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Abstract

Examining multigenerational effects on health in Latin American populations from grandparents to subsequent generations is a fruitful area for research. Many Latin American populations have experienced rapid demographic and nutritional changes across generations with possible consequences for older adult health and subsequent generations. Understanding the multigenerational effects of obesity—an important health concern internationally—and early life nutritional status on child stunting merits further consideration. Using comprehensive data collected on households and individuals throughout Colombia (**ENDS, ENSIN**), we examine differences in child health according to whether grandparents are living/not living in the household and the degree to which obesity and height in older generations predicts child obesity, overweight and stunting in multigenerational households. We find that households with children living with grandparents have a higher prevalence of child obesity and lower prevalence of stunting; junk food consumption is similar across all types of households. In multigenerational households, we find strong intergenerational associations between grandmother-mother obesity and mother-female child obesity (overweight), and strong multigenerational associations between (1) grandfather obesity and female child obesity and overweight; (2) grandmother obesity and male child overweight; and (3) grandparent height and child stunting, mediated by mother height. We conclude that grandparent proximity, family resources, and relationship to household head play an important role in child obesity, overweight and stunting. In spite of grandparent proximity, mother being present in the household is important in terms of child health. Puzzling gender patterns for obesity/overweight raises the possibility of additional multigenerational factors affecting child health.

Key words: multigenerational, obesity, overweight, stunting, child health, grandparents

Introduction

The examination of multigenerational effects on health in Latin American populations from grandparents to subsequent generations is a fruitful area for research that has not been fully explored. Multigenerational effects on health have been examined using social science survey data (Currie & Moretti 2007; Davis, McGonagle, Schoeni, & Stafford 2008). However, the call to examine multigenerational effects within the context of major social and demographic transitions (Mare 2011)—transitions that have characterized the Latin American and Caribbean (LAC) region in the later part of the 20th century—has largely been unanswered.

Within this context, understanding the multigenerational impact of obesity—an important health concern both within the LAC region and internationally (He, Goodkind, & Kowal 2016)—merits further consideration. Although individual lifestyle at older ages provides partial explanations for obesity (Kuh & Ben-Shlomo 2004), poor environmental conditions in early life, such as poor nutrition and infectious diseases in combination with the rapid demographic transitions of the last century, provide relevant explanations for the increasing risk of chronic conditions including obesity in older adults (Palloni & Souza 2013). Rapid improvements in mortality without parallel improvements in standard of living produced more survivors of poor early life conditions who, at older ages, are at increased risk of chronic conditions including obesity because of their early life environmental conditions (McEniry 2014; Palloni & Beltran-Sanchez 2016; Palloni, McEniry, Wong, & Peláez 2006; Samper-Ternent, Michaels-Obregón, Wong, & Palloni 2012).

A large portion of older adults in middle income countries were born or grew up in rural areas with limited access to good nutrition and proper medical care (Flórez, Guataquí, Mendez, & Cote In press; Flórez & Méndez 2000; López-Alonso 2007). Inadequate nutrition *in utero* during critical periods can lead to poor intrauterine and post-birth growth, low birth weight and stunted babies, and an increased risk of heart disease, diabetes, and obesity at older ages (Barker 1998). Predictive adaptive responses made *in utero* as a result of cues from a nutritionally resource scarce environment prepare the individual to survive in a similar environment by altering an individual's physiology but a mismatch occurs when exposed to a nutritionally richer environment later in life, leading to disease (Bateson & Gluckman 2011; Gluckman & Hanson 2005). Major demographic and epidemiological changes leading to increased urbanization and exposure to non-traditional foods high in saturated fats (Popkin 2006; Schmidhuber & Shetty 2005) may compound early life effects by increasing the risk of a mismatch between early life physiological changes and later life environment, thereby increasing the risk of poor health at older ages.

Undoubtedly, there is a complex interplay between environmental, behavioral, genetic, and epigenetic mechanisms explaining differences in the risk of obesity (Gluckman & Hanson 2005; Somer & Thummel 2014). In terms of multigenerational transmission of obesity, behavioral components are particularly relevant. Grandparents may encourage unhealthy eating habits; proximity (living in the same household) between children and their grandparents may increase child exposure to unhealthy eating habits, especially in very young children (Pearce et al. 2010; Tanskanen 2013). Obese children also tend to have obese grandparents (Davis et al. 2008; McKinney

2015). Family composition (gender, number of children within the household) may also play a role in explaining obesity (Suomalainen 2017).

In some developing economies, children living with their grandparents in multigenerational households are more likely to be obese in part due to traditional roles and perceptions of health in households where the grandparent is the primary caregiver and where grandparents view heavier children as being healthier (Li, Adab, & Cheng 2015). Age and gender differences in caretaking by grandparents may also be important, especially in households where children are living with their grandparents. In LAC, the traditional role of grandmothers is one where grandmothers are caretakers, cook, and influence a child's well-being and education whereas grandfathers have a different role and teach them how to survive, work and play (Suomalainen 2017).

Epigenetic transmission due to poor nutrition also provides a compelling explanation for multigenerational effects (Davis et al. 2008; Dijk, Tellam, Morrison, Muhlhausler, & Molloy 2015; Kelleher et al. 2014; Nielsen, Nielsen, & Holm 2015). It is very relevant to LAC given the historical circumstances of rapid demographic and nutritional transitions within the context of poor early life nutrition during the 20th and 21st centuries. The early life effects of older adults on health born during these circumstances, if then transmitted to future generations, could not only influence nutritional status but also result in an increasing risk of obesity for many generations to come, neutralizing the effect improvements in nutrition can afford.

Epigenetic factors modify gene expression which affect one generation and can then be transmitted as epigenetic inheritance to future generations through phenotypic to phenotype transmission or through direct germ line transmission (Kuzawa &

Eisenberg 2014). The importance of the mother's nutrition cannot be denied in terms of intergenerational and possibly multigenerational transmission (Battista, Hivert, Duval, & Baillargeon 2011; Currie & Moretti 2007; Susser et al. 2012). A mother's diet may have a long-lasting influence on the health of upcoming generations, including the propensity to obesity, independent of later diet changes (Cooney 2006; Cropley, Suter, Beckman, & Martin 2006). Long-term nutritional history of one's ancestors is important and nutritional supplements during pregnancy may not be sufficient to change the long-term nutritional history of the family (Kuzawa & Eisenberg 2014). However, transmission through the germ line of epigenetic information (either male sperm or female egg) can also produce lasting gender-specific effects across generations affecting health (Curley, Mashoodh, & Champagne 2011; Pembrey et al. 2006; Pembrey, Saffery, Bygren, & Epidemiology 2014). Thus, male transmission of early life effects is a very relevant consideration and illustrates the importance of examining gender differences to elucidate the presence of possible epigenetic mechanisms at play. Evidence of transgenerational transmission of epigenetic effects occur when gender-specific associations are observed between the paternal grandparent and their grandchildren (Kuzawa & Eisenberg 2014).

Colombia: A case study

Colombia is an important setting because it is a large, middle income country with a growing population of older adults and an increasing prevalence of obesity and chronic conditions (Cano-Gutierrez, Reyes-Ortiz, Samper-Ternent, Gélvez-Rueda, & Borda 2015). During the last decades of the 20th century, urban areas in particular benefited from increased modernization, urbanization, and education. However, unlike other LAC countries, the social and political situation had profound effects on population aging. Many resources have been devoted to the armed conflict, which resulted in the death of a large percentage of young adults, left areas of Colombia with many older adults, and affected the country's aging process overall (Gomez, Curcio, & Duque 2009).

Patterns of rapid decline in mortality amidst slower economic growth and dramatic improvements in life expectancy in the last century in Colombia fit the pattern described in other LAC countries (Palloni & Souza 2013). Colombia experienced rapid mortality decline starting at end of the 1930s through the 1980s from improvements in infant and child mortality due to public health policies and interventions and medical technology (Flórez et al. In press; Flórez & Méndez 2000). The decline in IMR (infant mortality rate) was most rapid between 1935 and 1979 in contrast to steady and slower economic growth (Figure 1). Because inequality was relatively high (GINI index in the low 50s), the benefit of increased economic growth was not equally distributed in the population. In terms of the impact on generations, by the end of the 20th century, IMR was much lower on average for children born during this period as compared to IMR when their mothers were born and certainly in regards to when their grandparents were born in the late 1930s and early 1940s. Accompanying the rapid decrease in IMR was the rapid increase in life expectancy (Flórez et al. In press; Flórez & Méndez 2000).

Throughout the 20th century in Colombia, caloric intake dramatically increased (Figure 2), meaning grandparents were born in a period of rather low country-level caloric intake (1940s-1950s), parents were born in a period of rapidly increasing caloric intake (1960s-1980s), and children were born in period of a steadily increasing and high caloric intake (last decade of the 20th century and early 20th century). Changes occurred particularly during the period from 1965 to 2005 when caloric intake at the country level increased by about 35%. Children born in the last 20 years experienced a period of relatively high caloric intake as compared to their mothers, when dramatic changes were occurring, and to their grandparents, when nutritional supply was more stagnant. However, higher total caloric intake for these children clearly does not mean better nutrition as evidenced by recent data that show a remarkable consumption of foods high in saturated fat and sugar, especially among young children (Figure 3), exposing them to increased risk of conditions such as obesity.

[Insert Figures 1-3 about here]

The living arrangements of Colombian families dramatically changed in the later portion of the 20th century (Flórez et al. In press; Flórez & Méndez 2000). Whereas multigenerational households were predominant in the early 20th century, by 1993 and 2010, their presence had dropped to about 11% and 8% of households, respectively. Today's grandparent generation was born and raised mostly in the 1950s-1960s in a context where the predominant type of household was a two-parent household while the child generation of the last decade of the 20th century and early 21st century was born in the context of single-parent households and the loss of importance of multigenerational households. Nevertheless, grandparents remain an important component of Colombian society, especially for working mothers with young children. Almost 40% of mothers depend on grandparents to take care of their children when they must be absent from the home (Instituto Colombiano de Bienestar Familiar 2011).

Given the theoretical framework of the social determinants of health, these different social, economic, and demographic contexts in which the different generations are born and raised have implications for their health conditions. Colombia is an ideal setting in which to examine the multigenerational effects of obesity and early life nutrition because it has experienced rapid demographic, nutritional, and social changes. The behavioral component regarding unhealthy eating habits and proximity in relation to children and their grandparents could play a role in health either independently or by compounding the effects of historical circumstances of grandparents leading to higher risk of obesity and overweight in subsequent generations. The conditions of rapid improvement in infant mortality in the generation of grandparents of the 1940s-1970s combined with rapid improvement in nutrition as measured by caloric intake in mothers (1970s-1995) and their children (1990s-present) could have produced the type of mismatch resulting in not only a higher prevalence of obesity in older adults but, potentially, a higher risk of obesity or overweight in mothers and their children (Bateson & Gluckman 2011; Gluckman & Hanson 2005). On the other hand, rapid improvements in early life nutrition in children in the last several decades may have partially interrupted the chain of multigenerational transmission in regards to child stunting.

We first examine the health of children either living or not with their grandparents and then examine in more depth the health of children in multigenerational households. Our focus is on children ages 5-17; for multigenerational households we focus on households where the maternal grandparent is head of the household. We examine questions regarding health, obesity, and nutritional status:

1. What is the health profile of multigenerational households in terms of nutritional status (obesity, overweight, stunting) and self-reported health? How does it compare with households with children not living with grandparents?
2. Is grandparent health associated with child health in multigenerational households? Is child obesity and overweight associated with mother and grandparent obesity? Is nutritional status of children (stunting) associated with the poor early life nutritional status of their mother and grandparents?

Material and Methods

Data

The data come from two large national surveys of households in Colombia: **ENDS** (National Demography and Health Survey/Encuesta Nacional de Demografía y Salud) and **ENSIN** (National Survey of the Nutritional Situation/Encuesta Nacional de la Situación Nutricional). ENDS is a household survey carried out by ProFamilia in Colombia (ProFamilia 2011) on a recurring 5-year basis since 1990 and is comparable to demographic and health surveys from other countries. ENSIN, administered by the Colombian Institute for Family Wellbeing (Instituto Colombiano de Bienestar Familiar 2011), gathers extensive information on nutrition on a recurring 5-year basis. ENDS and ENSIN contain a wealth of information on households and individuals. Variables such as age, gender, years of education, measured height and weight, residence, and a wealth index are available for individuals and households. We selected 2010 because the sample was the same for both surveys and we could draw upon the comprehensiveness of each survey to obtain in-depth profiles of the health of family members. ENDS and ENSIN 2010 sampled 51,447 households and 204,459 individuals.

ENSIN also collected information regarding daily food consumption from a subset of randomly selected respondents (n=17,897).

Measures

For health-related variables, we defined **obesity** in adults (ages 18 and older) as a body mass index (BMI) greater than or equal to 30 and used it to predict child obesity (overweight). For children (5-17 years of age), we used the child growth standards of the World Health Organization (WHO) to define obesity as greater than two BMI standard deviations from the mean and overweight as being greater than one BMI standard deviations from the mean (World Health Organization 2016). For **stunting** in children, we used height/age standard deviations, according to WHO, and defined stunting as less than negative two standard deviations from the mean (World Health Organization 2017). All of these variables were ENDS-created variables. We defined **poor self-reported health** (SRH) as those answering either "regular" or "not good" on a 5-point scale using the ENDS-created variable.

We use **age**, **gender,** and **current residence** as controlling variables. The variable for current residence indicates, to some degree, the socio-economic context of the household: living in one of the principal cities of Colombia (Bogotá, Medellín, Cali, Barranquilla), all other urban, or rural (see Appendix A for more detail in regards to how we created the data files for children with their mothers and grandparents). We defined an indicator of consumption of **junk food** at least three times daily for children ages 5-17 (1=yes, 0=no) using ENSIN consumption data.

Analyses

We selected households with children (ages 5-17) with grandparents living or not living in the household. For households with no grandparents, the parent was the head of the household for the selected child. For households with grandparents, the grandparents were heads of households and the mother of the child (daughter of the household head) was either present or not in the household. We selected children ages 5-17 because obesity often appears in older children, in particular during the years of rapid growth (Costa-Font, Jofre-Bonet, & Grand 2016). If the mother was present, we identified biological maternal grandparents with a high degree of certainty; if the mother was not present, some of the grandparents may not be biological and there may be a mix of maternal and paternal grandparents. The selection resulted in a group of 5,279 children in 3,749 households.

Our descriptive analyses provide profiles of children, their mothers, and grandparents in multigenerational households according to age, gender, poor self-reported health, height, obesity, overweight and stunting. We compare the health and consumption of junk food of children (ages 5-17) in households of children living with/without grandparents; the comparison also includes other children ages 5-17 related or not to the household head. We then examine multigenerational households and estimate a series of logistic regression models for child obesity, overweight and stunting controlling for age and gender of child, age and obesity of mother and grandparent when relevant, and current residence. We considered controlling for daily consumption of junk food (Figure 3). However, because there was no association between child obesity (overweight) and actual consumption of junk food (curiously, the prevalence of consumption of junk food in the ENSIN data tended to be higher among children who were not obese), we did not control for consumption of junk food in logistic models.

Our focus is on biological maternal grandparents but we estimate separate models for groups of children where we know and do not know with certainty the biological relationship of the grandparents (i.e. mothers living and not living in the household). We examine separate nested logistic regression models for biological grandmothers and grandfathers with children and then by gender of children, controlling for mother obesity (height), to determine the degree to which the effects of grandparents are attenuated when adding mother obesity (height). We examine relationships between height of mothers and grandparents with ordinary least squares regression models, controlling for age of mother and grandparent.

Missing values or missing information

In most cases, there were few missing values for age, gender, or current residence. Missing values appeared for obesity and/or height: biological grandfather (28%), biological grandmother (10%), mother of child if living in household (14%), child (9%), household head (female or male) (15%), and child stunting (9%). We examined possible reasons for missing values for grandfather obesity. In about 6% of the cases, in households of children 5-17, we found that the grandfather was older than 64 years and was therefore not measured for height or weight. When we excluded these older individuals, there was no difference in age, poor self-reported health, household wealth, or current residence between grandfathers with/without missing values for obesity (see Appendix B, Table B.1).

Results

Sample characteristics

There were slightly more male than female children (Table 1). The prevalence of poor self-reported health, obesity, overweight, and stunting was lowest among children: 15%, 5%, 19%, and 9%, respectively. Mothers of children showed a higher prevalence of obesity and poor self-reported health. Mother height increased on average by about 4 cm (about 1 ½ inch) from grandmother height. The highest prevalence of obesity and poor self-reported health was found in grandparents and in particular grandmothers (37% and 51% respectively); obesity appeared in the middle to higher wealth households (see Appendix B, Table B.2). About 50% of household heads were female. For the most part, fathers were not present in the households and mothers were not always present in the households. Most households were in urban areas and there were instances of multiple children living in the same household with grandparents as heads of households.

A comparison of health according to household type (whether children are living with their grandparents or not) (Table 2, Panels A and B) shows that the prevalence of obesity among children aged 5-17 living with their grandparents is slightly higher (5%) then that of children not living with grandparents (4%); the difference is significant (p=0.002). Notably there is no difference between households in terms of overweight children 5-17. Children aged 5-17 who are not related to the household head are more likely to be stunted but not obese. An examination of health within households with grandparent heads of households (Table 2, Panel C) shows large differences between households comprised only of children living with their grandparents and households where there are also children of the household head aged 5-17 living. The prevalence of obesity (overweight) is 5.8 (21) % in the former and 2.6 (11) % in the later; the differences are significant at p<0.000. It is notable that, within households where both children living with grandparents and children of the household head aged 5-17 are present, there are no significant differences in obesity or stunting whereas the children of the head tend to be overweight.

Significant differences appear in wealth between types of household, as the poorest tend to be multigenerational households with the grandparent as heads of household (Appendix, Table B.3). There are no differences in residence between household types but grandparent households are larger in size with a greater number of children under the age of five and a lower percent having spouses living in the household (Appendix, Table B.4). There were no significant differences in consumption of junk food between household types for children aged 5-17 (Appendix, Table B.5).

[Insert Tables 1 & 2 about here]

Obesity and overweight

When we examined only those cases where the mother was living in the household and was the daughter of the head of the household (Table 3, Panel A), we saw strong associations between: (1) mother and child obesity [OR 2.63, p<0.001] but particularly with her female children [OR 3.44, p<0.001]; (2) grandfather and mother obesity [OR 2.57, p<0.001]; (3) grandmother and mother obesity [OR 2.93, p<0.001]; (4) grandfather and child obesity [OR 3.04, p<0.001] which attenuated when adding mother obesity [OR 2.80, p<0.01]; and (5) grandfather obesity and female child obesity [OR 3.93, p<0.01] although these effects attenuated slightly when adding mother obesity [OR 3.39, p<0.05]. Whereas in the grandmother models, mother obesity was significant in nested models (p<0.001), except for models with the male child p<0.05, mother obesity was not significant in nested grandfather models (later results not shown in table). For children whose mothers were not living in the household, we found strong associations between the female head of household and child obesity [OR 2.27, p<0.01], in particular with female children [OR 3.81, p<0.01].

In terms of child overweight (Table 3, Panel B), we observed strong associations for mother obesity and child overweight [OR 2.44, p<0.001] regardless of gender, and grandfathers and female children [OR 2.45, p<0.01] even when controlling for mother obesity [OR 2.12, p<0.05]. We also observed opposite sex effects between grandmother obesity and male child overweight [OR 1.66, p<0.01], although the effects attenuated when adding mother obesity [OR 1.45, p<0.05]. Mother obesity was significant in both nested grandmother and grandfather models (p<0.001 except for grandfather to child, p<0.05) (results not shown in table).

In terms of magnitude of results, there was a 2-3 times higher probability of female child obesity and overweight if grandfather was obese versus grandfather not obese (Figure 4). If grandmothers were obese, the magnitude was smaller in terms of male children being overweight—a little over 1 times higher probability of male child being overweight when compared to those with non-obese grandmothers.

[Insert Table 3, Figure 4 about here]

Stunting

For child stunting (Table 4), we found strong associations between grandfather and mother height [OLS 0.44, p<0.001] and slightly stronger associations between grandmother and mother height [OLS 0.49, p<0.001]. Strong associations appeared between mother height and children stunting [OR 0.87, p<0.001], with little difference in gender of child. We observed strong associations between grandfather height and child stunting [OR 0.92, p<0.001], although it appeared much stronger in male children [OR 0.89, p<0.001]. Adding mother height attenuated these effects and grandfather effects became not significant except for male children [OR 0.94, p<0.05]; mother height was highly significant (later result not shown in table). Grandmother height was associated with both female child [OR 0.92, p<0.001] and male [OR 0.95, p<0.01] stunting. When adding mother height, significant grandmother effects completely disappeared; mother height was highly significant and stronger (later results not shown in table). For those children whose mothers were not living in household, we found strong associations between the height of the household head regardless of gender of their children [OR 0.92, p<0.001]. There appeared to be very small differences between male or female heads of households and children. Predicted probabilities showed a steep decline in child stunting as mother height increases, and a similar higher probability of child stunting if grandfather was short (Figure 4), although the grandfather results become largely attenuated when adding mother height. Short grandmothers show a much lower probability of child stunting, which largely disappears with the addition of mother height.

[Insert Table 4 and Figure 5 about here]

Conclusions

Using representative household data from Colombia, we compared the prevalence of obesity, overweight and stunting in children (ages 5-17) in households with/without grandparents and then examined grandparent and child health in multigenerational households. Overall, the health profile across generations showed an expected increase in poor self-reported health and obesity as age increased, with taller mothers. Comparisons between households with/without grandparents showed similarities in that the prevalence of obesity was highest for children with grandparents and children of heads of households and lowest among children not related to the household head. There were no significant differences within households in terms of being overweight and in the consumption of junk food across and within households. However, child obesity and being overweight was higher in households where grandparents were heads of households but none of their own children aged 5-17 (if any) were living in the household. In terms of multigenerational households, we found evidence for strong intergenerational associations in obesity between mothers and their children (grandmother-mother, or mother-female child) and between mother obesity and child overweight. We found strong multigenerational associations between grandfather obesity and female child obesity and overweight, and between grandmother obesity and male child overweight, although the effects were partially mediated by mother obesity. We found strong associations between maternal grandparent height and child stunting of all ages, although mother's height mediated the effects of grandparent's height.

Our comparisons of households with/without grandparents produced relevant conclusions for child obesity, overweight and stunting in relation to grandparents. The striking difference in child obesity and stunting between non-related and related children of the household head independent of whether grandparents are living in the household suggests differences in care, food habits and consumption that favors those related to the household head. No difference in consumption of junk food within and across households further suggests that overfeeding (and not consumption of junk food) of favored children may be a relevant explanation for child obesity. Household resources may influence health, as the prevalence of child obesity and overweight was higher for households when the grandparents' own children aged 5-17 were not living in the household. The differences in child obesity across households suggests a grandparent effect due to proximity that increases the likelihood of child obesity; the noted health consequences for young children living with their grandparents as suggested in other studies (Li et al. 2015). On the other hand, the similarities between child overweight across most households suggests the presence of external factors affecting overweight for all children regardless of their position within the household and regardless of the presence of grandparents in the household. Access to junk food across all types of households and children provides one possible relevant explanation. The consumption of junk food in children 5-17 across all types of households does not bode well because consumption at a young age may be an important risk factor that adversely affects health later in life.

Missing values for grandfather obesity require caution in making a more definitive interpretation. Although we found no significant differences in age, residence, or household wealth for missing/non-missing obesity in grandfathers (results available upon request), there may be other differences that we cannot adequately capture with our data. The slight attenuation of grandfather and grandmother effects when adding mother obesity suggests a mediation role for mother obesity, although curiously mother obesity was not significant in the nested grandfather models for child obesity (whereas in the nested grandmother and grandfather models for child overweight it was). The associations between the obesity of the grandmother head of household (but mother not living in the household) with female children ages 5-17, again point to the possible importance of the maternal line of transmission of obesity, although in this group of children, we cannot identify biological relationships because the mother of the child is not present in the household.

Although we cannot identify specific mechanisms of multigenerational transmission of health beyond the possible effects of proximity, resources, and relationship to the household head, the possibility of epigenetic transmission remains an intriguing possibility. The finding of strong intergenerational associations between the female line (grandmother obesity to mother obesity to female child obesity) regardless of the age of the child is consistent with what other studies have shown (Susser et al. 2012) and point to the importance of understanding the long-term history of maternal nutrition. The multigenerational associations found between maternal grandfather obesity and child obesity (overweight) could reflect a unique and special relationship found only between grandfathers and female children and grandmothers and male children in Colombia. Age and gender differences of grandparents may be relevant in terms of caring for children. It may be that, in multigenerational households, these roles are strictly enforced, resulting also in gender preferences with children. Nevertheless, there is little evidence from other studies of grandparent care and gender differences in children leading to differences in health. Thus, the results showing contrasting patterns of health according to the gender of children and grandparents could also point to evidence of paternal epigenetic inheritance and transgenerational transmission (Kuzawa & Eisenberg 2014). Evidence of same-sex transmission appears through paternal grandparents (Pembrey et al. 2006) and animal studies suggest transmission can either be same sex or opposite sex across generations (Soubry 2015; Wang, Liu, & Sun 2017). Epigenetic analyses will help clarify our results.

The direct strong associations between grandparent height and child stunting in children of all ages suggests the importance of multigenerational transmission of poor early life nutrition. The mediating effects of mother height suggests that, in part, nutrition has improved in Colombia for children and that perhaps, if it exists, the chain of multigenerational transmission of stunting has been partially interrupted. It may very well be that the dramatic differences between the environmental exposures between child and grandparents now results in weaker associations between grandparent height and child stunting. However, a long family history of maternal undernutrition is not easily overcome in one generation of improved nutrition due to phenotypic inertia (Kuzawa & Eisenberg 2014) and animal models suggest that it takes several generations to eliminate the effects of poor nutrition (Martorell & Zongrone 2012). Intergenerational transmission of stunting between mother and child is well established (Martorell & Zongrone 2012). Without data on multigenerational effects prior to the dramatic changes in Colombia, it is difficult to ascertain the degree to which our findings indeed indicate improvement in breaking the multigenerational cycle of stunting.

Colombia continues to face stunting in children along with increasing prevalence of obesity in older adults. Obesity in older adults is a relatively recent phenomenon, partially due to the rapid demographic transitions of the past (Palloni & Souza 2013), whereas stunting in children has been common for decades. Thus, it may be too early to examine fully the effects of grandparent obesity on children. Colombia has not yet seen what is occurring in other countries, such as the combination of simultaneous stunting (undernourishment) and obesity (overnourishment) in children (Black et al. 2013). Nevertheless, our results do suggest the potential increased importance of multigenerational transmission of obesity while at the same time the diminished importance of multigenerational transmission of poor early life nutrition resulting in child stunting.

There are implications for settings such as Colombia experiencing increased prevalence of obesity in older adults. If grandparent effects on child eating habits are an important consideration for child obesity, then appropriate public interventions to reduce child obesity through grandparents are relevant. If poor early life conditions are transmitted across multiple generations resulting in increased risk of obesity, then public policy must address an increasing prevalence of obesity among children due to the early life conditions of their grandparents and not due to current lifestyle. Our understanding of the determinants of health in future generations will need to reflect this wider perspective into how not only the present but the past affects future health and develop interventions that reflect this information. Increasingly, understanding the long-term nutritional history may have the potential to help explain current health and point to directions of future research and public policy.

Our study has limitations. First, while a comparison of child health in households with/without grandparents is insightful, our study presents a partial view of the multigenerational transmission of health in that the only available detailed data on grandparents in Colombia is for multigenerational households. In households with no grandparents, we have no information regarding the health of grandparents. Second, we cannot control for possible confounding care-mediated effects between grandparent and child because our data do not contain information regarding child-grandparent care relationships including information regarding working mothers, nor the length of time living with grandparents and exposure of children to dietary habits of grandparents. Third, our data do not include information on obesity in adults 65 and older—the generation born in the 1930s-1940s when these rapid transitions began—which may help illuminate our multigenerational analysis. Fourth, the higher number of missing values for grandfather obesity could be problematic, even though for the most part we did not find significant differences between groups of grandfathers along with basic characteristics of age, poor self-reported health, residence and wealth of household. Women tended to be more available to answer survey questions. Fifth, models, which examine gender differences between children and their grandparents, tend to have smaller sample sizes. Sixth, not having information on height and obesity for mothers not living in the household and fathers limits our full examination of child health. Both parents being obese is a risk factor for having obese children (Costa-Font et al. 2016).

In spite of these limitations, our examination of multigenerational effects on health in a middle-income country such as Colombia that has experienced tremendous changes in the last 50-60 years across generations is a starting point in a field where there are few studies from the LAC region of this nature. Rapid changes potentially increasing the risk of obesity among older adults due to early life nutrition combined with dramatically different exposures in early life between the oldest and youngest generations provide fertile ground to examine theories of early life conditions regarding transmission of health risks across generations. Questions regarding the degree to which future generations may bear the burden of the past continue to be relevant.

Appendix A: Data

Mothers living in the household

We used mothers living in the household who were daughters of the household head to determine the biological relationship between grandparents and children. If mother was not present (children 5-17), we were not able to ascertain biological relationships but then conducted separate analyses on children with and without mothers living in the household.

Maternal versus paternal grandparents

In households with children 5-17 who have no mother living in the household we not only cannot determine biological relationships but we cannot determine with certainty if the head of household is the maternal or paternal grandparent. However, given the traditions of Colombian society, most of these households are probably headed by maternal grandparents.

Household heads, ages 65 and higher

We excluded this group of household heads because measurement of height and weight was only obtained in those less than 64 years of age. Spouses who were 65 years and older were not measured for height either.

Fathers of children

We do not examine fathers of children living in households with grandparents as heads of households because, for the most part, there is a small portion of fathers living in the household.

Appendix B: Wealth and grandparent obesity, and missing values

Table B.1: Understanding missing obesity values of grandfather according to household wealth

Wealth	Poorest	Poor	Middle	Rich	Richest
Grandfather					
Missing OB	17	22	15	27	19
Not missing	21	16	16	25	22

Notes: weighted percentages. No significant differences between wealth and missing values for obesity. Household wealth indicator was developed by the ENDS 2010 research team using World Bank methods to define household wealth according to household assets and characteristics (ProFamilia 2011). These are biological grandparents.

Table B.2: Prevalence of obesity according to wealth of households

Obesity/Wealth	Poorest	Poor	Middle	Rich	Richest
Grandmother	24	32	40	42	43
Grandfather	9	23	21	20	17

Notes: weighted percentages; households of children 5-17 where mother is daughter of household head. Age ranges for grandmothers 30-64 and grandmothers living in households with children 5-17. Household wealth indicator was developed by the ENDS 2010 research team using World Bank methods to define household wealth according to household assets and characteristics (ProFamilia 2011). These are biological grandparents.

Table B.3: Differences in wealth by type of household

Household/Wealth	Poorest	Poor	Middle	Rich	Richest
Grandparent HH	22	21	19	21	17
No grandparents	19	21	22	20	19

Notes: Weighted averages. Unique households (n=3749 grandparents, 18,522 no grandparents). Level of significance for differences: p=0.000. Grandparent HH are households where the grandparent is the head of household and the children living with grandparents are aged 5-17. No grandparents in the household means no grandparent heads of household and no other grandparents within the household for children with grandparents aged 5-17.

Table B.4: Differences in residence, household size and children under five by type of household

Type household	Urban (%)	Household Size (#)	# children under five (%)	Spouse present (%)
Grandparent HH	74	6	0.62	56%
No grandparents HH	75	4	0.43	77%
p-value	0.199	0.000	0.000	0.000

Notes: Weighted averages. Unique households (n=3749 grandparents, 18,522 no grandparents).

Table B5: Differences in consumption of junk food for children 5-17 by household type

Children 5-17	%
A. Grandparent HH	
Child 5-17 living with their grandparents (n=1573)	49 [a]
No grandparents living in household	
Child 5-17 not living with their grandparents (n=7970)	51
p-value	0.839
B. Grandparent HH	
Child 5-17 living with their grandparents, no child 5-17 of HH (n=1505)	49 [b, c]
Child 5-17 living with their grandparents plus HH's own child 5-17	
Child living with their grandparents (n=68)	39 [b]
Child of head (n=75)	45 [a ,c]
p-value	0.719

Source: ENSIN, subset consumption data; weighted

Notes: Consumption of junk food at least 3 times daily. There were no significant differences between consumption of junk food comparing different groups of children aged 5-17 as noted by a, b and c in table. Grandparent HH are households where the grandparent is the head of household and the children living with grandparents are aged 5-17. No grandparents in the household means no grandparent heads of household and no other grandparents within the household for children with grandparents aged 5-17.

Appendix C: Additional information for Tables 2 and 3 in text.

Table 2, Panel A:

Sample sizes with significance of estimated models for Panel A:

Mother: child (2178***), female child (1057***), male child (1121)
Grandfather: mother (792***), child (768**), female child (378**), male child (390)
Grandfather + mother: child (768*), female child (378**), male child (390)
Grandmother: mother (1961***), child (1906), female child (916), male child (990*)
Grandmother + mother: child (1906***), female child (916***), male child (990**)
Household head female: child (1157*), female child (552*), male child (605*)
Household head male: child (1022), female child (491), male child (531)

Table 2, Panel B:

Sample sizes with significance of estimated models for Panel B:

Mother: child (2178***), female child (1057***), male child (1121***)
Grandfather: child (768*), female child (378*), male child (390)
Grandfather + mother: child (768***), female child (378**), male child (390**)
Grandmother: child (1906**), female child (916*), male child (990***)
Grandmother + mother: child (1906***), female child (916***), male child (990**)
Household head female: child (1157**), female child (552**), male child (605**)
Household head male: child (1022**), female child (491**), male child (531)

Table 3

Sample sizes, significance of estimated models is all at $p<0.001$ except where noted below:

Mother: child (2179), female child (1057), male child (1122)
Grandfather: mother (793), child (769), female child (378), male child (391)
Grandfather + mother height: child (769), female child (378), male child (391)
Grandmother: mother (1962), child (1908), female child (917), male child (991)
Grandmother + mother height: child (1908), female child (917), male child (991)
HH female: child (1159), female child (605), male child (554**)
HH male: child (1023), female child (464**), male child (532)

*p<0.05, **p<0.01, ***p<0.001

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Table 1: Sample characteristics according to age of child

	Households of children 5-17
Child age	9 (3)
Female (%)	48
Poor SRH (%)	15
Obesity (%)	5
Overweight (%)	19
Stunting (%)	9
Mother age	30 (5)
Poor SRH (%)	27
Obesity (%)	15
Height (cm)	156 (6)
Grandfather age	58 (7)
Poor SRH (%)	45
Obesity (%)	18
Height (cm)	165 (6)
Grandmother age	54 (6)
Poor SRH (%)	51
Obesity (%)	37
Height (cm)	152 (6)
Context	
Female head of household (%)	52
Mother living in household (%)	56
Father living in household (%)	18
Residence (%)	
Principal urban city	25
Other urban	48
Rural	27
# Children (ages 5-17)	5729
# Households	3749

Notes: Data are weighted using sample weights. Grandparents are biological grandparents. Households with children 5-17: grandfather (n=1225) and grandmother (n=2485). Obesity (overweight) of other children (i.e. not grandchildren) ages 5-17 also living in household (other relative n=137; not related or foster child n=92).

Table 2: Comparison of prevalence of obesity, overweight and stunting in children 5-17 according to type of household

	Obesity	Overweight	Stunting
PANEL A: GRANDPARENTS HH			
Child 5-17 living with their grandparents (n=5218)	5 [a]	19	9
Other relative 5-17 to HH (n=137)	2	20	14 [b]
Not related 5-17 (n=92)	0	18	17
p-value	0.030	0.813	0.006
PANEL B: NO GRANDPARENTS HOUSE			
Child 5-17 not living with their grandparents (n=30,406)	4 [a, **e**]	18 [**e**]	10 [**e**]
Other relative 5-17 to HH (n=717)	5	17	9 [b]
Not related 5-17 (n=348)	1	15	14
p-value	0.226	0.665	0.035
PANEL C: GRANDPARENTS HH			
Child 5-17 only living with their grandparents (n=4040)	**6** [c, d]	**21** [c, d]	8 [c, d]
Child 5-17 living with their grandparents plus child of HH			
Child 5-17 living with their grandparents (n=1178)	3 [c]	11 [c]	13 [c]
Child 5-17 of HH (n=1331)	3 [d, e]	16 [d, e]	11 [d, e]
p-value	0.558	0.020	0.151

Notes: Shown are percentages, rounded to the nearest whole number. Data are weighted using sample weights; households with grandparents as heads of households (HH) (n=3749) and households with no grandparents (n=18,522). No grandparents households have no grandparents are household heads and parents/parent in-law of household head who may be grandparents. Significant differences within groups are noted above by p-values in table; significant differences across groups are noted by superscripts in table and below.

[a] p=0.002.

[b] p=0.048.

[c] p=0.000.

[d] p=0.000.

[e] p=0.044 obesity; p=0.007 overweight; p=0.000 stunting.

Table 3: Effects of grandparent and mother obesity on children ages 5-17

A. Child Obesity	(1)Mother	(2) Child	(3) Female Child	(4) Male Child
Mother in HH				
Mother		2.63***	3.44***	2.09*
		[1.74-3.99]	[1.86-6.38]	[1.18-3.70]
Grandfather	2.57***	3.04***	3.93**	2.59*
	[1.58-4.18]	[1.57-5.88]	[1.47-10.50]	[1.02-6.54]
Grandfather + mother		2.80**	3.39*	2.45
		[1.43-5.47]	[1.23-9.32]	[0.96-6.28]
Grandmother	2.93***	1.62*	1.67	1.58
	[2.27-3.78]	[1.07-2.47]	[0.86-3.23]	[0.91-2.74]
Grandmother + mother		1.32	1.22	1.42
		[0.85-2.04]	[0.61-2.45]	[0.81-2.49]
Mother not in house				
HH female		2.27**	3.81**	1.56
		[1.29-3.99]	[1.48-9.82]	[0.75-3.24]
HH male		2.23*	2.75	1.83
		[1.14-4.39]	[0.99-7.63]	[0.72-4.64]
B. Child overweight				
Mother in HH				
Mother		2.44***	2.39***	2.47***
		[1.87-3.18]	[1.64-3.49]	[1.70-3.58]
Grandfather		2.18***	2.45**	1.90
		[1.39-3.42]	[1.31-4.56]	[0.99-3.68]
Grandfather + mother		1.92**	2.12*	1.70
		[1.21-3.04]	[1.12-4.03]	[0.86-3.34]
Grandmother		1.36*	1.05	1.66**
		[1.07-1.72]	[0.73-1.50]	[1.20-2.30]
Grandmother + mother		1.16	0.89	1.45*
		[0.91-1.49]	[0.61-1.30]	[1.04-2.03]
Mother not in house				
HH female		2.02***	2.14***	1.86**
		[1.45-2.81]	[1.35-3.40]	[1.16-2.99]
HH male		1.49	1.60	1.32
		[0.98-2.27]	[0.86-2.98]	[0.73-2.38]

Source: ENDS (ProFamilia 2011), children 5-17, n=5729. Odds ratios appear in table along with 95"% confidence intervals. *p<0.05, **p<0.01, ***p<0.001

Notes: Each cell represents a different model; models control for child age, gender, mother age and obesity, grandparent age and obesity, and residence, where relevant. For sample sizes with significance of estimated model see Appendix C. HH (household heads) are also grandparents but some may not be biological grandparents.

Table 4: Effects of grandparent and mother height on stunting in children 5-17

		Child Stunting		
Height (cm)	(1)Mother height (OLS coeff)	(2) Child (OR)	(3) Female Child (OR)	(4) Male Child (OR)
Mother in HH				
Mother		0.87***	0.86***	0.88***
		[0.85-0.89]	[0.82-0.89]	[0.85-0.91]
Grandfather	0.44***	0.92***	0.96	0.89***
	[0.39-0.51]	[0.89-0.96]	[0.91-1.01]	[0.85-0.93]
Grandfather + mother hgt		0.97	1.00	0.94*
		[0.93-1.01]	[0.95-1.06]	[0.89-1.00]
Grandmother	0.49***	0.94***	0.92***	0.95**
	[0.45-0.53]	[0.91-0.96]	[0.89-0.95]	[0.92-0.98]
Grandmother + mother hgt		0.99	0.98	1.00
		[0.96-1.02]	[0.94-1.02]	[0.97-1.04]
Mother not in house				
HH female		0.92***	0.92***	0.92**
		[0.89-0.96]	[0.88-0.97]	[0.88-0.97]
HH male		0.93***	0.94**	0.93***
		[0.91-0.96]	[0.90-0.98]	[0.90-0.96]

Source: ENDS (ProFamilia 2011), children 5-17, n=5729. Missing values for height result in samples slightly smaller. *p<0.05, **p<0.01, ***p<0.001

Notes: Mother height models based on ordinary least square linear regression (OLS); all other models based on logistic regression and show odds ratios (OR); 95% confidence intervals shown in brackets. Each cell represents a different model; models control for child age, gender, mother age and obesity, grandparent age and obesity, and residence, where relevant. For sample sizes, significance of estimated models is all at p<0.001 except where noted in Appendix C. HH (household heads) are also grandparents but some may not be biological grandparents.

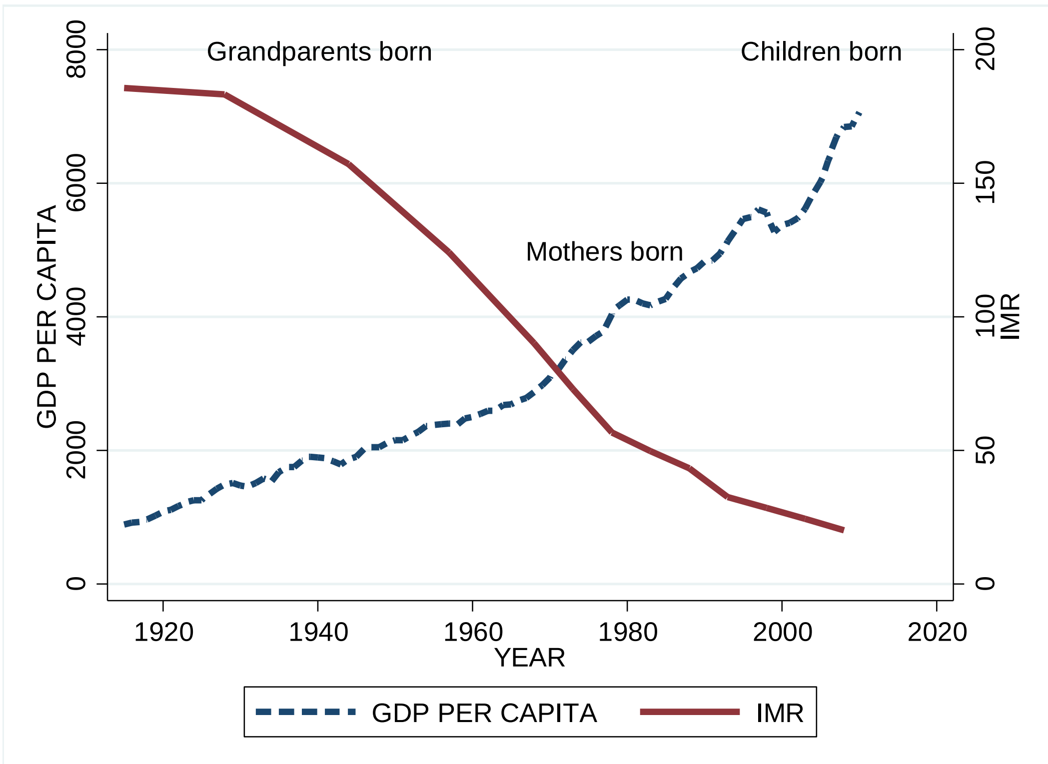

Figure 1: GDP per capita and IMR in Colombia: 1915-2007

Sources: (Flórez et al. In press; The Maddison Project 2013); in 1990 international Geary-Khamis dollars

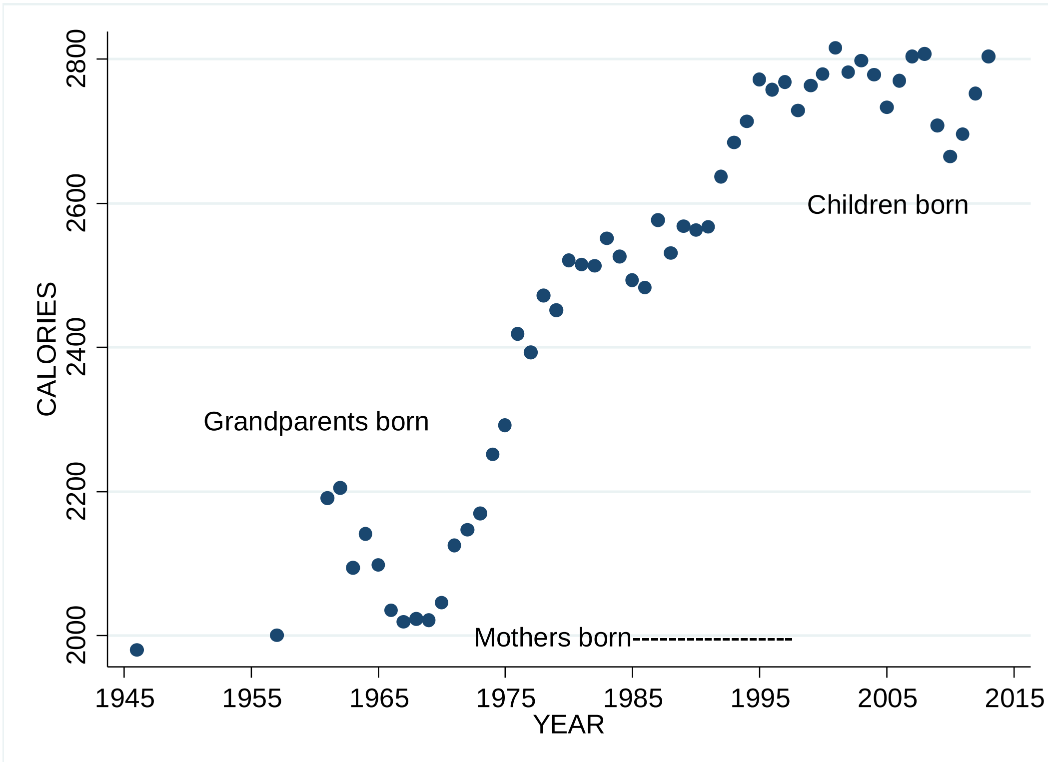

Figure 2: Net daily caloric intake per capita over time in relation to birth dates of grandparents, mothers and their children

Sources: (Food and Agriculture Organization of the United Nations 1946; The Food Security Portal 2012; United Nations Statistical Office & the Department of Economic and Social Affairs 1958)

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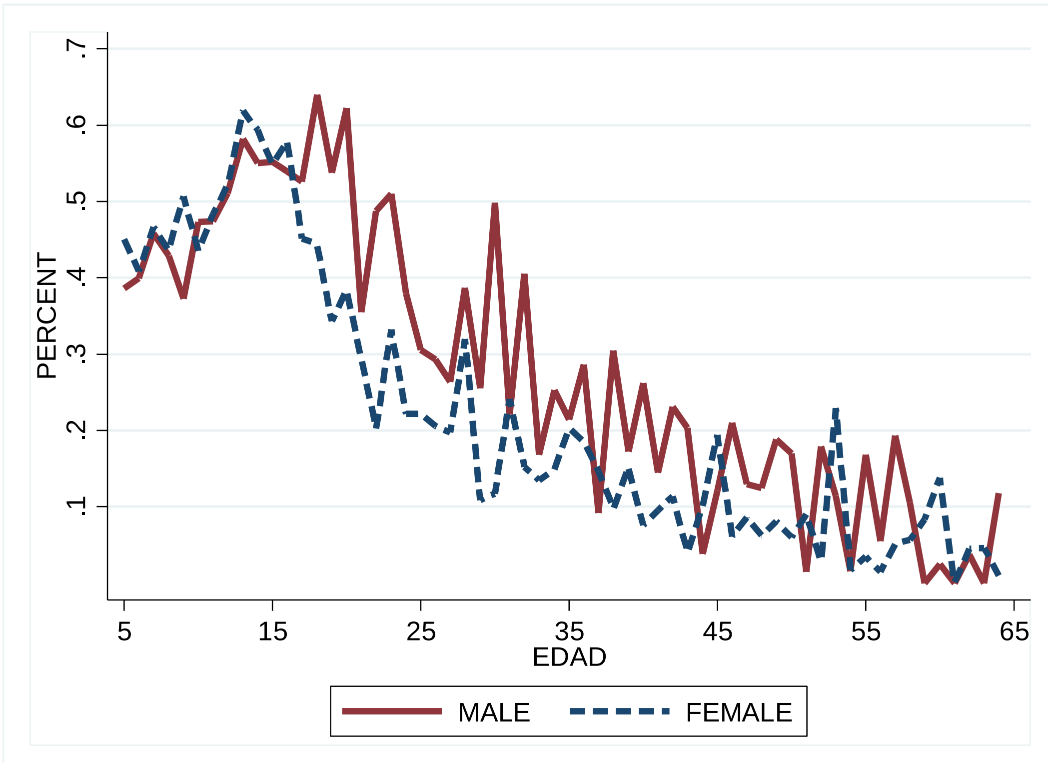

Figure 3: Percent eating junk food at least 3 times daily according to age
Source: (Instituto Colombiano de Bienestar Familiar 2011)

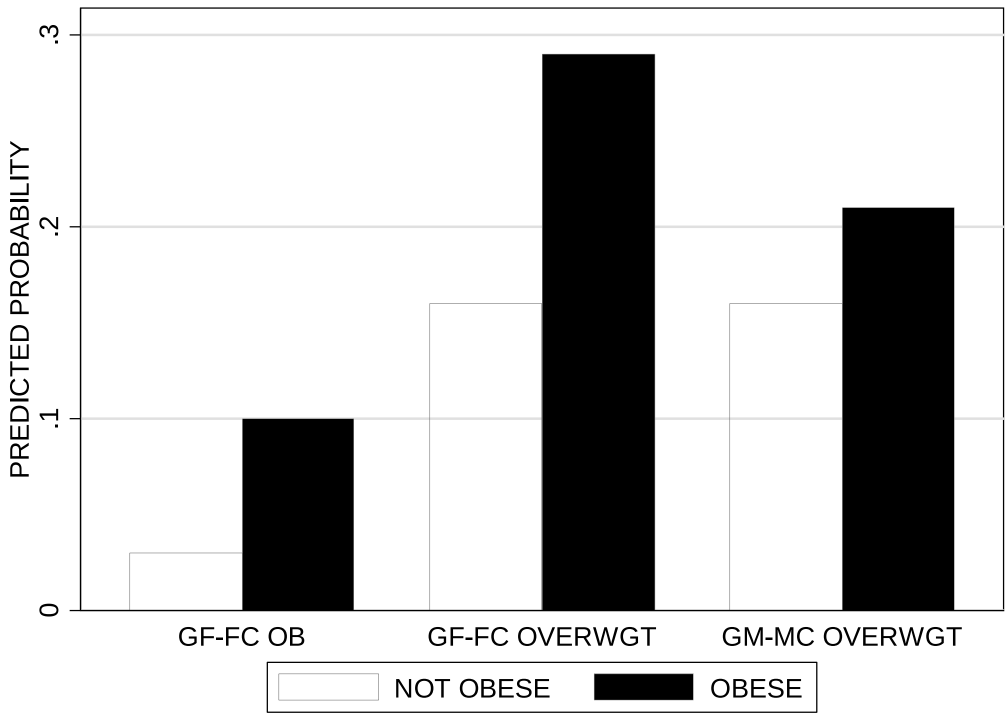

Figure 4: Predicted probability of child obesity/overweight according to grandfather or grandmother obesity

Source: Using estimated models from Table 2, (Panel A, Model 3; Panel B, Models 3 and 4), controlling for mother obesity:

Notes:

Models (all controlling for mother obesity) from left to right:

GF–FC OB: grandfather obesity predicts female child obesity: 0.03 (not OB), 0.10 (OB)

GF-FC overwgt: grandfather obesity predicts female child overwgt: 0.16 (not OBt), 0.29 (OB)

GM-MC overwgt: grandmother obesity predicts male child overwgtt: 0.16 (not OB), 0.21 (OB)

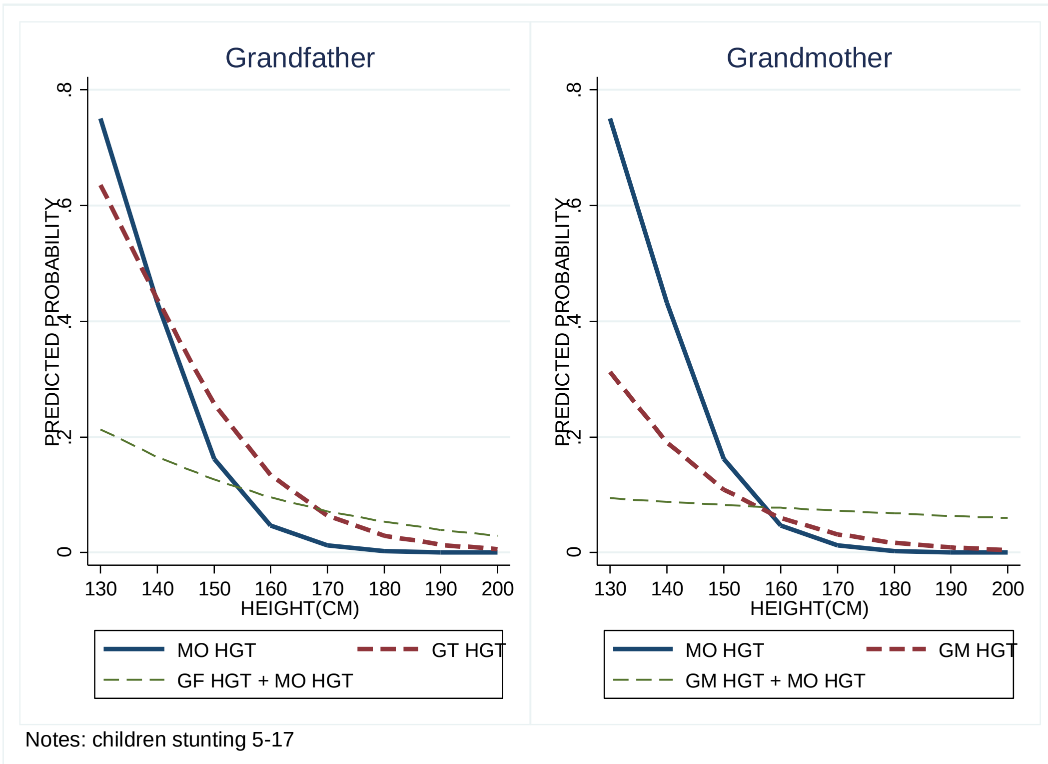

Figure 5: Predicted probability of child stunting according to the height of grandparents and mother

Source: Using estimated models from Table 3, Models 2: mother height predicting child stunting; grandfather and grandmother height predicting child stunting.

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