The shape of things to come?

Obesity prevalence among foreign-born vs. US-born Mexican youth in California

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ABSTRACT

Until recently, patterns of obesity prevalence among Hispanic children in the US mirrored those of Hispanic adults: prevalence was highest among US-born Hispanic children, and lowest among foreign-born children. However, recent trends in Mexico suggest that this pattern may be shifting. The well-documented rapid nutrition transition in Mexico has contributed to dramatic increases in obesity prevalence among Mexican children, adolescents, and young adults. In this study, based on data from the Los Angeles Family and Neighborhood Survey and the California Health Interview Survey, we find support for the hypothesis that overweight/obesity prevalence is no longer lower for foreign-born compared to US-born Mexican-origin youth. In fact, higher obesity prevalence among the foreign-born was observed for boys (ages 4-10) and for young adult males (ages 18-24). The previously-observed protective effect on obesity risk among recent immigrants from Mexico is likely to erode as current child and youth cohorts age into adulthood.

Hispanic children in the US are a large and rapidly-growing group: The 5-17 year-old Hispanic population will increase from 11 million in 2006 to 28 million in 2050, at which point there will be more Hispanic than non-Hispanic white school children in the US.[1] This group is growing in other ways as well: Overweight and obesity among Hispanic children and adolescents have increased substantially in the past 20 years, particularly for Mexican-origin adolescents.[2] NHANES 1999-2002 recorded an overweight prevalence of 40% for Mexican-origin children ages 6-18 (vs. 28% for non-Hispanic whites), and an obesity prevalence of 22% (vs. 14% for non-Hispanic whites).[3] A pattern of higher obesity prevalence for Hispanic children relative to non-Hispanic white children emerges as early as preschool.[4, 5]

High obesity prevalence in the young Hispanic population raises concerns about social disparities in current and future chronic disease burden. Children who are even moderately overweight are at risk for high blood pressure, hyperlipidemia, and diabetes.[6] Hispanic-origin school children have already been shown to have higher prevalence of all three of these conditions compared to non-Hispanic whites. [7-10] Dietary and physical activity patterns established during adolescence often persist into adulthood, making obesity difficult to reverse. Indeed, Hispanic-origin and particularly Mexican-origin adults in the US have been shown to have higher prevalence of high blood pressure, hyperlipidemia, and diabetes compared to non-Hispanic whites.[11-14] Therefore, the weight status of the young Hispanic population may point to the shape of things to come.

Understanding the mechanisms that produce race-ethnic disparities in obesity prevalence is important for designing effective obesity prevention programs. For the Hispanic population, nativity and extent of exposure to US culture have been a focus of obesity studies. Generally, adult obesity prevalence has been shown to be higher for US-born (second- and higher-generation) Hispanic adults compared to the foreign-born (first-generation).[15-17] Within the first generation, longer stay in the US has also been associated with higher risk of obesity and obesity-related health behaviors.[18] Until recently, nativity patterns of obesity prevalence and

the role of acculturation for Hispanic-origin children in the US mirrored those of Hispanic adults, with BMI and obesity increasing for subsequent generations and more acculturated children.[19-22]

Two related strains of research, however, point towards a shift in this pattern. First, several studies have questioned whether increasing acculturation accounts for differences between first- and second-generation immigrant children in obesity status.[23-25] Recent work on Hispanic children in the US hints that obesity prevalence may now be similar or even higher among the foreign-born compared to the US-born.[26-28]

Second, recent trends in Mexico, the birthplace of most foreign-born Hispanics in the US[29], also suggest that this pattern may be shifting. The very rapid nutrition transition in Mexico has been well-documented and has contributed to dramatic increases in obesity prevalence among Mexican children, adolescents, and young adults.[30-34] At the same time, continued Mexican migration to the US may influence obesity on both sides of the border. For example, children in Mexico living in households with migrant networks are at higher risk for obesity than children who are not exposed to migration[35, 36]. Mexican adult migrants also appear to bring their health behaviors with them to the US[37].

In this study, we hypothesize that the accelerated nutrition transition in Mexico has eliminated the previous immigrant advantage in obesity prevalence for Mexican-origin children and adolescents. Our analysis is focused on California, where 37% of the US Mexican-origin population lives[38], and exploits two data sets: the second wave of the Los Angeles Family and Neighborhood Survey (L.A.FANS-2) and the California Health Interview Survey (CHIS). L.A.FANS-2 offers two important strengths: (1) a large Mexican-origin sample, including first-, second-, and third-generation immigrants and (2) measured height and weight, avoiding the biases inherent in self-reported height and weight in other surveys. We also analyze data from CHIS, a statewide telephone survey with a very large sample size. We find support for our hypothesis that obesity prevalence for foreign-born Mexican-origin children is no longer lower than that for their US-born counterparts. In fact, we find higher obesity prevalence among

foreign-born boys ages 4-10 and foreign-born young adult males (ages 18-24). These findings highlight the need for more research on the role of Mexico's nutrition transition in shaping current and future obesity prevalence in the US.

METHODS

The first set of analyses use data from L.A.FANS-2, collected in 2006-2008. L.A.FANS is a longitudinal study based on a stratified probability sample of 65 neighborhoods (census tracts) in Los Angeles County with oversamples in high poverty census tracts.[39] Wave 1 was collected in 2000-2001. In Wave 2, panel respondents still living within Los Angeles County were re-interviewed and a sample of new entrants was added. Detailed residential histories and migration status were collected for all respondents, as well as mother's place of birth. Height and weight were measured for adults and children.

This analysis focuses on respondents ages 4-24 in one of four race-ethnic and nativity groups: Foreign-born Mexicans living in the US ("1st generation"); US-born Mexican-origin with Mexican-born mother ("2nd generation"); US-born Mexican-origin with US-born Mexican-origin mother ("3+ generation"); and US-born non-Hispanic whites ("whites"). Other (non-Mexican) Hispanics, foreign-born whites, and other race-ethnic groups are excluded. Outcome measures of interest include BMI (kg/m^2, calculated from measured height and weight), and overweight/obese status (using established pediatric and adult cut-offs)[40, 41]. We exclude five respondents who have no census-tract identifier (required to estimate multilevel models); 79 respondents who are missing height and/or weight measurements; and 16 respondents with outlier BMI values (defined as more than one interquartile range below the 25^{th} percentile or more than two interquartile ranges above the 75^{th} percentile of the BMI range). For an additional 63 adolescent and young adult respondents who are missing measured height and/or weight but who have self-reported height and/or weight, we impute the measured value from their self-

report.[1] The final analytic sample comprises 1,116 respondents ages 4-24 from 762 households and 275 census tracts. The average number of respondents per household is 1.5, and the average number of respondents per census tract is 4.1.

We repeat our analyses with data from CHIS, a biannual telephone survey of California residents. As of 2007, the sample includes both landline households and cell-phone only households via random-digit dialing. Several of California's race-ethnic minority groups are over-sampled, resulting in a complex sampling scheme. The 2007 survey included 53,611 households, comprising 51,048 adults, 3,638 adolescents and 9,913 children. The sample is designed to be representative at the county level for the state's 41 largest counties. Respondents report a wide range of sociodemographic and economic indicators, as well as health status, health behaviors, and health services use. For these analyses, we focus on respondents ages 4-24 to conduct parallel analyses to our L.A.FANS analyses. We measure race-ethnicity and nativity using the same categories as in L.A.FANS. In an additional set of analyses, we further split the first generation Mexican-origin sample into those who have been in the US for less than two years, and those who have been in the US for two or more years. In CHIS, BMI and overweight/obese status are calculated from self-reported height and weight (for adults and adolescents ages 12-17) and parent-reported height and weight (for children ages 4-11). After excluding 955 respondents with missing height and/or weight and an additional 182 respondents with outlier BMI values (defined as for L.A.FANS), we have a final analytic sample of 8,492.

We use logistic regression to estimate the odds of being overweight or obese as a function of age, gender, and race-ethnic and nativity categories. We estimate models separately for the L.A.FANS and CHIS samples. In both cases, we examine the full sample of respondents ages 4-24 and then stratify by age-sex groups. For L.A.FANS, we estimate a multilevel random-

[1] Regression analyses presented here do not control for whether height or weight was imputed; however, results from regression models that include a dummy variable for imputed height or weight are substantively identical to results shown here.

intercept logistic model using the *xtmelogit* command in Stata 11.0 (StataCorp, College Station, Texas). The multilevel model explicitly accounts for the clustering of obesity status for children in the same household and in the same community. The CHIS analyses are weighted according to the CHIS sampling scheme.

RESULTS

Descriptive statistics for the L.A.FANS and CHIS samples are presented in Table 1. In the L.A.FANS sample, almost half of respondents are obese or overweight. In the CHIS sample, 35% are obese or overweight. This difference is due in part to the larger proportion of Mexican-origin respondents in the L.A.FANS sample, and to the fact that height and weight were self-reported (for young adults) and parent-reported (for children and adolescents) in CHIS, which has been shown to underestimate obesity prevalence [42-50] .

Our hypothesis of little or no immigrant advantage in obesity for Mexican-origin children and youth relative to subsequent generations is confirmed by the unadjusted prevalences shown in Figure 1: for the L.A.FANS sample, overweight/obesity prevalence is higher for 1st generation Mexican-origin respondents than for 2nd and 3+ generation. The CHIS sample distinguishes between recently-arrived 1st generation Mexican-origin respondents (those in the US less than two years) and 1st generation respondents with longer duration in the US. In the CHIS sample, the highest overweight/obesity prevalence is observed for the recently-arrived Mexican-origin respondents, while the three other Mexican-origin groups are similar to each other. Consistent with the large literature on Hispanic obesity in the US, overweight/obesity prevalence is higher for the Mexican-origin populations relative to whites in both samples.

We explore these relationships in more detail with regression analysis. Odds ratios from logistic regression models predicting overweight-obesity and controlling for age and gender are presented in Tables 2 (L.A.FANS) and Tables 3 and 4 (CHIS). For the full sample of L.A.FANS respondents, 1st generation Mexican-origin youth have the highest odds ratio of

overweight/obesity (OR = 3.76, 95% CI 1.98-7.14) relative to whites, followed by 2nd (OR = 2.74, 95% CI 1.73-4.33) and 3+ generation (OR = 2.74, 95% CI 1.56-4.82). The 1st generation is not significantly different from 2nd or 3+ generation Mexican-origin respondents. Similarly, results for age-sex subgroups do not show significantly higher odds of obesity prevalence for 3+ generation Mexican-origin respondents compared to other race-ethnicity groups. In fact, the only marginally significant comparison among the Mexican-origin respondents shows 1st generation female adolescents with much higher odds of overweight/obesity (OR = 16.42, 95% CI 1.57-171.58) than 3+ generation (OR = 2.56, 95% CI 0.55-11.80). These results are suggestive of a higher prevalence of obesity among the foreign-born for male children, young adult males, and female adolescents, but are not significant.

For the overall CHIS sample (Table 3), odds of obesity/overweight are almost identical for the three Mexican-origin populations, at about twice the odds for whites. Third and higher generation Mexican-origin respondents do not have higher odds of obesity than other ethnicity-nativity groups in any age-sex subgroups, and, among young adults males, have significantly *lower* odds (OR = 1.13, 95% CI 0.62 – 2.04) than the 1st generation (OR = 2.78, 95% CI 1.68-4.62, p = .009).

If the very recent nutrition transition in Mexico is affecting obesity prevalence among Mexican-origin youth in the US and reducing any previous health advantage enjoyed by migrants, then we would expect even higher prevalence among more recent migrants, who have been exposed to the obesogenic nutrition transition in Mexico for a longer period of time than earlier migrants. To examine this possibility, we divided the 1st generation Mexican-origin CHIS sample into those who have been in the US for less than two vs. two or more years (the L.A.FANS sample size does not permit a similar analysis). Results (Table 4) are again consistent with the Mexican obesity epidemic "crossing the border" and eroding the immigrant health advantage among young adult men: odds of overweight/obesity are significantly higher for the recently-arrived 1st generation (OR = 6.10, 95% CI 2.04-18.25) compared to 3+

generation (OR = 1.13, 95% CI 0.62-2.04, p =.006) and marginally higher than the 2nd generation (OR = 2.13, 95% CI 1.30-3.50, p = .071).

Notably, Tables 3 and 4 suggest that the relationship between nativity and obesity for females in all three age groups conforms to the expected pattern of highest prevalence among the US-born (3+ generation) Mexican-origin, although the only (marginally) significant difference is for recently-arrived first generation Mexican-origin girls (ages 4-10) compared to 3+ generation Mexican-origin girls of the same age (Table 4.)

DISCUSSION

We investigated the hypothesis that the rapid nutrition transition in Mexico has led to changes in the ethnic pattern of obesity in the US. Specifically, we evaluated whether the lower overweight/obesity prevalence previously observed among 1st generation Mexican-origin children and youth compared to second or later generations has disappeared. Our results confirm this pattern generally. In addition, we find higher obesity prevalence among immigrants for young adult males (ages 18-24). This is first study of which we are aware to find higher obesity/overweight prevalence among a foreign-born Hispanic adult population compared to a similar US-born sample. Moreover, where previous studies of adults have found higher obesity prevalence associated with longer stays in the US among foreign-born Hispanics,[37] our results suggest the opposite: Among young adult males, at least, prevalence is highest for Mexican-origin immigrants who have been in the US for less than two years.

Our second important finding is that, among Mexican-origin boys ages 4-10, the first generation may have higher odds of overweight/obesity than later generations. While the alarming obesity prevalence among Mexican-origin boys in this age group has been documented elsewhere[3, 51, 52], our analysis highlights the important contribution of first-generation Mexican boys to this problem and the need to examine the gendered aspects of culture and acculturation that may underlie these differences [53].

Our results prompt a rethinking of previous research linking acculturation to obesity risk for the Hispanic population. Acculturation hypotheses posit that protective health behaviors (such as a healthy diet or regular physical activity) accompany migrants from their country of origin, but their protection erodes as immigrants spend more time in the US and adopt less healthy behaviors. For example, there is some evidence that the diets of non-acculturated or more recently-arrived Mexican women are better than diets of acculturated Mexican women.[54-58] Similarly, first-generation Hispanic adolescents consume significantly more servings of fruits and vegetables and glasses of milk and significantly fewer cans of soda per day than second- or third-generation Hispanic adolescents[59]. If these dietary habits are substantial enough to lead to changes in body weight, then they could result in increasing obesity prevalence for later generations.

However, acculturation arguments rest on the assumption that health behaviors in the sending country are better than adopted health behaviors in the US. Evidence from food and nutrition surveys in Mexico suggest that this may have been the case as recently as 10-15 years ago (when some of the studies cited above were conducted) but is no longer so. Specifically, increased consumption of fats[32] and processed foods[60] have transformed the Mexican diet over a very short time period from high-fiber to high-calorie density. In this context, higher levels of acculturation and longer stays in the US may actually improve diets compared to living in Mexico.

Finally, it is important to remember that complicated dynamics between acculturation, migration and obesity risk for children and youth operate on both sides of the border. Two recent studies set in Mexico find that children in households with extended family members in the US are at higher risk for obesity/overweight than children in households without these networks [35, 36]. Children with migrant kin (who are at higher risk for obesity) are also more likely to migrate themselves. Previous work has shown that health behaviors accompany Mexican

adult migrants across the border [37]. The present study suggests that the same is true for Mexican children.

Limitations

Our study has several limitations. The completion rates for CHIS are low (e.g., 18.7% for the 2007 adult landline sample and 15.9% for the 2007 adult cell phone sample). Parent-reported and self-reported height and weight in the CHIS survey may have led to underestimates of overweight/obesity, and the extent of underestimation may differ by ethnicity/nativity group and body size. The CHIS sample also had higher rates of missing and outlier values for measured height and weight among the foreign-born Mexican population relative to other groups. However, a recent study using L.A.FANS found that while Hispanic adolescents had higher odds of failing to report height and weight in a survey, and of misreporting their height, non-response and error in self-reported height and weight were *not* selective on weight status for this population.[61]

An unanswered question is whether our results can be generalized to a nationally-representative sample of Mexican-origin children and youth. Although we explored using the National Health Interview Survey (NHIS), the NHIS suffers from higher rates of non-response for (parent-reported) height and weight for foreign-born Mexican-origin adolescents compared to both US-born Mexican-origin respondents and whites. The NHIS also does not collect information on height and weight for children under age 12.

Conclusions

Addressing the obesity epidemic among Mexican-origin children and youth is clearly a priority on both sides of the border[62]. Among OECD countries, Mexico now has the second highest adult overweight prevalence (after the US), and among the highest child and youth prevalence[63]. A key research priority will be to calculate the expected relative contribution of

increases in obesity prevalence among the Mexican-origin population and increases in the size of the Mexican-origin population in the US to overall obesity prevalence. At a programmatic level, prevention and surveillance programs in the US must account for the rising obesity prevalence in Mexico, particularly among children and youth. Opportunities may exist to exploit well-known geographic patterns of Mexico-US migration to target childhood obesity prevention programs in regions of Mexico that send substantial numbers of migrants to the US.

The obesity patterns observed among Mexican-origin youth in the United States today will follow these cohorts into middle and older ages, and will have important implications for the prevalence of obesity-related diseases including diabetes, cardiovascular disease, and cancer in this population. Obesity is poised to be a critical driver of social disparities in health between Hispanic and non-Hispanic white groups. Until recently, research in this area focused on the role of acculturation and length of stay in the US in driving higher rates of obesity. Our results suggest that this pattern is rapidly reversing. To reduce future disparities, attention must be focused on the causes and consequences of Mexico's obesity epidemic as well.

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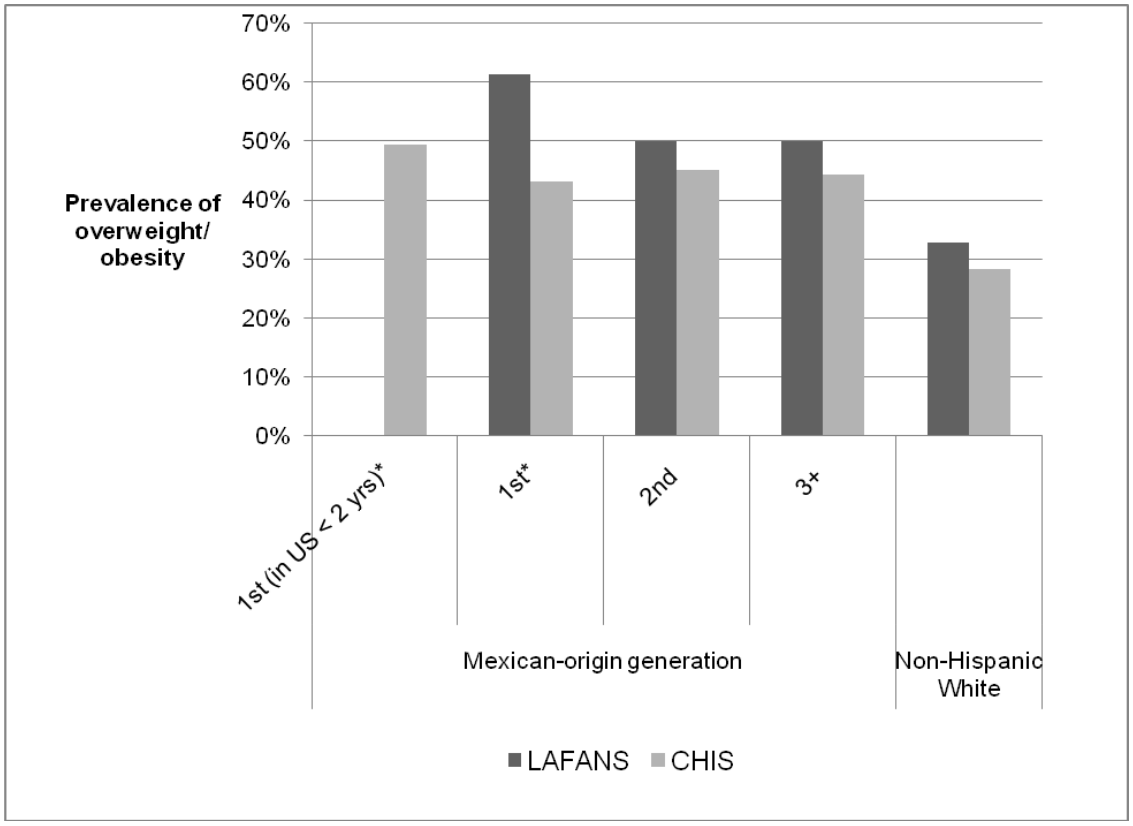
Figure 1: Proportion overweight/obese by ethnicity-nativity category, respondents ages 4-24, L.A.-FANS-2 (2006-2008) and CHIS (2007).



*All L.A.FANS-2 first generation Mexican-origin respondents are included in the "1st" generation category. CHIS first-generation respondents are divided into those who have ben in the US for <2 years (first column) and those who have been in the US for 2+ year (second column). Prevalence for L.A.FANS-2 respondents is unweighted as weights were not available at the time of submission. Prevalence for CHIS respondents is weighted according to the CHIS sampling scheme.

Table 1: Percentage Distribution by Selected Characteristics: California Children, Adolescents and Young Adults, L.A.FANS-2 (2006-2008) and California Health Interview Survey (2007).

	L.A.FANS		CHIS	
	Number (N=1116)	%[a]	Number (N=8492)	%[a]
Ethnicity-Nativity				
Foreign-born Mexican-origin (1st gen.)	123	11	510	9
US-born Mexican-origin, Mexican-born mother (2nd gen.)	517	46	1117	18
US-born Mexican-origin, US-born Mexican-origin mother (3+ gen.)	190	17	1006	16
Non-Hispanic white (US-born)	286	26	5859	57
Weight status				
Obese	266	24	1117	12
Overweight	276	25	1850	23
Normal weight/underweight	574	51	5525	65
Sex				
Male	566	51	4380	51
Female	550	49	4112	49
Age group				
4-10	311	28	3385	28
11-17	486	44	3306	38
18-24	319	29	1801	34

Notes: L.A.FANS = Los Angeles Family and Neighborhood Survey Wave 2 (2006-08). CHIS = California Health Interview Survey 2007. [a] Values are expressed as percentages. L.A.FANS-2 numbers and percentages are unweighted as weights were not available at the time of submission. CHIS numbers are unweighted, percentages are weighted.

Table 2: Odds ratios from multilevel random-intercept logistic models predicting overweight/obese as a function of ethnicity-nativity, Mexican-origin and white respondents ages 4-24, L.A.FANS-2 (2006-2008) (N=1116)

		Child (4-10)		Adolescent (11-17)		Adult (18-24)	
Overweight/obese	Full sample	Female	Male	Female	Male	Female	Male
Ethnicity-nativity (Ref: US-born white)							
1st generation Mexican-origin	3.76**	3.10	25.31	16.42*	5.20	1.20	4.65
	(1.98 -7.14)	(0.14 - 69.35)	(0.79 - 815.41)	(1.57 - 171.58)	(0.86 - 31.61)	(0.48 - 3.04)	(0.53 - 40.80)
2nd generation Mexican-origin	2.74**	5.07	4.74	5.51*	2.71	2.24	1.47
	(1.73 -4.33)	(0.67 - 38.10)	(0.78 - 28.95)	(1.17 - 25.95)	(0.88 - 8.36)	(0.98 - 5.08)	(0.49 - 4.41)
3+ generation Mexican-origin	2.74**	3.26	3.91	2.56†	6.23*	2.31	2.38
	(1.56 -4.82)	(0.34 - 31.35)	(0.57 - 26.65)	(0.55 - 11.80)	(1.18 - 32.91)	(0.89 - 6.02)	(0.50 - 11.28)
N	1116	145	166	239	247	166	153

** p<0.01, * p<0.05 for test of significant difference from US-born non-Hispanic whites. † p<.01, †† p<.10 for test of significant difference from 1st generation Mexican-origin. All models control for age in years. Model of full sample also controls for gender. 95% confidence intervals (in parentheses) are adjusted for clustering at the household and census tract levels.

Table 3: Odds ratios from logistic models predicting overweight/obese as a function of ethnicity-nativity, Mexican-origin and white respondents ages 4-24, California Health Interview Survey 2007 (N=8492).

		Child (4-10)		Adolescent (11-17)		Adult (18-24)	
Overweight/obese	Full sample	Female	Male	Female	Male	Female	Male
Ethnicity-nativity (Ref: US-born NHW)							
1st generation Mexican-origin	2.09**	1.63	3.63**	2.30**	2.02*	1.49	2.78**
	(1.59 - 2.75)	(0.29 - 9.30)	(1.39 - 9.48)	(1.30 - 4.07)	(1.15 - 3.57)	(0.81 - 2.74)	(1.68 - 4.62)
2nd generation Mexican-origin	2.09**	1.54*	2.36**	2.56**	2.63**	1.86*	2.13**
	(1.72 - 2.55)	(1.02 - 2.34)	(1.62 - 3.44)	(1.72 - 3.80)	(1.65 - 4.19)	(1.02 - 3.40)	(1.30 - 3.51)
3+ generation Mexican-origin	2.02**	2.06**	2.36**	3.54**	1.88*	1.95*	1.13††
	(1.67 - 2.44)	(1.31 - 3.24)	(1.54 - 3.63)	(2.48 - 5.06)	(1.16 - 3.05)	(1.05 - 3.63)	(0.62 - 2.04)
N	8492	1589	1796	1641	1665	882	919

** p<0.01, * p<0.05 for test of significant difference from US-born non-Hispanic whites. † p<.01, †† p<.10 for test of significant difference from 1st generation Mexican-origin. All models control for age in years. Model of full sample also controls for gender. 95% confidence intervals are shown in parentheses. N is unweighted. Analyses are weighted for the CHIS sampling scheme.

Table 4: Odds ratios from logistic models predicting overweight/obese as a function of ethnicity-nativity, Mexican-origin and white respondents ages 4-24, California Health Interview Survey (2007) (N=8492)

		Child (4-10)		Adolescent (11-17)		Adult (18-24)	
Overweight/obese	Full sample	Female	Male	Female	Male	Female	Male
Ethnicity-nativity (Ref: US-born NHW)							
1st gen. Mexican-origin, in US <2 years	2.57	0.73	6.51**	2.13	2.48	1.55	6.10**
	(0.95 - 6.94)	(0.22 - 2.41)	(1.59 - 26.67)	(0.41 - 11.16)	(0.56 - 10.92)	(0.02 - 121.76)	(2.04 - 18.25)
1st gen. Mexican-origin, in US 2+ years	2.06**	1.68	3.42*	2.32**	1.99*	1.49	2.66**
	(1.55 - 2.75)	(0.59 - 4.82)	(1.24 - 9.48)	(1.30 - 4.17)	(1.07 - 3.68)	(0.80 - 2.79)	(1.59 - 4.45)
2nd generation Mexican-origin	2.09**	1.54*	2.36**	2.56**	2.63**	1.86*	2.13** †
	(1.72 - 2.55)	(1.03 - 2.32)	(1.62 - 3.44)	(1.72 - 3.80)	(1.65 - 4.19)	(1.02 - 3.40)	(1.30 - 3.50)
3+ generation Mexican-origin	2.02**	2.06** †	2.36**	3.54**	1.88*	1.95*	1.13††
	(1.67 - 2.44)	(1.31 - 3.24)	(1.56 - 3.58)	(2.48 - 5.06)	(1.16 - 3.05)	(1.05 - 3.63)	(0.62 - 2.04)
N	8492	1589	1796	1641	1665	882	919

** p<0.01, * p<0.05 for test of significant difference from US-born non-Hispanic whites. † p<.01, †† p<.10 for test of significant difference from 1st generation Mexican-origin, in US < 2 years. All models control for age in years. Model of full sample also controls for gender. 95% confidence intervals are shown in parentheses. N is unweighted. Analyses are weighted for the CHIS sampling scheme.