How do variation in familial circumstances and the timing of stressors influence body proportions within Punjabi migrant families?

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Abstract

Background: The idea that leg length may be a more sensitive biomarker of developmental circumstances is currently debated. Studies evaluating this debate suggests that issues related to the methodology and differences between generations in the timing and characteristics of physiological stressors may influence whether height or leg length differences are more sensitive indicators of changing circumstances. **Aim:** The aim of this research was to further investigate the issues surrounding the ongoing debate about the importance of leg length as a biomarker of developmental circumstances within Punjabi families. This research addresses the aim through a framework that includes developmental plasticity, migration and political economy. **Methods:** A total of 34 Punjabi families were recruited consisting of father, mother and young adult offspring, with four families only consisting of one parent and offspring. Each family member was interviewed to estimate their developmental circumstances when young. This was complemented with greater detail about physiologically stressful experiences of participants as judged from linear enamel hypoplasia identified on casts made from their anterior dental impressions. **Results:** Statistical analyses for individuals, considering generation, gender, and place they grew up, suggested birth place was an important factor impacting growth outcomes. Also, water quality and toilet facilities were positively associated with height and lower leg length in the offspring generation. In the parental generation variables associated with sanitation did not follow expectations. Further, individual analysis of repeated stress events measured using enamel defects and their influence on anthropometric measures found that mothers' leg length measure and fathers' height and leg length were influenced by repeated stress events. Intergenerational analysis found no relationship between differences in father-son early circumstances and anthropometric measures, but for mothers and daughters there was a relationship between lower leg length and differences in circumstances, particularly when parent dimorphism was included in the model. Overall outcomes of this research suggest that there may be evidence of leg length being more influenced by early circumstances than height, but inconsistencies were also found. There may be opportunities to further improve the study design when assessing this debate.

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- *Sabah Moughal*

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Table of Contents

Abstract .... **i**
Acknowledgements .... **ii**
Table of Contents .... **iii**
List of Figures .... **v**
List of Tables .... **vi**
Chapter 1: Introduction **1**
1.1 Theoretical frameworks 2
1.1.1 Developmental plasticity 3
1.1.2 Migration 3
1.1.3: Political economy 5
1.2: Thesis organisation 5
Chapter 2: Literature Review **7**
2.1: Infancy, childhood, and risks of permanent stunting 7
2.2: Factors affecting growth and development 8
2.2.1: Impacts of synergisms of disease and poor nutrition on growth during infancy and childhood 9
2.3: Height as a biomarker of early life conditions 15
2.4: Leg length as a biomarker of early life conditions 16
2.5: Possible impacts on interpretations of differences in research designs and differences in how developmental environments are characterised 20
2.5.1: Population or group level interpretations of developmental circumstances 20
2.5.2: Analysis of developmental circumstances related to individuals or family members 23
2.6: Linear Enamel Hypoplasia as a marker of stressful episodes during childhood 26
Chapter 3: Participants and Methods **29**
3.1: The Punjab: Background information related to participating families 29
3.2: Recruitment and study participants: 31
3.3: Methods: 32
3.3.1: Collection of Life Course Information 32
3.3.2: Analysis of qualitative data: 36
3.3.3: Statistical method for analysis of qualitative data: 39
3.3.4: Collecting Anthropometric Information and Dental Impression/Casts 39
3.4: Analysis of the extent of stress and development outcomes 43
3.5: Analysis of the timing of stress and development outcome 43

3.6: Intergenerational analysis....44
Chapter 4: Results....45
4.1: A Description of Participating Families....45
4.2: Anthropometric Description of Families....50
4.3: Descriptive Analysis –Linear Enamel Hypoplasia....51
4.4: Interpretation of anthropometric measures in relation to early developmental conditions within each generation....53
4.5: Relationship between presence or absence of LEH and anthropometric measures....63
4.6: Relationship between early and repeated stress events and anthropometric measures....64
4.7: Tests of hypotheses related to the impact of changing early circumstances on differences of growth outcomes for parents and offspring....66
4.8: Stature increase between generations as a result of lower limbs....69
Chapter 5: Discussion....72
5.1: Social histories and family backgrounds....72
5.1.1: Political and economic environment....73
5.1.2: Biosocial environment....74
5.1.3: Migration....77
5.1.4: Growth studies in Punjab....81
5.2: Evaluating relationship between developmental circumstances of parents and offspring and anthropometric measures....83
5.3: Evaluating relationship between developmental circumstances of parents and offspring and linear enamel hypoplasia....88
5.4: Future research directions....91
Appendix....93
Bibliography....95

List of Figures

FIGURE 2.1.1: Graph showing distance and velocity curves for different stages of human growth (Bogin et al., 2014) *8*
FIGURE 2.4.1: Cephalocaudal gradient of growth (Changes in body proportions during prenatal and postnatal period; from Bogin, 1999) *16*
FIGURE 2.4.2: Velocity curve for leg length and crown rump length for girls and boys (adapted from Gasser et al., 1991) *17*
FIGURE 2.6.1: Threshold model for the formation of LEH (Henry and Ulijaszek 1996) .. *27*
FIGURE 3.1.1: Map of Punjab (http://eastmanpowertools.com/contactus.html) *29*
FIGURE 3.2.1: Scatter plot of sons' heights across age in decimal years *32*
FIGURE 3.3.4.1: Lower leg length measurement (adapted from Bogin and Varela-Silva, 2010). *41*
FIGURE 3.3.4.2: Diagram of enamel units used for recording the position of an enamel defect (Littleton, 2005 as modified from Hillson, 1996). *42*
FIGURE 4.4.1: Boxplot of height and lower leg length of father and mother across two categories of household crowding (Father, No crowding, 13; Fathers, Crowding, 18; Mothers, No crowding, 10; Mothers, Crowding, 23) *59*
FIGURE 4.4.2: Box plot of height and lower leg length of sons and daughters across two categories of household crowding. (Son, No crowding, 19; Son, Crowding, 2; Daughter, No crowding, 8; Daughter, Crowding, 5) *59*
FIGURE 4.4.3: Box plot of height and lower leg length of father and mother across three categories of drinking water quality. *60*
FIGURE 4.4.4: Box plot of height and lower leg length for sons and daughters across categories of drinking water qualities. *60*
FIGURE 4.4.5: Box plot of height and lower leg length of father and mother across four categories of toilet facilities. *61*
FIGURE 4.4.6: Box plot of height and lower leg length of sons and daughter across four categories of toilet facilities. *62*
FIGURE 4.4.7: Box plot of height and lower leg length of sons and daughter across birthplace categories *63*
FIGURE 4.8.1: Box plot of mean difference in gains in lower leg length vs height for same-sex parent and offspring across the two categories of birthplace. *70*
FIGURE 4.8.2: Box plot of mean difference in gains in leg length vs height for same-sex parent and offspring across the two categories of birthplace. *71*
Figure 5.2.1: Scatterplots of Father-son height differences vs father-son leg length and lower leg length differences *85*
Figure 5.2.2: Scatterplots of Father-son percentage gains in leg length and lower leg length relative to gains in height *85*
Figure 5.2.3: Scatterplots of mother-daughter gains in leg length and lower leg length vs height *86*

List of Tables

TABLE 3.1.1: Literacy rate in Punjab as per census year 1971-2011 30
TABLE 3.3.2.1: Justification of variable rankings[a] 37
TABLE 3.3.2.1: Justification of variable rankings…continued 38
TABLE 4.1.1. Variation in family composition among the 34 participating families[a]. 45
TABLE 4.1.2. Where family members were born and where and when they moved by generation and gender 46
TABLE 4.1.3. Occupations of parental caregivers when participants in each generation were young. Offspring are divided into those who were born and grew up in India and those who were born in New Zealand or who moved here by the age of 2 years. 47
TABLE 4.1.4. Information about educational attainment for parental caregivers when participants in each generation were young. Offspring are divided into those who were born and grew up in India and those who were born in New Zealand or who moved here by the age of 2 years. 48
TABLE 4.1.5. Measures of sanitation within households when participants in each generation were young. Offspring are divided into those who were born and grew up in India and those who were born in New Zealand or who moved here by the age of 2 years. 49
TABLE 4.2.1. Means, medians and standard deviation of anthropometric variables[a] for 21 families with son and 13 with daughters 51
TABLE 4.3.1: Distribution of presence and absence of LEH amongst parent[a] and offspring by gender 52
TABLE 4.3.2: Numbers of defects per father, mother, son or daughter as distributed in the three developmental units[a] 52
TABLE 4.3.3. The number and percentage of mothers, fathers or offspring with LEH defects occurring in a given enamel unit (where available)[a]. 53
TABLE 4.4.1.1: Principle component analysis: loadings on composite variables for parents 54
TABLE 4.4.1.2: Principle component analysis: loadings on composite variables for offspring 55
TABLE 4.4.2: Results of regression analyses of reduced models examining the influence of early circumstances of parents and changes on height or lower leg length. 56
TABLE 4.4.3: Results of regression analyses of reduced models examining the influence of early circumstances of offspring and changes on height or lower leg length. 57
TABLE 4.5.1: Mean comparison of anthropometric measures across presence and absence of enamel defects among parents. 63
TABLE 4.5.2: Mean comparison of anthropometric measures across presence and absence of enamel defects among offspring. 64
TABLE 4.6.1: Results of regression analysis examining the influence of repeated stress events on anthropometric measures for fathers and mothers. 65
TABLE 4.6.2: Results of regression analysis examining the influence of repeated stress events on anthropometric measures for daughters[a]. 66
TABLE 4.7.1: Results of regression analyses examining the influence of difference in mother-daughter component score ranking on lower leg length for same sex parent-offspring pairs. 67
TABLE 4.7.2: Results of regression analyses examining the influence of other parent on the difference in mother-daughter component score ranking on changes in body proportion for same sex parent-offspring pairs. 68
TABLE 4.7.3: Results of regression analysis of the reduced model examining the influence of other parent on the difference in father-son or mother-daughter

component score ranking on changes in body proportion for same sex parent-offspring pairs. *69*
TABLE 4.8.1: Results of paired t-tests assessing whether percentage gains from parent to offspring in lower leg length significantly exceed percentage gains in height. *69*
TABLE 5.1.1: Height, leg length and lower leg length of fathers born around the time of Partition and those born during economic growth *74*
TABLE 5.1.4.1: Studies assessing anthropometric measures of people from Punjab representative of the parents. *81*
TABLE 5.1.4.2: Studies assessing anthropometric measures of people from Punjab representative of the offspring generation. *83*

Chapter 1: Introduction

The purpose of this study is to further investigate issues surrounding the ongoing debate about relative leg length as a bio-marker of developmental circumstances. It has been argued that increasing differences in developmental circumstances impact leg growth to a greater degree than trunk growth, at least under some circumstances (Gunnell et al., 1998; Bogin et al., 2002; Wadsworth et al, 2002; Floyd, 2007; Azcorra et al., 2013). This is argued to be likely, in principle, because longitudinal studies of human height growth under healthful conditions show that leg growth is more rapid than trunk growth into early adolescence in most individuals (Gasser et al., 2001). Because permanent stunting is much more likely to accrue in the first few years of life, these authors argue that leg growth is the most vulnerable component of stature to stunting. As a consequence, several authors hypothesize that increasing difference in developmental circumstances will be accompanied by increasing differences in relative leg length. Other authors challenge these claims, arguing that variation in height growth may be an equally sensitive indicator of variation in developmental circumstances, at least in developing settings (Greulich, 1976; Webb et al., 2008; Padez et al., 2009; Kinra et al., 2011; Sohn, 2015). In considering these inconsistent results, it has been suggested that relationships may not be simple. Differences in relative leg length may reflect differences in both the extent and timing of developmental stressors (Floyd, 2007; Sohn, 2015). Hence a careful analysis of the timing and extent of stressors is important, though difficult to achieve given the indirect nature of available information.

The relationship between physical growth and environment has been documented since the early nineteenth century. Stature is considered to be among the most sensitive biomarkers of an individual's health. It is considered a good indicator of an individual's wellbeing and a useful marker of social inequalities in human development (Onis and Branca, 2016). This is because height is not just determined by genetic influences but represents complex interactions between genetic factors and net nutrition that may vary through the growth course (Deaton, 2007). Deaton (2007) explains net nutrition as the total food intake and loss of nutrients through disease and exercise. Individuals that experience poverty when young are shorter, on average, and have higher rates of stunting than others from the same population who are better off. The proximate determinants of growth processes contributing to stature include dietary quality and the frequency and intensity of disease exposures that interact synergistically. These factors are in turn influenced by a community's lifeways and the socioeconomic status (SES) of an individual's family. Several studies report that chronic protein-calorie under-nutrition results in growth stunting (Adair and Pollitt, 1985; Kusin et al., 1992). This is likely because being exposed to pathogens results in either nutrients being diverted to immune function to combat the infection or disease processes (e.g. diarrhoea) resulting in poor absorption of nutrients. This results in the body being deprived of nutrients required for the growth and development, hence resulting in stunting (Ulijaszek, 1996).

A major drawback in interpreting studies relevant to the debate of height or leg length as a better biomarker is the inconsistency in how developmental circumstances have been characterised. The challenge is that these studies have characterised the differences in developmental circumstances at levels ranging from sub-populations distinguished, for example by migration status (Bogin et al., 2002; Greulich, 1957, 1976) or supplementation status (Kinra et al., 2011) to variation among families within a community (Bogin et al., 1992; Kaur and Singh, 1981; Padez et al., 2009) to individuals within families (Gunnell et al., 1998; Wadsworth et al., 2002; Floyd, 2007). Inconsistency in age range used in studies represents another important complication when some or all of the individuals have not completed growth (Greulich, 1957; Gunnell et al., 1998; Bogin et al., 2002; Azcorra et al., 2013). This will be explained more fully later in the chapter.

The aim of this study is to determine how much of the difference in height due to changing developmental circumstances is a result of changes in leg length between Punjabi India parents and their young adult offspring in families who migrated to New Zealand. Recruiting families allowed for a more effective analyses of circumstances and greater control of genetic influences on growth. Differences between parents and offspring will tend, on average, to be a result of changes in developmental circumstances. Comparing parents and offspring within families has advantages, though there are limitations given the retrospective nature of data.

1.1 Theoretical frameworks

The theoretical frameworks used in this thesis to address the debate are developmental plasticity, political economy and migration. Each is briefly outlined below.

1.1.1 Developmental plasticity

Developmental plasticity represents one among several ways a species can respond to changing circumstances. Developmental plasticity theory is explained as the production of different phenotypes in response to the changing environmental conditions during growth and development (Lasker, 1969; Hochberg, 2011). Lasker (1969) defined plasticity as an intermediate type of adaptation, between inherited genetic adaptations and reversible acclimatization responses. He suggested that plasticity is a special case of acclimatization, but is distinguishable because the process cannot be reversed after growth completion. While the idea of plasticity among organisms was recognised earlier in other biological fields (Kaplan, 1954), the concept of plasticity was first used in anthropology by Boas in the late 19th century. Boas determined that with changing environments there were significant changes in the head dimensions among descendants of European immigrants in America. Boas also found that American born children were taller than their parents and their counterparts living in Europe. This study and other studies on other nationalities in America suggested that the taller stature and medium cephalic index of immigrants in America was a result of exposure to American environmental conditions. Hence, analysing the environmental conditions during early life stages across generations may be a useful approach to estimating the effects of changes in environmental conditions on stature and leg length, if environmental conditions can be effectively characterised.

1.1.2 Migration

The work by Boas not only validated the concept of plasticity, but his work also established the idea of using migration as a paradigm for plasticity studies (Mascie-Taylor and Bogin, 1995). The process of migration involves the movement of people from one geographic location to another. These movements can be local or international and either temporary or permanent (Bhugra and Becker, 2005). There may also be dramatic differences in the motivations for movement – refugees' vs economic privilege. A common reason for migration to a western country is the hope of better education, employment opportunities and better lifestyles (Taylor et al., 2007). Given widely varying circumstances and motivations for migration, movement of people is likely to expose them to diverse environmental conditions different to those experienced at an earlier age. These may in turn influence the way their bodies respond or adapt. Mascie-Taylor and Krzyzanowska (2017) suggest that migration is not just a simple act of movement from one place to another. These authors suggest that there are biological implications not only for migrants, but their populations of origin and residence.

The history of migration studies in relation to human biology dates back to early 20th century (Mascie-Taylor and Little, 2004). Fishberg in 1905 was one of the first to study the effects of migration on human stature. He compared the stature of immigrant Jews in New York to Jews of Eastern Europe. Results from his study suggested that immigrants were taller than counterparts in their native land. And the second generation immigrant were taller than the first generation. He emphasised that these difference were a result of better conditions for the migrant population. Since then a wide range of studies have been done assessing the effect of migration on individuals (Ito, 1942; Goldstein, 1943; Lasker, 1952; Greulich, 1957; Malina et al, 1982, Bogin et al., 2002). Results from these studies suggest that changes in social, physical and political environment due to migration do influence growth and development of individuals. An important factor to consider with migration is the age at which an individual migrates (Boas, 1912 and Mascie-Taylor and Little, 2004). Age at migration is important to determine the length of exposure to the new environmental condition and also to determine the age at which developmental conditions changed. Mascie–Taylor and Little (2004) review of migration studies found that differences in anthropometric measures were dependent on the age at migration. An example of Boas (1912) migration study found that there was a greater physical difference in children who had longer exposure to urban environments. Individuals who migrated to New Zealand within the first six months of life are anticipated to have been exposed to similar conditions as individuals who were born in New Zealand. Similarly, if an individual migrated to New Zealand at the age of 25, the New Zealand environment will play virtually no role in their physical development.

Although, migration to developed nations has been linked to positive impacts on the growth and development of individuals, there may be negative aspects to migration as well. Migration can be an extremely stressful event for individuals (parents in this study) in terms of coping with a new social, cultural and political context (Hattar-Pollara and Meleis, 1995). Social support after migration is considered important with regards to dealing with the stress (Levitt et al., 2005; Chae et al., 2014). Hence, analysing the pre and post migration circumstances of family members in the present study may allow for a better understanding of the aspect of changes in environmental conditions due to migration on stature.

1.1.3: Political economy

Political economy, another useful perspective, is defined as the study of how people living in environment with limited resources distribute these resources based on hierarchy (Orlove, 1980). Current research suggests that the proximate environmental factors influencing the growth of individuals are influenced and filtered by a hierarchy of historic and social relationships (Gravelee et al., 2005; Leatherman, 2005). Goodman and Leatherman (1998) also emphasise the importance of using a biocultural perspective to understand human growth patterns. Hence, combined with the developmental plasticity theory, the political economic framework provides a useful additional lens to understand impacts of changing familial circumstances.

The political economic framework allows for a better understanding of the many forces that interact with human biology. In this study, these include the history of partition that influenced the movement and circumstances of parents' families and changes in agricultural technology which resulted in rapid economic growth of Punjab around the time of many parents' births.

Also the social class/caste and economic and social circumstances of those able to migrate to New Zealand are important. These forces are described more fully in chapter three. Using this framework will allow me to analyse broader socio-historic and economic relationships plausibly influencing environmental conditions experienced by my participating parents and offspring, and how these conditions influenced their growth and development.

1.2: Thesis organisation

This thesis is organized into five chapters. The next chapter of this thesis provides a review of existing literature and is broken into several sections. The first section provides background on the debate of which component of stature is a better biomarker of early conditions, highlighting and evaluating relevant aspects of the debate. In considering this debate, I discuss each of the following issues in turn. Firstly, a brief introduction of human growth patterns is presented to highlight the basis of the argument, followed by the history of height as a biomarker and issues related to using height. Next a more thorough evaluation of literature that uses leg length as a marker of developmental circumstances is presented along with the debate surrounding leg length as a sensitive biomarker. Subsequently, I will further assess aspects of the argument, mainly issues raised around inconsistency in methods of characterising developmental circumstances and inconsistencies in age range of participants. I also review an alternative method (i.e. linear enamel hypoplasia) of analysing stress experienced during early stages of life that includes estimation of age groups when stress manifested as enamel defects. Lastly, I present an outline of the all the hypotheses tested in this study.

The third chapter provides a description of participant recruitment and methods used for this research. The chapter begins with background information about the social, demographic and economic structure of the Punjab in the mid-20th century important for understanding the experiences of participating families. This is followed by a description of recruitment methods, specific information collected and statistical techniques and ethical considerations in their implementation. Chapter four reports the main findings obtained through qualitative methods and descriptive statistical information about the anthropometric dimensions and enamel defects of parents and offspring. This chapter also reports the results of the analyses used to examine hypothesized relationships between anthropometric measures and developmental circumstances. Chapter five presents the discussion of these results, considers limitations associated with this study and concludes with suggestions for future research directions.

Chapter 2: Literature Review

This thesis examines a debate about whether leg length as a component of height is a more sensitive indicator of developmental environments than height overall. It does this by considering variation in anthropometric measurements among parents and young adult offspring in Punjabi families who migrated to New Zealand.

In order to understand probable source of variation, and complications in the interpretation of such variation, among individuals within and between generations, I begin by a more thorough consideration of the processes argued to contribute to growth stunting and their timing, and a discussion of evidence of factors within the environments that are linked with variation in growth outcomes. Next, I provide an outline on the debate, whether leg length is a better biomarker than height. Furthermore, I also consider the fundamental issues related to this debate, including differences in the characterisation of developmental circumstances and differences in the age range used in studies assessing this debate.

2.1: Infancy, childhood, and risks of permanent stunting

The pattern of post-natal human growth and development is divided into five stages (Bogin, 1999). These stages include infancy, childhood, juvenile, puberty, adolescence and adulthood. Infancy and childhood represent the first two stages of human post-natal growth (Bogin, 1999) and these are the two most important stages for risk of growth stunting in humans. Infancy begins at birth and ends with the cessation of weaning. It is variable in duration but often lasts into the third year of life among foraging peoples. Weaning remains an important factor in studies of growth. The timing and process of weaning, particularly how, when and what weaning foods are introduced is important for infant growth. Infancy is the most rapid period of post-natal skeletal growth. Bogin (1999) notes that during this period an infant may add an average of 28 cm to the height which is typically a bit more than 50% of their birth length. During infancy brain growth is very rapid as well. Childhood occurs following weaning and ends with the eruption of the first permanent teeth (1st molar) around age 6 to 7 years, on average. As individuals enter childhood, skeletal growth tends to plateau at a rate much slower than during early infancy. It reaches its lowest rate during the juvenile period just before puberty (Bogin, 1999). Almost all individuals experience an increase in growth velocity of all skeletal tissues during adolescence, known as the adolescent growth spurt (See Figure 2.1.1). The age related pattern of change in growth velocities from infancy onward is important in terms of assessing the timing of changes in developmental circumstances, and relationships between the timing, the extent of physiological stress, and growth.

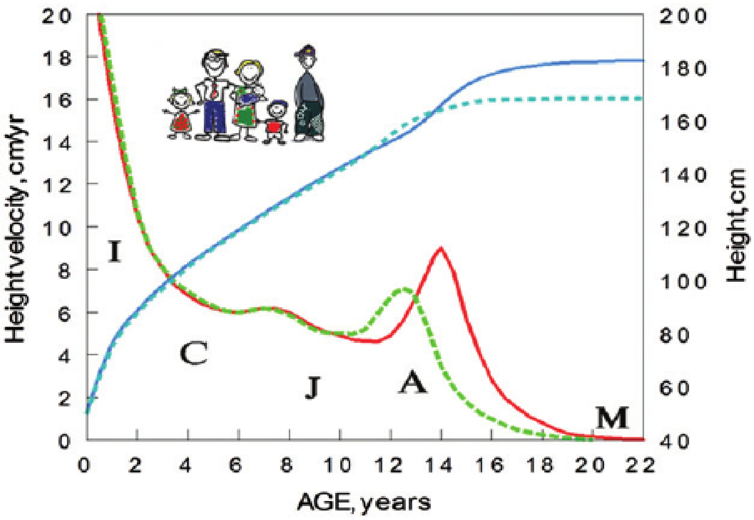

FIGURE 2.1.1: Graph showing distance and velocity curves for different stages of human growth (Bogin et al., 2014)

During infancy, tissues are continuously growing and require a lot of energy, especially the growth of brain tissue which is highly canalised (Bogin, 1999). Hence, deficiencies of important nutrients required for growth will result in trade-offs between growths of different tissues. Skeletal growth deficits are more likely both because of the potentially very rapid growth and the likelihood of competition for resources given rapid brain growth as well. Hence, most deficits sustained into adulthood tend to accumulate during infancy. Therefore, final growth outcomes of an individual are mainly studied in relation to their early developmental circumstances, though some evidence suggests smaller deficits may accrue at later ages during development (Prentice et al., 2013).

2.2: Factors affecting growth and development

There are several different factors affecting the growth and development of an individual. While proximate factors are important, they are often not assessed directly, and they will not be measured directly in this study either. Therefore, how more proximate factors in environments have been assessed using specific proxies, and how these influence and constrain interpretations are important in this and other studies. Nutrition and exposure to pathogens are two proximate factors that are most commonly discussed as associated with growth and development. Aspects of socioeconomic status or subsistence strategies that mediate these two more proximate factors are also most commonly discussed as associated with growth and development.

2.2.1: Impacts of synergisms of disease and poor nutrition on growth during infancy and childhood

Human body cells require an adequate amount of nutrition for growth, repair and maintenance. The energy from the nutrients is allocated in order so that maintenance and repair of cells occurs first and the remaining energy is used for growth (Bogin, 1999). Growth studies consistently document growth delays when food sources are scarce (Howe and Schiller, 1952; Kimura and Kitano, 1959; Billewicz and McGregor, 1982). Results from these studies have found in the event of food shortages, during wartime or because of local agriculture cycles or low socioeconomic status, individuals are shorter than individuals growing in more plentiful environmental conditions. Lack of nutrition is not only determined by the lack of food sources but exposure to disease also plays an important role. Diseases may decrease the absorption of food intake and may result in all energy directed towards combating the disease. Billewicz and McGregor (1982) analysed the longitudinal growth of individuals who are reliant on agriculture for most of their food. The two villages in the Gambia, West Africa, which they evaluated have the lowest food supplies during the rainy season. The authors report that during the dry season, with food from the last harvest available, children grew faster in height than during the rainy season. The authors also suggest that the difference in height growth between the two seasons may not be only because of the weather but during the rainy season there is an increase in incidence of malaria and gastrointestinal infections. Results from this study not only suggest the importance of nutrition on growth and development, but also demonstrate the negative impact of exposure to disease on growth.

2.2.1.1: Nutrition

Before I further review the literature assessing the impact of synergism of disease and nutrition on growth, I will first review literature assessing the impact of nutrition and disease, separately, on growth. The impact of nutrition during postnatal life is well documented in the literature. The effect of lack of key macro and micro nutrients (protein, zinc and iron) on the linear growth of individuals has been studied thoroughly in the literature (Lampl et al., 1978; Allen, 1994; Rogol et al., 2000; Silventoinen, 2003). A study done by Lampl et al (1978) analysed the effects of protein supplementation on growth of New Guinean school children. The age range of these children were 7.7 to 13.0 years. Prior to supplementation these children had relatively low intakes of some essential amino acids from proteins in diets heavily composed of vegetables. The children were divided into three groups, group one served as the control group, group two received 10 g of protein for five days a week and the last group received 20 g of protein five days per week. Each of these groups received a different dietary program for eight months. Height increased more in supplemented than un-supplemented children (mean $\Delta = 1.7$ cm), but there was no significant difference between the two supplemented groups. The results from this study suggest lack of essential nutrient in diet affect growth outcomes in individuals. Despite the fact that results of this study suggest that reductions in protein – energy undernutrition through supplementation improve growth outcomes under at least some circumstances, there are limitations to this study. A major limitation is that it does not account for other factors that may influence growth outcomes, mainly patterns of pathogen exposure and whether these may have changed during the study. Another important idea these authors suggest is the importance of supplementation during pregnancy. The authors suggest that nutritional status of mothers during pregnancy is an important factor in the well-being of their baby.

Studies have suggested that the impact of undernutrition may begin during the prenatal period (Kardjati et al., 1988; Cameron, 1991). During the prenatal period protein is considered the most important macronutrient. Therefore, most studies assess the effect of protein supplementation on birthweight. Results from studies assessing the impact of nutrition before and following birth found that the women experiencing nutritional stress and who received high protein caloric supplement during pregnancy gave birth to heavier babies. And in studies that follow the offspring, they were taller (Adair and Pollitt, 1985; Prentice et al., 1987; Kusin et al., 1992; Imdad and Bhutta, 2012). Therefore, careful analysis of mothers' circumstances during the time of pregnancy is important (though beyond the scope of the present study).

2.2.1.2: Disease

There are studies that look at the effect of infectious diseases during early childhood has on growth (Martorell et al., 1975;Black et al., 1982; Rowland et al., 1988; Moore et al., 2001). The results from these studies conclude that exposure to pathogens (esp. those resulting in diarrhoea) during the early stages of life increase the likelihood of linear growth faltering.

Diarrhoea and pneumonia are two major components of disease burden in children of developing nations. Diarrhoea is a widespread result of infections common throughout developing nations according to the World Health Organization (WHO, April 2013). The spread of diarrhoea is most often through contaminated water and food, and also from person to person as a result of poor hygiene. The high prevalence of diseases like pneumonia and diarrhoea in developing countries is a result insufficient access to clean water, absence of adequate waste disposal, and poor primary health care (Ribeiro, 2000; WHO, April 2013). Studies show that both diarrhoea and pneumonia may result in slower growth (Rowland et al., 1988; Moore et al., 2001; Checkley et al., 2002). Moore et al., (2001) did a longitudinal study in a town in Northeast Brazil, analysing the effect of childhood infection in the first two years of life on growth from age 2-7 years. Results from this study showed that an increasing difference among children in episodes of infections during the first two years resulted in an increasing difference in their growth outcomes.

A study by Biritwum et al. (1986) on growth of rural Ghanaian children under five years of age further demonstrates the greater impact of disease during the first two years. Results from this study suggested that children ranging in age from seven months to 12 months had the highest incidence of diarrhoea. Checkley et al, (2002) found diarrhoea during the first 6 months was a significant determinant of growth retardation. It has been suggested that diarrhoea impacts this age range more due to the introduction of weaning foods (Cameron, 1991). The age when weaning foods are introduced, the type of weaning foods introduced and whether or not they are sanitary are all important. These are associated with mothers' knowledge about the benefits of appropriate practises related to weaning foods. A study by Ashworth and Feachem (1985) reviewed data from 12 developing countries that assessed the importance of weaning education to improve the health of infants. Results from this review suggested that weaning education improved the nutrition status of the infants. Weaning education allowed women to make decisions about the type of supplementary foods to introduce, when to introduce them and how to reduce the contamination of weaning foods by following hygiene practices.

Potentially related to weaning education, another measure associated with a child's health in some settings is maternal education. Several authors suggest mother's education level may influence the care provided for their offspring (Caldwell and Caldwell, 1993; Glewwe, 1999; Abuya et al., 2012). Although the mechanism behind this relationship is not understood well, there are several assumptions that link mother's education to child's health. A number of authors have argued that health of children in countries with poor environmental conditions and low levels of sanitation is influenced by the education of mothers (Bicego and Boerma, 1993; Chen and Li, 2009). Chen and Li (2009) analysed the effect of maternal education on children being adopted in China. They presented the evidence that additional years of maternal education is associated with increasing height of children who were adopted. The claim that educated mothers provide a more hygienic developmental environment for their children is further tested in this study. The authors use three measures of a hygienic environment. These include access to running water, access to own water source and access to a flush toilet. The results from this study suggest that better educated mothers do provide a hygienic environment for their children to develop, though the authors have very simplistic characterisations of nature vs nurture. There is a possibility that better educated mothers are more often found in homes that have economic wherewithal but that mothers' education is not actually directly related. This possibility needs to be further explored. In relation to the developmental context of potential participants of my proposed study, maternal education, as well as water sources and flush toilets, may be an important proxy to help assess health, which in turn may affect leg growth. Consequently, maternal developmental environments during her own development that may be partially assessed using proxies for SES prior to pregnancy, including social class during mothers' childhoods, may play an important role in the growth and development of their own children.

Assessment of studies of nutrition and disease impact on growth both suggest that these two factors play an important role when considering growth of individuals. Furthermore, it has been argued that there is a synergistic relationship between nutrition and disease in their impact on growth.

The relationship between pathogen exposure and nutrition is bidirectional. Pathogen exposure reduces the absorption of key nutrients and on the other hand malnourishment weakens the immune system and increases the risk of contracting disease (Brown et al., 1995). Walter et al. (1997) suggest, for example, that disease effects nutrition, but undernutrition can also increase the risk of developing diseases. This is because insufficient nutrients tend to weaken immune system response, which in turn affects the severity of infections. Walter et al. (1997) looked at the effect of infection on iron metabolism and the effects of anaemia on immune function. Results from this study found that children who received iron supplement were better protected from diarrhoeal infection. The authors argue that nutrient deficiency like iron may result in a weak immune system. This, in turn, will result in greater probability of being sick. Several other studies show interactions between lack of key nutrients and exposure to pathogens impact growth (Waterlow, 1988; Lunn, 2000; Salgueiro et al., 2002). A review by Salgueiro et al. (2002) analysed the impact of the synergism between nutrition and disease on growth. The authors use results from a range of zinc supplementation studies on infants to discuss the effect of zinc supplementation on growth and development. Results from the review of studies suggested that zinc supplemented children had improved linear growth, reduced episodes of diarrhoea and faster recovery time compared to children that had no zinc supplementation.

Based on this review and other literature it can be inferred that nutrition combined with exposure to pathogens plays an important role in the growth and development of individuals and even indirect considerations of this factor in this study will prove useful. These considerations will incorporate the view that lack of adequate nutrition may lead to an increase in stress from exposure to infectious disease and vice versa.

Lack of adequate nutrition and exposure to pathogens is often linked with low socioeconomic status. Studies show individuals living in poor environments suffer from higher incidence of diseases and lack adequate nutrition (Martorell, 1989; Bogin, 1998; Muller and Krawinkel, 2005). Muller and Krawinkel (2005) argue poverty is a major factor which results in higher exposure to infectious disease, leading to growth retardation. The authors also argue that the factors that contribute to difference in distribution of nutrients and disease exposures across poor environments reflect the political and economic situation, access to clean water, health care, and sanitation. Therefore, analysing the age at which the individual was exposed and the length of exposure to stressors, like infectious disease, and careful analysis of developmental circumstances is important when determining the effect of these factors on leg growth relative to height overall.

Bogin (1999) suggest that although nutrition and disease are proximate determinants of growth associated with socioeconomic status (SES), SES serves as a useful proxy, though difficult to characterise in consistent ways across different settings found in the present study. There are many studies that assess the growth outcome of population or individual in relationship with SES (Bogin and MacVean, 1978, 1984; Lasker and Mascie-Taylor, 1989). Results from these studies find children living in higher SES areas are larger in comparison to children living in low SES areas. It has been argued that families who are "better-off" as marked by measures of SES (education, income and occupation) may often be able to provide better nutrition, more hygienic environments, safe drinking water and health care for their children, which in turn will result in better health outcomes (Winkleby et al., 1992; Baum et al., 1999; Adler and Newman, 2002; Gordon-Larsen et al., 2006). Hence, instead of just using occupation or income as a proxy for SES it may be important to assess other aspects of the developmental conditions like access to clean water or toilet facilities. There are several proxies used to determine the SES of an individual or population. The choice of proxies and how they are defined vary depending on the setting individuals are living in. Studies that measure SES of individuals living in industrialized or urban settings used proxies like education and occupation. In rural settings or third world nations a different set of proxies may be used. These proxies range from access to basic needs like clean drinking water or toilet facilities, household crowding, ownership of a car, phone and type of cooking fuel used. Growth and development studies in populations are often explored in relation to local social environments, though these environments are often characterised using only one or a few variables (Kinra et al, 2011; Sohn, 2015). Less often are these environments contextualised within socio-political and historic settings (Leatherman, 2005).

For the purpose of this study changes in growth and development will be assessed by considering changes in social environments and how these may be related to changes in developmental environments. The changes in developmental environment will be assessed in terms of conditions that precede and follow migration. Conditions pre and post migration may also reflect changes in the developmental environment during movements within a region or to New Zealand as international migrants. The conditions that will be assessed include circumstances of individuals during infancy and early childhood and, indirectly, the level of exposure to pathogens by the individuals then.

2.3: Height as a biomarker of early life conditions

Height has been recognised as a biomarker for centuries. Boas was among the first to actively use height as a biomarker of early life conditions. There are several studies that analyse the effect that changing developmental circumstances, broadly characterised, have on final growth outcomes of individuals (e.g. Boas, 1912; Ito, 1942; Greulich, 1957; Froehlich, 1970; Smith et al., 2003). These studies argue that changes in developmental circumstances as a result of migration resulted in an increase in overall height. As an example, the study by Froehlich (1970) on Japanese migrants in Hawaii who were all from Hiroshima prefecture. This study finds that there is a 10.6 cm increase in mean height between the first generation of men born in Hawaii as compared to those who were born in Japan. The difference between women who migrated to Hawaii and those who were born there is smaller (mean Δ = 4.2 cm). Though this study is comparing related individuals there is no direct measure of changes in early circumstances leading to differences. The author notes several limitations, but suggests these limitations are not affecting the results. One of these major limitations is aging effects, as the males and females who were born in Japan have mean ages of 79.5 and 70.3 years, respectively. Those in the 2nd generation born in Hawaii were 43.5 years for males and 50.6 years for females. Though the author provides support for the position that age is not influencing the interpretation a great deal, the age differences in these groups still bias outcomes, more for the difference between the males than for their female counterparts. The importance of age will be further discussed.

Based on the results from this study and other studies examining the relationship between environmental conditions and height, a generalised claim can be made about inferred improvements in environmental conditions, likely during the first few years of post-natal life, typically resulting in increases in mean height.

A major issue with using height as a biomarker of an individual's circumstances is that height is composed of two components, leg and trunk length. These components of height develop at different rates, with legs growing faster from about 9 months until the pubertal spurt. This is reflected in approximately 1.5% higher gain in leg length per year than trunk height (Gasser et al., 1991). Therefore, stress experienced at a given age during growth and development plausibly influences risks of stunting in these two components differently. Even though the idea that height as a useful biomarker of developmental circumstances is well established, it is now debated whether leg length, as a sub-component, is a more sensitive biomarker of developmental environment variation due to the earlier more rapid pace of the leg growth as compared to trunk growth.

2.4: Leg length as a biomarker of early life conditions

The idea that leg length might be a better indicator of developmental circumstances was first proposed by Leitch in 1951. He argued that children experiencing better developmental circumstances associated with their family's higher socioeconomic status will have both absolutely and relatively longer legs. Occupying a higher socioeconomic status commonly results in better nutrition and better health generally. His argument was based on the cephalocaudal gradient of growth proportions of the human body (Figure 2.4.1). During infancy, from about six months of age through to puberty, legs grow faster than the trunk (Gasser et al., 1991) (Figure 2.4.2), hence any disturbance due to lack of nutrition combined with exposure to pathogens arguably increases the likelihood of permanent stunting disproportionately in leg length (Bogin and Varela-Silva, 2010).

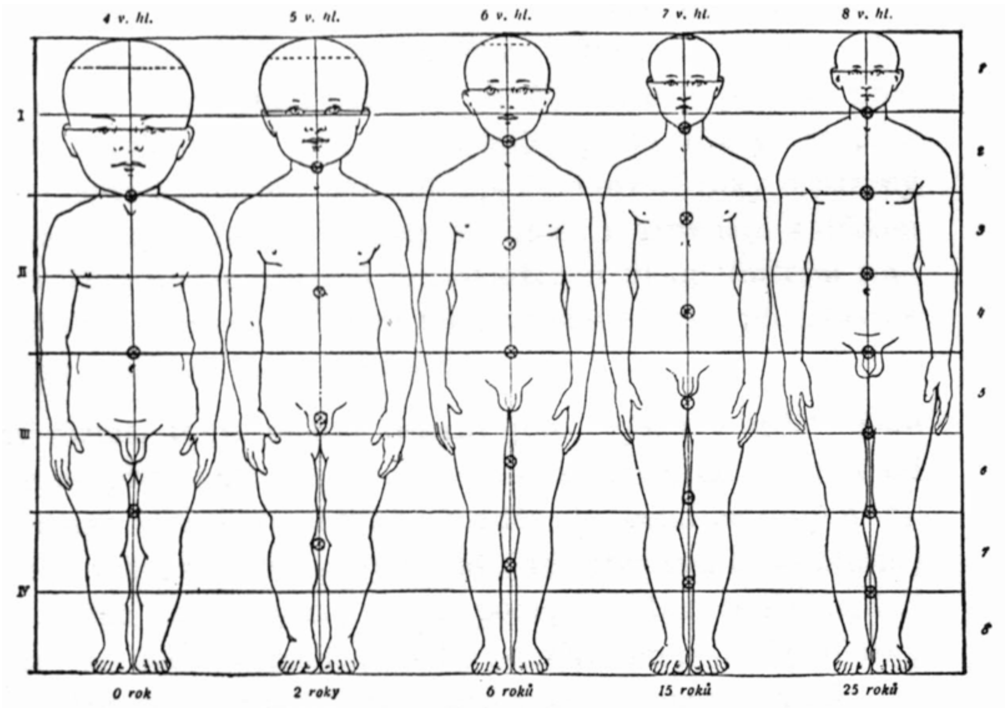

FIGURE 2.4.1: Cephalocaudal gradient of growth (Changes in body proportions during prenatal and postnatal period; from Bogin, 1999)

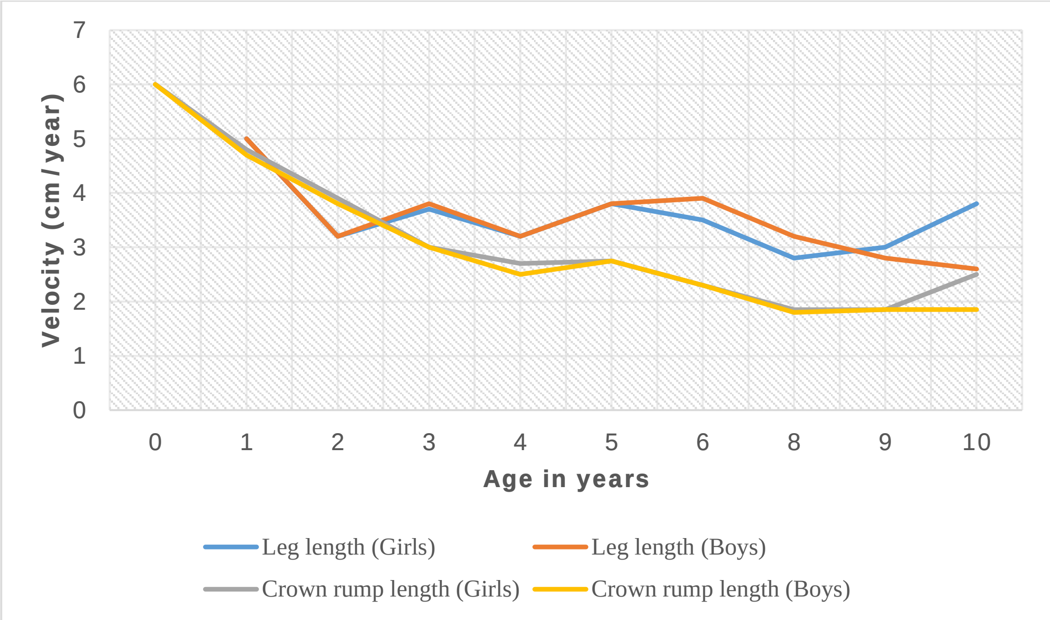

FIGURE 2.4.2: Velocity curve for leg length and crown rump length for girls and boys (adapted from Gasser et al., 1991)

Before the idea of leg length as a biomarker of developmental conditions was introduced, Ito in 1942 compared the height and sitting height of young adult Japanese women growing up in Japan and in the United States (U.S.). This study analysed two sets of hypotheses about the changes in growth pattern seen in Japanese in the U.S. One hypothesis was that the increase in height in Japanese living in U.S. was a result of differences in developmental environments. The alternative was that Japanese that migrated to U.S. belonged to a subset of the Japanese population with relatively taller statures. He separated the participants into four groups: women who were born and reared in Japan (n = 150), women born and reared in the U.S. (n = 135), women born in the U.S. but who returned to Japan between six months and nine years of age (n = 125) and women born in Japan but who migrated to the U.S. as infants or children (n = 7). For the last three groups, the author argues that earlier migration of the women's families to the U.S. resulted in their better nutrition, better hygiene, improved socioeconomic status and better health. The Japanese women born and raised in the U.S. developed more rapidly, as assessed using self-reported age at menarche. The Japanese girls born and raised in U.S. were also about 4 cm taller than the women in Japan while those who migrated back to Japan at variably early ages are about 2 cm taller, on average. The small group that migrated to the U.S. as infants had an average height nearly the same as the group that was born and raised in U.S. Out of these four groups, the women who were born and raised in Japan were the slowest to develop. Ito also tested for difference in absolute and relative sitting height and trochanteric height between the groups. The largest mean sitting height was reported for women born and raised in the U.S. and the smallest for women born and raised in Japan. Ito suggested that the difference in stature observed in these groups is due to the effects of environment but the relative sitting height distribution is characteristic of Japanese no matter where they grow up.

The study by Ito was very good overall, but did have limitations. Like many studies, Ito does not demonstrate directly that differences in environment influence differences in stature, though this is the most reasonable inference from indirect evidence. Apart from the birthplace and where the women were reared there is no other information about the difference in early environments at the individual level. His attention to racial differences is typical for the time of publication, but the pattern of change in the relative sitting height and relative trochanteric height across the three major groups should not be ignored. The results of relative trochanteric height demonstrate that the Japanese women born in U.S. have a greater average relative trochanteric height when compared with women in Japan. This suggests that women who were reared in the U.S. have both absolutely and relatively longer legs than women who were born and reared in Japan. The data from Ito's U.S.-Japan group can be used to further explore ideas central to this research. Curiously, it is evident that there is consistently greater variability in all anthropometric measures for the group that was born in U.S. and migrated to Japan. This may have been influenced by the difference in the timing of migration to Japan. The women who were born in the U.S. migrated to Japan at different ages, ranging from 0.5 to 9 years. If available, further analysis of these data could assess the influence of age at departure on leg length vs the influence of departure age on height. This may provide insight into understanding whether height or leg length is a more sensitive marker of changes in development circumstances during early development.

Since this idea of relative leg length being a more precise biomarker of developmental conditions was introduced, there has been several studies testing for this relationship (Greulich, 1957, 1976; Bogin et al., 1992; Gunnell et al., 1998; Wadsworth et al., 2002; Floyd, 2007; Padez et al., 2009; Azcorra et al., 2013, 2015; Sohn, 2015). These studies provide conflicting results. Some of these studies report that increasing height is primarily a result of increasing relative leg length in better circumstances. Individuals that experienced better conditions were taller than their counterparts that were exposed to adverse conditions, and this increase in height was primarily a result of increase in leg length (Tanner et al., 1982; Bogin et al., 1992, 2002; Gunnell et al., 1998; Wadsworth et al., 2002; Floyd, 2007, 2008; Azcorra et al., 2013, 2015).

Other studies, however, report no effect of presumably better developmental circumstances on relative leg length (Greulich, 1976; Kaur and Singh, 1981; Kinra et al, 2011; Sohn, 2015). These studies have reported increase in height as a result of difference in developmental circumstances but there was no disproportionate increase in leg length.

These conflicting results have been further interpreted by at least two authors (Floyd, 2007; Sohn, 2015). Sohn (2015) made an attempt to resolve the conflict of whether height or leg length is a better indicator of early life conditions in a developing setting. Sohn (2015) uses information on participants' years of schooling from the life survey done in Indonesia as a proxy for socioeconomic circumstances of their families when participants were young to analyse this relationship. Sohn notes that it is the only relevant variable from the survey available. The author justifies the use of this variable based on the time period within which the participants were born (1936-1968). The author argues that during this period, education was expensive and the availability limited so poor families could not afford the cost of educating their children. Although a necessary compromise, this proxy appears to be a rather crude marker of early life circumstances for individuals included in the study.

Additionally, the study participants' age range of 40-70 years is not ideal because of the potential for stature loss with aging among older participants. This may result in biased outcomes for older individuals as most of the shrinkage occurs in the trunk as humans age. The author does, however, acknowledge this source of bias and adjusts for age-related shrinkage using the model described by Cline et al. (1989). They suggest it is not a great concern. The author states that this age range is used because life survey data only collected sitting heights for respondent aged 40 and above. The results from this study suggest that the environmental conditions associated with education level influence growth in leg length, but the size of influence is smaller than that influencing height growth. He argues that in developed nations the influence of early circumstances on leg length is larger than in developing nations. He errors, though, in this regard by identifying participants from Taiwanese families reported by Floyd (2007) as from a "developed" setting. This is only true of the offspring generation. Although, Sohn suggests that analysing how much of the difference in height and leg length is due to changes in environmental conditions is particularly important, his study, like most others, only very incompletely addresses the issue. The question of why developed settings may, or may not, have a greater impact on relative leg length will be taken up again in the Discussion.

Floyd (2007) investigated the relationship between leg length and changes in environmental conditions in Taiwanese families who experienced variably rapidly changing circumstances. Developmental conditions were assessed for both parent and offspring generation using life course data and evidence of linear enamel hypoplasia. Results from this study suggest that the parent-offspring differences in relative leg length were greatest when parents and offspring experienced substantial differences in early circumstances and less when both generations experienced more similar conditions early on. The author suggest that difference in the extent and timing of stressors will result in different effect on relative leg length, while acknowledging that further research is needed. Therefore, a careful analysis of the developmental circumstances at important stages of life, and the extent of the stressors is crucial, though difficult to accomplish in this and other retrospective studies. The author also suggest that the inconsistency in the results may be a result of inconsistency in research study designs.

2.5: Possible impacts on interpretations of differences in research designs and differences in how developmental environments are characterised

The inconsistency seen in the results from the studies analysing leg growth may partially be a result of variation in the methods used for characterising developmental circumstances as well as inconsistencies in anthropometric measurements and variation in age ranges (Hauspie et al, 1996; Floyd, 2007).

2.5.1: Population or group level interpretations of developmental circumstances

Most studies when evaluating the effect of environment on growth of individuals characterise changes in developmental circumstances at a population or sub-population level (Boas, 1912; Ito, 1942; Greulich, 1957, 1976; Bogin et al., 1992, 2002; Smith et al., 2003). They have, for example, described changes in developmental circumstances as a result of migration from a country with poor developmental circumstances (i.e. poor sanitation, poor nutrition and limited or no access to health care services) to a country with access to clean water, proper nutrition and access to public health services. There is typically an absence of information about individual circumstances. For example, Greulich (1957) suggests that better developmental conditions result in American born Japanese being taller with distinctly longer legs prior to, but not after, their pubertal period than their counterparts in Japan. The sitting height ratio of older children resembles that of native Japanese. The author argues that this difference between native and American- born Japanese prior to reaching puberty illustrates the favourable conditions experienced by American-born Japanese. The outcomes as adults do not, however, suggest greater reductions in infant and early childhood stunting among the Japanese-Americans, unlike results reported by Ito (1942). Differences in nutrition experienced somewhat later in childhood could, however, account for their more generally rapid pace of maturation during adolescence. This, in turn, could explain their relatively longer legs during adolescence as compared to Japanese. These possibilities remain as hypotheses in the absence of more direct information about circumstances, including the timing of stressors during the life course of individuals.

Studies by Bogin et al (2002) and Smith et al (2003) are good examples of population or group level interpretation of developmental circumstances. These authors tested the hypothesis about the effect of changing circumstances on the body proportions of Mayan children. They assessed the effects of migration on growth and development of children of Mayan immigrant families in the U.S. Inferences from previous research are made about the circumstances of children living in Guatemala. They are described as frequently being low SES with no health services or safe drinking water. Guatemalan parents who migrated to the U.S. earned better wages and are assumed to provide more growth-promoting environments for their children. The authors argue that migration to the U.S. resulted in better health and nutrition in comparison to living in Guatemala. In the study by Bogin et al, comparisons were made between NHANES, American born Mayan and children in Guatemala who were 5-12 years old. Whereas, Smith et al., (2003) assessed the height and sitting height of Mayans in Guatemala, Mayans in U.S. in 1992 and Mayans in U.S. in 2000 who were 6-12 years old. The authors inferred that the difference in stature seen among the migrant and non-migrant is because migrating from rural areas of a country with poor environments to the U.S., where migrants were poor but still much better off than in Guatemala, resulted in better access to health care and sanitation. There is evidence for changing environmental conditions resulting in greater growth in leg length than trunk length, but there are limitations to characterising developmental circumstances at population or group levels. The descriptions of these families do not provide background information about them specifically in relation to stressors experienced during early life, but are based upon inferences about conditions reported from other sources.

Also while these results support the argument that there is an increasing difference in leg length with an increasing difference in the developmental conditions, an unknown portion of this difference in body proportions may be related to differences in maturational tempo in the two groups. The problem with assessing individuals that have not completed growth is it is hard to distinguish between stunting and maturational tempo. Maturational tempo or tempo of growth as explained by Bogin (1999) represent differences in timing of growth and skeletal maturation of earlier and later maturing individuals. Some individuals may mature early while some may take more time. Early maturing individuals may be taller with relatively longer legs, but are ahead in the skeletal development when compared with late maturing individuals. Hence, if we assess individuals that are still growing the results may be biased and hard to interpret. To avoid these problems, it is best to use individuals that have completed growth.

Population or group level interpretation of developmental circumstances of individuals who have completed growth find inconsistent support for the hypothesis (Greulich, 1976; Tanner et al., 1982). Tanner et al., found substantial gains in leg length relative to height among Japanese 17 to 18 year old males and females in 1957 and 1977. This pattern, however, was not reported in a study of Japanese-Americans (Greulich, 1976). The aim of the study done by Greulich (1976), an extension of a study done in 1957, was to see if the improvements in economic conditions altered body proportions of individuals of Japanese ancestry growing up in California as compared to those growing up in Japan. The difference in body proportions between the Japanese-American and native Japanese during adulthood were smaller in comparison to those of the same individuals when they were adolescents. As compared to Japanese of similar age, the Japanese-American had relatively longer legs as adolescents, but when a subset were re-measured as adults, they had relatively shorter legs. These two related studies do not, however, directly measure the change in environmental conditions within families. The study by Greulich, (1976) had other limitations as well. Greulich (1976) was only able to find 35% of the original participants for comparison. This minority of original participants who could be found and who were willing to participate in the second study may not be representative of all those who participated initially. If the group was representative of the original sample, the results from this study suggest two things. First height is a better biomarker of developmental circumstances than leg length in this specific setting. Second, it is important to evaluate individuals that have completed growth to assess the debate about whether legs are a better biomarker than height.

Although in these growth studies, the characterisation of developmental circumstances are mainly based on assumptions about the nature of life in a given place and generation, some authors have considered the assessment of development circumstances related to individuals or family members.

2.5.2: Analysis of developmental circumstances related to individuals or family members

There are several studies that analysed the developmental circumstances of families or individuals as they relate to growth outcomes in both individuals that are still growing and individuals that have completed growth. The results from these studies are inconsistent as well. Some support the argument that leg growth is more sensitive to early stressors (Bogin et al., 1992; Gunnel et al., 1998; Wadsworth et al., 2002; Floyd, 2007; Azcorra et al., 2015) and some studies argue against this idea (Kinra, 2011; Sohn, 2015). One of the most common proxies for early environments used in these studies is socioeconomic status (SES), operationally defined in a number of different ways.

Results from literature assessing leg length as a biomarker of early conditions in still growing individuals are less inconsistent than the studies that assess individuals that have finished growth, but potential differences in maturational tempo make interpretations uncertain. Gunnell et al (1998) and Frisancho et al (2001) assessed individuals that had not completed growth and found support for the hypothesis that leg length is more sensitive to developmental circumstances. To illustrate, Gunnell et al. (1998) assessed the effects of childhood circumstances on the leg length vs. trunk length. The study by Gunnell et al (1998) examined SES information associated with children in Britain in 1930s whose ages ranged from 2 years to 15 years. Developmental circumstances were analysed at the individual level using familial socioeconomic status and diet of individuals. Socioeconomic status was assessed using the number of children in the household, the number of persons per room and occupational class of head of household. Diet was assessed using food expenditures and total calorie and protein consumption. The authors argue that infection and under-nutrition are the key factors that result in difference in stature. Results from this study showed that differences in height across different developmental circumstances for this population were primarily a result of differences in leg length and not trunk length. Similarly, Frisancho et al., (2001) who assessed Mexican Americans ranging in age from 2 to 17 years old also noted that leg length was significantly associated with developmental circumstances. Individuals from families with a high socioeconomic status had relatively longer leg legs than height.

Even when studies where immature participants' developmental circumstances are analysed at an individual or family level were found to support the hypothesis, there are studies which do not consistently find leg length to be a better biomarker than height (Padez et al., 2009). Padez et al. (2009) tested the hypothesis that leg length was a more sensitive indicator of the quality of the environment than overall height in Mozambique. The data were collected from six primary and secondary schools. Three of these schools were located in a somewhat better-off urban centre and three schools were located in slum areas. The slum areas, as stated by the author, did not have any electricity, water or sanitation. Families in the higher SES urban area had access to all of these resources. This study further used parent's education and size of the family as an indicator of social status for individual children. They carefully note that this socio-demographic information is not reported for every family, with specific response frequency reported in their Table 1. The age range of children measured in this study is 9.00 to 17.99 years. All participants are born during wartime and the youngest participants' prenatal and first year of post-natal life coincides with the war. The relative leg length was determined using the sitting height ratio. To determine if an individual is stunted all anthropometric data were standardized by age and sex into z-scores. Using the z-scores each participant was classified in one of six groups: no stunting or wasting (reference age-specific median height ± 1.99 z), stunting (from -2.00 to -2.99 z), severe stunting (< 3.0 z), wasting (< -2.0 z age-specific weight-for-height), overweight (2.0 to 2.99 z BMI) and obesity (> 3 z BMI). These groups were classified using the cut-off point recommended by the WHO. The results from this study showed a higher stunting in the slum area. The slum area and the urban area were further compared with the NHANES (African-American) reference. These data were further grouped according to age as an approximation of their maturational status. These groups consisted of preadolescent (9 to 11 years old), early adolescent (12 to14 years old) and lastly middle to late adolescent (15+ years). Somewhat surprisingly, the same categories were used for both girls and boys. This revealed that all age groups in the slum, both girls and boys had shorter legs in comparison to the urban area except for girls that were 15 years or older. For the higher SES area, in the age group 9-11 years boys have relatively longer legs than the NHANES reference. There was no difference found in the early adolescent group. The age group 15+ have significantly higher sitting height ratio, relatively shorter legs compared to the reference. Girls in higher SES area have relatively shorter legs than the NHANES references for all ages. The authors suggest that this difference in the leg length among the age groups in the higher SES area is seen due to the timing of the changes in developmental circumstances. They argue that the older individuals in the urban areas were born during the war time and during their developing years they experienced adverse conditions. Adverse conditions during developing stages may have resulted in shorter legs. In contrast to the younger generation (individuals in younger age groups, i.e. 11 year olds and younger) are argued to have not experienced the same adverse environmental conditions, therefore showing evidence of longer legs.

The authors also compare the higher SES and the lower SES area to determine if leg length is more sensitive to environmental conditions. There is a significant difference between relative leg lengths of boys for the two areas in the age group 9-11 years. The rest of the age groups show no significant difference. Hence, the results from this study do not uniformly agree with the hypothesis that relative leg length is more sensitive to adverse conditions. The authors suggest that the inconsistency within their sample population may be a result of unmeasured variables that are associated with the history of war. Therefore, a thorough evaluation of the environmental conditions using the political economic framework is an important addition in evaluating individual developmental circumstances.

Based on the review it can be reasoned that while difference in the characterisation of developmental circumstances and assessment of individuals who have or who have not completed growth may contribute to inconsistencies, relationships remain complex even if these issues are dealt with. Differences in outcomes may be hypothesised as tied to differences in individuals' ages and maturation at the time stressors are experienced as well as the strength and duration of the stressors themselves. Exposure to pathogens during the early developmental stages can be measured more directly and may prove useful in narrowing estimates of the timing of stressful event. Evaluation of linear enamel hypoplasia provides a useful way of analysing these stressful episodes and the timing and extent of stressors during infancy and childhood, though heterogeneity of frailty complicates interpretations (Goodman et al., 1991).

2.6: Linear Enamel Hypoplasia as a marker of stressful episodes during childhood

To be able to obtain a better indicator of stress response during early childhood, dental impressions of the anterior teeth of individuals were taken with permanent casts made from these impressions. Linear enamel hypoplasia (LEH) is a dental indicator of environmental stress. Periodic environmentally induced stress events may disrupt crown formation (Scott 1997). LEH is formed as deficiencies in the thickness of the enamel in response to physiological stress during the secretory phase of amelogenesis. LEH is considered as the most observable indicator of systematic growth disturbance during childhood. Zhou and Corruccini (1998) argue that LEH has great potential as an indicator of population nutritional stress. Studies suggest that LEH is more pronounced on the anterior teeth and these teeth have higher hypoplastic rates (Goodman and Armelagos, 1985; Scott, 1997). Many studies use LEH as an indicator of stress experienced among past peoples whose remains are found in bio-archaeological contexts (King et al., 2005; Boldsen, 2007). King et al (2005) examined LEH patterns in two burial collections from London in the 18th and 19th century. King et al (2005) suggests that variation in LEH in the two study groups reflects differences in socioeconomic status and standards of living between members of the two communities. While most studies examining relationships between LEH and stress experience are bioarchaelogical, it is more difficult in such studies to make connections between LEH as an indication of stress experience with measures of response that follow. The relationship between LEH, stress and growth have, however, been evaluated in living populations too (Goodman et al, 1980, 1991; Floyd and Littleton, 2006; Floyd, 2007).

A study done by Goodman et al., (1991) looked at the effects of nutrition on the development of LEH in Mexican children. Results from this study determined that un-supplemented children had a significantly higher prevalence of LEH then supplemented children. This study also determined that a relationship exists between the duration of illness and likelihood of LEH formation. A study by Infante and Gillespie (1974) suggested that undernutrition alone is not the determinant of LEH. The level of exposure to pathogens and the duration of illness needs to be considered. Hence, taking dental impression to asses LEH may assist in determining the physiological stress experienced during childhood as a result of lack of adequate nutrition and exposure to severe illness. However, this approach may have limitations. The main limitation to this approach is that not all stressful episodes during childhood typically result in the formation of LEH. There is likely to be a threshold for the formation of LEH that varies among individuals within a group. Henry and Ulijaszek (1996) suggest that the threshold for ameloblasts to cease function may be determined by a range of unknown etiological factors, acute undernutrition and acute morbidity. Figure 2.6.1 shows how the formation of LEH may operate. While using LEH to characterise environmental stress experience during childhood may have limitations, the information obtained from the participants and the information obtained from the dental impression combined, can contribute to a better understanding of childhood circumstances.

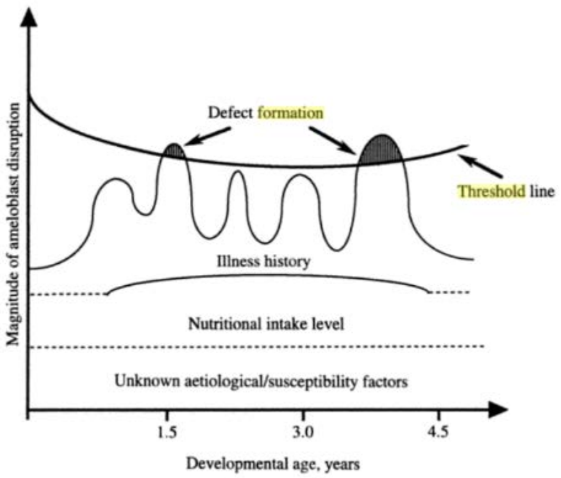

FIGURE 2.6.1: Threshold model for the formation of LEH (Henry and Ulijaszek 1996)

I will estimate the level of exposure to pathogens and individuals' responses to them during early life stages using both life course data from parents and their offspring and information about their enamel development assessed using anterior dental casts. This approach will allow me to make inferences about similarities or differences in the level of stress experienced during early childhood. The advantage of combining these two sources of data to characterise early circumstances in each generation follows from strengths and limitations of the two approaches. Information about childhood stress gained from self-reported information about peoples early lives may be useful, if imprecise. It is highly dependent on how well the individual are able to recall this information. Stress markers on teeth are analysed to attain a more thorough understanding about the stressful episodes experienced by individuals when young. They indicate when these episodes were of sufficient intensity or duration to result in deficits in enamel matrix deposition. While not a complete record of stress events, those recorded are likely to be partially associated with skeletal growth deficits retained as adults.

It is not known to what extent developmental circumstances of Punjabi families may result in difference in the leg length. Though, subjective evidence from other studies suggests that at least some of difference in leg length between parents and offspring may be a result of changes in developmental circumstances. The review of the literature involving research around the issue of leg growth as a sensitive biomarker of developmental circumstances has identified that it is important to gain a fuller understanding of the developmental context at an individual level in which the participants spend most of their growing phase and thoroughly analyze the timing and extent of the stressors experienced by individuals.

Therefore, developmental circumstances of the participants will be measured at the individual/family level. To assess stressful episodes experienced during childhood, linear enamel hypoplasia will be examined using anterior dental casts (methods are explained below). All willing participants that are likely to have completed growth are part of the study. I anticipate based on existing research that parent-offspring differences in both stress markers (i.e. linear enamel hypoplasia (LEH)) and relative leg length will increase with increasing difference in developmental environments during infancy and childhood. Evaluation of these expectations require me to assess parents' circumstances when young, their circumstances at the time they decided to migrate to New Zealand, and circumstances following their move. This information will, in turn, be related to when and where their children were born. Both parent and offspring circumstances plausibly relate to access to and quality of public health, income, housing, diet and health care when they were young, and the age of the children when they departed for New Zealand with their parents, or the circumstances that they were born into given their parents' migration experience. All of these factors are conditioned by the political-economic considerations related to caste or class within histories of both places of origin and settlement.

Chapter 3: Participants and Methods

3.1: The Punjab: Background information related to participating families

This section will provide a brief background about the people of Punjab, mainly the history of social, demographic and economic structures related to the early circumstances of the participating families. The history will include the 1947 India-Pakistan partition, the Green Revolution and important events related to education, and health in Punjab. All these events are important to understand the background of both parents and offspring.

Punjab is a state in India. It is located in the North of India. Punjab shares borders with Jammu and Kashmir (a disputed territory) and also shares a border with Pakistan (Figure: 3.1.1). Before the 1950s the caste system in India was used to divide people based on their social status. In the 1950s the government of India outlawed the caste system, but many people in India still practise the caste system. In Punjab there are several castes but Jat-Sikh is the strongest caste, holding the most political power.

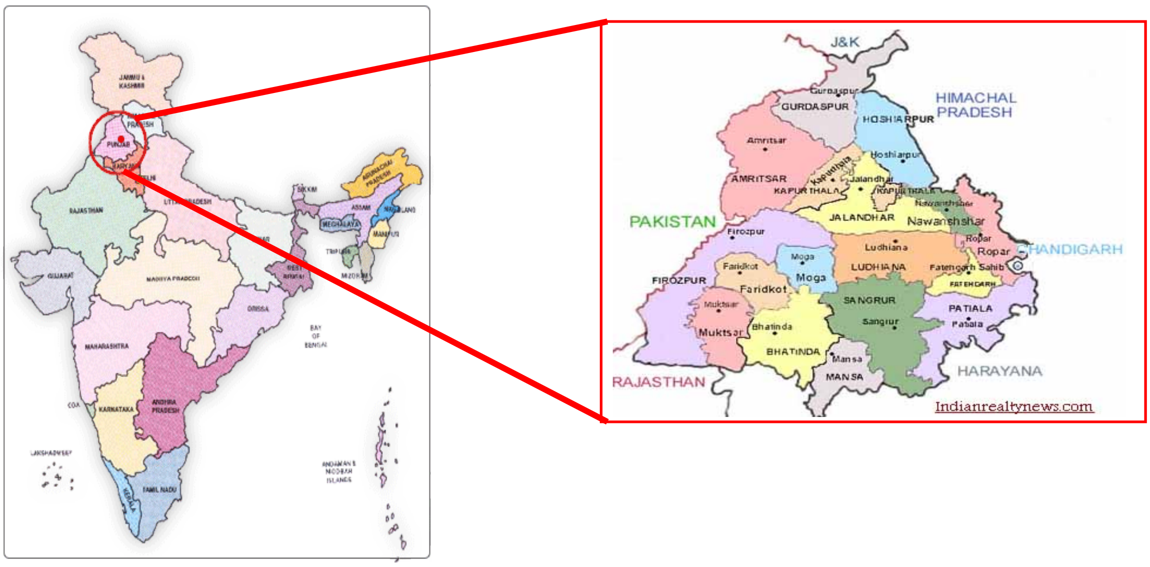

FIGURE 3.1.1: Map of Punjab (http://eastmanpowertools.com/contactus.html)

In 1947 partition of India and Pakistan took place. In recent Indian history this event is considered the most catastrophic. The partition affected a large number of people in Punjab (Kleinman et al., 1997). The time after partition resulted in violence and riots. Due to communal violence most Sikhs and Hindus that were in Pakistan migrated to India. Similarly, Muslims in Punjab India migrated to Pakistan. This event is identified as one of the largest mass migration events in modern history (Hill et al., 2008). People who migrated from Pakistan Punjab to India post-partition lived in India Punjab as refugees. These people were most affected by this partition because they lost their land, property and other means of making a living. The Indian government offered these people houses and lands for agriculture, but the size and proportion of land was often smaller then what they originally owned.

The first few years after the partition were spent in recovering from the effects of partition. During the 1950s as part of free India there were several different public investments made. Most of the policies formed as part of “free India” neglected public health reforms. These policies were more focused on developing industry and agriculture. One of these investments included the Green Revolution. The “Green Revolution” was introduced in Punjab in the 1960s. This revolution led to the rise of Punjab’s economy. As a result of increase in agriculture the state government invested in better water supplies to farms and built proper roads to be able to transfer stock. Urbanization took place early in Punjab in comparison to other states. The state of Punjab has well developed infrastructure, transport system and health services. An increase in the states GDP eventually resulted in major changes in clean water availability and health care and education reforms. Sanitary reforms are suggested to have taken place early on in Punjab mainly after the Green Revolution, but there is no evidence available of the specific timing of these changes. Education has been an important agenda for the state government of Punjab. Post-partition a large number of schools and universities were opened in Punjab. There is evidence of an increase in the literacy rate, for both males and females, after the Green Revolution (Table 3.1.1) (Department of Planning Punjab, 2014). Based on the census results there is a greater increase in the literacy rate of females over the years as compared to males, though female literacy remains lower.

TABLE 3.1.1: Literacy rate in Punjab as per census year 1971-2011

Year	Total Population	Literacy rate (%)	
		Male	Female
1971	13,551,060	42.23	24.65
1981	16,788,915	51.23	34.35
1991	20,281,969	65.66	50.41
2001	24,358,999	75.63	63.55
2011	27,743,338	80.40	70.70

The history of Punjab suggests that during the partition many people were exposed to adverse environmental conditions, but rapid changes in economic conditions of the state during the Green Revolution exposed the later generation to better environmental conditions. Many of the parents who participated in my study were from this later generation.

3.2: Recruitment and study participants:

After receiving university ethics committee approval on January 16th, 2017 (Reference number: 018540), the recruitment of participants began through several different organizations. In total, 34 Punjabi families were recruited, each being provided with information about the study before they agreed to participate. Families were initially recruited from Punjabi community organisations, Sikh temples, and migrant services. Participating families also introduced me to other families who agreed to participate. I learned that there were a total of five Gurudwaras (Sikh temples) in Auckland. The majority of these Gurudwaras are located in the Southern part of Auckland with one located in West Auckland. There was an important difference between the Gurudwara in New Lynn (West Auckland) and the Gurudwaras in the South Auckland. The Gurudwara in New Lynn was attended by more recent immigrants, whereas the Gurudwaras in South Auckland was attended by people who have been in Auckland for decades. A formal request was made to these organizations to advertise for recruitment. Further, when permission was granted, informal presentations explaining my research were made at these organizations. The aim of the presentations was to provide potential participants with sufficient understanding of what the study involved and what was required of them as participants so that they could make informed decisions. Participant information sheets were distributed to families expressing an interest and they were asked if it was OK for me to follow up with them in a few days. All potential participants were given a chance to have any questions asked and answered before they signed consent forms. All participants were assigned a unique number. A sheet, kept separately in a lock cabinet, is maintained to link the unique ID numbers to the family members involved.

To be able to analyse the intergenerational differences in height and leg length, my initial goal was to only recruit families consisting of mother, father and at least one adult child. During recruitment, I included 4 families where only one parent was available. Selection of individuals within families allows for more effective analyses of circumstances as this partially controls for genetic influences; differences or similarities between parents and offspring present will tend, on average, to be a result of changes in developmental circumstances.

The age range of offspring in this study varied from 18 to 33 years. Based on literature, virtually all daughters and most sons in this age ranges are likely to have completed height growth in reasonably good circumstances. To check this assumption a scatter plot of sons' heights across age in decimal years was evaluated. The scatterplot (Figure: 3.2.1) suggests that as age increases there is no further increase in height. Parents selected for this study ranged in age from about 40 to 75 years of age. Only 11 parents (two mothers and nine fathers) were over 60 years. Curvilinear adjustments for aging estimated from a mixed longitudinal study (Cline et al, 1989) were applied to all parents' heights. For all fathers the maximum adjustment was 2.48 cm ($\bar{x}$ = 0.71 ± 0.71 cm SD) and for all mothers the maximum adjustments was 1.21 cm ($\bar{x}$ = 0.16 ± 0.30 cm SD).

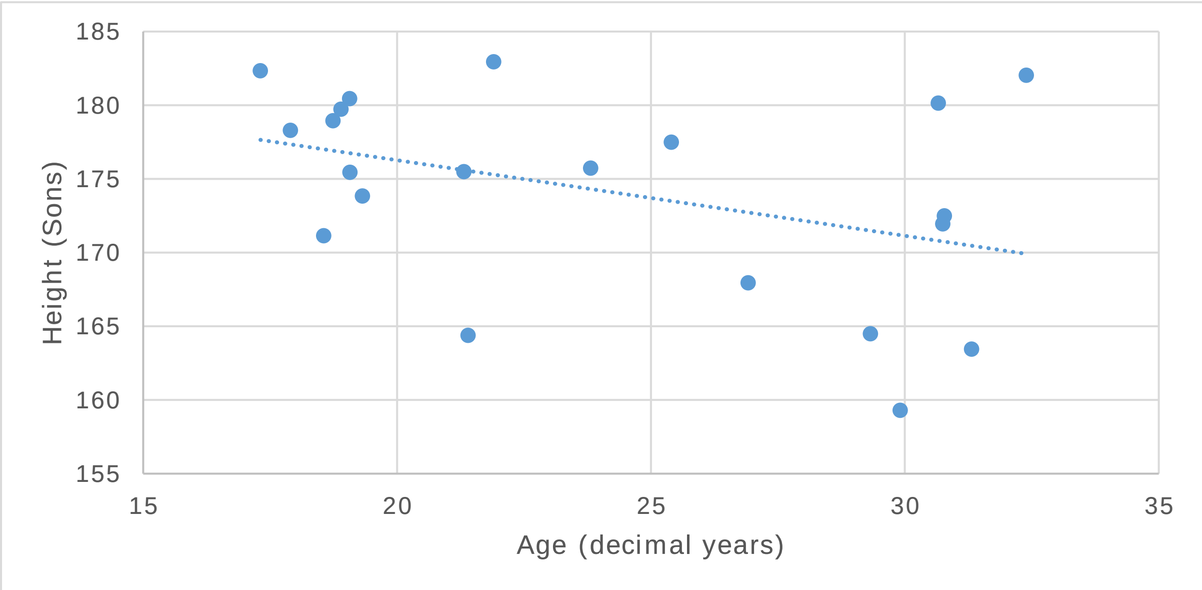

FIGURE 3.2.1: Scatter plot of sons' heights across age in decimal years

3.3: Methods:

This study involved collection of two different, but related, sets of data using different methods. The first method employed short semi-structured interviews. The interviews allowed me to collect life course information about the participants. The second set of methods allowed me to collect anthropometric measurements and take anterior dental impressions from the participants from which permanent casts were made and analysed for presence and location of linear enamel hypoplastic defects.

3.3.1: Collection of Life Course Information

Talking to each family member allowed me to gather information about the participant's family backgrounds and childhood experiences. There were a total of 98 interviews conducted. These interviews ranged from about 50 to 60 minutes. No interview was recorded. Participants were also made aware that they could decline to answer any question that they did not feel comfortable answering. All these questions were asked in English or Punjabi/Hindi. The questions for the semi-structured interview were developed based on evidence from relevant literature, and information I obtained from Indian friends and acquaintances prior to beginning the actual study. During the semi-structured interviews participants were asked open-ended questions that elicited a potentially wide range of responses.

The questions for interview are divided into three categories. The first category includes questions about basic demographic information. The second category includes information that may be linked to early developmental circumstances of each family member. The final category of questions helped me to indirectly assess the health status of individuals during development.

3.1.1.1: Basic demographic information

I gathered similar background information about all family participants. These questions included participant's age, where they were born, what caste/ religion they belong to, numbers of siblings in their birth family and each sibling's gender and approximate age relative to the participant, the participant's birth rank, the participant's age when they departed India, the date/year of arrival in New Zealand, and whether and how many other relatives were already present in New Zealand at that time. Participant's age when they departed India / arrived in New Zealand is valuable as a marker of time spent in various contexts. This is important especially to differentiate between individuals who arrived in New Zealand early in infancy and those who arrived after the first few years of life. Caste and number of sibling in the family are analysed when assessing the socioeconomic status of a given participant's family when they were very young. Participant's age when they arrived in New Zealand (if not born in New Zealand) is important in estimating their maturational status and the potential for changes following migration to influence growth. Using the date of arrival in New Zealand, the length of time in New Zealand was determined. The presence of relatives in New Zealand before the arrival of the participant to New Zealand is assumed to typically be beneficial for migrants arriving to a new country. This assumption was checked following interviews.

3.1.1.2: Assessing developmental circumstances when young

An important aim of the interview was to reliably assess the socioeconomic status of these Punjabi families and extended families at important points in members' lives. The estimate of socioeconomic status (SES) at important stages of life allowed me to assess the developmental circumstances of both parent and offspring when they were young. This assessment assumed that indications of greater family resources were generally associated with better infant and early childhood care while acknowledging the potential for gendered differences in resource allocation.

Socioeconomic status for participants growing up and raising their children in India is measured using the Demographic and Health Survey as a guide (ICF, 2011). Participants were asked to comment on cooking fuel used, availability of electricity in homes and household composition. All these are considered useful proxies for estimating the SES of families in India.

Participants were also asked to comment on the nature and access of toilet facilities and drinking water facilities that were available as early as they could remember, and for parents, when their children were young. Information obtained from this not only allowed me to better interpret aspects of reported SES, but also helped me assess the public health infra-structure and sanitation experienced by participants. These, in turn, help infer probable participant health and the likelihood of growth stunting because outdoor, publically used, toilet facilities tend to lower sanitation. This is linked with the high numbers of diarrhoeal infections present before the public health measures were put in place (Cairncross et al., 2010). Similarly drinking water is an important factor as exposure to contaminated water during the early stages of life may result in the higher levels of gastrointestinal infections. To have access to clean water, one way is to routinely boil water for a sufficient period to control microorganism in drinking water. Hence, participants were also asked to comment if they routinely boil the drinking water before consuming it and whether this was also routine when they were children.

Socioeconomic status for participants growing up and/or raising their children in New Zealand were measured using NZ deprivation index as a guide (Salmond et al., 1998). Participants were asked questions about the employment status of the participant (as a parent), highest qualification achieved (and qualification required of job), type of property they lived in (i.e. rent or own a house), number of bedrooms in the house, access to a car and access to a telephone. Water sources and toileting facilities are similar throughout New Zealand, therefore those questions are only applied in the context of participants that were born in India.

3.1.1.3: Estimating early health of participants

Exposure to pathogens during early life can be measured in many ways. For the purpose of this study I am using two measures. The first measure was asking individuals questions about their health and their children’s health when each person was young. This approach recognizes that recalled information, particularly from infancy and early childhood, is likely to be incomplete, and sometimes inaccurate. The second approach (described more fully below) partially compensates for these limitations by using a stress marker (linear enamel hypoplasia, LEH) to estimate exposure and response to pathogens when the participant was young. Using semi-structured interviews, participants were asked to recall information about the length and type of sickness affecting them when they were young. Recalled descriptions about the length of sickness allowed me to estimate the severity of the illness. Short term illnesses without severe symptoms are unlikely to have similar effects on growth as illnesses where symptoms were acute but severe or where symptoms affected the individual for a long period. Each participant was also asked about the kinds of treatment received in all those instances that they remembered being sick.

The types of questions asked were, for example, if they were treated at home or if they were taken to the doctor or hospital. Again severity of illness can be partially determined if the individual was required to be taken to the doctor. This may, however, not be true in all cases. It may also reflect parental SES and/or concerns about particular children.

People’s perception of their health and their perceptions of their status interact to play a major role in seeking medical help (Leatherman, 2005). Parents and offspring recollections may differ. Depending upon age of occurrence, parents’ accounts will be given priority.

Apart from looking at water sources and sanitation as the most common reason for an increase in exposure to pathogens, I indirectly assessed the role of breastfeeding. The change from breast milk to weaning food early on in life often results in increase exposure to pathogens if weaning foods are unsanitary. Breastfeeding is considered important for development of immune function (McDade and Worthman, 1999). Studies suggest that introducing weaning foods before six months may result in higher rates of diarrhoea (Mata, 1979; Motarjemi et al., 1993). Mothers were asked about the timings when their offspring were introduced to any supplementary foods.

3.3.2: Analysis of qualitative data:

The type of qualitative data that I am dealing with is unstructured data. Once the interviews were completed all information from interview was entered into an excel spreadsheet. Initially all data were entered in the spreadsheet as they were obtained from the interview, without any processing. Data were then cleaned. The process of data cleaning included checking if the data were accurately entered, typographical errors, missing entries and organising data according to generations. After the completion of all interviews, similar information or responses for each variable was grouped together. The response for variables varied, hence I extracted similar responses for each variables and then formed groups for these responses. This grouping was done for parent and offspring generations separately.

Ranking of variables for the parent generation, and offspring born in India who spent most of their early life there, was done using the demographic health survey (DHS) of India and also information provided by participants or other people from Punjab. For offspring who were born in New Zealand, different measures were used to rank variables. Most of the ranking was based on information provided by these participants, combined with studies of socioeconomic status of people in New Zealand. The justification of ranking is presented in Table 3.3.2.1.

TABLE 3.3.2.1: Justification of variable rankings[a]

Variable	Rank	Descriptor	Justification
Relatives in NZ	0	No Relatives	No support was reported to be available
	1	Friends/Extended Family	Some emotional support but little guidance. Very little or no financial support.
	2	Immediate family	A lot of support in all areas (financial, emotional, social and moral support).
Education level	0	No Schooling	Indian schooling system is divided into 3 stages: Primary education is a total of 5 years. The government made this stage compulsory for children under the age of 14 years in 1968. Next is secondary schooling, where all the states follow the same education pattern. And lastly, tertiary education which includes graduate, post-graduate and doctorates. The Indian schooling system is used here because all parents and grandparents completed their schooling in India.
	1	Primary education (Up to class 5)	
	2	Secondary education /college(Up to class 12)	
	4	Tertiary Education	
Fathers Occupation (India)	0	Unemployed	Ranking of fathers' occupations in India is based on information obtained about the pay scales of various jobs obtained from participants during interviews and from literature available. In the labour/service/retail category all jobs including truck driver, teacher at a private school, retail jobs, priest, labour worker in a foreign country working on farms and construction jobs. In category 3, I have included all business owners as participants provided similar descriptions of business they owned. People who owned farms are ranked 4th because of information obtained from participants and from literature about the economy of the state (Punjab) related to agriculture. And lastly, all government employees (5) including defence force, bankers (working in government banks), professors, service collectors and other government employees. Information obtained from participants suggests that all government employees were the most well paid and most desired jobs in India.
	1	Labour/ Service/Retail	
	2	Sales job	
	3	Business owner/Professionals	
	4	Agriculture (Owned Farms)	
	5	Government employees	
Fathers Occupation in NZ (if offspring was born in NZ)	0	Unemployed	The ranking is based on information provided by the participants about occupations around the time their children were born in NZ. Labour workers (1) include people working at kiwifruits farms. People who worked in jobs that are considered semi-skilled (2) include bank teller, sales rep or customer service rep. In category (3) I have included people who own small businesses and work as an IT professional. Lastly, I have placed taxi drivers in the highest ranked category because when their children were young Auckland Co-op taxi company had monopoly, and paid very well. Business owners during the time when their children were young owned very small and new businesses. Hence, the income of these business owners are categorised as lower income than taxi drivers. Although, in current times these business owners have a higher income than taxi drivers, but the income was not the same when their children were young.
	1	Labour	
	2	Bank/Finance/Retail/Sales	
	3	Business/IT	
	4	Taxi drivers	

[a] Table continued on next page

TABLE 3.3.2.1: Justification of variable rankings…continued

Variable	Rank	Descriptor	Justification
Mothers Occupation (India)	0	Cared for home	A similar system is used as father's occupation. Again government employees are the highest paid and include mothers working at government banks, working as a doctors at a government hospital and working as teachers or principals at government schools.
	1	Labourer	
	2	Business owner	
	3	Sales job/Skilled worker	
	4	Own farm	
	5	Government employees	
Type of dwelling	0	Mud house	Type of dwelling is ranked based on information obtained from relevant literature combined with the information obtained from the demographic and health surveys used in India.
	1	Brick and MUD	
	2	Brick	
	3	Tile/Timber	
	4	Brick and tile OR timber	
Location of House	0	Rural	Homes in rural villages were frequently described as having relatively poor sanitation. Among urban homes there were no marked differences described
	1	Urban	
Cooking Fuel	0	Animal Dung	Type of cooking fuel is ranked using the information provided in the demographic and health surveys used in India.
	0.5	Wood and animal dung	
	1	Wood	
	1.5	Coal and wood	
	2	Coal	
	3	Kerosene	
	4	LPG	
	5	Electricity	
Electricity	0	No	
	1	Yes	
Property	1	Rented	
	2	Own	
Assets (Phone and Car)	0	No	
	1	Yes	
Household crowding	0	Yes	More than two people sharing a room was considered as a crowded house. This was defined based on literature using household crowding as a proxy for health and status.
	1	No	
Toilet facilities	0	No toilet facilities	Toilet facilities are ranked using the information provided in the demographic and health surveys used in India.
	1	Outside house	
	2	Inside house, with septic tank	
	3	Flush toilet	
Drinking water facilities	0	Unfiltered, from Well	Drinking water facilities is ranked using the information provided in the demographic and health surveys used in India.
	1	Public taps/Hand pumps	
	2	Piped into dwelling and/or filtered	

3.3.3: Statistical method for analysis of qualitative data:

All statistical analyses were done using the R software. I computed descriptive statistics for each variable. There were a total of 30 predictor variables so it was not appropriate to run analyses for each variable in relation to height, leg length and lower leg length. The dispersion matrix is too large to interpret, many of the predictor variables are likely to be moderately correlated, and the adjustments for so many independent multiple comparisons may miss relevant relationships. It is important to reduce the number of variables to be able to interpret the data. Hence a variable reduction procedure was used known as principle component analysis (PCA). Principal component analysis is a procedure which converts sets of correlated variables into smaller sets of uncorrelated composite variables, referred to as components. From these set of components, the first component accounts for the most variability, followed by succeeding components accounting for the remaining variability (King and Jackson, 1999; Abdi et al., 2010).

After applying the orthogonal rotation on the components, the first four components were used for final analysis for parents and offspring. These components were selected on the basis of eigenvalue and scree plots. Each component was named after the variable that is most highly loaded on that component.

I evaluated anthropometric variation for fathers, mothers and offspring using PCA scores for the four components. These were also used to create variables that estimated the difference in early circumstances between parents and offspring. The PCA scores were ranked for mother, father and offspring separately. These rankings were done using the rank function in Excel. The PCA results are further explained in Chapter 4. These ranked variables were used to compute difference in early circumstances between parents and offspring. The differences was computed by subtracting the offspring first ranked principal component (which accounts for most variation in the data), with parents first ranked principal component, offspring second ranked component was subtracted from parents second component, difference in parent and offspring third ranked component and lastly difference in the fourth ranked component for parent and offspring.

3.3.4: Collecting Anthropometric Information and Dental Impression/Casts

Once the interviews were completed, anthropometric measurements and dental impression were collected from each participant. All participants within the same family were measured at the same time of the day if it was possible. This is to avoid the diurnal changes in height affecting the overall results (Botsford et al., 1994). There were only two families with whom difficulties were faced arranging a time suitable for both parents and offspring to be measured. In these instances, offspring were measured later in the day. Although bias introduced is relatively small (Floyd, 2007), this approach avoids increasing the likelihood of finding significant intergenerational gains in height as an artefact of measurement timing.

I took two replicate measurement of height, leg length and lower leg length. These were taken 10 to 15 minutes apart, to minimize measurement error. For all analyses the average of the two measurements for each characteristic was used. Standing height was measured using a GPM anthropometer held in an adjustable aluminium frame. For greater stability a tripod was used. It also included a bubble level to maintain appropriate orientation. Each individual was asked to stand near the anthropometer with heels together and head in the Frankfurt plane. After requesting each participant to stand straight, an aluminium headboard was lowered into contact with his or her head. As discussed in the literature review, relative leg length and relative lower leg length may be an important indicator of environment and the extent of permanent growth stunting accruing during infancy and early childhood. Relative leg length was estimated from a more direct measure of leg length, iliac height. These were measured using the anthropometric procedures described in Cameron's (1984). This measurement was difficult to measure reliably given different levels of adipose tissue covering the site among participants and their frequent discomfort with me finding its correct position. Hence it was not possible for me to confirm if the iliac height was being measured correctly in every instance. Because of these problems and the potential imprecision that resulted from them, I assessed the standard deviation (SD) of leg length from studies that used iliac height or trochanter height (this measure of leg length also has potential imprecisions like measures of iliac height) as a measure (Ito, 1942; Kim et al., 2008). The SD for leg length, for participants aged 65 years or over, reported in Kim et al., (2008) is 7.4 cm. The average SD of height of trochanter for Japanese women in Ito (1942) studies was reported as 3.7 cm. The SD for iliac height measure for my participants ranged from 3.7 to 5.7 cm (see Chapter 4, page 50), which lies within the SD of the two studies reported. I further assessed the correlation between height, leg length and lower leg length for father, mother, sons and daughters. Results from this analysis found a strong correlation between leg length and other measures (height and lower leg length) suggesting leg length was accurately measured. Hence, leg length will be included in the descriptive analysis and in evaluating evidence of the impacts of physiological stress on growth using enamel defects.

To measure the lower leg length, knee height was measured with the Harpenden anthropometer to the nearest millimetre. Each participant was asked to sit on a table or chair with the lower legs perpendicular to the thighs, the sliding blade of the Harpenden anthropometer was placed at the top of the knee cap (see figure 3.3.4.1). A bubble level (added to equipment) was used to maintain the correct position of the anthropometer. Left leg was measured for both lower leg and total leg length. The height, leg length and lower leg length were almost all measured for parent and offspring at the same meeting, within 30 minutes.

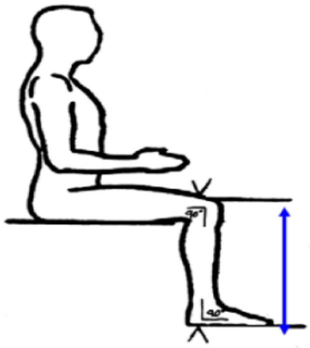

FIGURE 3.3.4.1: Lower leg length measurement (adapted from Bogin and Varela-Silva, 2010).

As discussed earlier because individuals recall of the presence and severity of illness during infancy and childhood is incomplete, I also gathered another measure that may be somewhat more directly related to physiological stress influencing skeletal growth, linear enamel hypoplasia (LEH).

After gathering other data from participants, anterior dental impressions were obtained from 86 participants. There were 11 parents with dentures, 7 fathers and 4 mothers. First I explained to the participants the useful information that can be obtained about their childhood health by examining their front teeth. Participants were then told about the whole procedure of making the dental impression and why it is the best approach. Dental impressions that always included at least the incisors and canines were obtained for both the maxilla and mandible. Dental putty (Take 1 Advanced Putty (base and catalyst)) impression material was used to create impressions of participant's teeth. The base and catalyst were mixed properly and placed on the dental tray. The participant was then asked to place the tray, with the putty, in their mouth. A timer was set once the participant had bitten down on the material. Participant was asked to leave the tray in their mouth for 1 minute and 30 seconds. Once the tray was removed from the mouth it was labelled with the participant's ID and placed in a re-sealable bag with ID written on the bag as well.

For the one participant who did not agree to having dental impressions made, they were asked if their front teeth can be inspected using a small flash light for evidence of LEH. The participant agreed to this alternative method. For this individual whose teeth were inspected using a flashlight, all information was recorded on a separate diagram showing each anterior tooth that had their ID number added.

These impressions were then used to make casts that were further analysed for LEH at the Auckland University lab. To be able to make these casts the impression trays obtained from participants were sealed using play-dough to avoid leakage of the casting material. The cast were made using Resin with Hardener. After mixing the Resin and Hardener a drop of white acrylic paint was added to the mixture. White paint was added to obtain a cast with a surface that was more easily assessed. These casts were made in sets of two families per session, so there were a total six pairs of casts at any one time. Once the mixture was poured into the impression trays, they were left for two days to set completely. After two days these casts were removed from the tray and placed in a new re-sealable bag and labelled with the individual ID.

All casts are further inspected using a magnifying glass and a device with a flexible neck that provides a narrow bright light source that can be focused obliquely on the surface of the cast. All information from one maxillary or mandibular cast was recorded on a separate diagram, identified with ID number, showing the position of defects on each anterior tooth. The method used for recording the position of enamel defects (Hillson, 1996) is shown in Figure: 3.3.4.2, a representation of the diagram used for recording LEH. Each unit in the diagram represents the approximate age at which the portion of the tooth was formed.

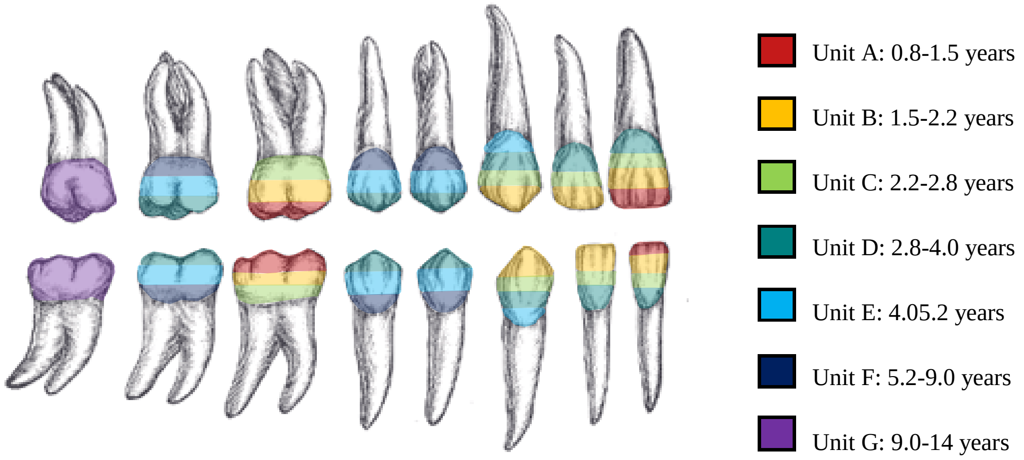

FIGURE 3.3.4.2: Diagram of enamel units used for recording the position of an enamel defect (Littleton, 2005 as modified from Hillson, 1996).

Two weeks after all casts were first assessed, a random sample of 40 individual casts were selected and analysed again for enamel defects. The information obtained from these was recorded in a similar way as explained before. An intra-observer error study is reported on in the appendix section below.

3.4: Analysis of the extent of stress and development outcomes

To analyse the relationship between timing and extent of stress and development outcomes, I first conducted within generation comparisons and then between generation comparisons, using regression models described as follows. An alpha level of 0.10 is used here to identify potentially significant outcomes. This approach is in response to practical limitations associated with time available to recruit families. The outcome variables are height or lower leg length for participants within each generation, or differences in these measurements between same sex parent-offspring pairs when intergenerational differences are considered. The predictor variables are the scores for the four principle components, or the difference between the ranked scores for each of these components.

I then generated the descriptive statistics for height, leg length and lower leg length for important qualitative variables in each generation. Subsequent to this, for each qualitative predictor variable a preliminary graphical representation with each anthropometric measure was plotted in R. I used ANOVA in further preliminary analyses to compare means of anthropometric variables across groups. Post-hoc tests were used to judge whether there were statistically significant differences in the means in the outcome variables between each group.

3.5: Analysis of the timing of stress and development outcome

Further, interaction between early and later repeated stress events influence on height and lower leg length variation was determined using evidence of enamel defects. Using regression models the interaction between early and later repeated stress events are measured using presence and absence of defect in the first two years of life combined with total number of defects at later stages. The predictor variables in this model are presence and absence of defect in the early unit, total number of defects on the later units and the interaction between the two. The outcome variables are height, leg length or lower leg length.

3.6: Intergenerational analysis

I also considered assessing the relationship between the timing of enamel defects between parent-offspring and growth outcomes. To determine if the combination of parent-offspring early stress events influenced anthropometric measures, I divided up the data into four categories for both mother-offspring and father-offspring. These categories are as follow: presence of LEH in both parent and offspring for early units, present in the parent and absent in offspring, absent in parent but present in offspring and the last category, absent in both parent and offspring. However, very small sub-sample sizes prevented effective interpretations so these results are not reported below.

Chapter 4: Results

This chapter has two primary goals. The first is to describe the members of participating families with respect to their backgrounds, their anthropometric variation, and the number of linear enamel hypoplastic defects identified from examination of anterior dental impressions. The second is to examine results of tests of a series of hypotheses related to growth outcomes. Those related to individuals within generations will be presented first, followed by comparisons of intergenerational differences within families. The hypotheses I test evaluate expectations that the individuals experiencing less stressful environments, particularly early on, will show greater gains in leg length relative to gains in height. This is expected for individuals in both generations, but particularly offspring who grew up in New Zealand.

4.1: A Description of Participating Families

This section provides descriptive statistics of the participating families that include the number of families, the numbers of participating fathers, mothers, daughters and sons. I will then describe information about their backgrounds, and mean ages when participants migrated.

The composition of the 34 participating families is reported below in Table 4.1.1. All but four families had a father, mother and one adult offspring. Of those four, three were missing a father and one was missing a mother. The one family missing a mother consisted of a father and son.

TABLE 4.1.1. Variation in family composition among the 34 participating families[a].

Composition	N
Father, Mother, and Son	19
Father, Mother, and Daughter	11
Father and Son	1
Mother and Son	1
Mother and Daughter	2

[a] Four of the families were missing either a mother (1) or father (3).

Parental background:

Table 4.1.2 indicates that virtually all parents, and about two thirds of the offspring were born and raised in the Punjab. The remaining offspring were born in New Zealand, with the exception of one who was born in Australia but moved to New Zealand before one year of age. Within these families, mothers tended to be about five years younger than their husbands when they migrated to New Zealand. Offspring who migrated were similar in age, mostly in their teens. Only a very few individuals in either generation migrated to New Zealand before they were three years of age.

TABLE 4.1.2. Where family members were born and where and when they moved by generation and gender

Question	Parental Generation				Offspring Generation			
	31 Father		33 Mother		21 Sons		13 Daughters	
Where were participants born?								
Punjab, India	31	100%	32	97%	14	67%	9	69%
Other locations in India	0	0%	1	3%	0	0%	0	0%
New Zealand or Australia	0	0%	0	0%	7	33%	4	31%
How many participants moved before 3 years, and where?								
To Delhi	2	6%	3	9%	0	0%	0	0%
To Punjab	0	0%	1	3%	0	0%	0	0%
To New Zealand[a]	0	0%	1	3%	1	5%	1	8%
Participants who moved from India to NZ after 3 years of age	31	100%	32	97%	13	62%	8	62%
Age when participants moved to New Zealand?								
Mean age (years) ± (SD)	40.9	(15.8)	35.7	(12.8)	15.1	(8.0)	15.0	(8.3)
Age range in years	17 to 73		0.67 to 60		0.17 to 28		2 to 26	

[a] One mother moved from the Punjab to New Zealand when eight months old and one son moved from Australia to New Zealand when two months old.

Parents' occupations may be an important proxy for judging the early circumstances of individual participants in each generation when they were very young. Table 4.1.3 shows a detailed breakdown of occupations by generation and where offspring grew up. It shows that in the parental generation, distributions of their own parents' occupations were similar for fathers and mothers when they were young. More than half of the grandfathers occupied high income jobs and grandmothers cared for homes. For the offspring generation that were born in India the distribution varies amongst fathers of sons and fathers of daughters, but mothers' occupations across sons and daughters are similar. A higher number of fathers of sons (79%) occupied well paid jobs (government job or cab drivers, owned farm or IT professional and business owner) in comparison to fathers of daughters (56%). For offspring that were born in New Zealand, distributions of parents' occupation for sons and daughters are similar when they were young. A higher proportion of grandparents, both maternal and paternal, had relatively higher paying jobs in comparison to parents. It is also evident in the results that a higher percentage of grandmothers and mothers in India cared for home in comparison to mothers in New Zealand.

TABLE 4.1.3. Occupations of parental caregivers when participants in each generation were young. Offspring are divided into those who were born and grew up in India and those who were born in New Zealand or who moved here by the age of 2 years.

	Parental Generation				Offspring (in India)				Offspring (in New Zealand)			
Occupation of parents when participant was young	31 Father		33 Mother		14 Sons		9 Daughters		7 Sons		4 Daughters	
Grandfather or father												
Government job or cab drivers[a]	5	16%	9	27%	6	43%	2	22%	5	71%	3	75%
Owned farm or IT professional[a]	15	49%	12	36%	1	7%	1	12%	2	29%	0	0%
Business owner	6	19%	7	21%	4	29%	2	22%	0	0%	0	0%
Sales job	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Labourer	5	16%	4	12%	2	14%	2	22%	0	0%	1	25%
Unemployed	0	0%	1	4%	1	7%	2	22%	0	0%	0	0%
Total	31	100%	33	100%	14	100%	9	100%	7	100%	4	100%
Grandmother or mother												
Government job	2	6%	2	6%	3	21%	2	22%	0	0%	0	0%
Own farm	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Business owner	0	0%	0	0%	0	0%	0	0%	1	13%	0	0%
Sales job/Skilled worker	0	0%	0	0%	0	0%	0	0%	2	29%	4	100%
Labourer	2	7%	2	6%	1	8%	2	22%	2	29%	0	0%
Cared for home	27	87%	29	88%	10	71%	5	56%	2	29%	0	0%
Total	31	100%	33	100%	14	100%	9	100%	7	100%	4	100%

[a] IT profession and cab drivers are occupations only related to fathers of offspring that are born in New Zealand or who moved here by the age of 2 years.

Parents' educations not only serve as proxies for socioeconomic status but have also been argued by several authors (Anker and Knowles, 1980; Ware, 1984; Wachs et al., 2005) to be particularly relevant as a proxy of care provided to offspring, especially mother's education level. Table 4.1.4 shows a detailed breakdown of education by generation and where offspring grew up. The distribution of paternal grandparents with tertiary education is similar for both grandmother and grandfather. Whereas, the difference between the maternal grandfathers and grandmothers with secondary education is considerable. Grandparents with no schooling are distributed similarly across paternal and maternal grandparents. For the offspring that were born in India, all fathers of sons were schooled and almost all had tertiary education. A similar distribution was present for the sons that were born in New Zealand. Mothers of sons born in India and New Zealand also have a very similar distribution with about half of the mothers in both setting with a tertiary education. Fathers' education attainment of daughters born in India is variable across the four categories, with a higher number of fathers with a tertiary education. All mothers for daughters born in India have attained some level of education. A large number of mothers have primary education. This is evident in both locations of daughters' births.

TABLE 4.1.4. Information about educational attainment for parental caregivers when participants in each generation were young. Offspring are divided into those who were born and grew up in India and those who were born in New Zealand or who moved here by the age of 2 years.

Education of parents when participant was young	Parental Generation				Offspring (in India)				Offspring (in New Zealand)			
	31 Father		33 Mother		14 Sons		9 Daughters		7 Sons		4 Daughters	
Grandfather and father												
Tertiary	9	29%	7	21%	12	86%	5	56%	6	86%	1	25%
Secondary	4	13%	14	42%	1	7%	1	11%	0	0%	0	0%
Primary	9	29%	1	3%	1	7%	2	22%	1	14%	3	75%
No schooling	9	29%	11	33%	0	0%	1	11%	0	0%	0	0%
Total	31	100%	33	100%	14	100%	9	100%	7	100%	4	100%
Grandmother or mother												
Tertiary	6	19%	4	12%	7	50%	3	33%	3	43%	1	25%
Secondary	9	29%	9	27%	1	7%	2	22%	0	0%	1	25%
Primary	3	10%	6	18%	6	43%	4	44%	4	57%	2	50%
No schooling	13	42%	14	42%	0	0%	0	0%	0	0%	0	0%
Total	31	100%	33	100%	14	100%	9	100%	7	100%	4	100%

This next section of the chapter will further describe the participant backgrounds using several variables representing sanitation as described in Chapter 3 (see Table 4.1.5). The variables used are household crowding, nature and access to drinking water and nature and access to toilet facilities.

In the parental generation there are fewer mothers living in crowded houses when they were young in contrast to fathers. Whereas in the offspring generation born in both locations, more daughters were living in crowded houses than sons when they were young.

The distribution of the drinking water facilities is similar when compared within generation. Many of the fathers and mothers obtained drinking water from a well. Very few families in the parental generation had piped filtered water. Around 86% of sons and 78% daughters born in India had filtered and piped drinking water. The remaining 14% sons and 22% daughters in India reported using wells as a source of drinking water.

TABLE 4.1.5. Measures of sanitation within households when participants in each generation were young. Offspring are divided into those who were born and grew up in India and those who were born in New Zealand or who moved here by the age of 2 years.

	Parental Generation				Offspring (in India)				Offspring (in NZ)			
	31 Father		33 Mother		14 Sons		9 Daughters		7 Sons		4 Daughters	
Household crowding[a]	13	42%	10	30%	1	7%	3	33%	1	14%	2	50%
Drinking Water												
Unfiltered, from Well	22	71%	21	64%	2	14%	2	22%	0	0%	0	0%
Public taps/Hand pumps	8	26%	8	24%	0	0%	0	0%	0	0%	0	0%
Piped into dwelling and/or filtered	1	3%	4	12%	12	86%	7	78%	7	100%	4	100%
Total	31	100%	33	100%	14	100%	9	100%	7	100%	4	100%
Toilet Facilities												
Flush toilet	1	3%	1	3%	8	57%	5	56%	7	100%	4	100%
Inside house, plumbed to local septic tank	6	19%	14	42%	1	7%	1	11%	0	0%	0	0%
Outside house	5	16%	2	6%	1	7%	3	33%	0	0%	0	0%
No toilet facilities	19	61%	16	48%	4	29%	0	0%	0	0%	0	0%
Total[b]	31	99%	33	99%	14	100%	9	100%	7	100%	4	100%

[a] Household crowding is described as more than 2 people sharing a room.
[b] Totals within rounding error.

In the parental generation only one father and one mother clearly identified having flush toilets piped to a sewer system when they were young. About 61% of fathers had no toilet facilities available when they were young, in contrast about 48% of mothers had no toilets. These parents, when young, went out in the fields.

Most offspring experienced better sanitation and hygiene in comparison to their parents when young. Even the toilet facilities were better for the offspring generation who grew up in the Punjab. Nineteen out of 23 offspring that were born in Punjab had toilets in the house. Four sons, however, that were born in India reported no toilets facilities were available. The rest of the sons and daughters had toilets facilities, though not all from India had flush toilets.

The presence and nature of social support after migration is important to this research because it relates to the implications for the kinds of environment that infants and young children grew up in here in New Zealand. The presence and nature of social support available when families migrated was divided into three categories; 1) no friends or relatives involved; 2) friends and/or extended family involved; and 3) immediately family who had already settled were involved. Social support varied amongst families. This is because not all family members of a given family migrated together from India. There were seven families where the offspring, as young adults, arrived before their parents. There were 11 families that migrated with their offspring but offspring age ranged from 17 to 28 year old. These 11 families' migration experience is less important as their offspring were adolescents or adults when they arrived, and their growth and development will be less impacted by the changing environment. The remaining 23 families either arrived here before their children were born, very soon after children were born, or their children age ranged anywhere up to 15 years old. The social support available to these families is important in this research. There were eight families where fathers arrived in New Zealand long before the mother and child arrived. Clearly, the eight families that had fathers present in New Zealand had better social support than the other families. In these families fathers arrived somewhere between seven years to 11 years before the arrival of the other parent and offspring. Of the remaining 15 families who arrived with their offspring or the offspring was born straight after migrating, 10 had support of immediate or extended family member. Only five families had no support available post-migration. Overall, most families who migrated when their offspring were infants or young children appear to have had good social support. Good social support post-migration implies that even though migration can be a stressful event for families and individuals, infants and children in these families were likely exposed to relatively good developmental environments.

4.2: Anthropometric Description of Families

Table 4.2.1 reports descriptive statistics for age, anthropometric measurements and indices of fathers, mothers, sons and daughters separately for families with sons or daughters. Parents of sons, both fathers and mothers, tend to be taller than parents of daughters on average. Fathers with sons are about 2.5 cm taller in height than fathers with daughters. Mothers with sons are also taller on average than mothers with daughter (Δ = 2.9 cm). An exception is that mothers of daughters have modestly longer lower legs, on average, than mothers of sons (Δ = 0.3 cm). Fathers with sons have relatively longer legs and longer lower legs, on average, than fathers with daughters, though differences are small. Mothers with daughter have relatively (though not absolutely) longer legs and longer lower legs, on average, as compared to mothers with sons. Finally as measured by SD, fathers of sons are more variable than fathers of daughters for height, leg length and lower leg length. Variability of measurements for the two groups of mothers is less consistent.

TABLE 4.2.1. Means, medians and standard deviation of anthropometric variables[a] for 21 families with son and 13 with daughters

	Families with a son[b]			Families with a daughter[c]		
Variable	20 Fathers	20 Mothers	21 Sons	11 Father	13 Mothers	13 Daughters
Age (year)						
Mean	54.6	48.6	23.5	55.5	51.9	24.8
Median	54.0	49.0	21.0	54.0	50.0	28.0
SD	9.5	7.6	5.4	7.9	6.1	6.0
Height (cm)						
Mean	171.6	160.5	175.5	169.1	157.6	159.3
Median	170.9	159.7	175.8	169.6	157.4	159.0
SD	7.9	6.2	6.6	5.7	8.2	5.7
Leg length (cm)						
Mean	99.6	91.9	100.6	97.4	90.1	89.6
Median	99.4	92.3	99.6	98.2	90.8	88.0
SD	4.6	5.3	4.4	3.7	5.7	5.7
Lower leg length (cm)						
Mean	54.4	49.6	55.6	53.0	49.9	49.8
Median	53.7	50.1	55.5	53.1	49.6	50.2
SD	3.3	3.7	2.6	1.8	3.3	2.6
Relative leg length (%)						
Mean	58.0	57.2	57.3	57.6	57.3	56.2
Median	57.9	57.5	57.8	57.8	57.7	55.9
SD	1.2	2.0	2.3	1.7	2.0	2.2
Relative lower leg length (%)						
Mean	31.7	30.9	31.7	31.4	31.7	31.2
Median	31.2	31.2	31.7	31.4	31.9	31.5
SD	0.9	2.0	0.7	0.9	1.0	1.0

[a] Variable descriptions are provided on pages 39 - 41 of Chapter 3.
[b] One son is in a family without a father and one is in a family without a mother
[c] Two daughters are in families who do not have a father

4.3: Descriptive Analysis –Linear Enamel Hypoplasia

This section presents the descriptive analysis of linear enamel hypoplasia in the parental and offspring generation.

Table 4.3.1 presents the proportion of individuals, in both parent generation and offspring generation, with presence and absence of enamel defects. For parents, fathers have a lower prevalence of linear enamel defects than mothers, 63% and 86% respectively. In the offspring generation the prevalence of LEH is less than the parental generation, with 41% having identifiable enamel defects. The gendered trend seen in the parental generation, though, is reversed among the offspring. A higher frequency of sons (52%) have defects as compared to daughters (23%). A higher proportion of offspring with enamel defects were raised in India. Eight out of 11 sons and two out of three daughters who had defects were born and raised in India

TABLE 4.3.1: Distribution of presence and absence of LEH amongst parent[a] and offspring by gender

LEH Present	Fathers (n = 24)		Mothers (n = 29)		Sons (n = 21)		Daughters (n = 13)	
Yes	15	63%	25	86%	11	52%	3	23%
No	9	38%	4	14%	10	48%	10	77%

[a] The numbers of parents are reduced here because some did not have teeth available

The distribution of number of defects per father, mother, son and daughter in the three enamel units are presented in Table 4.3.2. The enamel units are divided into three time periods: early stress events (0.8 - 2.2 years), stress events during 2.2 years to 4 years and late stress events (4 - 9 years). A large number of defects are present in the first four years of development for both mothers and fathers. Results suggests that mothers and fathers must have experienced a greater number of stressful events during the early stages, particularly in mothers. A Chi-square test of mothers and fathers patterns suggested there is no statistically significant difference across the three enamel units (chi-square = 0.11, df = 2, p = 0.95). Sons with defects had multiple events of stress during the 2.2 to four years old period, but less often very early. Three daughters had evidence of defects and a total of seven defects were present. The distribution of defects in daughters with LEH were found more often in first two years as compared to sons.

TABLE 4.3.2: Numbers of defects per father, mother, son or daughter as distributed in the three developmental units[a]

Enamel Unit	Fathers (n = 15)	Mothers (n = 25)	Sons (n = 11)	Daughters (n = 3)
0.8-2.2 years	19	33	9	3
2.2-4 years	20	31	18	2
4-9 years	8	12	5	2
Total defects	47	76	32	7

[a] The numbers of parents are reduced here because some did not have teeth available

Table 4.3.3 presents a breakdown of number of mothers, fathers and offspring who had evidence of defects by each enamel unit. The distribution of fathers with defects follow a similar pattern as the mothers, a large proportion of those with defects have them in the first two units. A greater number of mothers with defects, had those defects present on the first two units, 62% and 59% respectively.

The higher frequency of parents who have stress events in the first as well as second period is somewhat different among sons. Fewer sons have defects in the earliest period, with most showing defects in the second period, from 2.2 to 4 years of age. There were only three daughters with defects present and these are fairly evenly distributed across units.

TABLE 4.3.3. The number and percentage of mothers, fathers or offspring with LEH defects occurring in a given enamel unit (where available)[a].

Enamel Unit	Fathers (n = 15)		Mothers (n = 25)		Sons (n = 11)		Daughters (n = 3)	
0.8-2.2 years	11	44%	18	62%	5	45%	2	67%
2.2-4 years	9	36%	17	59%	10	91%	2	67%
4-9 years	5	20%	9	31%	4	36%	1	33%

[a] The numbers of parents are reduced here because some did not have teeth available

4.4: Interpretation of anthropometric measures in relation to early developmental conditions within each generation

One of the hypothesis being tested in this study is the expected negative impacts of stressful events during early developmental periods on growth of individuals. The extent of stressful events are first assessed using the early developmental circumstances of individuals from interview data. The variables used to determine the early developmental circumstances represent composites of variables using principle component analysis (PCA). The procedure of PCA is explained in Chapter 3, page 39.

The loadings of the PCA for fathers and mothers are presented in Table 4.4.1.1. Those for offspring are shown in Table 4.4.1.2. The name of a given component is based on the variable that is most highly loaded on the component. There are in many instances, however, a few other variables that are also highly or moderately highly loaded on components (see footnotes).

I evaluated anthropometric variation for fathers, mothers and offspring using PCA scores for the four components initially. These were also used to create variables that estimated the difference in early circumstances between parents and offspring. The PCA scores were ranked for mother, father and offspring separately in Excel. Ranks of scores from the component with the highest eigenvalue for offspring, were then subtracted from the corresponding rank of the component with the highest eigenvalue for fathers, or mothers. The same was then done for ranks of the next highest loading component in the two generations and so forth.

TABLE 4.4.1.1: Principle component analysis: loadings on composite variables for parents

	PCA Components & Loadings			
	Father			
Variable Measured	**Water quality**[a]	**Urban/Rural**	**Electricity**[b]	**Household crowding**[c]
Access to car	0.41	-0.08	0.04	0.43
Birth rank	0.33	0.16	-0.09	0.01
Cooking fuel used	0.50	0.44	0.09	0.49
Electricity	0.16	0.23	**0.81**	0.20
Highest Degree(Father)	0.25	0.50	0.17	0.36
Highest Degree(Mother)	0.20	0.51	0.20	0.33
Household crowding	0.01	-0.13	0.26	**0.62**
Location and nature of toilet	0.17	0.56	0.26	0.51
Medical treatment received	-0.06	0.15	**0.81**	0.21
Mothers Occupation	0.24	0.13	0.09	-0.01
Own or Rented house	-0.39	-0.05	-0.21	**0.59**
Quality of drinking water	**0.91**	0.08	0.13	0.04
Source of water	**0.88**	-0.05	0.14	0.09
Type of dwelling	0.07	0.22	0.67	0.02
Urban/Rural area	0.47	**0.73**	0.16	0.25
	Mother			
Variable Measured	**Urban/Rural**[d]	**Water source**[e]	**Electricity**[f]	**Medical treatment**
Access to car	**0.81**	0.01	0.29	-0.10
Birth rank	-0.03	0.13	-0.06	0.13
Cooking fuel used	**0.70**	0.30	0.24	0.17
Electricity	0.11	0.37	**0.75**	0.19
Highest Degree(Father)	0.13	0.12	0.58	0.21
Highest Degree(Mother)	0.34	0.25	0.49	0.28
Household crowding	0.03	0.03	0.05	0.06
Location and nature of toilet	0.58	0.33	0.16	0.40
Medical treatment received	-0.07	0.03	0.11	**0.89**
Mothers Occupation	0.05	0.11	0.28	-0.12
Own or rented house	-0.08	-0.05	-0.01	0.01
Quality of drinking water	0.30	**0.88**	0.09	0.10
Source of water	0.08	**0.93**	0.11	0.11
Type of dwelling	0.43	0.14	**0.72**	-0.02
Urban/Rural area	**0.87**	0.18	0.01	0.08

[a] Highly loaded on both quality and source of water

[b] Equally highly loaded on availability of electricity and medical treatment received

[c] Most highly loaded on household crowding, but moderately loaded on own or rented house

[d] Most highly loaded on urban/rural, but also highly loaded on access to car and cooking fuel used

[e] Highly loaded on quality and source of water

[f] Most highly loaded on availability of electricity as well as type of dwelling

TABLE 4.4.1.2: Principle component analysis: loadings on composite variables for offspring

	PCA Components & Loadings			
Variable Measured	**Birthplace**[a]	**Offspring Water quality**[b]	**Birth rank**	**Father's education**
Access to car	0.49	0.37	-0.32	0.32
Birth rank	-0.12	-0.10	**0.83**	-0.03
Birthplace	**0.92**	0.19	-0.04	0.06
Cooking fuel used	0.66	0.06	0.04	0.31
Fathers occupation	0.22	-0.02	0.17	0.19
Highest Degree(Father)	-0.10	0.20	0.06	**0.69**
Highest Degree(Mother)	-0.13	0.19	-0.56	0.35
Location and nature of toilet	0.42	0.11	-0.01	0.03
Mothers Occupation	0.39	0.03	-0.03	0.08
Own or rented house	**0.80**	0.20	0.06	-0.18
Quality of drinking water	0.15	**0.84**	-0.04	-0.07
Social support post-migration	0.58	-0.13	0.49	-0.12
Source of water	0.20	**0.83**	-0.17	0.14
Type of dwelling	0.17	0.26	-0.23	0.30
Urban/Rural area	-0.02	0.23	-0.12	-0.05

[a] Most highly loaded on birthplace as well as own or rented house

[b] Highly loaded on quality and source of water

Results of the regression analyses evaluating the relationships between the anthropometric variation and the four principle components representing differences in early developmental environments for the parental generation (see Chapter 3 for details) were considered first. For fathers, the four components used as predictor variables are water quality, urban/rural, electricity (equally loaded on medical treatment received) and household crowding. Water quality is weakly significantly positively associated ($p = 0.0708$) with height. Urban/Rural is also significantly negatively associated with height ($p = 0.0838$). The regression model with all four components as predictors explains 15.8% of the variance in height (AIC = 121.84).

Results of the analysis on fathers' lower leg length variation found no statistically significant results. Less of the variance in lower leg length is accounted for (15.8% vs. 8.9%) when results from the same model using all four components are compared.

For mothers, the four components used as predictor variables are urban/rural, water source, electricity and the type of medical treatment received. While there is only a weak statistically significant association with the presence of electricity, as the quality of housing materials improve and as parents' education increase (type of dwelling and parents education are also highly loaded on component 3), heights tend to increase. The regression model with all four components as predictors explains only 6% of the variance in height (AIC = 83.67).

Results of the same analysis on mothers' lower leg length variation indicate that water source is significantly negatively associated with lower leg length (P = 0.089). However, even less of the variance in lower leg lengths is accounted for (3.8%) when results from the same model using all four components are compared.

Further a stepwise AIC method for variable selection was used on the regression models just described. The results from the stepwise AIC are presented in Table 4.4.2.

TABLE 4.4.2: Results of regression analyses of reduced models examining the influence of early circumstances of parents and changes on height or lower leg length.

Criterion variable	Predictor (Component Scores)	Slope est.	SE	P	Adjusted R^2 (sub-model)	AIC (sub-model)
Fathers						
Height	C1: Water quality	-2.281	1.209	0.070	0.161	120.9
	C2: Urban/Rural	-2.177	1.209	0.083		
	C4: Household crowding	1.695	1.209	0.172		
Mothers						
Height	C3: Electricity	2.132	1.215	0.089	0.101	130.07
	C4: Medical treatment	-1.929	1.215	0.123		
Lower leg length	C2: Water source	-1.033	0.570	0.078	0.100	79.73
	C4: Medical treatment	-0.849	0.570	0.144		

The variables, taken together, that explain the most variation in height for fathers are water quality, urban/rural and household crowding. Water quality and urban residence are significantly negatively associated with height (p = 0.0699 and p = 0.0828, respectively), but household crowding is not statistically significant (p = 0.1722). This reduced model for fathers explains 16.14% of the variation in height. The model with water quality and urban/rural as predictors only explain 13.2% of the variance in height.

The reduced regression model for mothers suggest electricity and medical treatment as predictors explain the most variation in height (Adjusted R^2 = 0.101). Electricity is significantly positively associated with height (p = 0.0895). A reduced model that includes water source and medical treatment accounts for a similar percentage of the variation in lower leg length for mothers (Adjusted $R^2 = 0.100$).

Statistical tests within the offspring generation

The same approach is used to report results for regression analyses evaluating relationships between the anthropometric measures and various components representing differences in early developmental environments for offspring. The four components used as predictor variables load most highly on birthplace, water quality, birth rank and father's education. Results of the full model suggest that heights of sons are significantly positively associated with water quality ($p = 0.019$). The regression model with all four components as predictor accounts for 16.2% of the variance in height (AIC = 79.6).

Relationships between lower leg length and the same predictors of early developmental conditions are similar, but stronger. The regression model suggests variation in water quality is significantly positively associated with lower leg length ($p = 0.004$), and more variance is accounted for by the full model (25.6%).

Birthplace and water quality may be weakly positively associated with daughters' heights ($p = 0.067$ and $p = 0.081$ respectively). The regression models with all four components explain 30.7% of the variance in height (AIC = 44.34). There was no relationship suggested between variation in lower leg length and early circumstances for daughters.

As above, a stepwise AIC method was used for variable selection. The results from the stepwise AIC are presented in Table 4.4.3.

TABLE 4.4.3: Results of regression analyses of reduced models examining the influence of early circumstances of offspring and changes on height or lower leg length.

Criterion variable	Predictor (Component Scores)	Slope est.	SE	P	Adjusted R^2 (sub-model)	AIC (sub-model)
Son						
Height	C2: Water quality	3.757	1.286	0.009	0.274	74.17
Lower leg length	C2: Water quality	1.643	0.496	0.004	0.330	34.17
Daughter						
Height	C1: Birthplace	2.991	1.428	0.066	0.332	43.38
	C2: Water quality	2.737	1.452	0.092		
	C3: Birth rank	-2.273	1.492	0.162		

The variable that explains the most variation in height and lower leg length for sons is water quality. Water quality is significantly positively associated with height and lower leg length ($p = 0.009$ and $p = 0.004$, respectively). The reduced model with water quality as a predictor explains 27.4% of the variance in son's height and explains 33% of variance in lower leg length.

The reduced regression model for daughters suggest birthplace, water quality and birth rank as predictors explain the most variation in height (Adjusted $R^2 = 0.332$). Birthplace and water quality are both significantly positively associated with height ($p = 0.066$ and $p = 0.092$, respectively). There is no significant relationship between birth rank and height. The reduced model explains more variation in height compared to the full model (25.6% vs 33.2%).

The variables that were highly loaded on various components that appeared to influence growth outcomes were further analysed separately in relation to height and lower leg length. These variables included household crowding, drinking water facilities and toilet facilities, and birthplace for offspring. I evaluated the mean height and lower leg length across the categories for each variable. I first assessed the mean height and lower leg length for fathers, mothers, sons and daughters across household crowding. From the boxplots (Figures 4.4.1 and 4.4.2) it appears that heights and lower leg lengths tend to be greater when there is no household crowding among fathers and mothers. For sons and daughters, height and lower leg length tends to be shorter when there is no household crowding. A t-test suggested there is a significant difference in the mean height for fathers ($t = 2.15$, $df = 29$, $p = 0.04$). Across the two measures for mothers, only lower leg length ($t = 1.97$, $df = 31$, $p = 0.06$) for the two categories is statistically significant. There was no significant difference between the mean height and lower leg length across the two categories of household crowding for sons and daughters, but the pattern shown is opposite to that anticipated.

I further assessed the relationship between drinking water facilities and anthropometric measures among participant groups. From the boxplot (Figure 4.4.3) it can be seen that fathers whose families used hand pumps are somewhat taller and have longer lower legs than those who gathered water from wells. The difference in height across the two categories is statistically significant ($t = 2.2$, $df = 28$, $p = 0.03$). Mothers, however, show a different pattern. Mothers whose families obtained drinking water from wells are taller in height, when compared to mothers whose families used hand pumps or had piped drinking water. The lower leg length for mothers is similar for well water and piped water sources. Statistical tests showed no significant difference in means across the three categories for mothers and fathers.

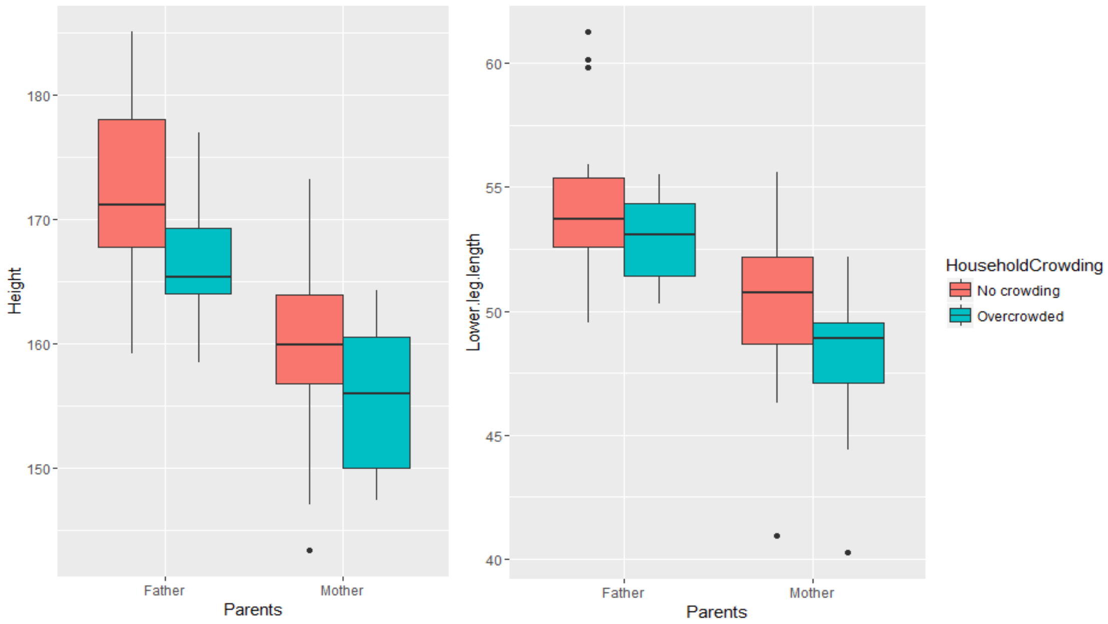

FIGURE 4.4.1: Boxplot of height and lower leg length of father and mother across two categories of household crowding (Father, No crowding, 13; Fathers, Crowding, 18; Mothers, No crowding, 10; Mothers, Crowding, 23)

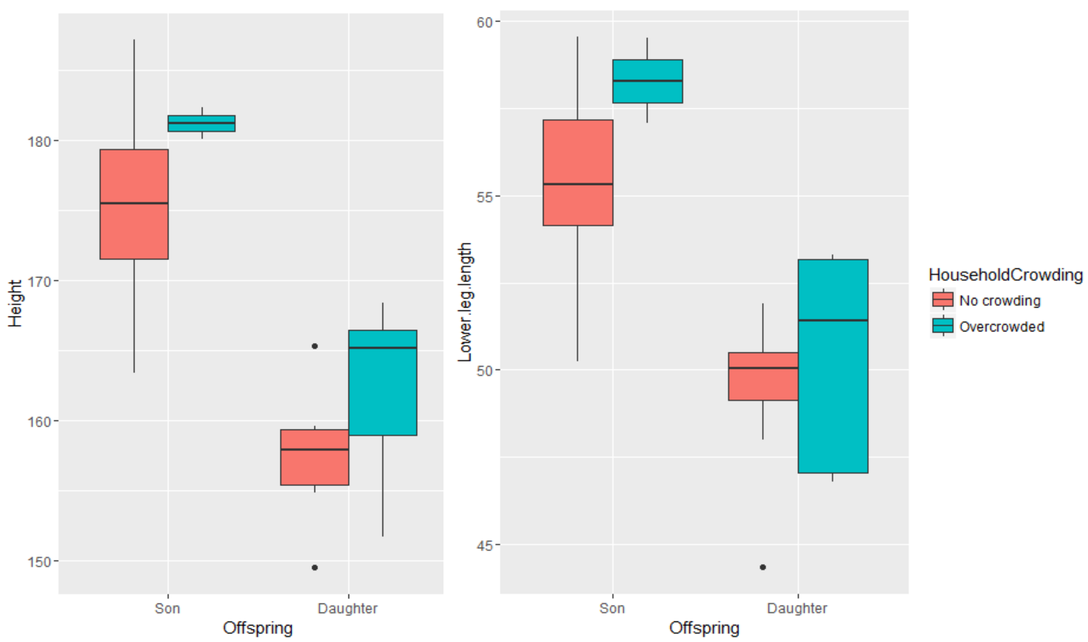

FIGURE 4.4.2: Box plot of height and lower leg length of sons and daughters across two categories of household crowding. (Son, No crowding, 19; Son, Crowding, 2; Daughter, No crowding, 8; Daughter, Crowding, 5)

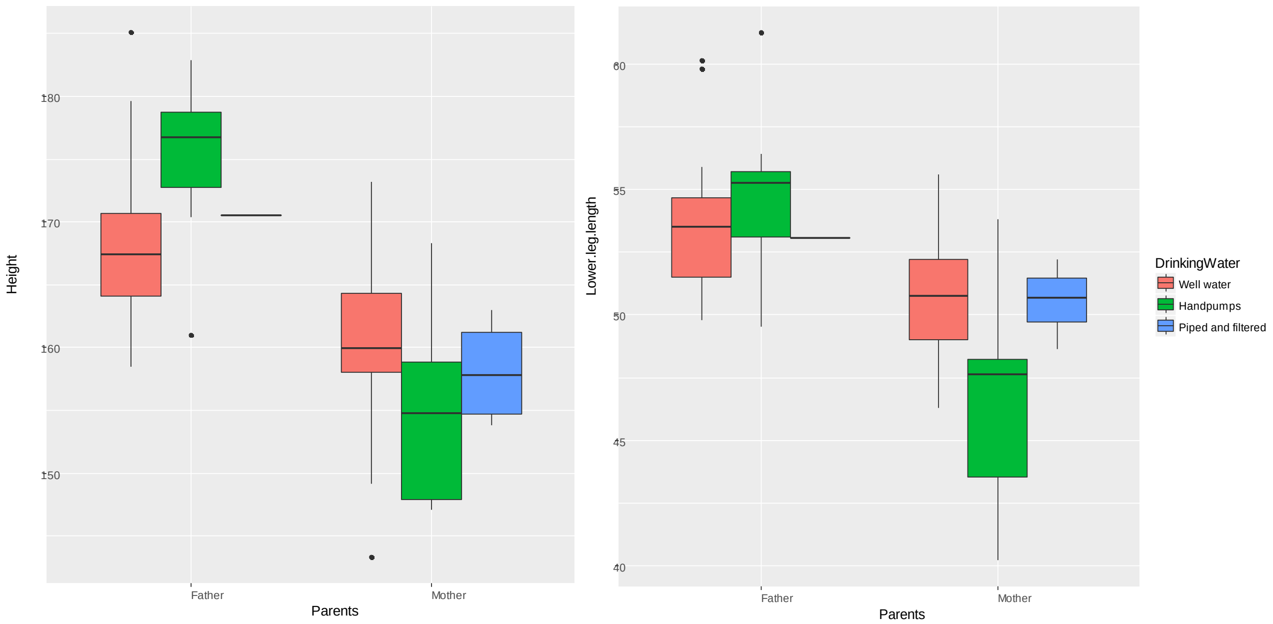

FIGURE 4.4.3: Box plot of height and lower leg length of father and mother across three categories of drinking water quality.

Fig. 4.4.4 suggest that sons and daughters who had piped drinking water are taller and have longer lower legs compared to those who drank water from wells. Statistical tests, however, showed no significant difference between the 13 daughters' mean height and lower leg length across the drinking water categories. There was a significant difference in the mean lower leg length ($t = -1.77$, $df = 19$, $p = 0.092$) of 21 sons who drank water from well ($\bar{x} = 52.57$ cm) and those who had filtered installed ($\bar{x} = 55.86$ cm).

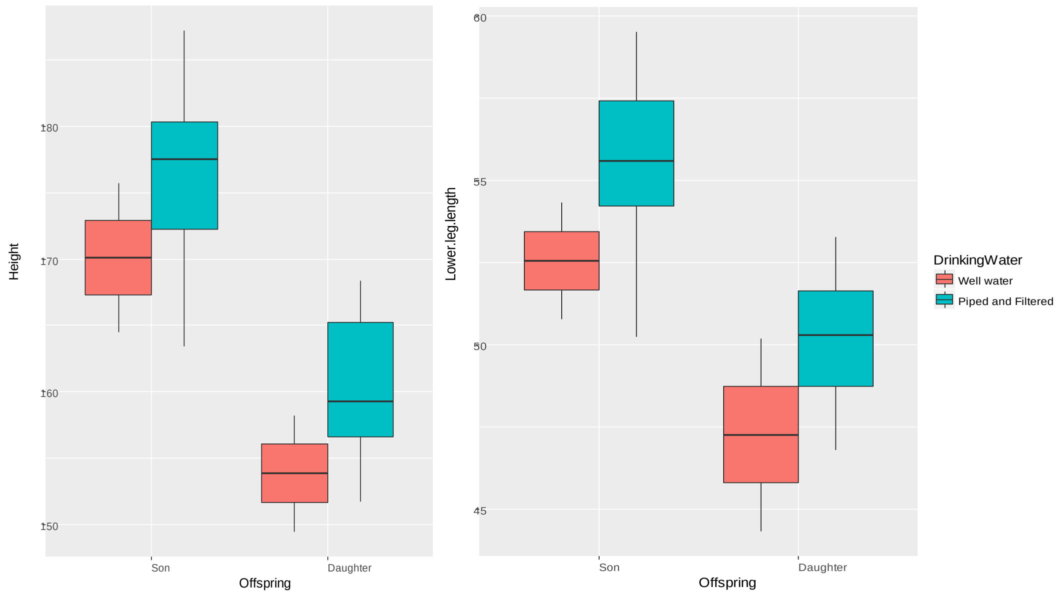

FIGURE 4.4.4: Box plot of height and lower leg length for sons and daughters across categories of drinking water qualities.

Height and lower leg length were also assessed for different toilet facilities (Figures 4.4.5 and 4.4.6). From the boxplot it appears that fathers who had no toilets or had toilets outside the house when they were young are taller and have longer lower legs on average, in comparison to fathers who had in-built toilets. The difference in mean heights for fathers is statistically significant ($p = 0.078$). Mothers' average heights are more similar for those who had no toilets or had toilets in the house. However, like fathers, the average lower leg length for mothers with no toilets is greater than mothers who had toilets in the house. The mean difference of lower leg length in mothers across the four categories is statistically significant ($p < 0.0005$). These results for the parents are inconsistent with expectations. Height and lower leg length of sons with flush toilets are greater than sons with toilets outside the house or those who had septic tanks. Daughters with flush toilets are also taller and have longer lower legs on average, when compared to daughters who had septic tanks. The difference between the average lower leg length for daughters with flush toilets or septic tanks is statistically significant ($p = 0.062$).

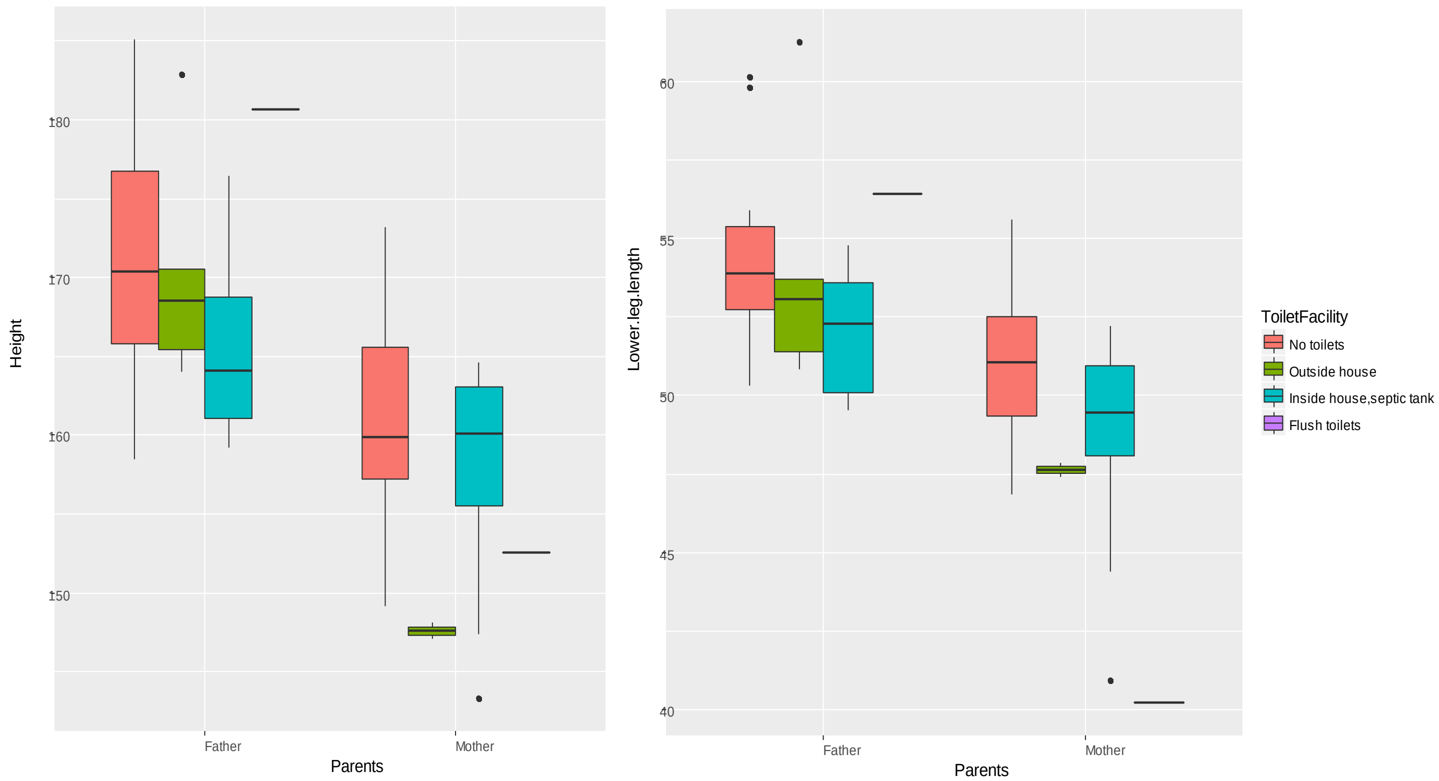

FIGURE 4.4.5: Box plot of height and lower leg length of father and mother across four categories of toilet facilities.

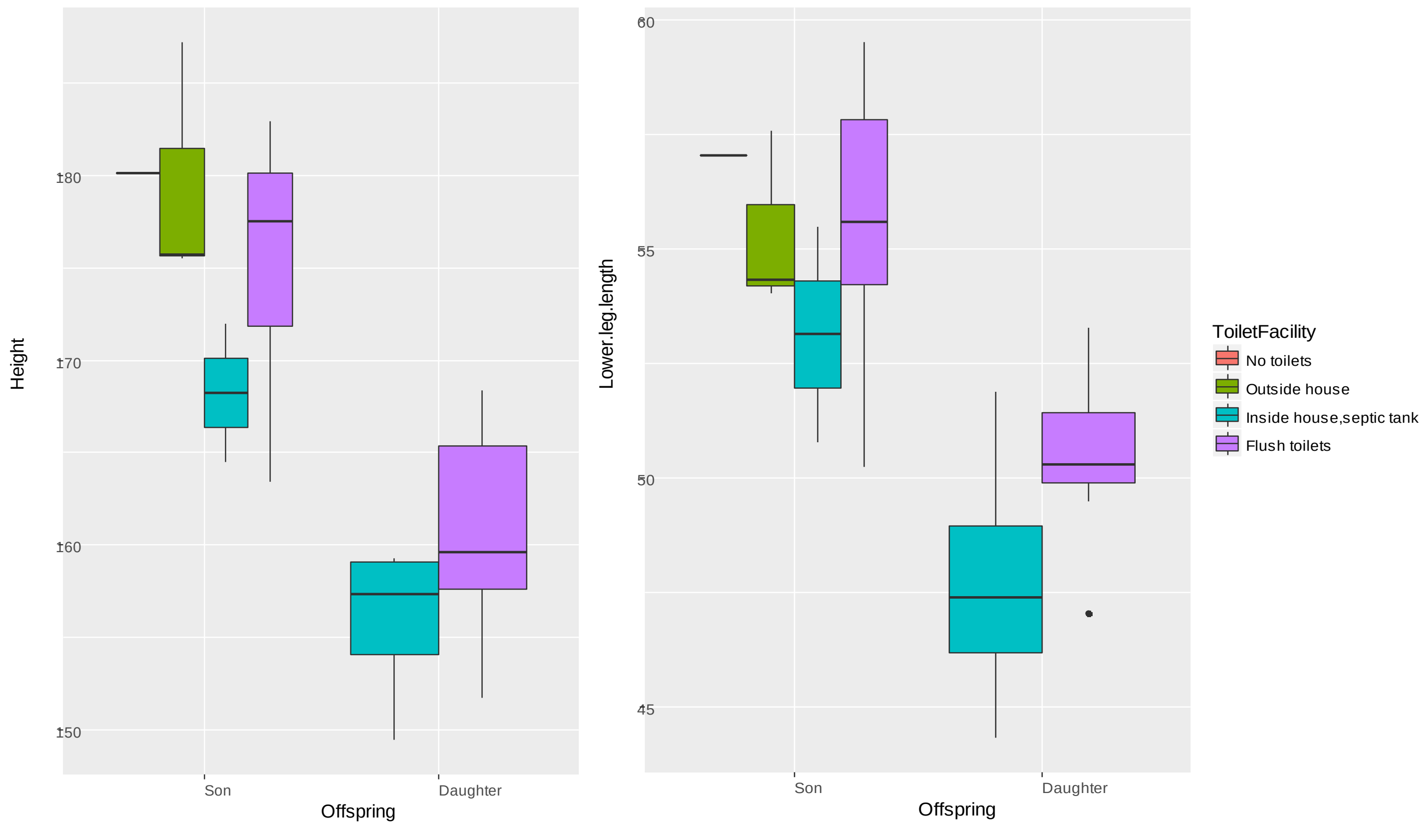

FIGURE 4.4.6: Box plot of height and lower leg length of sons and daughter across four categories of toilet facilities.

Lastly, I assessed the relationship between place of birth and anthropometric measures for sons and daughters. Boxplot 4.4.7 indicates that 7 sons and 4 daughters that were born in New Zealand or migrated to New Zealand within the first two years are, on average, taller and have longer lower legs, in comparison to 14 sons and 9 daughters born in India, though these differences for sons are not statistically significant. However, there is a significant difference in the mean height and lower leg length for daughters who are born in Punjab and those who are born in New Zealand ($t = -2.959$, $df = 11$, $p = 0.015$ and $t = -2.273$, $df = 11$, $p = 0.044$ respectively).

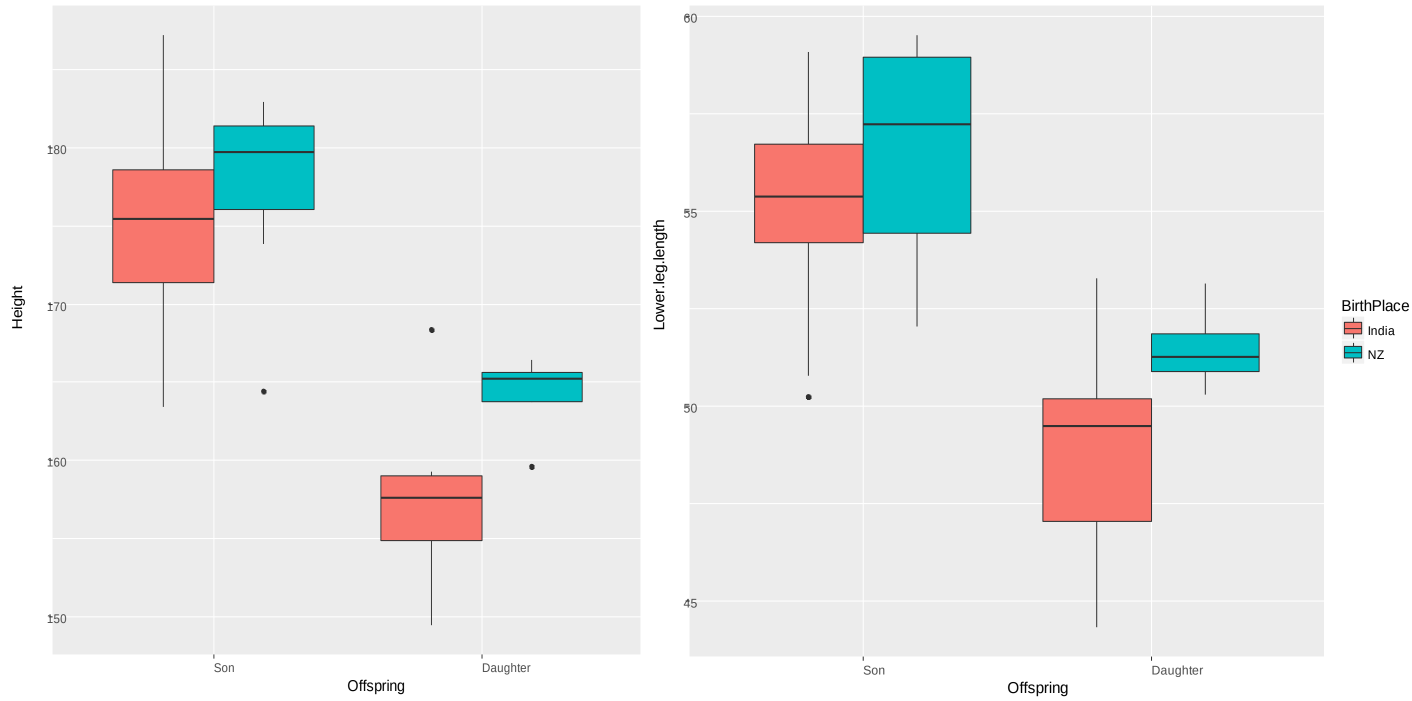

FIGURE 4.4.7: Box plot of height and lower leg length of sons and daughter across birthplace categories

4.5: Relationship between presence or absence of LEH and anthropometric measures

Further to test the hypothesis about how the extent of stress, measured in a more direct way, influenced the growth outcomes of individuals, I tested the relationship between the presence or absence of LEH and anthropometric measures.

Mean heights of parents with and without LEH defects are reported in Table 4.5.1. Fathers with enamel defects are on average shorter than fathers with no defects ($\Delta = 2.3$ cm). Mothers with defects are, however, taller on average than mothers with no defects ($\Delta = 3.7$ cm). The average lower leg length in each category is similar in both groups of parents.

TABLE 4.5.1: Mean comparison of anthropometric measures across presence and absence of enamel defects among parents.

Parent	LEH Present	N	Height (Mean)	Height (SD)	Lower leg length (Mean)	Lower leg length (SD)
Father	No	9	173.6	5.2	54.4	2.7
	Yes	15	171.3	7.8	54.6	2.9
Mother	No	4	156.0	4.7	49.6	2.7
	Yes	25	159.7	7.5	49.9	3.2

Table 4.5.2 reports the means of height and lower leg length for the offspring generation. Both sons and daughters with defects are, on average, shorter with shorter lower limbs in comparison to individuals with no defects. Statistical tests showed no significant differences in mean height or lower leg length across the two categories for sons or daughters. Among sons and daughter standard deviations for height and lower leg length are consistently greater for those with LEH defects. This is also true for the parental generation (Table 4.5.1). These outcomes support the view that defects reflect physiological stress contributing to greater variability in skeletal growth.

TABLE 4.5.2: Mean comparison of anthropometric measures across presence and absence of enamel defects among offspring.

Offspring	LEH Present	N	Height (Mean)	Height (SD)	Lower leg length (Mean)	Lower leg length (SD)
Daughter	No	10	160.1	5.2	49.9	2.2
	Yes	3	156.8	7.9	49.2	4.2
Son	No	10	177.2	4.9	56.3	1.7
	Yes	11	174.1	7.7	55.0	3.2

4.6: Relationship between early and repeated stress events and anthropometric measures

Regression analysis was used to further evaluate the influence of early stress and repeated stress events on growth in height, leg length and lower leg length. The interaction effect, early and repeated stress events, was computed by combining the presence or absence of defects in the earliest unit with the total number of defects on the later units. The model used was: Criterion = Constant + $\beta_{(early)}$ + $\beta_{(late)}$ + $\beta_{(early\ *late)}$.

The hypothesis being tested here is the interaction between early and later repeated stress events will result in a greater influence on leg length or lower leg length as compared to height. This section reports the influence of early and repeated stress events on anthropometric measures for fathers, mothers, sons and daughters. The criterion variable is height or leg length or lower leg length. The predictor variable is the interaction between early and repeated stress events. Table 4.6.1 reports the results from the regression analysis for mothers and fathers.

Results of this analysis, for fathers, suggest that the relationship between anthropometric variables (height and leg length) and the interaction effect is weak, but statistically significant (p = 0.099 and p = 0.011, respectively). Early and repeated stress events were significantly negatively associated with height and leg length. Only small percentages of variance in height (3%) and somewhat greater percentage of variance in leg length (21.8%) are accounted for. However there was no significant relationship between lower leg length and the interaction between early and repeated stress events. For mothers, interaction between early and repeated stress events is significantly negatively associated with leg length (p = 0.038). This model explains 16.3% of the variance. Among mothers, there was no significant relationship between height or lower leg length and the interaction term (results not shown).

TABLE 4.6.1: Results of regression analysis examining the influence of repeated stress events on anthropometric measures for fathers and mothers.

Parent	**Criterion variable**	**Predictor variables**	**Slope est.**	**SE**	**P**	**Adjusted R^2 (Full Model)**
Fathers	Height	Early stress event	1.113	1.908	0.566	0.026
		Later and repeated stress events	1.225	1.168	0.307	
		Interaction term[b]	-1.133	0.654	0.099	
	Leg length[a]	Early stress event	0.924	1.096	0.409	0.218
		Later and repeated stress events	1.587	0.671	0.028	
		Interaction term[b]	-1.046	0.376	0.011	
	Lower leg length	Early stress event	0.374	0.754	0.626	0.041
		Later and repeated stress events	0.886	0.462	0.069	
		Interaction term[b]	-0.408	0.259	0.130	
Mothers	Leg length[a]	Early stress event	0.862	1.130	0.453	0.163
		Later and repeated stress events	1.455	0.963	0.144	
		Interaction term[b]	-2.189	0.997	0.038	

[a] Leg length is included in this analysis due to its significance despite some doubts about consistency of measurement

[b] Interaction between presence or absence of defects on early unit combined with total number of defects on the later units

Results from regression analysis for daughters are presented in Table 4.6.2. There were no significant relationships found between sons' anthropometric measures and repeated stress events and are therefore not reported. Results, for daughters, also suggest that there was no statistical significant relationship between the anthropometric variables and the interaction term. However, later and repeated stress events were significantly negatively associated with both height and lower leg length (p = 0.09 and p = 0.04, respectively).

TABLE 4.6.2: Results of regression analysis examining the influence of repeated stress events on anthropometric measures for daughters[a].

	Criterion variable	Predictor variables	Slope est.	SE	P	Adjusted R square (Full Model)
Daughters	Height	Early stress event	2.55	2.74	0.38	0.17
		Later and repeated stress events	-3.52	1.83	0.09	
		Interaction term[b]	-3.44	6.10	0.59	
	Lower leg length	Early stress event	0.75	1.18	0.54	0.27
		Later and repeated stress events	-1.86	0.78	0.04	
		Interaction term[b]	3.08	2.62	0.27	

[a] Regression model for sons found no significant relationship

[b] Interaction between presence or absence of defects on early unit combined with total number of defects on the later units

In both generations there was no significant relationship found between lower leg length and the interaction term. Although, there was a significant relationship indicated for mothers between leg length and early and repeated stress events and for fathers, between height and leg length and early and repeated stress events. For the offspring, only daughters indicated a relationship between later stress events and height and lower leg length.

4.7: Tests of hypotheses related to the impact of changing early circumstances on differences of growth outcomes for parents and offspring

This section reports the results of the regression analyses evaluating the relation between anthropometric measures and various components representing differences in early developmental environments between same-sex parents and offspring first without adjusting for parents' height ratios. Differences in early circumstances between the parents and offspring are computed by subtracting offspring ranked component from parents' ranked component. Differences in height or lower leg length of same sex parent-offspring pairs were computed by subtracting the anthropometric measures of sons or daughter from the corresponding measures of fathers or mothers, respectively.

Father- Son:

Results from regression analyses comparing fathers and sons suggest that there was no significant relationship between differences in early circumstances and differences in anthropometric measures (results not shown).

Mother-daughter:

Results from regression analysis for mother–daughter comparisons suggest that there was no relationship established between any of the predictor variables and difference in height. Table 4.7.1 reports the results of the regression analyses evaluating the relation between lower leg length and various components representing differences in early developmental environments between mothers and daughters. There is a weak, but significant relationship found between difference in component three (C3) and mother-daughter lower leg length differences.

TABLE 4.7.1: Results of regression analyses examining the influence of difference in mother-daughter component score ranking on lower leg length for same sex parent-offspring pairs.

Criterion variable	Predictor	Slope est.	SE	P	Adjusted R^2 (Full Model)	AIC (Full model)
M-D Δ in Lower leg length	M-D Δ in C1	0.091	0.064	0.195	0.317	25.680
	M-D Δ in C2	0.129	0.081	0.154		
	M-D Δ in C3	-0.085	0.042	0.082		
	M-D Δ in C4	-0.101	0.063	0.151		

Once preliminary relationships between same-sex parents and offspring were assessed, I evaluated the role of the other parent in the relationship between anthropometric differences and early circumstances of same-sex parents and offspring. To do this I used the within family height or lower leg length ratio of father and mother as covariates in the models.

Father–son (Influence of mothers' measures as a covariate):

While father-son height and lower leg length was significantly associated with the parent height ratio ($p \leq 0.005$) or lower leg length ratio ($p = 0.044$), results indicated that father-son height and lower leg length differences were not significantly associated with any of the component predictor variables (results not shown).

Mother-daughter (Influence of fathers' measures as a covariate):

Results from regression analysis for mother-daughter height and lower leg length differences with influence of father-mother ratios included, are presented in Table 4.7.2. The inclusion of parent height ratio in the model makes the relationship between difference in component 3 modestly more statistically significantly associated with differences in mother-daughter height ($p = 0.061$). The regression model with all components included explain 48.1% of the variance in difference in mother-daughter height, though most of the variance is accounted for by the covariate.

Unlike results for height differences just reported, the relationship between mother-daughter differences in lower leg length and their differences in early circumstances suggest that all predictor variables are significantly associated with the outcome variable when parent height ratio is included as a co-variate. This model explains 81% of the variance in differences in lower leg length for mother-daughter. However, there were no significant outcomes found when these analyses were performed on leg length.

TABLE 4.7.2: Results of regression analyses examining the influence of other parent on the difference in mother-daughter component score ranking on changes in body proportion for same sex parent-offspring pairs.

Criterion variable	Predictor	Slope est.	SE	P	Adjusted R^2 (Full Model)	AIC (Full Model)
M-D Δ in Height	F:M height ratio	-88.664	29.563	0.024	0.481	42.46
	M-D Δ in C1	0.109	0.129	0.429		
	M-D Δ in C2	0.130	0.166	0.465		
	M-D Δ in C3	-0.195	0.085	0.061		
	M-D Δ in C4	-0.124	0.128	0.368		
M-D Δ in Lower leg length	F:M lower leg length ratio	-25.749	5.876	0.005	0.8102	10.41
	M-D Δ in C1	0.118	0.032	0.013		
	M-D Δ in C2	0.139	0.043	0.017		
	M-D Δ in C3	-0.081	0.022	0.011		
	M-D Δ in C4	-0.114	0.033	0.014		

The full regression model with mother-daughter lower leg length differences, with fathers measures controlled for, was the most effective model with lowest AIC (AIC = 10.41). Therefore, no other reduced models were considered for mother-daughter lower leg length differences. However, a reduced model of mother-daughter height differences with fathers measures included is presented in Table 4.7.3. Results from this analysis indicate that the model with differences in component 3 and component 4 as predictors, explains the most variance in differences in mother-daughter height (56.2% vs 48.1%). Differences in component 3 remain significantly negatively associated with mother-daughter height difference.

TABLE 4.7.3: Results of regression analysis of the reduced model examining the influence of other parent on the difference in father-son or mother-daughter component score ranking on changes in body proportion for same sex parent-offspring pairs.

Criterion variable	Predictor	Slope est.	SE	P	Adjusted R^2 (Reduced Model)	AIC (Reduced Model)
M-D Δ in Height	F:M height ratio	-93.151	26.482	0.008	0.562	39.88
	M-D Δ in C3	-0.187	0.077	0.041		
	M-D Δ in C4	-0.146	0.115	0.239		

The influence of mothers' measures, indicated indirectly using father/mother height ratios, on the father-son relationships between differences in early circumstances and growth measures is not as strong as the influence of fathers' measures on the relationships between developmental conditions and lower leg length of mothers and daughters.

4.8: Stature increase between generations as a result of lower limbs

This study concludes by more directly examining the hypothesis that significant increase in stature between generations is primarily a result of increase in leg length and lower leg length. Table 4.8.1 reports the mean intergenerational height and lower leg length gains as percentages of parent values (among the 33 families with same sex parent and offspring). I only adjusted for parental aging effects on height (no adjustment needed for lower leg length). This table also reports the paired t-tests results examining whether the mean percentage gains in the lower leg length significantly exceeded percentage gains in height for same-sex parent and offspring. Daughter gains in lower leg length over those of mothers are not greater than height gains, these differences are statistically significant, but in the direction opposite to the initial hypothesis. Whereas son gains in lower leg length over those of fathers are slightly greater than height gains (see Table 4.8.1 below). These results do not suggest that lower leg length is a more sensitive indicator of changing circumstances among these Punjabi families.

TABLE 4.8.1: Results of paired t-tests assessing whether percentage gains from parent to offspring in lower leg length significantly exceed percentage gains in height.

	Offspring/parent lower leg length (%)	Offspring/parent height (%)	Mean Δ	t	df	p
Father-Son	102.20	102.10	0.11%	0.16	19	0.44
Mother-Daughter	100.62	102.10	-1.48%	-1.42	12	0.09

Figure 4.8.1 presents the differences in the proportional gains in lower leg length vs height for same-sex parent and offspring born in India and offspring born in New Zealand. From the boxplot it appears that relative gains in lower leg length for sons born in India were near zero. Whereas, sons that are born in New Zealand have greater gains in height relative to lower leg length over those of their fathers. On the other hand, birthplace of daughters have a different impact on gains in lower leg length as opposed to height over those of mothers. Both, daughters that are born in India and New Zealand have greater gains in height relative to lower leg length over those of mothers. However, the average gains in height relative to lower leg length are smaller for daughters born in New Zealand than those born in India,

(-0.36 and -1.99, respectively).

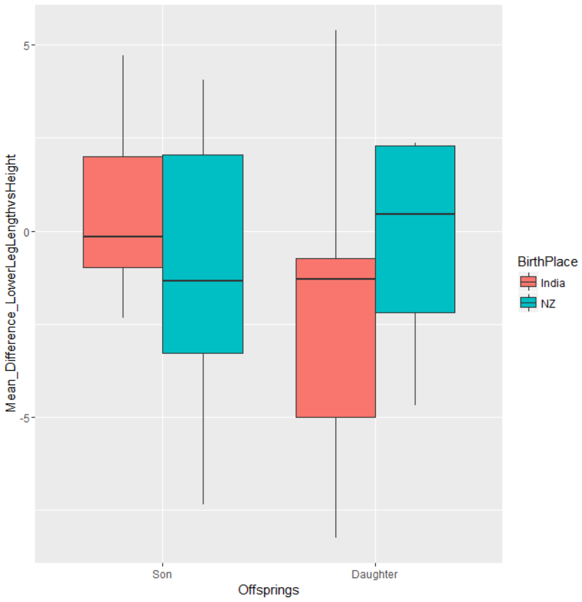

FIGURE 4.8.1: Box plot of mean difference in gains in lower leg length vs height for same-sex parent and offspring across the two categories of birthplace.

Furthermore, I also assessed the gains in leg length relative to height between same-sex parent offspring using boxplots (Figure 4.8.2). It is evident in the box plot that the sons born in New Zealand have greater gains in leg length than height over those of fathers ($\bar{x}\,\Delta$ = 2.572). Sons that are born in India show greater gains in height as opposed to leg length ($\bar{x}\,\Delta$ = -2.467). Daughter gains in leg length as opposed to height across the two birthplaces show similar outcomes as lower leg length gains relative to height.

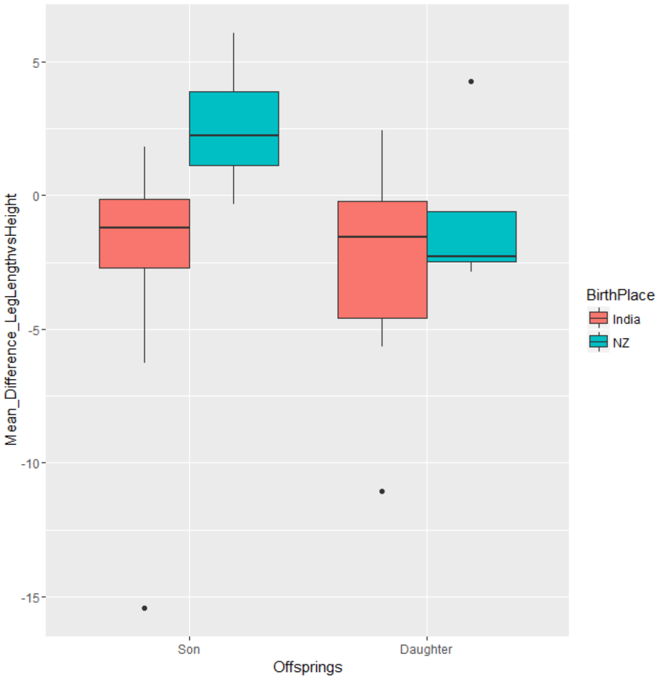

FIGURE 4.8.2: Box plot of mean difference in gains in leg length vs height for same-sex parent and offspring across the two categories of birthplace.

Chapter 5: Discussion

The focus of this study is to examine the impact of changing developmental circumstances of Punjabi parents and offspring living in New Zealand on height, leg length and lower leg length using the theoretical frameworks of developmental plasticity, migration and political economy. I strive to determine how the differences in the timing and extent of developmental stressors across individuals of the same family affects height, leg length and lower leg length and whether height or leg length is a better biomarker of early circumstances. The answers to these questions are not straight-forward, both because of the complexity of the issues and the challenges faced in this study. The aim of this chapter is to address these questions using the findings obtained from Punjabi families who migrated to New Zealand and discussing them in light of existing research. The first section of this chapter presents the research outcomes within each generation and how the results relate to expectations. These are followed by outcomes obtained from between generation comparisons. The final sections reflect on the study design as a whole and proposals for future research.

5.1: Social histories and family backgrounds

One of the important aims of this study was to investigate which component of stature, height or leg length, is a better biomarker of early circumstances. As discussed in Chapter 2 the idea that leg length is a better biomarker of early circumstances is currently debated in the literature. Literature suggests that a careful analysis of the timing and extent of stressors may prove useful in understanding the relationship between early circumstances and height or leg length. The rationale behind this is that between infancy and puberty leg grow relatively faster, therefore stress experienced during these times will impair leg growth. To contribute further to this debate my research carefully analysed the timing and extent of stressors using both indirect evidence from recalled family circumstances and more direct methods. The idea proposed by Floyd (2007) to assess enamel defects on dental casts as evidence of past physiological stress is a more direct method this research incorporated. Further, assessment of enamel defects in this study suggests that LEH is as important marker of stressful events in living people as it is in bio-archaeological contexts. This study is one of the few to assess relationships between early circumstances and growth among migrants from Punjab, India. The people of Punjab, India were exposed to rapidly changing environmental conditions. The effects of changing environmental conditions on the physical growth of the people of Punjab are not very well documented. This research makes a small, but meaningful contribution, into the impacts of changing environments on the growth of Punjabis.

5.1.1: Political and economic environment

There has been substantial changes in the social, political and economic environment of Punjab from the parental to the offspring generation. There are two major political and economic events related to the developmental environment of my participants. These include the 1947 partition and 1960s Green Revolution. These two events mainly coincide with the parental generation and allowed me to assess their developmental circumstances at a population level. The people of Punjab were most affected by the partition of India and Pakistan. The impact of partition affected political, social, economic and cultural aspects of the people of Punjab. Partition of India also led to an increase in violence. It was the people of Punjab who had to bear the brunt of this partition, with a large number of people living in their own country as refugees, left with no homes and land (Wilcox, 1964). Post partition the social, political and economic conditions of Punjab deteriorated. However, few years after the partition there were improvements in the living conditions as Punjab's economy started recovering. The introduction of the Green Revolution in 1960s resulted in major improvements in the economy of Punjab. Based on the political economic history of Punjab it is inferred that the range of birth year of parents (1943 – 1981) coincides with some of the key events in the history of Punjab. Parents born during the time of partition (1947) and years after the partition are likely to be exposed to stressful environmental conditions, due to the political unrest. However, parents born after the economic growth of Punjab as a result of the Green Revolution during 1960s may have been exposed to improved developmental conditions.

Variation in the circumstances within the parental generation is likely to produce a range of growth outcomes. Parents born around the time of partition are expected to have experienced very stressful developmental environments, resulting in a greater impact on height and leg length. After few years of partition Punjab's government implemented programmes which resulted in improvements in the economy of Punjab from the 1950s onwards. During the 1960s when Green Revolution was introduced Punjab saw great improvements in the economy which also resulted in industrialization, improved infrastructure and improvements in sanitation. It would be expected that parents born after the 1950s will have experienced improved developmental environments. There are a total of 31 fathers from who the data were collected. Out of these 31 fathers there are four fathers in my study that were born around the time of partition (1943 to 1948) and the remaining 27 were born after 1950. It was anticipated that there will be a greater difference in height and leg length between these two groups of fathers. Fathers that were born during partition were on average shorter than those that were born after 1950. Leg length in these two groups of fathers did not follow expectations, but lower leg length of fathers born after 1950 were longer than those born during partition. The mean difference in height between the two groups was 0.76 cm and the difference in lower leg length was 0.68 cm. Fathers born after 1950 had relatively longer lower legs than fathers born during partition. These outcomes somewhat follow the expectations that increase in stressful developmental conditions may have resulted in the impaired growth outcomes, mainly impacting length of lower legs relative to height. However, these results were not statistically significant given the small number who were born around the time of the partition. It was not possible to use a direct measure of stress (i.e. LEH) to assess the difference in growth outcomes because three fathers that were born during the partition had no available teeth. Also all mothers were born after the time of partition, therefore it was not possible to assess the impact of partition on growth outcomes of mothers.

TABLE 5.1.1: Height, leg length and lower leg length of fathers born around the time of Partition and those born during economic growth

Birth year	N	Height	Leg Length	Lower Leg Length
1943-1948	4	170.08	100.13	53.28
1952-1977	27	170.84	98.58	53.96

5.1.2: Biosocial environment

A social process important in the growth outcomes of both parent and offspring from Punjab is gender bias. In India, the existence of gender bias is clearly identified in the literature. Literature suggest that in the northern states of India son preference is higher than other states of India (Murthi et al., 1995; Gupta and Bhat, 1997; Arnold et al., 1998; Bhat and Zavier, 2003; Gupta et al., 2003). Skinner (1997) argues that patrilineal joint family systems like those in Punjab may have biased family planning decisions in favour of sons. Gender bias is evident in the literacy rate, mortality rate of females in Punjab and the sex ratio of Punjab. In Punjab, during the years most parents were born (1960 to 1980), the sex ratio ranged from 1.171 to 1.138. No data is available before the 1960s. Census years most closely associated with the offspring generation are the years 1991 and 2001. The sex ratio in Punjab during 1991 was 1.134 and in 2001 was 1.142. Over these years adult ratio of males relative to females has increased in Punjab slightly, the sex ratio remaining skewed, with a higher preference for male children in Punjab than found in most societies. It has been argued that in India from 1981 onwards a decrease in fertility resulted in an even greater preference for son, which is evident in the sex ratio of the under 6 age group. (Gupta and Bhat, 1997). The sex ratio in Punjab for under 6 year olds during 1981 was 1.10, increasing to 1.25 by 2001. Gender inequality is also evident in the mortality rate of Punjab, India. Demographic data from Punjab also suggest that there is greater number of female infants dying in comparison to male infants, but the female infant mortality rate has declined over recent years. Gender bias not only skews the sex ratio or the infant mortality rate of the country, but there are other implications for females in societies who give preference to male children. In such settings, inequality often prevails in access to education, health care and allocation of food. Arokiasamy (2004) also suggests that gender bias exposes women to an increase in workload at the household level, where she is expected to cook, clean, care for children or the elderly and collect water in places where water is not piped into the dwelling. The distribution of occupations of grandmothers and mothers relative to grandfathers and fathers in my study sample hint at gender bias in family roles. More than 80% of both paternal and maternal grandmothers cared for homes. For sons and daughters who were born in India there is still a higher proportion of mothers who exclusively cared for homes, 71% and 56% respectively. However, only 29% of mothers of offspring born in New Zealand cared for home exclusively. These differences cannot necessarily be interpreted as suggesting greater gender bias among families in Punjab, India. Mothers who cared for home exclusively may also suggest that the fathers' income was sufficient to run the household and therefore mothers were not required to work as among many families in New Zealand.

Education is another element that is highly influenced by gender bias. Gender bias is evident in the female literacy rate of Punjab. As discussed in Chapter 3 female literacy rate has been increasing in Punjab over the years, but it is still lower than males. Female literacy is important to this study because maternal education is argued to be an important factor in determining the health of the offspring. Grandmothers, both paternal and maternal, in my group have a higher proportion with no schooling (42%), than grandfathers. But all mothers of offspring had some sort of degree attained.

Growth studies testing the hypothesis that mothers with greater qualifications have a positive impact on growth outcomes of children found evidence in support of the hypothesis

(Horton, 1986; Handa, 1999; Boyle et al., 2006). However, in this study there was no significant relationship found between maternal education and growth of individuals. Mothers' education in this population is not related to growth outcomes of the offspring. This may be because maternal education may not serve as an effective marker of mothers' early circumstances in this study, but in this population maternal education is evidence of gender inequality present in Punjab. Also studies assessing the relationship between maternal education and height of children do not always find a linear relationship between the two variables. It has been argued that maternal education does not have a direct effect on height, but should be considered as a proxy for other underlying factors like mothers own health and the offspring's health (Behrman and Wolfe, 1987). This idea could be further built upon in future research.

Studies in Punjab also showed that weaning practises are more closely related to gender bias, but there are studies that suggest gender bias is more common in household with fewer resources (Pettigrew 1986; Gupta, 1987). A study addressing the evidence of preferential treatment for boys in India found that women were breastfeeding sons for longer than daughters (Barcellos et al., 2014). The results also found that females were significantly lighter than males. Assessment of weaning age in my study sample suggested daughters were on average weaned at a later age than sons (average age at weaning equals 0.74 and 0.62 years, respectively). These results do not suggest that breastfeeding in my study sample was impacted by gender bias. However, no information about the parental generation is present. Based on findings from Gupta (1987) it can be argued that the absence of a greater difference in age at weaning in my study sample may be a result of the relatively high socioeconomic status of many of the families or smaller family size.

Family composition is suggested to be an important factor in impacting growth outcomes, mainly in societies where gender bias is present. It has been argued that family composition influences the treatment of children (Skinner, 1997). The differences in treatment of male and female child will in turn influence growth outcomes. However, improvements in socioeconomic status of families is an important factor that determines the differential treatment (Gupta, 1987). In the parental generation there were only two families out of the 64 families who had no male children. For mothers, family size ranged from two offspring to eight offspring. Whereas, fathers family size ranged from one child to 12 children. In the 31 families of fathers, 10 families had no female children. Whereas, only two families out of the 33 families in which mothers were born had no male children.

In the offspring generation the family size ranged from one child to three children. The differences between the average number of children between the parental and offspring generation suggest that even though the sex ratio may be skewed in both generations, in the offspring generation due to small family size both sons and daughters would have received somewhat more similar treatment. The similarities in the average age at weaning for sons and daughters supports the claim that sons and daughters in my study sample were less influenced by gender bias.

Gender bias may have influenced the parental generation more than the offspring generation in my study sample. Based on available information reported about family composition, the sex ratios of both the parental and offspring generations were obtained. The sex ratio in the parental generation was 1.37. The skewed sex ratio for the parental generation suggests mothers in this study may have been exposed to gender bias. Thus, exposing mothers to more stressful developmental environment than fathers in this group. This is evident in the distribution of enamel defects in the parental generation. Mothers in my study sample may have experienced more stressful environments than the fathers, and a higher number of enamel defects present in mothers supports this claim.

The sex ratio in the offspring generation is 1.17. This sex ratio of offspring, obtained from reported family composition, also suggests evidence of gender bias. It was anticipated that daughters in this sample may have experienced more stressful developmental environments than sons. However, in the offspring generation more sons have enamel defects than daughters. A possible reason for this reversed pattern might be that even though the sex ratio is biased in favour of males, small family size in the offspring generation and improved socioeconomic status of families reduced the impact of gender discrimination. As Gupta (1987) suggested gender bias is more evident with poor socioeconomic status. Smaller families and improved SES are interlinked and may have resulted in an absence of the impact of gender bias on daughters. Furthermore, in the absence of gender bias in the offspring generation this pattern is consistent with studies of gender differences in vulnerability to infections during infancy. Evidence from literature suggests males are modestly more susceptible to infections during infancy than females (Washburn et al., 1965; Wells, 2000).

5.1.3: Migration

Another, key social event in the life of my research participants is migration from Punjab to New Zealand. In growth studies migration to “developed” country, results in improvement in sanitation and better access to health care. In this study migration played a role in altering the developmental environments of offspring, mainly those that migrated as young children or those that were born in New Zealand.

Migration to New Zealand exposed offspring that were still growing or offspring that were born in New Zealand to improved developmental conditions. Studies suggest individuals born and raised in countries with access to clean water, toilet facilities and access to health services are more likely to be taller and longer legged (Ito, 1942; Bogin et al., 1992, 2002; Smith et al., 2003). Based on evidence obtained from these studies I posited that offspring that were born and raised in New Zealand would be taller and have longer lower legs. Results from this study follow these expectations. It was found that both sons and daughters that were born in New Zealand were on average taller and had longer legs. Offspring born in New Zealand had access to clean water, toilet facilities and access to health care, which in turn resulted in tall stature and longer legs. All daughters born in New Zealand are taller and longer legged as anticipated. However, seven sons were born in New Zealand, out of which four were considerably taller and longer legged than their fathers. The remaining three sons were shorter compared to their fathers. Among the three sons that were shorter than their fathers, only one had shorter lower legs and legs. Further assessment found no evidence of LEH for this offspring who was both shorter and had shorter leg. However, information obtained for interview about their health when young, it was found that at the age of 3 years the participant was in the hospital with fever for a month.

Offspring were not only exposed, on average, to better developmental conditions as a result of migration to New Zealand but all offspring were probably exposed to better developmental environments than their parents. The policies implemented in Punjab around sanitation reform suggests that there were major improvements in sanitation and hygiene from parental to offspring generation. Almost all sons and daughters (excluding the older offspring) had access to piped filtered drinking water and some sort of toilet facilities available. There were only four sons that had no toilet facilities and two sons and two daughters who drank unfiltered water from well. Sons and daughters who drank piped filtered water and had flush toilets were taller and longer legged than those who obtained water from wells and had septic tanks.

However, in the parental generation improvements in water and toilet facilities do not follow a similar pattern as the offspring. Only fathers' with improved water facilities were taller and had longer lower legs and these outcomes were significant. The remaining outcomes were inconsistent with anticipated growth outcomes. The inconsistency might be partially explained by considering the limitations surrounding retrospectively collected data. This type of data while useful, are limited in the assessments of growth differences that they permit given their characteristics. The water sources in the parental generation may not be a good representation of the quality of the water. The water sources may not be representing the typical relationship between sanitation (bacterial sources) and water sources.

I further assessed the distribution of enamel defects across categories of water and toilet facilities for fathers and mothers. Improved water facilities impact on height and lower leg length of fathers was consistent with expectations. Assessment of enamel defect found that 10 out of 16 fathers who drank well water had evidence of enamel defects. Of the total defects, 87% of the defects were present on the early units (0.8 months to 4 years). Fathers who obtained there drinking water from hand pumps had evidence of 75% of the defects on the early units. The distribution of enamel defects across the two categories of drinking water is consistent with expectations (but not statistically significant). Mothers' growth outcomes across the categories of drinking water did not follow expectations. Eighteen out of the 20 mothers who drank well water had evidence of LEH and 81% of these defects were present on the early units. Whereas, mothers who obtained their drinking water from hand pumps had 92% of total defects on early units. The distribution of defects across the two categories of water sources may to some extent explain the inconsistent growth outcomes observed among mothers and improvements in water facilities.

Assessment of enamel defects across fathers and mothers who had toilets and those who did not have toilets found similar results. Parents who had no toilets in the house were found to be taller and this might be very partially explained with lower number of defects present on the early units for parents with no toilets. Whereas, parents who had toilet facilities available had more evidence of defects on early units. Fathers with no toilets have 83% of the defects on early units, where as those had toilet facilities available to them have 87% of the defects on early units. Mothers with no toilets and mothers with toilets showed a similar distribution of enamel defects on early units, 83% and 85% respectively. These differences are too small to form any conclusions. These outcomes, however, are consistent with the idea that the relationship between reported improvement in water and toilet facilities and sanitation is not straightforward. They are also consistent with the view that stress may variably impact dental and skeletal development.

Another important factor related to growth outcomes assessed in studies is household crowding. Household crowding is used as a measure of hygiene and sanitation. Living in crowded houses leads to exposure to unsanitary environment resulting in increased exposure to infectious diseases. Studies assessing the influence of overcrowded houses on height or leg length suggest that overcrowded houses result in impacts on height and leg length, but importantly this association is argued to be greater for leg length (Li et al., 2007; Gigante et al., 2009). Based on the literature it was hypothesised that individuals living in crowded houses will be shorter and have shorter legs, on average, and there will be a significant effect of household crowding on the average lower leg length. In the parental generation results of association between overcrowding and anthropometric measures followed expectations (see Fig 4.4.1). When fathers and mothers are not living in overcrowded houses they are on average taller and have longer lower legs. However, household crowding had no impact on the growth outcomes in the offspring generation.

Assuming the information of household crowding is reliably recalled by participants, they typically represent indirect categorical proxies for relevant processes. Their value is based upon relationships documented in other studies. The particular relationships between a given proxy and a given growth outcome may not apply for all, or even most, families if their particular historic and social characteristics alter the underlying significance of the proxy for the growth outcome.

The inconsistencies in the outcomes may be a result of variability in the number of people sharing a room across the two generation. Household crowding is measured with the total number of people living in a room. More than two people in a room is considered as overcrowded. In the parental generation the number of people sharing a room was somewhere between 1 person to 20 people. The maximum number of people sharing a room in the offspring generation was 6 people, for only one participating family. For the remaining families in the offspring generation the maximum number was three people sharing a room. In the offspring generation because the average number of people sharing a room is very low, it is speculated that there is no impact of overcrowded houses on height or leg length of offspring. Another speculation is that reduced family size in the offspring generation meant that enough resources were more often available for all members of the family. So even when overcrowded houses may have exposed the offspring to infectious disease, the small family size may have allowed for offspring to get medical treatment. In the offspring generation the largest family was composed of 3 offspring and parents. Whereas, in the parental generation the smallest family comprised of one offspring with parents and the largest family had 12 offspring and parents.

5.1.4: Growth studies in Punjab

In light of participant's backgrounds when compared with data from other studies in Punjab, I inferred that participants in my sample belonged to well-off families. There are several studies that assess the growth of Punjabi living in Punjab, India (Table 5.1.4.1). The goal of these studies are not the same as my study, but these studies provide the height of Punjabi adult males and females.

TABLE 5.1.4.1: Studies assessing anthropometric measures of people from Punjab representative of the parents.

Year of data collection	Author (Year of publication)	Participants	Research location	Socio-economic status[a]	Height (SD or SE)	Height of parents (SD)
1971	Sidhu and Kansal, (1974)	Jat-Sikh males - 16 to 24 years. Recruited from university students	Punjab	Middle to high	170.7 (6.6)	170.7 (7.0)
1972	Singh et al., (1988)	Males -17 to 25 years. Recruited from college and university.	Punjab	Middle to high	170.4 (4.7)	170.7 (7.0)
1992	Singh and Harrison (1997)	40 Jat-Sikh males - 17 to 20.5 years. Recruited from government or state-aided schools.	Punjab	Low	169.6 (1.0)	170.7 (7.0)
1975 and 1976	Singal and Sidhu , (1981)	Jat-Sikh females - 20 to 80 years (only used information for ages 20 to 44). Recruited from villages	Punjab	Unknown	156.4 (5.5)	158.9 (7.2)
Unknown	Sidhu et al., (1982)	150 Jat-Sikh females - 16 to 23 year old. Recruited from educational institution	Punjab	Middle to high	157.9 (5.3)	158.9 (7.2)

[a] Socioeconomic status inferred from where the participants were recruited.

Most studies that assessed the height of people from Punjab are more comparable with my parental generation. The study by Singh et al., (1988) on Punjabi males studying in various colleges and universities found only 0.3 cm difference in height when compared to my fathers' mean height. Sidhu and Kansal (1974) collected height and sitting height of Jat-Sikh males and Bania males, recruited from educational institutes. The data were collected during 1971, therefore the participants 20 years and older were born during the time of partition. The height of Jat-Sikh males in this study were the same as fathers in my study. Because these individuals were recruited from educational institutes (mainly colleges and universities) it is reasoned that they belonged to well off families. From this it can be inferred that the fathers in my study sample are representative of relatively well-off Punjabis born around the same time.

There are very few studies that assessed height of Punjabi females. The study by Sidhu et al. (1982) assesses several anthropometric measures in two groups of Punjabi women. The aim of this study was to determine the difference in body composition of two groups of Punjabi women. The two groups were the Jat-Sikh and the Bania females. The anthropometric measures of Jat-Sikh women in this group are likely to be directly comparable to mothers in my study because all mothers described themselves as Jat-Sikh. The age range of the women in Sidhu et al.'s study ranged from 16 to 23 years. These girls were recruited from various educational institutes of Punjab, suggesting that these women belong to middle or high socioeconomic status families. The authors used a generalised description of their group to characterise the different lifestyles of both groups. These groups are distinguished based on the type of physical activity and the type of food consumed. The authors describe the Jat-Sikh females as involved in a lot of strenuous work, mostly living in villages whereas, the Bania women spend very comfortable lives in cities. Authors also point out that the Jat-Sikh female work very hard, not only caring for their homes but also lending a helping hand to their spouses on the farms. The Jat-Sikh women in this study are on average 1.0 cm shorter than the mothers in my study sample.

Another study assessed height, sitting height and subischial leg length of Punjabi women (Jat-Sikh and Bania women) across ages ranging from 20 to 80 year olds (Singal and Sidhu, 1981). The authors describe the Jat-Sikh women as very hardworking. They further suggest that Jat-Sikh diets are rich in animal fat and nourishing. However, most females are vegetarians. Although this study provides measures from 20 year olds to 80 year olds, I only assessed the average height of women in ages ranging from 20 to 44 years. The average height of mothers in my study is 2.5 cm greater than the height of women in this study. Assessment of anthropometric measures of Punjabis suggest that both male and female in my study sample, although exposed to varying degrees of stressful developmental conditions due to political and economic unrest, are representative of men and women in Punjab and most probable biased in favour of better off families.

Results from recent studies (see Table 5.1.4.2) were used to determine if the offspring were representative of people of a similar age in Punjab as a whole. Chawla et al., (2013) assesses relationships between height and arm length of Punjabi university students, ages ranging from 18 to 25 years old. Young men in this study were all university students, so I infer that most belonged to well off families. Height of university students in this study were 1.77 cm taller than sons in my study. Another recent study by Singh and Harrison (1997) on Punjabi males evaluated height of Jat males, ages ranging from 17 to 20 year. The participants in this study were recruited from government or state aided schools and villages. Based on the places of recruitment I judge that the participants' socioeconomic status ranged from low to middle income. The mean height of participants in this study was 169.64 cm, 5.9 cm shorter than the sons in my study. Based on the anthropometric measures obtained in both these recent studies it can be inferred that the sons in my sample belonged to better off families, though perhaps not very affluent. This is consistent with the SES data obtained from the participants. There were no recent studies found to compare the growth of daughters in my sample.

TABLE 5.1.4.2: Studies assessing anthropometric measures of people from Punjab representative of the offspring generation.

Year of data collection	Author (Year of publication)	Participants	Research location	Socio-economic status[a]	Height (SD or SE)	Height of my participants (SD or SE)
Unknown	Singh and Harrison (1997)	Jat males - 17 to 20 years. Recruited from government or state aided schools.	Punjab	Low to middle	169.6 (1.0)	175.5 (1.4)
Unknown	Chawla et al., (2013)	149 Males -18 to 25 years. Recruited from educational institute.	Punjab	Middle to high	177.3 (7.9)	175.5 (6.6)

[a] Socioeconomic status inferred from where the participants were recruited.

5.2: Evaluating relationship between developmental circumstances of parents and offspring and anthropometric measures

Research on growth outcomes in different populations suggests that human growth and development is influenced by a range of factors (Bogin, 1999). This is because of the plastic nature of human bodies. This is evident in the results obtained from various growth studies. Individuals belonging to different socioeconomic backgrounds results in a range of outcomes.

However, the complexity not only lies in determining the factors that influence growth outcomes but the complexity also lies in evaluating the relationship between a range of developmental circumstances an individual has been exposed to and their growth outcomes. This is evident in my study and in other growth studies. A major complexity of my research was assessing the relationship between anthropometric measures across different family backgrounds between generations. Intergenerational analysis evaluating differences in circumstances between parent and offspring only found a significant relationship between mother-daughter lower leg length differences when parent dimorphism was included as a covariate.

However, the relationship between differences in circumstances between generations and differences in anthropometric measures was complicated to assess. The complexity of evaluating development circumstances was faced when calculating the difference in circumstances between parent and offspring. This was because of the rapidly changing settings within Punjab as well as the challenge that offspring were born in both the Punjab and New Zealand. Hence, when calculating the difference using principle components, the variables in the components did not match for parents and offspring. But based on how the components are computed in PCA, with the first component accounting for the most variation, the component with the highest eigenvalue for offspring was subtracted from the component with the highest eigenvalue for parent. This procedure appears to have worked in mother-daughter comparisons.

To obtain a clearer relationship between difference in developmental circumstances and growth of individuals, I separately assessed the difference in some highly loaded variables (household crowding, parents’ education, parents’ occupation, and drinking water and toilet facilities) and their relationship with difference in height and lower leg length. The output of these analyses found similar results, with a highly significant relationship between difference in all these variables between mother and daughter and their lower leg length when opposite sex parent lower leg length is controlled for.

Comparison of father-son differences in height, leg length and lower leg length suggests that in this group the improved developmental conditions in the offspring generation had similar impact on height, leg length and lower leg length. Out of 20 father-son differences, 13 sons were taller, 11 of these had longer legs and 14 sons had longer lower legs. However, as noted earlier there is evidence of migration to New Zealand influencing height and lower leg length of sons and daughters. Therefore, when evaluating the impact of migration, the anticipated impact of differences in developmental conditions in father-son is limited to leg length alone among those sons who grew up in New Zealand (see Figure 5.2.1). From the scatter plot it is evident that New Zealand born sons have greater differences in height and leg length. Father-son leg length differences for offspring born in New Zealand are greater than differences in offspring born in India (mean difference is 2.572 and -1.471, respectively). Assessment of gains in leg length and lower leg length relative to gains in height suggests that almost all sons born in New Zealand had greater gains in leg length compared to height (see Figure 5.2.2). Based on this assessment it can be concluded that improved developmental conditions for sons influenced leg growth more than height and an even greater impact on leg length of sons that are born in New Zealand.

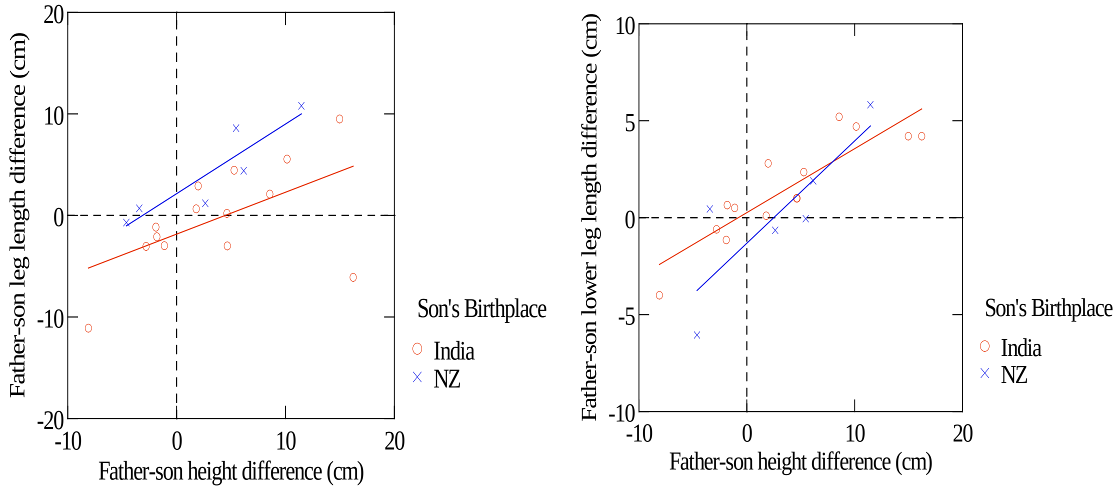

Figure 5.2.1: Scatterplots of Father-son height differences vs father-son leg length and lower leg length differences

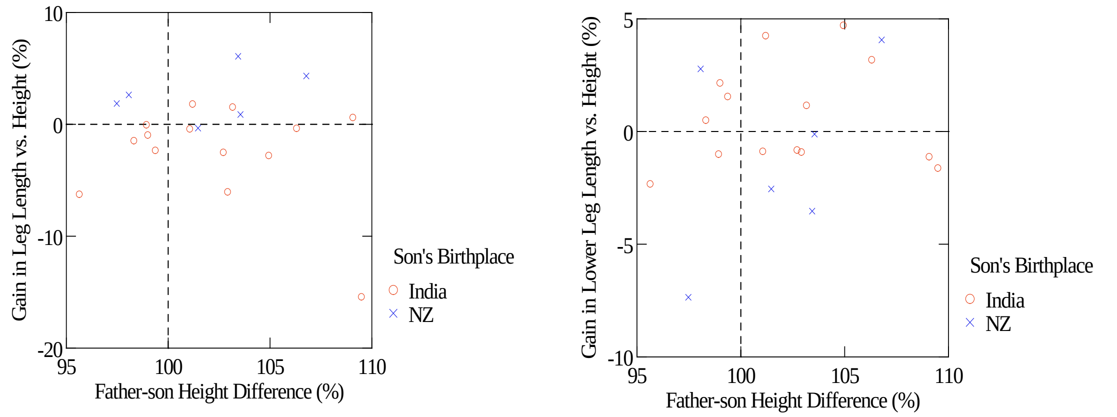

Figure 5.2.2: Scatterplots of Father-son percentage gains in leg length and lower leg length relative to gains in height

Comparisons of mother-daughter differences in height, leg length and lower leg length suggest that improved developmental circumstances for daughters also resulted in similar impact on height, leg length and lower leg length as among father-son comparisons. Out of 13 mother-daughter differences, 10 daughters were taller, eight of these had longer legs and nine daughters had longer lower legs. However, when birthplace is controlled for, three out of four daughters that are born in NZ are taller and have longer legs. But daughters only have absolute longer legs in New Zealand. Overall, mothers in my sample have relatively longer legs than daughters. However, the average mean difference in mother-daughter leg length for daughters born in New Zealand and those born in India suggest that there is greater difference in the developmental circumstances of mothers and daughters born in India Mean differences are -0.358 and -1.985, respectively. Relatively longer legs and lower legs of mothers in this sample suggest that mothers and daughters may have experienced relatively more similar developmental conditions. Assessment of relative gains in leg length and lower leg length vs height suggests that daughters born in New Zealand did not have greater gains in leg length or lower leg length compared to height (See Figure 5.2.3). Based on this assessment it can be concluded that improved developmental conditions, as a result of migration, for daughters did not influence leg growth more than height.

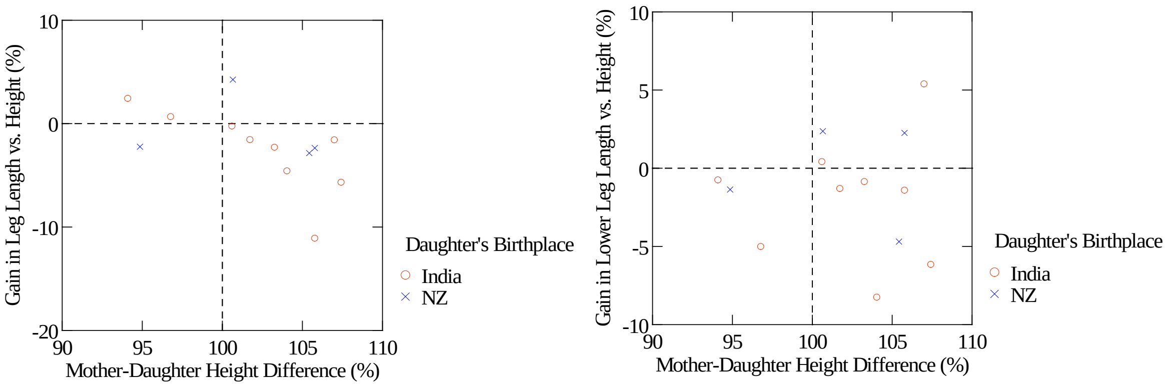

Figure 5.2.3: Scatterplots of mother-daughter gains in leg length and lower leg length vs height

The outcomes for father-son differences are consistent with outcomes, however mother-daughter differences are less clear. These outcomes are, however, more consistent when using the lens of a political-economic framework. Father-son differences are consistent with outcomes because there are fathers in this sample who were born during the time of political and economic unrest in Punjab. Mother-daughter differences are less clear because almost all mothers were born after the economic conditions of Punjab improved and therefore were not exposed to very stressful developmental environments.

Furthermore, the difference in outcome of leg length between sons born in New Zealand and India is consistent with the idea that Sohn (2015) presents. Sohn (2015) argues that in developed nations the influence of early circumstances is greater on leg length. However, he does not elaborate on the idea. He argued this notion based on outcomes of studies of assessed leg growth in developed and developing nations. A more thorough explanation underlying this idea of "developed vs developing nation" is that socioeconomic status of an individual will have a greater impact on leg growth relative to height in developed countries and not so much in the developing nations.

The key differences between developed and developing countries relevant to my research are associated with access to health services, access to clean and safe drinking water, which in turn influence likelihood of exposure to infectious diseases. In developed settings parents belonging to high socioeconomic status can provide better developmental environments for their offspring from a very early age. This is because parents have more control in providing better nutrition and health care that may result in positive growth outcomes of their offspring. However, in developing countries the number of infectious diseases are higher as compared to developed nation. Families belonging to a high socioeconomic status in a developing nation may not be able to control the influence of increased exposure to infectious diseases. It is evident in the pattern of LEH in the offspring generation, that offspring born in Punjab, India had a greater number of defects. Hence, supporting the idea that individuals born in Punjab are exposed to relatively more physiological stress. Therefore, during an individual's developmental years, the extent to which socioeconomic status of a family impacts growth outcomes in developing nations may be reduced. In the thesis by McFarlane (submitted), the author assessed the risk of mortality by socioeconomic status using the St. Bride's parish burial records. The two burial grounds used in the study are split based on clear divisions in socioeconomic status of those interred there. Results from this study suggest that in 18th Century London, the risks of mortality were similar in both high and low socioeconomic groups from birth through two years, though mortality risks were lower for children from the more affluent community at later ages. This evidence is consistent with the view that higher parental SES may be less able to influence early growth outcomes of individuals raised in developing countries.

Mother-daughter difference in height, leg length and lower leg length are similar for daughters born in New Zealand and daughters born in India. This suggests that relative to height, leg growth of daughters in New Zealand are impaired. There are two possible answers to why daughters' leg growth in New Zealand was impaired. First, I hypothesised based on social stress experienced post migration that daughters born straight after migration will show a greater impact on leg growth. Migration can be a stressful experience for most individuals. Of the four daughters that were born in New Zealand, two mothers were pregnant during the time of migration, one daughter was born a year later and one daughter was born four years after migration. The daughter that was born four years after migration had greater gains in lower leg length, but not leg length. The daughter that was born a year after migration was shorter than her mother. However, both the daughters that were born straight after the mother migrated to New Zealand show very different leg growth patterns. One daughter show a greater gain in both leg length and lower leg length in comparison to height, whereas the other show greater gains in height. These results did not support my hypothesis about stress related to migration. My second speculation was that lack of social support in relation to timing of migration from immediate families may have resulted in impaired leg growth. However, this hypothesis was rejected as well because mothers of all four daughters had immediate families present when they migrated to New Zealand.

I further analysed the health status of these four individuals based on recalled information about their health and LEH evidence. Two of the daughters that showed greater gains in leg length and/or lower leg length do not remember being sick and neither had evidence of LEH. The daughter that was found to be shorter than the mother, had no evidence of LEH but the parents did mention her having a club foot. And lastly, the daughter born straight after the mother migrated to New Zealand, had evidence of LEH present on the unit representing 0.8 months to 2.2 years old. Information obtained from mother and father also confirmed that their daughter was in the hospital for a month with severe chicken pox and fever when she was 1.5 years old. Based on this evidence it can be suggested that leg growth in daughters born in New Zealand was impaired due to increased physiological stress during their developmental years. This also supports the idea about impaired leg growth in developing nations is a result of higher exposure to pathogens. However, the sample size for daughters born in New Zealand is too small to make any conclusive statements.

5.3: Evaluating relationship between developmental circumstances of parents and offspring and linear enamel hypoplasia

Due to limitations surrounding retrospectively collected data and to be able to better understand the impact of stressful conditions experienced during the development years by my participants, it was important for me to assess developmental circumstances using a more direct measure of stressors. Linear enamel hypoplasia (LEH) is not only a more accurate representation of early circumstances but it is also used to obtain a better understanding of the relationship between the timing and extent of stressors and growth outcomes. Based on historical events it was hypothesised that the parental generation experienced more stressful environments in comparison to the offspring generation, hence both fathers and mothers were expected to have a higher number of enamel defects. The results obtained followed the expectations. In the parental generation 24 fathers had available teeth, of these 24 fathers 15 had evidence of defects. The number of mothers with defects is even higher, 25 mothers out of 29 had evidence of defects. In comparison, only 14 out of 34 offspring had evidence of LEH. The number of parents with defects may be an underestimate given probable wear on the anterior teeth and also the reduction in available teeth. Methods to measure tooth wear are being developed (McFarlane et al, in preparation), but tooth wear was not measured in this study. However, variation in tooth wear should be considered in future studies.

Studies assessing the influence of LEH on growth outcomes suggest that an increase in physiological stress as marked by LEH will have a negative impact on the growth outcomes and a greater impact on leg growth. There are few research studies available that assess the influence of LEH on growth in living populations. Literature assessing the relationship between LEH and growth in living population found short stature to be associated with a greater numbers of defects. Based on evidence from studies of both living and bio-archaeological population it is hypothesised that an increase in physiological stress during the developmental years will have negative impact on growth outcomes, and a greater impact on leg growth. However, results from this study, for the parental generation, does not support the hypothesis that an increase in physiological stressors (measured using LEH) will result in short stature and shorter legs. Mothers with defects are on average taller, but lower leg length between the two groups is virtually the same for fathers and mothers. Although, absolute difference in the lower leg length for mothers between the two categories do not follow expectations, the relative difference in the lower leg length does follow the expectations. Mothers with enamel defects have shorter lower leg length relative to height.

Results from the offspring generation follow expectations that increase in physiological stress will result in shorter statures. Both sons and daughters with defects are on average shorter and have shorter lower legs in comparison to those who do not have any defects. However, lower leg length relative to height for daughters with defects does not follow expectations. Daughters with defects have longer lower legs relative to height, suggesting the lower legs were not impacted by physiological stress to the same extent during developmental years. However, assessment of the relationship between presence of LEH and anthropometric measures only provide broad conclusions about the influence of timing and extent of stressors on growth outcomes.

Curiously, in both generations, those with enamel defects are anthropometrically consistently more variable as compared to those without. Linear enamel hypoplasia is a dental indicator of physiological stress influenced not only by variation in nutrition and disease exposures, but also by variation in individual frailty. Physiological stressors disruption of bone growth is probably similar, though not identical, to disruption of enamel formation. Importantly, too, bone growth sometimes recovers, but teeth do not. At an individual level an LEH defect likely indicates experience of stress, but there is not a one for one relationship. Two individuals who experience the same physiological stress, only one may show evidence of LEH and growth stunting. A related explanation is that depending upon developmental circumstances, within a small span of time after experiencing stressful conditions that produce an LEH defect and slowing of skeletal growth, some individuals may be able to return to normal bone growth but others do not fully recover. Judging from political and economic histories of Punjab in the parental generation there was a rapid turnaround in the economy. The rapidly changing economic conditions in Punjab were plausibly experienced by many parents when young. The parents in this sample may have not experienced stressful conditions all through their growth cycle. The variability observed in the growth outcomes of parents and offspring may be a result of the variability in physiological stress experienced by individuals who manifest LEH and their differing growth courses in response.

Literature assessing the relationship between growth and physiological stress suggest that repeated episodes of stress have a greater impact on growth outcomes. Statistical analysis to test the impact of repeated stress events on anthropometric measures for both generations provided inconsistent results. For fathers, repeated stress events had a negative association with both height and leg length. However, no relationship was established with lower leg length. Results for mothers were more consistent with expectations, with repeated stress events having a greater impact on leg growth. Similar analysis on sons and daughters found no relationship between repeated stress events and anthropometric measures. However, stress events in the later units (2.2 years to 9 years) is suggested to be influencing both height and lower leg length for daughters. Based on these outcome it can be suggested that even though there is evidence of repeated stress events impacting both height and leg length in both generations, no clear conclusion can be reached about the impact of stressful developmental environment on growth outcomes of individuals.

5.4: Future research directions

Overall outcomes of this research suggest that there is some evidence that leg length may be an important marker of developmental conditions. However, there were several important future research directions based on some key findings. Firstly, dietary information about the people of Punjab is an important factor contributing to the growth outcomes. There are a range of diets adopted by the people of Punjab. The differences in diets is a result of religious, cultural or personal choice (Nesbitt, 2000). Literature assessing growth of women in Punjab suggests that most Jat-Sikh women are vegetarians. A study that assessed body composition of Jat women found more than 90% of the females in both urban and rural settings to be vegetarians (Kaur and Talwar, 2011). A vegetarian is able to obtain all the important nutrients required for growth and development, but should have a range of vegetables included in their diet. Therefore, information about diets is important in assessment of the growth of people of Punjab. In the current study even if information about diets was obtained it would not have been reliably recalled. Therefore, a future longitudinal growth study that includes assessing the diets of people of Punjab during their developmental years will allow a more thorough description of the developmental environments.

Secondly, this study only considers a subset of the population. As stated most participants in this study belonged to well off families who were able to migrate to New Zealand. To better understand the relationship between early circumstances and growth outcomes it is important to recruit participants from a range of socioeconomic background. However, this is problematic when assessing migrants. This is because of the financial cost behind migration, only middle or high socioeconomic status families may be able to afford migrating. Therefore, to obtain participants from a range of socioeconomic backgrounds it would be ideal to conduct the study in Punjab.

Another possibility of obtaining parents and offspring from a range of backgrounds is to compare three generations. Grandparents born in Punjab would most likely be born during the time of partition and exposed to the stressful events during the time of development. Parents born in Punjab would have experienced somewhat better developmental condition than grandparents because of economic growth and stability in Punjab. And lastly, offspring either born in New Zealand or in Punjab would have experienced even better developmental circumstances than parents. However, there are two major problems with this study design. First, most grandparents would not have available teeth to assess linear enamel hypoplasia. And secondly, height shrinkage due to ageing effects would be difficult to adjust for given the age range of grandparents. The second limitation can be overcome by measuring legs, as aging does not influence leg growth.

Finally, to further evaluate the idea that socioeconomic circumstances in a developed country impacts leg length to a greater extent than in developing settings, a bigger sample with more New Zealand born offspring is required. This would have been achievable within the current study if more time was available for recruitment. This idea could also be further built upon by a cross-sectional study design comparing growth outcomes of parents and offspring in a range of socioeconomic backgrounds, living in Punjab with Punjabi parents and those living in New Zealand and their offspring who were born in New Zealand.

Appendix

Intra-observer study

Two weeks after the initial assessment of all casts a set of 40 casts were randomly selected. These casts were inspected again for enamel defects (inspection procedures are explained in Chapter 3, page 42) and all information was recorded on separate recording sheets, identified with ID numbers. Once data from second assessments were entered into an excel sheet, data from the first assessment were copied into this sheet. Technical error of measurement (TEM) was calculated using the formula stated below. The number of hypoplastic defects in the two assessments were treated as discrete ratio scale variables. The results are reported in Table 1.

Formula for calculating intra-observer error:

$$\textbf{Absolute TEM}=\sqrt{\frac{\sum d_i^2}{2n}}$$

Where: $\sum d^2$ = Sum of deviations raised to the second power

N = number of measurements

d_i = number of deviations

TABLE 1: Intra-observer technical error of measure (TEM) analysis[a] of total number of LEH defects performed on 40 randomly selected dental casts

	Total defects (1st assessment)	Total defects (2nd assessment)	Deviations	$(\text{Deviations})^2$	$\sum(\text{Deviations}^2)$	Absolute TEM
1	10	8	2	4	133	1.289
2	2	2	0	0		
3	1	0	1	1		
4	1	4	-3	9		
5	1	0	1	1		
6	0	0	0	0		
7	1	4	-3	9		
8	4	2	2	4		
9	1	0	1	1		
10	0	0	0	0		
11	0	0	0	0		
12	0	0	0	0		
13	0	0	0	0		
14	4	3	1	1		
15	0	1	-1	1		
16	0	0	0	0		
17	2	1	1	1		
18	0	0	0	0		
19	0	2	-2	4		
20	2	4	-2	4		
21	0	5	-5	25		
22	1	0	1	1		
23	0	1	-1	1		
24	0	0	0	0		
25	0	0	0	0		
26	0	0	0	0		
27	2	1	1	1		
28	5	2	3	9		
29	2	0	2	4		
30	0	0	0	0		
31	6	3	3	9		
32	2	5	-3	9		
33	1	0	1	1		
34	0	3	-3	9		
35	3	0	3	9		
36	1	0	1	1		
37	1	2	-1	1		
38	4	1	3	9		
39	0	0	0	0		
40	0	2	-2	4		

[a] Analysis treats number of LEH defects per cast as a discrete ratio scale variable

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