Title: **Global effects of income and income inequality on adult height and sexual dimorphism in height**

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Number of pages – 20

Figures – 3

Tables – 4

Text Box - 1

Key Words: Health, Gini coefficient, income per capita, GDP, social gradients

Abstract

Objectives: Average adult height of a population is considered a biomarker of the quality of the health environment and economic conditions. The causal relationships between height and income inequality, are not well understood. We analyse data from 169 countries for national average height of men and women and national level economic factors to test the two hypotheses: 1) income inequality has a greater association with average adult height than does absolute income; 2) neither income nor income inequality has an effect on sexual dimorphism in height.

Methods: Average height data come from the NCD-RisC health risk factor collaboration. Economic indicators are derived from the World Bank data archive and include Gross Domestic Product (GDP), Gross National Income per capita adjusted for personal purchasing power (GNI_PPP), and income equality assessed by the Gini coefficient calculated by the Wagstaff method.

Results: Hypothesis 1 is supported. Greater income equality is most predictive of average height for both sexes. Greater per capita purchasing power explains a significant, but smaller, amount of the variation. . National GDP has no association with height. Hypothesis 2 is rejected. With greater average adult height there is greater sexual dimorphism.

Conclusions: Findings support a growing literature on the pernicious effects of inequality on growth in height and, by extension, on health. Gradients in height reflect gradients in social disadvantage. Inequality should be considered a pollutant that disempowers people from the resources needed for their own healthy growth and development and for the health and good growth of their children.

This article is derived from the 2016 Human Biology Association Plenary Session titled “Worldwide variation in human growth – 40 years later.” The title of the symposium is taken from the 1st and 2nd editions of books of the same title by Phyllis Eveleth and James Tanner (Eveleth & Tanner 1991). Contributions to the symposium were meant to update the topics included in Eveleth and Tanner’s books. The purpose of this article is to update and evaluate worldwide variation in economic and social factors that influence the biology of adult height. We analyze national level data for measured heights for the year 1996 of men and women in 169 countries. We conduct the analysis based on two hypotheses: 1) that income inequality has a greater association with average adult height than absolute income, and 2) that sexual dimorphism in adult height remains fairly constant under different conditions of income and income inequality.

Previous analyses of national level economic indicators and adult height focused only on the association of income, measured as Gross Domestic Product (GDP) or GDP per capita (reviewed in Baten & Blum 2012). GDP is the monetary value of all the finished goods and services produced within a country's borders in a specific time period (we use calendar year values for all the economic indicators in the present analysis). GDP provides one measure of how well-off a country is compared with competitors. More detailed definitions of GDP and the other economic indicators used in the article are given in Text Box 1.

In the present analysis we employ as measures of income the national GDP (total income for a country) and the Gross National Income per capita adjusted for population size and Purchasing Power Parity (GNI_PPP). Gross National Income is similar to the GDP except that GNI includes income from international employees and from property that adds to a nation's total income production. The GNI, and especially the GNI per capita, have largely replaced use of the GDP. We include both measures of GDP and GNI in our analysis because GDP has been more often used in the literature. We explain in Text Box 1 why it is economically and biologically useful to express GNI per capita in terms of purchasing power parity (PPP) in international US dollars.

We also analyze the effect of income inequality on adult height and for this we use the Gini coefficient. The GDP is a proxy for the wealth of a nation and the GNI_PPP a proxy for the average income of individual citizens of a nation, but neither accounts for the fairness of the income distribution within a nation. The Gini coefficient measures the relative degree of income distribution equality within a nation (see Text Box 1). "The Gini coefficient has been the most popular method for operationalising income inequality in the public health literature" (De Maio, 2007) The analysis presented here finds that the combined usage of GDP, GNI_PPP, and the Gini coefficient, adjusted for health inequalities within a nation, demonstrates a more dynamic and satisfactory association of the impact of economic conditions on average adult human height than does the use of single economic indicators.

This new analysis is valuable to research in biological anthropology, human biology, economic history, demography, public health, and political policy. Each of these fields of inquiry uses human height as a measure of the quality of the living conditions of a society. Better living conditions leading to greater stature is important because shorter individuals and communities have, generally, higher risk of heart disease, stroke, respiratory disease, but lower risk for cancer, especially melanoma and cancers of the pancreas, endocrine and nervous systems, ovary, breast, prostate, colorectum, blood and lung (Batty et al., 2009; Maurer, 2010; Emerging Risk Factors Collaboration, 2012; Varela-Silva et al., 2016). Shorter height also associates with less education, lower social status, and earnings (Bogin, 1999, 2001; Hermanussen and Scheffler, 2016; NCD Risk Factor Collaboration (NCD-RisC), 2016). These associations suggest a positive feedback between greater height and better living conditions. Researchers and public health professionals are actively searching for the optimal ways to intervene to improve living conditions, human growth, and the economic well-being of communities and nations (World Health Organization, 2012; Bill and Melinda Gates Foundation, 2016; Goudet et al., 2016; Varela-Silva et al., 2016). One goal of this article is to contribute a better understanding of the relationship between height, living conditions, and macro-economic factors.

In Figure 1 are listed some of the more important categories of Living Conditions (Box 1) with a direct bearing on the Proximate Determinants (Box 2) of Population Height (Box 3, meaning average height as measured for communities of people within a nation or for the nation as a whole). Also listed are some of the Functional Consequences (Box 4) of height variation for individuals, communities, and populations (Steckel, 2012). Detailed discussion of the categories and factors of Figure 1 are available in the literature (Eveleth and Tanner, 1991; Komlos and Baten, 1998; Bogin, 1999; Steckel, 2009; Kuzawa and Quinn, 2009; Blum et al., 2011; Muñoz-Hoyos et al., 2011; Dubois et al., 2012; Hermanussen, 2013; Hwa et al., 2013; Simeone and Alberti, 2014; McDade et al., 2016).

In this article we concentrate on the Living Condition factors ‘Income’ and ’Inequality’ (in bold in Figure 1) and their association with some Proximate Determinants of Population Height. We propose that these two factors should head the list of Living Conditions because the impact of each of the other factors is exaggerated or ameliorated by variation in income and inequality. The association of income with height is well-studied in the literature. Generally, increases in total GDP or GDP per capita are positively associated with increases in the height of children, adolescents, and adults in communities or nations (Hatton and Bray, 2010; Baten and Blum, 2012). There are some exceptions, for example, a decline in heights of United States men in the 1850s even as income was rising (Margo and Steckel, 1983; Komlos and Baten, 2004). Most of the previous analyses are based on historic data for both height and income. Some discussion of effects of poverty and income inequality is given in those articles, but there were no direct or reliable measures of economic inequality.

The Gini coefficient was developed in 1912 by Italian economist and sociologist Corrado Gini (Gini, 1921). The Gini coefficient is applicable only where and when data for monetary income are available and partly for this reason it was little used until the late 20th century. The earliest use of the Gini coefficient by The World Bank is 1981 and regular reporting of the Gini coefficient for most nations begins in the late 1990s. To our knowledge, there are no peer-reviewed, scientific analyses of the relationship of the Gini coefficient with Population Height.

MATERIALS AND METHODS

Data for adult height are derived from the NCD Risk Factor Collaboration (NCD-RisC). This is a global network of health scientists sharing data to better understand and ameliorate risk factors for non-communicable diseases for people from all countries (http://www.ncdrisc.org/). Sources for the raw data, the statistical methods for data analysis, and analytical results are available open access (NCD Risk Factor Collaboration (NCD-RisC), 2016). Briefly, data were derived from, "…sources that were representative of a national, subnational, or community population and had measured height. We did not use self-reported height because it is subject to systematic bias that varies by geography, time, age, sex, and socioeconomic characteristics like education and ethnicity" (ibid, p. 12, see references given). The available data were for measured heights of more than 18.6 million people 18 years or older, born between 1896 and 1996, from 1,472 communities and populations. These data provided mean adult heights for 200 countries. Raw height data were converted into conditioned means for each country using a hierarchical statistical model that estimated mean height for each country over the 100 years of data, "…nested into regional levels and trends, which were in turn nested in those of super-regions and worldwide" (ibid, p. 12). The model structure allowed the sharing of information between data-sets to improve height estimates where information was weak due to small sample sizes.

For the present analysis we used the mean adult heights for men and women born in the year 1996, the most recent year in the NCD-RisC database. Because the NCD-RisC heights are statistically conditioned they might deviate from biological empirical heights. To investigate this, we compared the NCD-RisC data with adult heights available from Wikipedia (https://en.wikipedia.org/wiki/List_of_average_human_height_worldwide) and from the website http://www.averageheight.co. For data to be acceptable from these websites the original source needed to be given and we examined those sources to assure their quality. We preferred to use data for 18-29 year olds, but when unavailable some older age groups were used. Data for most countries are derived from Demographic and Health Surveys (http://dhsprogram.com). Some of the sources provide self-reported heights, and we included these from all valid data sources as our purpose was to look for systematic differences from the NCD-RisC data. We found some differences in average heights between the two datasets, but overall there were no systematic differences and few statistically significant or biologically meaningful differences. The correlation coefficient by country between the two datasets was r = 0.95 for both women and men.

Of the 200 counties with adult height data from the NCD-RisC database we were able to match economic data for 169 countries and these constituted our sample for analysis. All economic data for GDP and GNI_PPP are from the World Bank Open Data archives (http://data.worldbank.org/). Gini coefficient data are from Petrie and Tang (2008). Petrie and Tang used the World Bank Gini value for the year 2000 and then standardized those values to better reflect biological conditions within each country. The normal Gini coefficient varies from 0 to 1, with 1 indicating that one person has all the resources and all other people have none. This is not a reasonable proposition for any human biology analysis because all people in a population must have some amount of Living Condition resources if they are to survive, grow and develop to an adult height, and reproduce. Petrie and Tang's standardized Gini provides an estimate of the range of Living Condition resource distribution in the population. It does this by adjusting the normal Gini to account for the relative inequality in health and relative inequality in health-shortfall (Petrie et al., 2015). The shortfall method was developed by the economist and philosopher Amartya Sen to assess the poverty gap (i.e., shortfall) in a nation. The poverty gap measures the intensity of poverty as opposed to the overall percentage of people living in poverty. The poverty gap method calculates the average percentage of shortfall in income for the population from that nation's poverty line (Sen, 1976). People with a large shortfall, for example, are said to be living in extreme poverty. The poverty gap method is now used by the United Nations, World Health Organization, and the World Bank to better target segments of a population most in need of assistance (Hosseinpoor et al., 2012).

Petrie and Tang use the poverty gap 'shortfall' methodology to adjust the normal Gini to better reflect degrees of economic-related health disparities of Living Conditions in a nation. The adjustment is calculated by dividing the World Bank Gini value (the 'normal' Gini coefficient) by the maximal attainable Gini coefficient based on the maximal level of a health attribute an individual could achieve. The advantage of standardizing the Gini on a health attribute is that it better estimates inequality in Living Conditions in a population. Petrie and Tang use a lifespan of 102 years as the maximal health attribute. A lifespan of 102 years was chosen based on the World Health Organization life tables indicating that, "…in most countries, a person who lives to see his/her 100th birthday is expected to live for about 2 more years" (Petrie and Tang, 2008, p. 10).

Interested readers may refer to Petrie and Tang (2008) for mathematical details of the estimation of the standardized Gini coefficient , also called the Concentration index or Wagstaff index as its first formulation was by World Bank economist Adam Wagstaff (Wagstaff, 2009; Kjellsson and Gerdtham, 2013; Kjellsson et al., 2015; Petrie et al., 2015). Hereafter we refer to the standardized Gini as Giniw for Gini Wagstaff.

We prefer the Giniw to the normal Gini published by the World Bank because the latter comprises many unrealistically low values, especially for counties that are known to have relatively high rates of poverty and income inequality. Several African and Asian nations have a Giniw 20 to 36 points higher than their normal Gini, including Sierra Leone, Niger, Liberia, Mali, Burundi, Ethiopia, Burkina Faso, Pakistan, Mauritania, Nigeria, Cambodia, Chad, Bangladesh, Nepal, and Tanzania. Countries with normal Gini coefficients in the lowest 1st decile, such as Armenia (31.5) and Tajikistan (30.9), have a Giniw in the higher 3rd and 6th deciles (50.9 and 43.7, respectively). Overall, the mean (sd) difference in values for Giniw – normal Gini is 10.32 (9.27), with a range of difference from +36.2 to -10.6. Only 14 countries have a negative difference (that is, Giniw smaller than the normal Gini).

It is also useful to know that the Giniw has low correlations with the normal Gini and other purely economic measures of inequality (r = -.25 to +.39 for the Gini index, Erreygers index, Theil index and Atkinson index), and these alternative indices are highly correlated with each other and the normal Gini (r > .95) (Petrie et al., 2015).

The ranking of countries by the standardized Gini coefficient is not perfect solution to the limitations of the normal Gini, but as Petrie and Tang report the standardized

Giniw coefficients provide significantly improved explanatory value for the relationship of income inequality with health.

We were concerned that because Giniw is standardized on lifespan there would be an unacceptable level of multicollinearity with a Giniw analysis of height. Many published articles state that greater height is positively associated with longevity (Komlos and Baten, 1998; Crimmins and Finch, 2006; Samaras, 2012; NCD Risk Factor Collaboration (NCD-RisC), 2016). This is a misrepresentation of the data. Greater height is associated with lower risk for several adult-onset diseases (as presented above) and because these diseases are major causes of death it is tempting to assume that taller adults will have lower mortality and greater longevity. Greater height, however, is not the basis for increases in longevity over the past 100 years. Rather, it is that, "…modern medicine and improved sanitation have sharply reduced infant, maternal and childhood mortality" (Samaras 2012, p. 248). A direct association study by He and colleagues (He et al., 2014) reports that shorter adult height is associated with greater longevity in both Japanese and American men. Moreover, this association seems to be mediated by a single nucleotide polymorphism of the G allele of the *FOXO3* SNP (Willcox et al., 2008) that may also directly reduce growth in height. Evidence for a similar height-longevity association for women is not known, but we note that Japanese women are, on average, one of the longest lived populations but not one of the tallest – they rank 90th in the NCD-RisC height database. Given these published findings, we do not find any evidence for a multicollinearity problem between the Giniw and average adult heights.

Because World Bank data for GDP and GNI_PPP are not available for every year we computed the arithmetic mean value for those data available for each indicator for the period 2005-2014 – this is the most recent decade of data available. The 2005-2014 decade provided the most complete data and the maximum number of countries with data. Gini coefficient data from Petrie and Tang are year 2000 estimates. As the height data are estimated for people born in 1996 the economic data broadly overlap with their period of growth and should provide a reasonable association between adult height, income, and inequality.

RESULTS

The data used in the present analysis are shown in Table 1. Descriptive statistics are shown in Table 2. Mean heights for men and women vary over more than a 20 cm range. Considerable ranges are also found for the economic indicators with per capita income in purchasing power parity (GNI_PPP) ranging from US$576.00 for Liberia to US$87,267.00 for Kuwait. Based on the Mean-Median comparisons in Table 2, the anthropometric and the Giniw values are normally distributed but the GDP and GNI_PPP values are skewed. This is the real-world situation and we use the economic values as they are, rather than distort the reality by log-normalizing or using other techniques to artificially redistribute the data. This does not present statistical problems. It has been shown that large public health data sets, such as the NCD-RisC data used here, are validly analyzed by linear regression techniques even when the data are not normally distributed (Lumley et al., 2002; Tabachnick and Fidell, 2013). Furthermore, simulation experiments find that parameter estimates from linear multiple regression, as well as multilevel regression, prove to be robust even when residuals are non-normally distributed (Maas and Hox, 2004).

A forward stepwise multiple regression model was used to evaluate the predictive association of each economic factor on height. Separate regression models were calculated for men and women. The findings for men are presented in Table 3 and for women in Table 4. In these tables we provide the zero-order correlations and then the regression results. For men, all of the correlations are significant statistically ($p < .05$). The regression analysis indicates that Giniw and GNI_PPP are the two statistically significant predictors of adult height. Giniw has a negative standardized beta coefficient (β), meaning that a lower Giniw (more income equality) is associated with greater height. Giniw explains 46% of variance ($multr^2$) of height in our database of 169 countries. GNI_PPP (per capita income adjusted for purchasing power) has a positive association with height and its inclusion in the regression model explains and additional 3% of the variance in height. The stepwise regression model indicates that GDP is not a significant predictor of height.

For women the regression model findings are broadly similar. All of the correlations are significant. A lower Giniw predicts greater adult height, but the variance explained is only 30%. Greater GNI_PPP predicts greater adult height and accounts for an additional 4% of the variance. GDP is not retained in the model.

Graphic analyses of the association of Giniw and GNI_PPP with adult height are presented in Figure 2 for women and Figure 3 for men. A linear regression is the best fitting curve for these data. We tried fitting the data with second order polynomial regressions and exponential equations, but there was no statistical improvement in the residual estimates.

The slopes of the regression lines are steeper for men than for women, but the sex difference is not significant statistically. The 10 countries with the tallest men are all European, but spread across a geographic range from Iceland to Serbia (Table 1). The average Giniw for these 'tall' counties is 41.56. The black arrow in Figure 3 points to the height-Giniw data point for the Netherlands; with the tallest men, 182.54 cm, and a relatively low Giniw of 39.77. The black circle encloses the United States (177.1 cm, Giniw = 45.05), Greneda (176.97, Giniw = 44.61), and the Russian Federation (176.46 cm, Giniw 46.05).The similarities in mean male height and Giniw coefficient for these three nations are remarkable given differences in their economic-social-political histories over the past century. The 10 counties with the shortest men are Asian, African, Pacific Islands, and Yemen, with and average Giniw of 56.64. The lowest Giniw is for Cyprus, a small island nation with average heights for men and women in global perspective. The highest Giniw values are for Niger and Sierra Leone (and a few other African nations) and these nations have below average heights for men and women.

Sexual dimorphism in adult height averages 11.8 cm (sd 2.0) for the 169 counties in our database (Table 1). The variation is considerable and there is a significant positive association for greater sexual dimorphism with increasing height for both men ($r = .65$) and women ($r = .32$). The difference in correlation coefficients between men and women is statistically significant ($p = .0002$), indicating that the sexual dimorphism in adult height is more affected by changes in male than female stature. This was confirmed using forward stepwise regression. With sexual dimorphism as the dependent variable (height difference M-W) we entered the economic variables and height for men into the model. The overall model was significant ($p < .001$) and height for men ($\beta = .40$, multr^2 = 40%) and Giniw ($\beta = -.35$, multr^2 = 6%) were the significant predictors. We then modeled the same variables using height for women and the overall result was also significant ($p < .001$), but only Giniw ($\beta = -.61$, multr^2 = 38%) was a significant predictor. In these models, increases in male height, but not female height, predict greater sexual dimorphism. It is also noteworthy that greater income equality is associated with greater sexual dimorphism, but not our measures of income (GDP and GNI_PPP).

Discussion

Our analysis finds that global variation in adult height is better predicted by income inequality as measured by the Giniw coefficient than by two other measures of income, the GDP and the GNI_PPP. This supports our first hypothesis. We know of one informal, anonymous analysis of the normal Gini coefficient and height (a blog at http://www.bball.ninja/?p=11). That analysis used data for 60 nations from Wikipedia entries on average height and a variable termed the 'wealth Gini', but the source of this type of Gini coefficient is not given. Negative correlations were found, with r^2 = -0.17 for men and r^2 = -0.15 for women. These are similar to our findings, but the magnitude of the association is significantly smaller.

A peer-reviewed article investigated 439 growth studies from 130 countries published during the past 35 years for the relationship of height at age 2 and 7 years with GDP per capita and the normal Gini coefficient from World Bank data (Mumm et al. in press.). The Gini coefficient had a negative correlation with height and weight at both ages and GDP per capita had a positive correlation, although the magnitude of the Gini correlations (2 year olds, r = -.47; 7 year olds, r = -.54) were smaller than those found in the present study. Even so, the findings by Mumm and colleagues indicate that adult height differences associated with income inequality may be established by 2 years of age.

The human biology and economic history literature are replete with studies of height, GDP and GDP per capita. In the 1980s and 1990s some researchers tried to show the interdependence of GDP and height. Baten and Blum report that, "…over the past two decades evidence has emerged indicating that they should be regarded as independent indicators…GDP per capita is a measure of a nation's purchasing power, whereas height is more closely correlated with nutrition, health care, and inequality" (Baten & Blum 2012, p S76).

Popular media often report that nations with a higher GDP are, on average, taller than nations with lower GDP (e.g., http://usatoday30.usatoday.com/news/health/2007-07-15-height_N.htm ; https://www.theguardian.com/news/datablog/2014/oct/02/why-a-countrys-average-height-is-a-good-way-of-measuring-its-development). This seems to be too simplistic an explanation. The present analysis indicates that across 169 countries, national

GDP is not associated with adult height. A nation's average purchasing power as measured by GNI_PPP (a per capita measure) is a predictor of adult height. This was also found in the previous studies of GDP per capita reviewed in Baten and Blum (2012). Income inequality, as measured by the normal Gini, and especially by the Giniw, is an even stronger predictor of adult height, as well as sexual dimorphism in adult height.

The creators of the Giniw used in the present analysis write that the Giniw, "…can be considered an indicator of the distribution of related resources, or bias in related policies and institutions, and those factors may well be altered to generate more desirable outcomes in health equality in the future" (Petrie & Tang 2008 p. 6). We agree with this assessment as the present analysis finds that some of the tallest humans alive today are living in Netherlands, Belgium, Denmark, and Iceland - countries that promote social-economic-health equality through taxation and equitable distribution of human services (e.g., education, housing, medical care).

The association of policies and institutions with greater health and height is not perfect. The countries of Estonia, Latvia, Bosnia and Herzegovina, Croatia and Serbia are also among the top 10 tallest countries. These countries suffer from high unemployment, insufficient funding of schools, medical institutions, and social services (Stocker and Vogiazides, 2010). There may some genetic basis to the tall average stature of adults in these countries, but it is just as likely that their below average Giniw coefficients mean that whatever resources are available are being shared more equitably by their citizens. It is when a nation's poorest people are systematically excluded from social and health services that the average height of adults is reduced. One example from Table 1 is the United States, which ranks 35th in men's and women's height despite ranking 1st in terms of GDP and 9th in terms of GNI_PPP (6th if the oil-rich states of Kuwait, Brunei, and UAE are removed).

Previous research shows that biases in policies and institutions have a deep history. Analyses of skeletal samples of humans who lived during the past 40,000 years find that the popular notion that the average height of our species increased with time is incorrect. Based on skeletal remains, Upper Paleolithic adults from European, Eastern Mediterranean (Levant), and North African archaeological sites were, on average, about 10 percent taller and 30 percent heavier than living humans (Ruff et al., 1993; Mathers and Henneberg, 1996; Boix and Rosenbluth, 2014). Upper Paleolithic peoples were foragers and based on ethnographic studies of living foragers this style of subsistence promotes economic and social equality within groups (Hawkes, 2000; Bogin, 2001). A consortium of anthropologists and economists, led by Samuel Bowles, Eric Alden Smith, and Monique Borgerhoff Mulder, estimated Gini coefficients for 21 forager, pastoral, and non-mechanized agrarian societies (Smith et al., 2010). As these societies are without monetary systems the estimation of the Gini coefficient was based on household-level data for wealth measures in each population (see Smith et al, 2010 for details). The authors report Gini coefficients less than 0.2 among the foragers and in the range of 0.4–0.5 for the pastoral and agrarian societies. The authors do not report any height data, but do report 5 cases of body weight data. It appears that there is no association between the estimated Gini coefficient and body weight in these small-scale, pre-modern societies.

An analysis of the past 8,000 years of data on adult human height in Latin America (Bogin and Keep, 1999) reports an association of adult height with two proxies for economic inequality, social stratification and political hierarchy (Boix and Rosenbluth, 2014). Bogin and Keep found that average heights were at maximum when people subsisted as foragers and horticulturalists, prior to 5,000 years BP. Average heights declined over time as more intensive agrarian societies with greater social and political stratification emerged. Despite the overall decline in height of 2 cm, estimated statures from skeletal remains tended to increase for the elite leaders of agricultural state societies (Maya, Aztec, Inca). After the European Conquest of 1500 CE the height of all Latin Americans declined by a further ~5 cm, except again for the elite social classes. After 1940 an upward trend in average height was noted and seemed associated with economic and social modernization in Latin America after World War II and with economic investment programs from North America and Europe. But, even as late as the 1980s the average height of Latin American men and women was ~2 cm less than that for the pre-5000 BP foragers and horticulturalists.

The 8,000 years of height analysis also found that the sexual dimorphism in average stature remained fairly constant at all times, with a mean difference in height between men and women of ~12 cm. Even as measured heights declined by 10 cm between the years 1500 and 1940, the average difference between the sexes remained about equal. Based on that finding, we hypothesized that variation in the economic indicators would not affect the sexual dimorphism in height of men and women for the present analysis. This hypothesis is rejected.

There is much literature on the value of sex differences in morphology as an indicator environmental quality (Stinson, 1985; Bogin, 1999; Nikitovic and Bogin, 2014; Cámara, 2015). Human males grow, on average, larger and mature more slowly than females. This allows for greater male exposure to environmental influences and, in principle, to greater environmental alteration of the phenotype. When environments are adverse the height of adult men could be more negatively affected than the height of adult women and sexual dimorphism will be reduced. Conversely, under good environmental conditions men may grow to a greater height and sexual dimorphism may be increased. This is the finding of the present analysis. A recent analysis of long-term trends in height of South Korean men and women found increases in height with rising GDP and living standards for both sexes, but no change in average sexual dimorphism (Sohn, 2016). At this time, sexual dimorphism may not be as reliable an indicator of environmental quality as is height itself.

Conclusion

The global analysis of income and income inequality on adult height and sexual dimorphism in height presented here provides new evidence that human height is more sensitive to inequality than to absolute income. Our findings for height, and sexual dimorphism in height, support a literature of the past 30 years that argues compellingly for the greater impact of inequality, over absolute income, on human health. The publications of Amartya Sen, Richard Wilkinson and Kate E. Pickett, and Michael Marmot elegantly and passionately make the case for the pernicious effects of inequality on health (Sen, 2002; Wilkinson and Pickett, 2009; Marmot, 2015). Based on his analysis of gradients in social disadvantage, Marmot writes that, “The gradient in health in rich countries makes clear that we are discussing social inequalities more than absolute amounts of money” (Marmot, 2015, p. 2444). Marmot uses the word ‘pollutant’ to describe the impact of inequality and social disadvantage on human well-being. In his view, these pollutants disempower people from the resources needed for their own healthy growth and development and for the health and good growth of their children. The poor suffer from poverty (low income), but most people in modern nation-states exist along a gradient of access to resources that is determined by social, educational, and occupational status as much or more than income. Anthropologists know that this was also true for ancient state societies, as shown in the analysis above of Latin American height variation for the past 8,000 years. The social status differences not only influence income and wealth, but also decisions and behaviors related to diet, health care seeking, smoking, alcohol consumption, sexual activities, educational attainment and other similar variables that are associated with physical growth. There is also evidence that the social status differences themselves influence neuroendocrine activity that regulates growth in height (Bogin et al., 2015; Hermanussen and Scheffler, 2016). Economists such as Sen, public health researchers such as Marmot, and many anthropologists and physicians, including the present authors, agree that promoting greater equality is the most effective way to narrow the social gradient and improve the well-being of all members of society.

Author Contributions:

BB, CS, and MH contributed theoretical concepts and data. BB drafted the first version of the manuscript. MH and CS edited the manuscript for intellectual content and provided critical comments on the manuscript.

Acknowledgements

Our thanks to Prof. Darna Dufour and Dr. Robin Bernstein for the invitation to contribute to the Human Biology Association Plenary session and to this special issue of the AJHB. We thank two anonymous reviewers, Ines Varela-Silva, Timothy Hatton and Sofia Karina Trommlerova for helpful comments that improved the presentation of this article.

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Figure1: A flow diagram suggesting the relationships of living conditions to the proximate determinants of average adult height and some consequences of variation in height. Each term under the boxes (Income, Diet, Morbidity, etc.) represents a category that includes multiple factors. It is difficult to measure, or even estimate, the effect size of each category and its factors. More factors could be added within each category. Complex interactions exist between and within categories due to sex, gender, chronological age and biological maturation at the time of exposure, and past history of exposure to factors. Adapted with major modifications from (Steckel 2012).

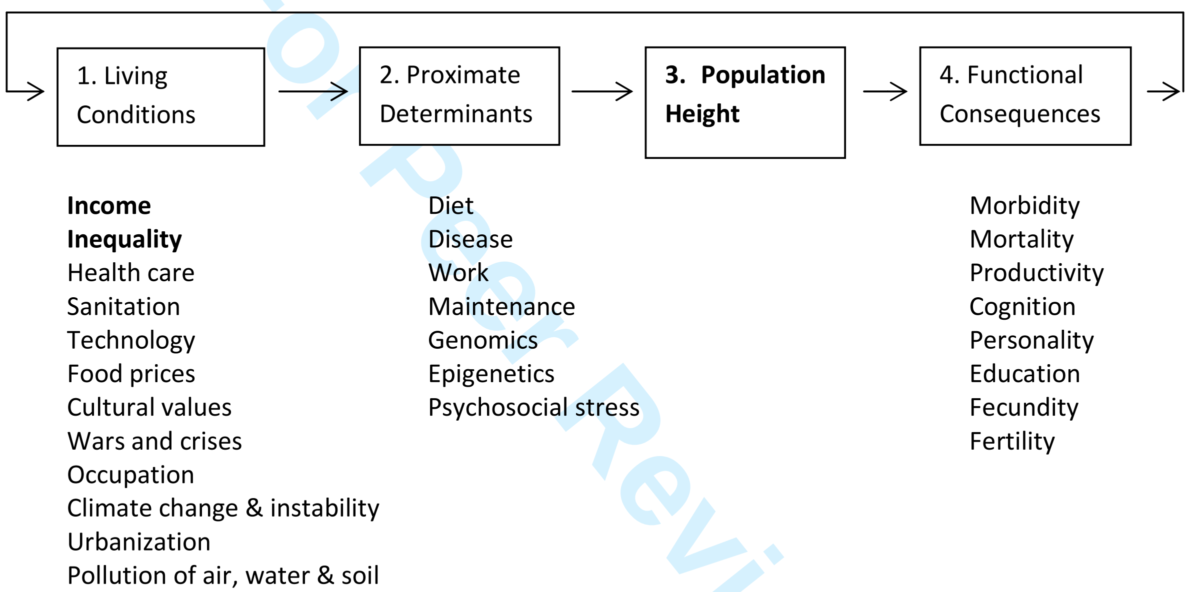

Figure 2. Scatter plots of mean national height for women by Gross National Income per capita adjusted for Personal Purchasing Power (GNI_PPP in $US) and Gini standardized by the Wagstaff method (Giniw). The data are fit by linear regression; regression equations shown above the graph.

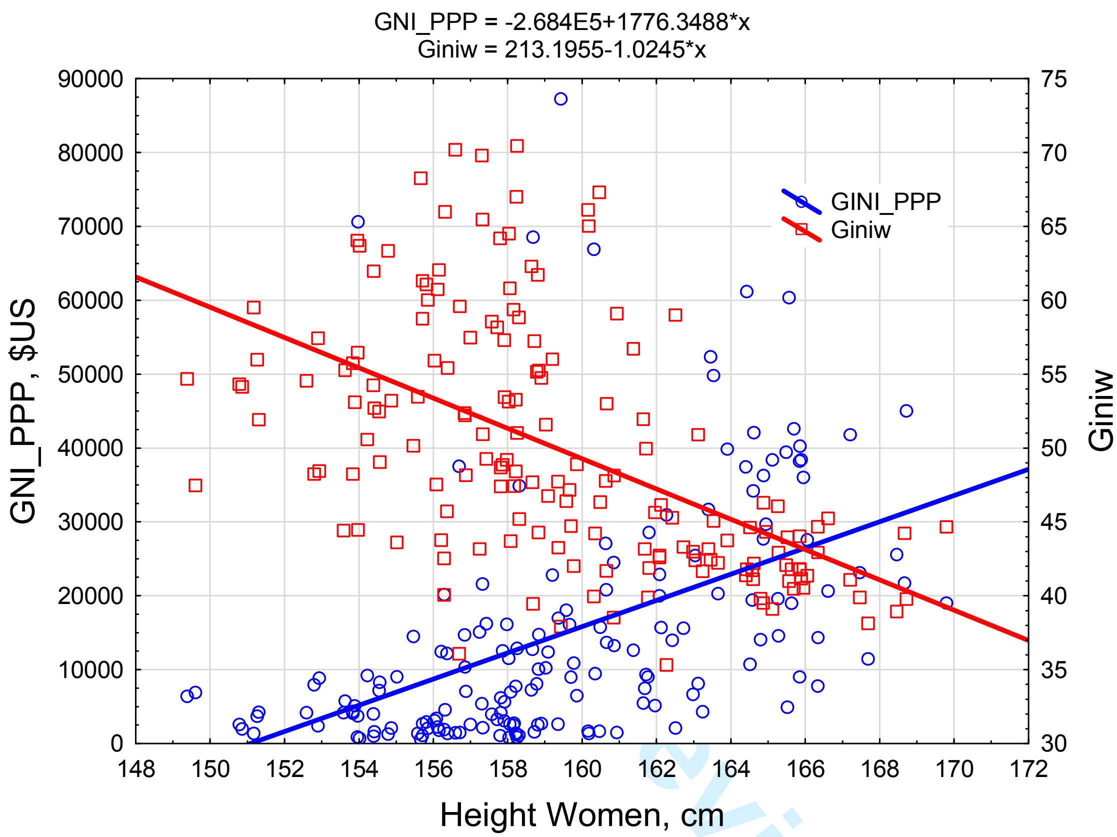

Figure 3. Scatter plots of mean national height for men by Gross National Income per capita adjusted for Personal Purchasing Power (GNI_PPP in $US) and Gini standardized by the Wagstaff method (Giniw). The data are fit by linear regression; regression equations shown above the graph. The black arrow points to the height-Giniw data point for the Netherlands; with the tallest men, 182.54 cm, and a relatively low Giniw of 39.77. The black circle encloses the United States (177.1 cm, Giniw = 45.05), Grenada (176.97, Giniw = 44.61), and the Russian Federation (176.46 cm, Giniw 46.05).

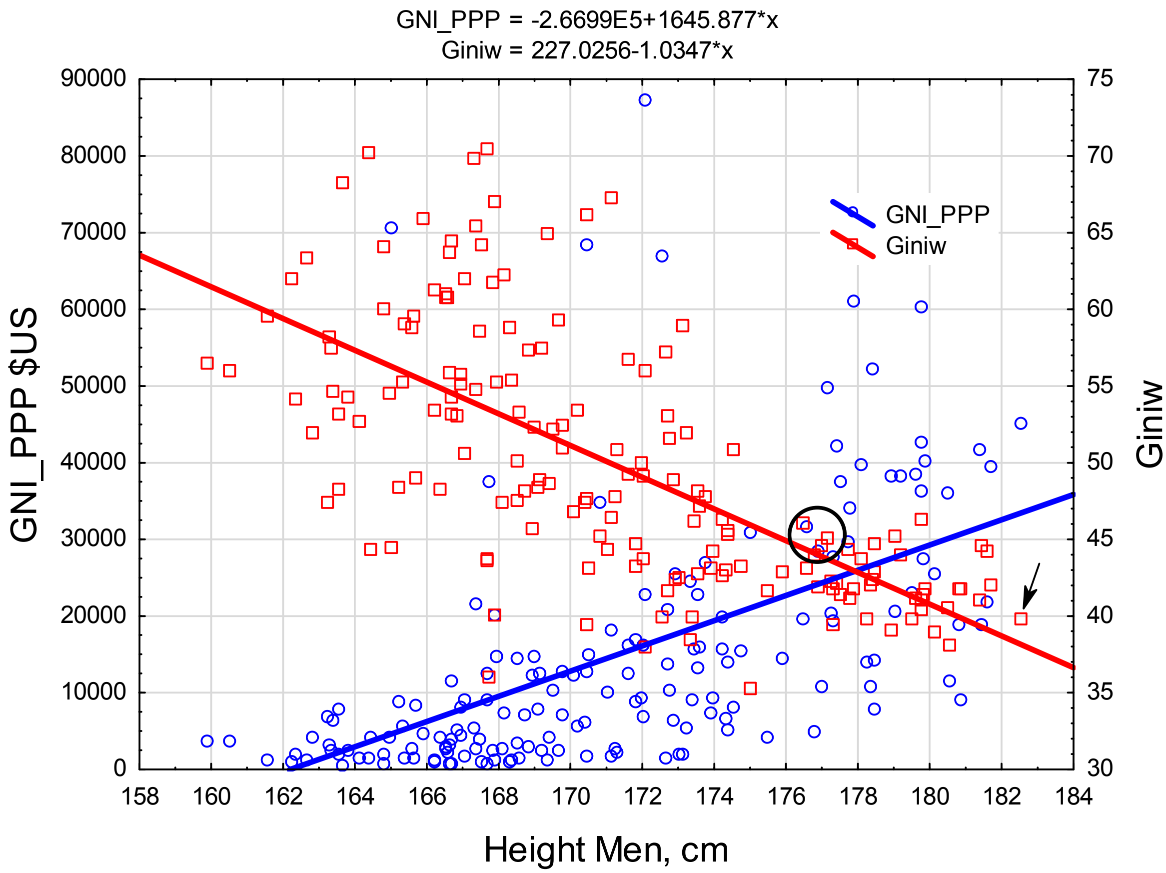

Table 1. Variable used in the analysis. The Countries are ordered by the height of men, from tallest to shortest.

	Country	Height Men, cm	Height Women, cm	Height difference M-W	GDP $US millions	GNI_PPP $US	Giniw
1	Netherlands	182.54	168.72	13.82	8364.40	45012	39.77
2	Belgium	181.70	165.49	16.21	4835.77	39451	42.07
3	Estonia	181.59	168.67	12.92	194.95	21717	44.22
4	Latvia	181.42	169.80	11.62	237.43	18994	44.65
5	Denmark	181.39	167.21	14.17	3198.11	41795	41.08
6	Bosnia and Herzegovina	180.87	165.85	15.02	171.63	8974	41.80
7	Croatia	180.78	165.63	15.15	596.81	18982	41.79
8	Serbia	180.57	167.69	12.88	394.60	11457	38.12
9	Iceland	180.49	165.95	14.55	132.37	36003	40.52
10	Czech Republic	180.10	168.46	11.65	2070.16	25553	38.93
11	Germany	179.88	165.86	14.02	34172.98	40263	41.76
12	Slovenia	179.80	166.05	13.75	480.16	27554	41.36
13	Norway	179.75	165.56	14.18	4285.25	60365	40.99
14	France	179.74	164.88	14.86	26469.95	36244	46.29
15	Sweden	179.74	165.70	14.04	4883.79	42596	40.46
16	Finland	179.59	165.90	13.69	2478.15	38433	41.15
17	Slovak Republic	179.50	167.47	12.04	892.54	23104	39.86
18	Australia	179.20	165.86	13.35	11422.51	38215	44.02
19	Lithuania	179.03	166.62	12.41	371.33	20626	45.22
20	Ireland	178.93	165.11	13.81	2200.76	38371	39.10
21	Ukraine	178.46	166.34	12.12	1364.19	7787	44.68
22	Belarus	178.44	166.35	12.09	552.21	14341	42.92
23	Switzerland	178.42	163.45	14.97	5812.12	52357	42.44

24	Macedonia, FYR	178.33	159.78	18.55	94.07	10864	42.00
25	Bulgaria	178.24	164.80	13.44	499.39	14040	39.81
26	Canada	178.09	163.91	14.18	16134.06	39854	43.73
27	Luxembourg	177.86	164.43	13.43	523.52	61173	41.78
28	Italy	177.77	164.61	13.16	21251.85	34184	41.11
29	New Zealand	177.74	164.94	12.80	1465.85	29657	44.32
30	United Kingdom	177.49	164.40	13.09	24035.04	37432	41.37
31	Austria	177.41	164.62	12.79	3902.35	42074	42.19
32	Poland	177.33	164.59	12.74	4792.43	19413	41.72
33	Greece	177.32	164.87	12.44	2993.79	27665	39.50
34	Hungary	177.26	163.66	13.60	1300.94	20269	42.21
35	United States	177.13	163.54	13.59	149643.72	49801	45.05
36	Grenada	176.97	164.51	12.45	7.71	10717	44.61
37	Israel	176.86	161.80	15.06	2343.22	28560	41.87
38	Tonga	176.76	165.52	11.24	3.70	4890	43.95
39	Spain	176.59	163.40	13.20	14316.73	31689	43.17
40	Russian Federation	176.46	165.27	11.19	15249.17	19597	46.05
41	Barbados	175.92	165.28	10.64	44.46	14580	42.92
42	Moldova	175.49	163.24	12.25	58.12	4257	41.67
43	Cyprus	174.99	162.27	12.72	252.47	30932	35.31
44	Romania	174.74	162.73	12.02	1679.98	15580	43.28
45	Jamaica	174.53	163.12	11.41	131.91	8109	50.89
46	Lebanon	174.39	162.43	11.96	380.10	13955	45.28
47	Samoa	174.38	161.97	12.41	6.57	5144	45.63
48	Georgia	174.34	162.98	11.36	116.39	6637	42.98
49	Seychelles	174.22	162.08	12.14	9.70	19962	42.60
50	Turkey	174.21	160.50	13.71	7311.68	15763	46.34
51	Tunisia	173.95	160.35	13.60	440.51	9431	44.21
52	Fiji	173.90	161.69	12.21	31.41	7455	43.17
53	Trinidad and	173.74	160.64	13.09	210.38	27052	47.77

	Tobago						
54	Iran, Islamic Rep.	173.57	159.67	13.90	4677.90	16057	47.15
55	Brazil	173.55	160.86	12.69	22088.72	13227	48.13
56	Libya	173.53	162.08	11.44	747.73	22881	42.72
57	Uruguay	173.43	162.13	11.30	402.85	15676	46.13
58	Albania	173.39	161.77	11.62	119.27	9003	39.88
59	Malta	173.32	160.85	12.47	81.63	24497	38.51
60	Cape Verde	173.22	161.65	11.57	16.64	5469	51.96
61	Senegal	173.14	162.52	10.62	129.32	2089	59.00
62	Syrian Arab Republic	173.00	156.30	16.70	404.05	1860	42.52
63	Portugal	172.93	163.04	9.89	2383.18	25435	42.40
64	Paraguay	172.83	159.86	12.98	200.31	6470	48.89
65	Dominican Republic	172.75	159.03	13.72	538.64	10200	51.56
66	Suriname	172.72	160.66	12.06	43.68	13669	53.00
67	Antigua and Barbuda	172.71	160.65	12.05	11.36	20815	41.69
68	Haiti	172.64	158.72	13.92	66.23	1557	57.23
69	Singapore	172.57	160.32	12.25	2364.22	66903	39.95
70	Puerto Rico	172.08	159.20	12.88	983.81	22781	56.00
71	Kuwait	172.07	159.43	12.64	1154.19	87267	37.92
72	Armenia	172.00	158.09	13.91	92.60	6950	43.70
73	Cuba	172.00	157.98	14.01	643.28	16119	49.19
74	Turkmenistan	171.97	161.73	10.24	225.83	9337	49.94
75	China - national 100%	171.83	159.71	12.12	60396.59	8948	44.71
76	Chile	171.81	159.36	12.45	2175.38	16986	43.25
77	Botswana	171.63	161.38	10.25	127.87	12603	56.72
78	Venezuela, RB	171.59	157.44	14.16	3938.01	16200	49.27
79	Tajikistan	171.26	157.33	13.94	56.42	2118	50.91

80	Kyrgyz Republic	171.24	159.35	11.89	47.94	2621	47.73
81	Kazakhstan	171.14	159.58	11.57	1480.47	18046	46.40
82	Mali	171.12	160.47	10.65	106.79	1643	67.29
83	Jordan	171.03	158.83	12.20	264.25	10059	44.29
84	Japan	170.82	158.31	12.50	54987.18	34862	45.17
85	Mauritius	170.50	157.24	13.25	97.18	15056	43.17
86	United Arab Emirates	170.46	158.68	11.77	2860.49	68530	39.45
87	Chad	170.44	160.17	10.27	106.58	1675	66.12
88	Iraq	170.43	158.67	11.76	1385.17	12732	47.68
89	Morocco	170.40	157.82	12.58	932.17	6179	47.40
90	Guyana	170.21	157.92	12.29	22.59	5621	53.44
91	Algeria	170.07	159.09	10.98	1612.07	12364	46.75
92	El Salvador	169.77	154.55	15.22	214.18	7158	52.46
93	Azerbaijan	169.75	158.25	11.50	529.03	12869	51.03
94	Kenya	169.64	158.16	11.48	400.00	2468	59.36
95	Colombia	169.50	156.85	12.64	2870.18	10355	52.20
96	Uzbekistan	169.38	157.82	11.57	393.33	4170	48.67
97	Burkina Faso	169.33	160.19	9.14	89.80	1355	65.01
98	Kiribati	169.20	157.00	12.20	1.50	2583	57.46
99	Thailand	169.16	157.87	11.29	3409.24	12529	48.86
100	Mongolia	169.07	158.22	10.85	71.89	7734	48.41
101	Mexico	169.01	156.85	12.16	10511.29	14687	52.36
102	Costa Rica	168.93	156.37	12.57	362.98	12181	45.71
103	Ghana	168.85	157.91	10.94	321.75	3037	57.31
104	Belize	168.73	156.88	11.86	13.97	7030	48.15
105	Zimbabwe	168.59	158.22	10.37	94.22	1383	53.25
106	Micronesia, Fed. Sts.	168.51	156.09	12.43	2.94	3377	47.51
107	Panama	168.49	155.47	13.02	289.17	14506	50.14
108	Eritrea	168.36	156.39	11.97	21.17	1329	55.41

109	Togo	168.33	158.30	10.03	31.73	1097	58.83
110	Swaziland	168.13	158.64	9.50	35.28	7273	62.30
111	Vanuatu	168.09	158.17	9.92	7.01	2713	47.43
112	Gabon	167.94	158.84	9.10	143.59	14720	55.26
113	Guinea-Bissau	167.90	158.24	9.66	8.47	1278	66.99
114	Malaysia	167.88	156.30	11.59	2550.17	20136	40.06
115	Cameroon	167.82	158.82	9.01	236.22	2523	61.72
116	Bahrain	167.74	156.69	11.05	257.13	37512	36.06
117	Palau	167.69	156.22	11.47	1.84	12405	43.76
118	Maldives	167.68	155.02	12.66	23.23	9048	43.61
119	Niger	167.68	158.25	9.42	57.19	798	70.45
120	Guinea	167.54	157.80	9.74	47.36	1054	64.19
121	Congo	167.45	157.57	9.87	120.08	3934	58.54
122	Sao Tome and Principe	167.38	158.91	8.48	1.95	2667	54.74
123	Equatorial Guinea	167.36	157.33	10.04	127.09	21560	65.47
124	Angola	167.31	157.31	10.01	824.71	5377	69.80
125	Ecuador	167.08	154.23	12.84	695.55	9182	50.58
126	Benin	167.06	156.16	10.90	69.70	1734	62.04
127	Namibia	166.96	158.78	8.19	112.82	8055	55.14
128	Pakistan	166.95	153.84	13.10	1774.07	4374	55.74
129	Bolivia	166.85	153.89	12.96	196.50	5071	53.09
130	Nicaragua	166.71	154.39	12.31	87.41	3968	54.24
131	South Africa	166.68	158.03	8.65	3753.49	11499	53.13
132	Central African Republic	166.67	158.04	8.64	19.86	788	64.50
133	Burundi	166.64	154.02	12.61	20.27	688	63.68
134	Sudan	166.63	156.04	10.59	656.34	3079	55.91
135	Djibouti	166.57	156.11	10.46	11.29	2220	60.72
136	Cote d'Ivoire	166.53	158.07	8.47	248.85	2595	60.81

137	Zambia	166.52	155.82	10.70	202.66	2885	61.07
138	Honduras	166.39	153.84	12.55	158.39	4066	48.24
139	Ethiopia	166.23	155.71	10.52	299.34	1035	61.31
140	Comoros	166.19	155.58	10.61	5.17	1332	53.45
141	Nigeria	165.91	156.32	9.59	3690.62	4549	65.98
142	Sri Lanka	165.69	154.56	11.12	567.26	8256	49.05
143	Uganda	165.62	156.72	8.91	201.82	1463	59.59
144	Lesotho	165.59	155.71	9.88	21.87	2649	58.76
145	Gambia	165.40	160.93	4.47	9.52	1483	59.10
146	Bhutan	165.31	153.63	11.68	15.85	5760	55.27
147	Peru	165.23	152.93	12.30	1485.22	8839	48.43
148	Brunei Darussalam	165.01	153.98	11.03	123.71	70608	44.44
149	India	164.95	152.59	12.36	17084.59	4151	54.53
150	Tanzania	164.80	155.86	8.94	314.08	2042	60.01
151	Mozambique	164.80	153.96	10.84	101.54	862	64.03
152	Vietnam	164.45	153.59	10.85	1159.32	4168	44.40
153	Sierra Leone	164.41	156.60	7.81	26.17	1417	70.19
154	Solomon Islands	164.14	154.42	9.73	6.72	1601	52.68
155	Bangladesh	163.81	150.79	13.02	1152.79	2563	54.32
156	Liberia	163.66	155.66	8.00	12.93	576	68.26
157	Papua New Guinea	163.57	154.87	8.70	97.16	2058	53.20
158	Indonesia	163.55	152.80	10.75	7550.94	7935	48.23
159	Guatemala	163.41	149.39	14.02	413.38	6389	54.69
160	Cambodia	163.33	152.91	10.42	112.42	2369	57.44
161	Mauritania	163.28	157.72	5.56	43.38	3270	58.16
162	Philippines	163.23	149.61	13.62	1995.91	6871	47.47
163	Marshall Islands	162.81	151.31	11.50	1.64	4242	51.92
164	Rwanda	162.68	154.79	7.89	56.99	1268	63.35
165	Nepal	162.32	150.86	11.46	160.03	1936	54.12

166	Malawi	162.23	154.40	7.82	69.60	971	61.96
167	Madagascar	161.55	151.18	10.37	87.30	1354	59.50
168	Lao PDR	160.52	151.27	9.25	71.81	3671	55.99
169	Yemen, Rep.	159.89	153.97	5.92	309.07	3707	56.45

Table 2. Descriptive statistics for all variables, n=169 countries. Abbreviations are: GDP - Gross Domestic Product, GNI_PPP - Gross National Income per capita adjusted for personal purchasing power, Giniw - Gini coefficient calculated by the Wagstaff method.

Variable	Mean	Median	Minimum	Maximum	Std.Dev.
Height Men, cm	171.23	170.50	159.89	182.54	5.43
Height Women, cm	159.44	158.78	149.39	169.80	4.43
Height difference, M-W, cm	11.79	12.05	4.47	18.55	2.02
GDP $US millions	368.00	264.25	1.50	149644	13781
GNI_PPP $US	14827.69	9003.00	576.00	87267.00	16113.68
Giniw	49.85	48.13	35.31	70.45	8.31

Table 3. Height of adult men related to economic indicators based on a forward stepwise regression analysis (N = 169). Abbreviations are: GDP - Gross Domestic Product, GNI_PPP - Gross National Income per capita adjusted for personal purchasing power, Giniw - Gini coefficient calculated by the Wagstaff method.

	Zero-Order *r*				β	*multr*^{2}	*p*
Variable	GDP	GNI_PPP	Giniw	Height			
Giniw				-.68*	-.54	.46	< .001
GNI_PPP			- .62*	.55*	.22	.49	<.001
GDP		.29*	-.15*	.19*			NS

Intercept = 187.73 *SE = 2.55*

*p < .05

Table 4. Height of adult women related to economic indicators based on a forward stepwise regression analysis (N = 169). Abbreviations are: GDP - Gross Domestic Product, GNI_PPP - Gross National Income per capita adjusted for personal purchasing power, Giniw - Gini coefficient calculated by the Wagstaff method.

	Zero-Order *r*				β	*multr*^{2}	*p*
Variable	GDP	GNI_PPP	Giniw	Height			
Giniw				-.55*	-.40	.30	< .001
GNI_PPP			- .62*	.49*	.24	.34	<.001
GDP		.29*	-.15*	.15*			NS
		Intercept =	168.99		*SE* = 2.27		

*p < .05

Text Box 1. Definitions of economic indicators. All definitions are based on The World Bank usage (Index Mundi data portal (http://www.indexmundi.com/facts/indicators/). Values for these indicators are most commonly calculated in current United States dollars.

GDP (Gross Domestic Product) is the monetary value of all the finished goods and services produced within a country's borders in a specific time period. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

GNI (Gross national Income) is the sum of value added by all resident producers plus any product taxes and minus subsidies not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad. The GNI has replaced the GDP for many economic analyses.

GNI per capita PPP (GNI_PPP) is the GNI adjusted for population size and purchasing power parity (PPP). GNI_PPP represents gross national income converted to international United States dollars using purchasing power parity rates. An international dollar has the same purchasing power over GNI as a U.S. dollar has in the United States.

It important to express GNI per capita in purchasing power parity (PPP) international dollars when comparing the more than 200 countries and territories with different currencies and with very different price levels. To compare economic statistics across countries, the data must first be converted into a common currency. Unlike market exchange rates, PPP rates of exchange allow this conversion to take account of price differences between countries. In this way, GNI per capita (PPP $) better reflects people's living standards uniformly. In theory, 1 PPP dollar (or international dollar) has the same purchasing power in the domestic economy of a country as US$1 has in the US economy).

Gini coefficient measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. A Lorenz curve plots the cumulative percentages of total income received against the cumulative number of recipients, starting with the poorest individual or household. The GINI coefficient measures the area between the Lorenz curve and a hypothetical line of absolute equality, expressed as a percentage of the maximum area under the line. Thus a Gini coefficient of 0 represents perfect equality, while an coefficient of 100 implies perfect inequality. The GINI coefficient is applicable only where and when data for monetary income are available – generally since the 20th century.

Giniw also called the Wagstaff index or Concentration index. It is a standardized Gini coefficient calculated by dividing the World Bank Gini value by the maximal attainable Gini coefficient. The latter is computed based on the maximal level of a health attribute an individual could achieve. In this article maximal lifespan is the health attribute as estimated by Petrie and colleagues (Petrie and Tang, 2008; Petrie et al., 2015).