denotes sample size for US and foreign born Mexican Americans in the Northeast < 5 and hence means and SD were not displayed.

include age, marital status, ethnicity/nativity, employment status, educational attainment, region of residence, urbanity, and family poverty income ratio (PIR). A PIR below 1, for example, indicates that a respondent is a member of a family whose income is below the official poverty threshold.[3]

Table 1 presents descriptive characteristics for the individual-level measures by ethnicity and gender. Since little is known about height variation across regions and urbanity in the U.S., we present regional and urban level estimates of height by ethnicity and gender (Table 2). The bivariate statistics suggest a height advantage in the West while no discernable pattern is found across urbanity.

We then estimated generalized linear models stratified by gender to more closely examine the association between region and height, adjusting for individual-level SES characteristics[4]. For females and males, we first estimated pooled models and then models stratified by ethnic groups. Results from the pooled female sample indicate that the tallest reside in the West, with an average height advantage of 2.3 cm over the shortest females who reside in the Northeast (Table 3). Females in the Midwest and South are on average 1.0 and 1.5 cm shorter, respectively, than their counterparts in the West. In stratified models, the regional patterns varied by ethnicity. The shortest White and Mexican-American females reside in the Northeast while the shortest blacks reside in the South. For males overall, height is more evenly distributed across regions, with only males in the Northeast being shorter with an average height disadvantage of approximately 1.6 cm (Table 4). In models stratified by ethnicity, Whites in the Northeast are 1.5 cm shorter than those in the West while the height distribution for blacks do not statistically vary across regions. Mexican-Americans are 6.6 cm and 1.3 cm shorter in the Northeast and South, respectively, compared to Mexican-Americans in the West.

3.3. Neighborhood context measures

We examine three neighborhood-level characteristics: neighborhood socioeconomic status, neighborhood educational concentration at the extremes, and population density. Each of these measures is computed at the level of the census tract.

3.3.1. Neighborhood socioeconomic status

We use a composite measure of neighborhood socioeconomic status (NSES) in order to capture the notion of overall neighborhood socioeconomic context. Used in previous studies, the composite measure is made up of the average of the following six socioeconomic indicators: proportion of individuals ages 25 and over with no high school degree, the proportion of individuals receiving public assistance, the proportion of households with children headed by females, the proportion of males who are unemployed, the proportion of households with income below the poverty line, and the median household income (Bird et al., 2010; Merkin et al., 2009). Proportion variables were transformed (i.e., 100-proportion) so that higher values reflected higher socioeconomic status and all variables were standardized.[5] The NSES index reflects the standardized sum of the six measures and thus has a mean of zero and a standard deviation of one. A positive score reflects a neighborhood with NSES above the sample average.

3.3.2. Education index of concentration at the extremes

Our second neighborhood variable, index of concentration at the extremes (ICE), measures the effects of concentrated affluence and poverty as a continuum (Massey, 2001). It measures the proportional imbalance between affluence and poverty and taps into the construct of neighborhood-level inequality. Here, we applied the index to the educational capital of a neighborhood,

[3] PIR levels for observations with missing information (approximately 7% of the analytical sample) were imputed as a function of age, sex, race/ethnicity, nativity, education level, marital status, employment status, and neighborhood characteristics, including: median household income, percent non-Hispanic white, percent foreign-born, percent renter-occupied housing units, and percent urban population. Inferences were consistent across nonimputed and imputed models.

[4] Analyses applied survey weights and adjusted for heteroskedasticity via sandwich variance estimates.

[5] All variables were standardized to a common scale by subtracting the variable mean and then dividing by the standard deviation. Each standardized variable is in units of standard deviations.

Table 3
Regional differences in height among Women, NHANES 1999–2004.

Characteristics	All females	White	Black	Mexican-American
Region [reference: West]				
Northeast	−2.287**	−2.495**	−1.721	−7.281**
Midwest	−1.007*	−1.149*	−0.857	−0.479
South	−1.551**	−1.713**	−2.029*	−0.298
Urbanity [reference: Large central metropolitan]				
Other metropolitan	−0.530		−0.548	0.499
Non-metropolitan	−0.733		−0.917	1.249
Race/Ethnicity [reference: Non-Hispanic White]				
Non-Hispanic Black	−0.472			
Mexican-American: US born	−4.757**			
Mexican-American: foreign born	−7.646**			
Race/Ethnicity [reference: Mexican-American: US born]				
Mexican-American: foreign born				−1.910**
Age	−0.206	−0.242	0.220	−0.718**
PIR: [reference: PIR ≥ 5 times PIR]				
PIR < 1	−0.341	−0.325	−0.292	−3.019**
1 ≥ PIR < 2	−0.139	−0.121	−0.263	−2.365**
2 ≥ PIR < 3	0.357	0.651	−0.978	−1.745*
3 ≥ PIR < 4	−0.094	0.013	−1.083	−1.281
4 ≥ PIR < 5	0.775	0.951	−0.660	−1.091
Employment status [reference: unemployed]				
Employed	−0.569	1.442	−0.251	−2.306
Not in the labor force	−0.344	−0.012	−0.884	−1.817
Education level [reference: no high school]				
High school graduate	0.129	−0.012	0.278	0.914
Some college	1.217**	1.442*	0.090	1.375*
College graduate	2.270**	2.391**	1.6663	1.813

Note: All models adjust for survey weight.
Coefficients for age reflect a 10 year change.
* $p < 0.05$.
** $p < 0.01$.

Table 4
Regional differences in height among Men, NHANES 1999–2004.

Characteristics	All males	White	Black	Mexican-American
Region [reference: West]				
Northeast	−1.608**	−1.536*	−1.111	−6.578**
Midwest	−0.577	−0.462	−1.749	0.920
South	−0.714	−0.598	−0.770	−1.285*
Urbanity [reference: Large central metropolitan]				
Other metropolitan	−0.046	−0.079	−0.151	0.366
Non-metropolitan	−0.029	−0.099	−0.280	1.411
Race/Ethnicity [reference: Non-Hispanic White]				
Non-Hispanic Black	−0.071			
Mexican-American: US born	−5.726**			
Mexican-American: foreign born	−8.888**			
Race/Ethnicity [reference: Mexican-American: US born]				
Mexican-American: foreign born				−2.428**
Age	−0.485**	−0.397**	−0.622*	−0.778*
PIR: [reference: PIR ≥5 times PIR]				
PIR < 1	−1.591**	−1.980*	0.826	−2.172
1 ≥ PIR < 2	−0.778	−0.952	1.255	−1.473
2 ≥ PIR < 3	−0.368	−0.440	−0.032	−0.208
3 ≥ PIR < 4	−0.282	−0.295	0.228	−0.535
4 ≥ PIR < 5	−0.450	−0.626	0.933	0.656
Employment status [reference: unemployed]				
Employed	0.545	0.297	2.753	−1.695
Not in the labor force	1.209	1.282	2.879	−2.603
Education level [reference: no high school]				
High school graduate	0.772	−0.045	1.992**	1.770**
Some college	1.570**	0.999	2.127**	1.949*
College graduate	2.662**	1.995*	3.658**	3.765**

Note: All models adjust for survey weight.
Coefficients for age reflect a 10 year change.
* $p < 0.05$.
** $p < 0.01$.

Table 5
Tract-level means and proportions by ethnicity and gender in NHANES 1999–2004.

	White		Black		Mexican-American			
					US-born		Foreign-born	
	Female	Male	Female	Male	Female	Male	Female	Male
NSES	0.51(0.69)	0.49 (0.68)	−0.72 (1.13)	−0.57 (1.12)	−0.16 (0.89)	−0.04 (0.89)	−0.45 (0.93)	−0.30 (0.86)
Education ICE index	12.29 (26.84)	12.91 (26.48)	−10.93 (22.93)	−7.96 (25.73)	−12.34 (30.83)	−7.96 (30.94)	−25.41 (28.21)	−20.80 (28.57)
Density								
LN Population density	7.12 (1.80)	7.24 (1.77)	8.30 (1.55)	8.29 (1.51)	7.87 (1.94)	7.81 (2.05)	8.31 (1.71)	8.30 (1.56)
Density quartiles								
1st quartile	36.41	33.60	14.67	14.66	21.07	18.40	15.13	14.69
2nd quartile	31.34	31.93	23.33	20.44	16.62	21.60	15.46	16.99
3rd quartile	20.81	21.89	29.73	32.14	29.38	30.80	23.87	25.49
4th quartile	11.44	12.58	32.27	32.76	32.94	29.20	45.55	42.83

Note: Standard deviations in parenthesis.

expressed as $(C_i - NHS_i/T_i) \times 100$, where C_i equals the number of individuals 25 or over who are college graduates, NHS_i equals the number of individuals ages 25 or over without a high school degree, and T_i equals the total population of individuals 25 or over in the neighborhood. The ICE ranges from −100 to +100, where negative one-hundred represents a neighborhood where all individuals ages 25 or older are uneducated and a positive one-hundred represents a neighborhood where all individuals 25 or older are highly educated. A zero reflects a neighborhood where the numbers of uneducated and highly educated are equally balanced.

3.3.3. Population density

We calculate population density as the number of persons per square mile of land in a census tract. We use the natural log transformed measure of population density to capture the likely diminishing marginal association of population density with height.

Table 5 presents descriptive characteristics for the three neighborhood measures by ethnicity and gender. Whites live in neighborhoods that are more socioeconomically advantaged, compared to black and Mexican-American minorities. The average NSES for whites is positive while the average NSES for blacks and Mexican-Americans is negative, ranging from −0.72 to −0.04. Whites tend to reside in neighborhoods with higher proportion of educated individuals, as evidenced by the positive education ICE. In contrast, both blacks and Mexican-Americans reside in neighborhoods with a disproportionate level of non-high school grads. Foreign-born Mexican-Americans live in neighborhoods that are most densely populated, followed closely by blacks and U.S. born Mexican-Americans. NSES and education ICE are highly positively correlated with each other while population density is only weakly to moderately correlated with NSES and education ICE (Table 6).

Table 6
Correlation of neighborhood predictors in NHANES 1999–2004.

	NSES	Education ICE	Population Density
NSES	1.00		
Education ICE	0.78	1.00	
LN population density	−0.32	−0.11	1.00

Note: All correlations are statistically significant at the 1% level.

3.4. Analytical strategy

To investigate the relationship between neighborhood context and height, we estimate two-level random intercept models.[6] Due to multicollinearity, our analytical strategy is to estimate separate models for each neighborhood context measure. We first assume that the relationship between neighborhood context and height are constant across the four ethnic groups. We then relax this assumption and allow for temporal trends and the relationship with neighborhood context to vary across ethnicity. Our two-level (e.g., individual, neighborhood) random-intercept model that allows for the relationship between neighborhood context, temporal trends, and height to vary by ethnicity is:

$$\begin{aligned} H_{ij} = {} & \beta_{00} + \beta_{10}(age_{1ij}) + \sum_{m=2}^{4}\beta_{m0}(ethnicity_{mij}) \\ & + \sum_{n=5}^{7}\beta_{n0}(ethnicity_{ij})(age_{ij}) + \sum_{h=8}^{p}\beta_{h0}(x_{hij}) \\ & + \beta_{01}(neighborhoodcontext_j) \\ & + \sum_{m=1}^{3}\beta_{m1}(neighborhoodcontext_j)(ethnicity_{mij}) + (r_{ij} \\ & + u_{oj}) \end{aligned}$$

where H_{ij} denotes the outcome variable, height, for person i residing in neighborhood j, and x is a vector of individual-level covariates (e.g., PIR, education). The cross-level interaction term between ethnicity and neighborhood

[6] Preliminary analyses of three-level models accounting for the nesting structure of individuals within tracts within counties revealed that the variance in height across counties was not significant and therefore, a more parsimonious model was warranted.

context allows for the association between neighborhood context and height to vary by ethnicity. Hence, β_{m1} refers to the difference in the association between neighborhood context and height for ethnic group m versus whites (the reference group). Similarly, the interaction term between ethnicity and age allows for trends across time to vary by ethnicity. The terms r_{ij} and u_{oj} represent the error components at the individual and neighborhood levels, respectively. Neighborhood context reflects the neighborhood level predictors—NSES, educational ICE, and density—for tract j. All models are stratified by gender and include individual-level controls as well as year dummies for the year in which the respondent was examined to account for temporal factors. Since SAS multi-level procedures do not support the use of sample weights directly, we included survey weights as a covariate to account for differences in the probability of selection (as a sensitivity analysis, we estimated generalized linear models with sampling weights; inferences were unchanged).

4. Results

Estimates for models 1–3 reflect results for models that constrained the association between neighborhood context and height to be constant across ethnicity (Tables 7 and 8). Estimates for models 4–6 reflect results that relaxed this assumption and allowed the association between neighborhood context and height to vary by ethnicity.

For all models, coefficients for NSES are based on a one standard deviation change, coefficients for the education ICE reflect a 10 point change, and coefficients for population density are based on a 10 percent change. For models with ethnicity interacted with neighborhood context and age specifications, all neighborhood context and age measures are centered to the gender specific sample mean. Centering allows for the ethnicity coefficients to be directly interpreted as the ethnic difference in height at the gender specific sample mean of the variables.

4.1. Results for females

In models that constrained the relationship between neighborhood context and height to be constant across ethnicity (Models 1–3, Table 7), neighborhood SES and education ICE are found to be positively and statistically significantly associated with height; for a standard deviation increase in neighborhood SES, the associated average female resident is 0.46 cm taller. Similarly, a 10 point increase in education ICE is associated with 0.20 cm average height advantage. No association is found for neighborhood density.

Results from models that allow the relationship between neighborhood context, time trend, and height to vary by ethnicity reveal a more nuanced relationship (Models 4–6). No significant time trend was found overall or within ethnic groups, indicating that height has remained stagnant for women during this period. Each unit increase in neighborhood SES is associated with a 0.60 and 0.85 cm height increase for whites and foreign-born Mexican-Americans, respectively, while no association is found for blacks or US born Mexican-Americans (rows 2–5, Model 4).[7] Similarly, neighborhood education ICE is positively associated with height for whites and foreign-born Mexican-Americans (0.24 and 0.31 cm increase, respectively, for a 10 point increase in education ICE) but not for blacks or US born Mexican-Americans (rows 7–10, Model 5). Population density is modestly inversely associated with height for foreign-born Mexican-Americans (rows 12–15, Model 6).

With respect to individual-level estimates, results indicate a consistent positive relationship between education and height across all models with a range of 1.7–2.2 cm advantage for college graduates (row 33). However, no association is found for employment status or income. The height of females varied by region: individuals in the West were the tallest and those in the Northeast were the shortest. Both U.S. born and foreign-born Mexican-American females have significantly lower heights than white females, net of the individual-level adjustments detailed above; specifically, U.S. born and foreign-born Mexican-American females are approximately 4 and 7 cm shorter than white females, respectively. Black females are estimated to have heights that are statistically similar to white females.

4.2. Results for males

In contrast to results for females, we found no evidence of any statistically significant association between any of the neighborhood context variables and height for males (Models 1–3, Table 8). However, results from the ethnic interaction models revealed a link between neighborhood context and height for U.S. born Mexican-Americans (Models 4–6). A standard deviation increase in neighborhood SES is associated with a 1.4 cm increase in height of US born Mexican-Americans, while no association was found for whites, blacks, or foreign-born Mexican-Americans (rows 2–5, Model 4). Similarly, each 10 point increase in education ICE is found to be positively associated with a 0.26 cm height increase for US born Mexican-Americans (row 9, Model 5). Population density remained not associated with height for all ethnic groups (rows 12–15, Model 6).

Similar to females, we find a gradient relationship between education and height for males. A statistically significant time trend indicates that the average height of US men has increased over time (age coefficient negative). Specifically, a height increase of approximately 0.6 cm is associated with each subsequent decade. The tallest males resided in the West and Midwest while the shortest resided in the Northeast. In addition, US born and foreign-born Mexican-Americans are estimated to have heights approximately 5 and 8 cm shorter, respectively, than

[7] The variations in NSES index, education ICE index, and density for blacks seem to be comparable to those for other ethnic groups (see Table 2). For example, blacks have an average NSES of −0.6 with SE = 1.1; foreign-born Mexican Americans have approximately mean NSES = −0.4 with SE = 0.9. Statistically significant findings were found for Mexican Americans. Hence, it is unclear whether the null findings for blacks are due to insufficient variation in NSES.

Table 7
Neighborhood effects on height in Women, NHANES 1999–2004.

		Model					
		1	2	3	4	5	6
	Neighborhood characteristics						
1	NSES (for all ethnicities)	0.462**					
2	NSES (for Whites)				0.602*		
3	NSES (for Blacks)				0.217		
4	NSES (for US born Mexican-Americans)				0.223		
5	NSES (for foreign born Mexican-Americans)				0.847**		
6	Education ICE (for all ethnicities)		0.196**				
7	Education ICE (for Whites)					0.236**	
8	Education ICE (for Blacks)					0.013	
9	Education ICE (for US born Mexican-Americans)					0.126	
10	Education ICE (for foreign born Mexican-Americans)					0.317**	
11	Density (for all race/ethnicity)			0.002			
12	Density (for Whites)						0.013
13	Density (for Blacks)						0.001
14	Density (for US born Mexican-Americans)						-0.004
15	Density (for foreign born Mexican-Americans)						−0.029*
	Individual-level socio-demographic characteristics						
	Ethnicity [reference: Non-Hispanic White]						
16	Non-Hispanic Black	0.029	−0.111	−0.410	−0.078	−0.217	−0.481
17	Mexican-American: US born	−4.516**	−4.395**	−4.744**	−4.484**	−4.418**	−4.820**
18	Mexican-American: foreign born	−7.357**	−7.131**	−7.563**	−7.100**	−6.774**	−7.432**
19	Age	−0.206	−0.195	−0.197			
20	Age (for Whites)				−0.262	−0.235	−0.220
21	Age (for Blacks)				0.138	0.147	0.126
22	Age (for US born Mexican-Americans)				−0.631	−0.657	−0.647
23	Age (for foreign born Mexican-Americans)				−0.272	−0.276	−0.254
	PIR: [reference: PIR $\geq$ 5 times PIR]						
24	PIR $<$ 1	−0.215	−0.219	−0.548	−0.195	−0.232	−0.537
25	1 $\geq$ PIR $<$ 2	−0.155	−0.126	−0.432	−0.173	−0.158	−0.427
26	2 $\geq$ PIR $<$ 3	0.088	0.133	−0.097	0.047	0.090	−0.106
27	3 $\geq$ PIR $<$ 4	0.047	0.057	−0.057	0.047	0.064	−0.065
28	4 $\geq$ PIR $<$ 5	0.549	0.551	0.432	0.539	0.544	0.453
	Employment status [reference: unemployed]						
29	Employed	−0.392	−0.353	−0.447	−0.374	−0.323	−0.443
30	Not in the labor force	−0.252	−0.213	−0.335	−0.247	−0.195	−0.325
	Education level [reference: no high school]						
31	High school graduate	0.337	0.353	0.466	0.360	0.367	0.471
32	Some college	0.905**	0.850*	1.065**	0.933**	0.873*	1.082**
33	College graduate	1.946**	1.746**	2.158**	1.960**	1.749**	2.131**
	Region [reference: West]						
34	Northeast	−1.847**	−1.946**	−1.997**	−1.884**	−1.963**	−2.025**
35	Midwest	−0.743*	−0.719*	−0.787*	−0.752*	−0.692*	−0.786*
36	South	−1.200**	−1.189**	−1.156**	−1.187**	−1.174**	−1.235**
	Urbanity [reference: Large central metropolitan]						
37	Other metropolitan	−0.452	−0.402	−0.275	−0.428	−0.382	−0.315
38	Non metropolitan	−0.427	−0.272	−0.336	−0.399	−0.239	−0.338
	Random effects						
39	Level-two variance: var(u_{oj})	0.506	0.490	0.609	0.552	0.628	0.641
40	Level-one variance: var(r_{ij})	36.33**	36.26**	36.36**	36.20**	36.01**	36.21**
	Fit statistic						
41	AIC	20808.1	20800.4	20819.0	20812.2	20802.0	20820.9

Note: $N = 3220$. All models adjust for survey year and survey weight.
Coefficients for NSES are based on a 1 standard deviation change.
Coefficients for the education ICE are based on a 10 point change.
Coefficients for density reflect a 10% change.
Coefficients for age reflect a 10 year change.
* $p < 0.05$.
** $p < 0.01$.

Table 8
Neighborhood effects on height in Men, NHANES 1999–2004.

		Model					
		1	2	3	4	5	6
	Neighborhood characteristics						
1	NSES (for all ethnicities)	0.374					
2	NSES (for Whites)				0.547		
3	NSES (for Blacks)				−0.173		
4	NSES (for US born Mexican-Americans)				1.377**		
5	NSES (for foreign born Mexican-Americans)				0.683		
6	Education ICE (for all ethnicities)		0.110				
7	Education ICE (for Whites)					0.145	
8	Education ICE (for Blacks)					−0.148	
9	Education ICE (for US born Mexican-Americans)					0.263*	
10	Education ICE (for foreign born Mexican-Americans)					0.188	
11	Density (for all race/ethnicity)			−0.004			
12	Density (for Whites)						0.002
13	Density (for Blacks)						0.011
14	Density (for US born Mexican-Americans)						−0.019
15	Density (for foreign born Mexican-Americans)						−0.026
	Individual-level socio-demographic characteristics						
	Ethnicity [reference: Non-Hispanic White]						
16	Non-Hispanic Black	0.619	0.494	0.324	0.278	0.270	0.174
17	Mexican-American: US born	−4.971**	−4.927**	−5.129**	−4.994**	−4.924**	−5.212**
18	Mexican-American: foreign born	−8.426**	−8.336**	−8.584**	−8.385**	−8.250**	−8.553**
19	Age	−0.545**	−0.532**	−0.555**			
20	Age (for Whites)				−0.497*	−0.466*	−0.487*
21	Age (for Blacks)				−0.540	−0.541	−0.565
22	Age (for US born Mexican-Americans)				−0.750	−0.688	−0.696
23	Age (for foreign born Mexican-Americans)				−0.542	−0.549	−0.597
	PIR: [reference: PIR ≥ 5 times PIR]						
24	PIR < 1	−0.938	−0.990	−1.174*	−0.870	−1.008	−1.170*
25	1 ≥ PIR < 2	−0.376	−0.395	−0.577	−0.303	−0.391	−0.565
26	2 ≥ PIR < 3	−0.164	−0.170	−0.295	−0.137	−0.185	−0.307
27	3 ≥ PIR < 4	−0.170	−0.169	−0.247	−0.116	−0.142	−0.266
28	4 ≥ PIR < 5	−0.126	−0.136	−0.224	−0.110	−0.132	−0.199
	Employment status [reference: unemployed]						
29	Employed	0.492	0.488	0.461	0.551	0.510	0.476
30	Not in the labor force	1.168	1.119	1.090	1.112	1.032	1.056
	Education level [reference: no high school]						
31	High school graduate	1.226**	1.255**	1.298**	1.267**	1.291**	1.323**
32	Some college	1.652**	1.629**	1.728**	1.721**	1.689**	1.754**
33	College graduate	2.698**	2.638**	2.874**	2.738**	2.676**	2.869**
	Region [reference: West]						
34	Northeast	−1.633**	−1.717**	−1.768**	−1.775**	−1.815**	−1.872**
35	Midwest	−0.861	−0.866	−0.920	−0.906	−0.874	−0.941*
36	South	−0.922*	−0.929*	−0.943*	−0.881*	−0.917*	−0.985*
	Urbanity [reference: Large central metropolitan]						
37	Other metropolitan	0.089	0.155	0.183	0.148	0.201	0.202
38	Non-metropolitan	0.190	0.283	0.095	0.326	0.362	0.139
	Random Effects						
39	Level-two variance: var(u_{oj})	3.012**	2.998**	3.137**	2.932**	2.969**	3.193**
40	Level-one variance: var(r_{ij})	43.75**	43.78**	43.72**	43.65**	43.67**	43.62**
	Fit statistic						
41	AIC	18169.9	18170.6	18174.1	18172.0	18174.9	18183.2

Note: $N = 2712$. All models adjust for survey year and survey weight.
Coefficients for NSES are based on a 1 standard deviation change.
Coefficients for the education ICE are based on a 10 point change.
Coefficients for density reflect a 10% change.
Coefficients for age reflect a 10 year change.

* $p < 0.05$.

** $p < 0.01$.

whites. Blacks show no statistically significant difference in height.

5. Discussion

This study investigated the potential associations between neighborhood context and height by gender and whether these relationships varied across ethnic groups. Our results demonstrated some link between neighborhood context and height, primarily among females, after adjustment of individual-level factors. In models that constrained the relationship between neighborhood context and ethnicity to be the same (Models 1–3), neighborhood socioeconomic and education ICE were found to be positively associated with height. Population density was not found to be associated with height for females or for males. No association between neighborhood context and height was found for males overall. Models that allowed for the relationship to vary by ethnicity (Models 4–6) revealed that the strength and pattern of the associations vary by ethnicity. Findings suggest that the significant associations observed for the overall female sample were primarily driven by the strong relationship among whites and foreign-born Mexican Americans. Significant associations for NSES and education ICE were driven by the associations for Whites and foreign-born Mexican-Americans.[8] That is, in ethnic interaction models, NSES and education ICE was predictive of height for whites and foreign-born Mexican-Americans females while no association was found for blacks or US born Mexican-Americans. For males, the ethnicity/neighborhood context interaction models revealed a salutatory connection between NSES and education ICE, and height for U.S. born Mexican-Americans, but not for other ethnic groups.

These results are somewhat in contrast to Komlos and Lauderdale's study (2007a) which did not find local economic conditions, as measured by zip code level median income, unemployment and poverty rate, to be associated with height for either men or women. Moreover, they found population density to be strongly negatively correlated with height for men. Several possible factors may account for the divergent findings. First, the NHANES draws from a nationally representative sample as opposed to Komlos and Lauderdale's convenience sample. In addition, only whites were considered in their analysis. While our strongest associations were for Mexican-Americans, significant associations were still found for white females for NSES and education ICE (Table 6, Models 4 and 5). However, our neighborhood measures are not identical to Komlos and Lauderdale's. Our composite index of NSES may better tap into the salient socioeconomic factors that are associated with height than a single measure. In addition, our neighborhood scale was at the tract level while Komlos and Lauderdale's was at the zip code level. It may be that tract-level may be the more appropriate scale for which socioeconomic context influences height. Similarly, our largely null findings for density in contrast to Komlos and Lauderdale's significant findings suggest that population density at a larger scale (e.g., zip code vs tract) may be more relevant to height. Each of these factors may contribute to the differences in findings.

It is noteworthy that some of our strongest findings are for Mexican-Americans. The association between NSES, education ICE, and height was largest for foreign-born Mexican-American females while the association between NSES and height was largest for US born Mexican-American males. The stronger association for Mexican-Americans is consistent with other studies that examined differences in the link between neighborhood characteristics and health across race/ethnicity (Do et al., 2007). Perhaps Mexican-Americans are more able to draw from community resources and social networks. Hispanics and Hispanic immigrants in particular, tend to cluster in co-ethnic enclaves, which are hypothesized to offer strong social networks and social cohesion. Neighborhoods and neighborhood environments, then, may have a relatively stronger influence on Hispanic health outcomes, including stature. This phenomenon would be consistent with the hypothesized beneficial effects of Hispanic enclaves that serve to buffer their relatively disadvantaged socioeconomic status. However, any inferences, especially for the foreign-born Mexican-American females, must be tempered by the greater possibility of self-selection of immigrants to certain neighborhood type. Immigrants who are taller may also tend to have more financial and social resources to reside in less disadvantage neighborhoods. Although individual SES controls were included, measurement issues may have not allowed for complete adjustments for individual characteristics.

While we found support for a link between neighborhood context and height, significant variation at the neighborhood level remained unexplained for all ethnicities. Perhaps other neighborhood conditions not investigated in this study may be predictive of height. Hence, further studies examining neighborhood environments not assessed here may provide additional insights to how place relates to height.

Inferences from our findings must also take into account several limitations. First, our data is repeated cross-sectional and does not contain information regarding the length of residency of respondents. Cross-sectional data may recover attenuated estimates of the relationship between neighborhood context and health because it does not distinguish long-term exposure from transient exposure (Do, 2009). However, self-selection may result in estimates that are larger than warranted. Hence, the direction of bias is ambiguous. Second, we only have information regarding the context of individuals during adulthood. Given that height is mainly determined by factors incurred during childhood, our usage of contextual factors measured after terminal age of growth is reached may have attenuated our estimates towards the null due to random noise if childhood neighborhood context is not highly correlated to adult neighborhood context.

[8] The variations in NSES index, education ICE index, and density for blacks seem to be comparable to those for other ethnic groups (see Table 2). For example, blacks have an average NSES of −0.6 with SE = 1.1; foreign-born Mexican Americans have approximately mean NSES = −0.4 with SE = 0.9. Statistically significant findings were found for Mexican Americans. Hence, it is unclear whether the null findings for blacks are due to insufficient variation in NSES.

Despite these limitations, this study significantly adds to the sparse literature that examines the association between height and neighborhood context. In terms of ethnicity, this study takes critical steps toward understanding the intersection between neighborhood context and height, as other ethnic groups are often not examined in detail because of lack of sample size. Our findings suggest that the relationship between height and contextual factors differs across gender and ethnicity. Importantly, we find height to be non-uniformly distributed across the U.S. Shorter individuals are clustered within neighborhoods of high disadvantage and low education among white females and among Mexican-born females as well as among U.S. born Mexican-American males. These results are consistent with findings of neighborhood deprivation and its correlates being predictive of a wide range of poor health outcomes. The spatial patterning of height across the U.S. landscape suggests that the social and physical environment may play an important role, over and above individual-level attributes, in influencing height.

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