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Original Research Article

Is Leg Length a Biomarker of Early Life Conditions? Evidence from a Historically Short Population

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Objectives: While one group (Positive Group) has argued that leg length is a more accurate biomarker of early life conditions than height, another group (Negative Group) has challenged this argument. Analyzing Indonesian data, we attempt to reconcile these contrasting arguments.

Methods: The sample consists of 4,193 men and 4,684 women, aged 40–70. We regress leg length, trunk length, and height each on education (a proxy for early life conditions), age, and ethnicity. We also adjust for hip size and shrinkage.

Results: The relationship is statistically significant for leg length, which is generally consistent with the assertion of the Positive Group. However, the relationship is smaller than that for height, which is generally consistent with that of the Negative Group. Specifically, an additional year of schooling is associated with a 0.080 cm longer leg length for men and 0.078 cm for women. The corresponding figures for height are 0.260 cm and 0.201 cm. This remains true when the magnitude of the relationship is compared with the mean length.

Conclusions: Small sample sizes appear to drive the Negative Group's finding that leg length is not statistically significantly related to early life conditions. However, the magnitude of the relationship confirms the Negative Group's argument that leg length is not a more accurate biomarker of early life conditions than height. Am. J. Hum. Biol. 27:538–545, 2015.

Early life conditions have been recognized as playing an important role in later life outcomes (e.g., Almond and Currie, 2011; Kuh and Ben-Shlomo 2004, for reviews). Later-life outcomes include not only monetary outcomes such as earnings but also nonmonetary outcomes such as health. When two events are separated over a long time, as in this case, longitudinal data are effective in determining how they are related. However, these are scarce and limited resources, particularly for developing countries. In this case, biomarkers of early life conditions provide an alternative way of relating the events. Height is one of the widely used biomarkers of early life conditions in many disciplines (Steckel, 2009, for a review), because, given genetic factors, an environment that provides sufficient nutrition and is free of diseases and extreme weather conditions increases a person's height (Silventoinen, 2003, for a review).

Building on this idea, recent research has investigated whether a certain component of height is more sensitive to early life conditions than others. One group of researchers (referred to as the Positive Group in this article) has argued that leg length is a more accurate biomarker than height, demonstrating that early life conditions had a greater relationship with leg length than with trunk length or height (Bogin et al., 2002; Floyd, 2007; Gunnell et al., 1998a; Li et al., 2007; Wadsworth et al., 2002); all of them used data collected from developed countries. Based on this idea, there have been attempts to relate leg length to later life outcomes (e.g., Frisancho, 2007; Gunnell et al., 1998b; Langenberg et al., 2003; Smith et al., 2001). At first, this idea is appealing, because it is consistent with the cephalocaudal gradient in mammalian growth (Leitch, 1951), which implies that leg length is more heavily compromised by malnutrition than trunk length. A natural extension of this argument is that as malnutrition is addressed, leg length grows faster than trunk length. In fact, this has been supported by secular trends in height components in Japan (Ali et al., 2000), Taiwan (Floyd, 2007), Europe (Cole, 2003), and the US (Jantz and Jantz, 1999).

If it is true that leg length is more sensitive to early life conditions, it can be an important tool for many disciplines that have used height for various purposes. Despite the initial appeals, however, it remains open to debate whether the cephalocaudal gradient can be generalized to human growth and whether the macrolevel associations can be applied to microlevel ones (i.e., ecological fallacy). To make matters more complicated, some studies have reported that an increase in height was not accompanied by an increase in relative leg length (e.g., Greulich, 1976; Kaur and Singh, 1981; Kromeyer-Hauschild and Jaeger, 2000). Thus, another group (referred to as the Negative Group in this article) has challenged the Positive Group, demonstrating that early life conditions did not have a statistically significant relationship with leg length, and, if present, the relationship was smaller than that with trunk length or height; all of them used data collected from developing countries (discussed in detail in the last section).

We join this debate, using Indonesian data. As dictated by the debate, the aim of this article is to relate early life conditions to height, leg length, and trunk length and to find a height component that has the greatest relationship with early life conditions. Although our aim is the same as that of the literature, it is not a simple replication study. An Indonesian case can contribute to the literature in

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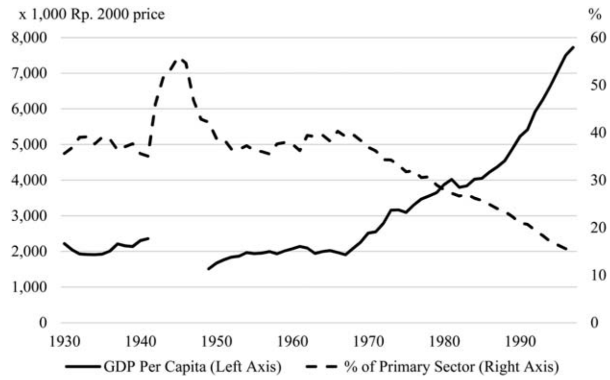

Fig. 1. Trend in Indonesian GDP per capita during 1930–1997. GDP per capita values are not available for 1942–1948.

several ways. First, Indonesia is a developing country, so it can check whether our results are consistent with those of the Negative Group. Second, the current developmental stage of the Indonesian economy is similar to the Chinese one, at least compared to other countries in the literature. Thus, if our results differ from those derived from Chinese data (Schooling et al., 2008a, b), as is the case to some extent, the explanations for the Chinese results will need to be modified. Third, the Positive Group's samples are nationally representative, while those of the Negative Group are not. Thus, it is difficult to claim whether the Negative Group's results concern specific or general populations. In analyzing nationally representative data of a country that is more similar to those of the Negative Group than to those of the Positive Group in terms of economic development stage, this article can improve on the Negative Group's results. Fourth, Indonesia belonged to the region that exhibited the shortest height in the world, at least during the past two centuries (Baten and Blum, 2012). This case can provide interesting insight into the intergenerational effect of early life conditions on height components. Schooling et al. (2008a, b) and Kinra et al. (2011) discussed this possibility. Fifth, related to the fourth contribution, Indonesians remain one of the shortest populations in the world at present. Thus, they can be used to address the question of threshold—that is, whether there is a threshold under which early life conditions have little influence on height components. Kinra et al. (2011) discussed this possibility. Sixth, although intrapopulation differences are largely determined by genetic factors, interpopulation differences are largely determined by environmental factors. As Indonesia exhibits dramatically different aspects of life than those found in the literature (e.g., religion, culture, food, to name only a few), an Indonesian case is interesting in itself.

HISTORICAL BACKGROUND

The Positive and Negative Groups' samples differed largely by the economic development that the samples experienced. The Negative Group's hypothesis is that the first generation to experience economic development in early life might not have longer legs than previous generations. Whether our results turn out to be consistent with the Negative or Positive Group, it is important for comparative purposes to understand the economic development that our sample experienced; the range of birth years is 1936–1968. Thus, this section briefly describes it (Booth, 1998; Sohn, in press a; Van Zanden and Marks, 2012, for details).

Figure 1 graphically summarizes this history using Gross Domestic Product (GDP) per capita and the percentage of the primary sector relative to GDP excluding the oil and gas sector (Van der Eng, 2010). The primary sector consists of food crops, animal husbandry, farm cash crops, estate crops, fisheries, and forestry. Including the oil and gas sector decreases the level of the proportion of the primary sector but does not change the pattern (not shown). The covered period is 1930–1997 to show a broad picture.

The difference between the two end points of the disconnected part in GDP per capita unambiguously shows the great reduction in material standards of living from which Indonesians suffered during the Japanese occupation in 1942–1945. Relatedly, the increase in the percentage of the primary sector during the period implies that the Japanese destroyed a substantial part of the industrial and service sectors.

As soon as the Second World War ended, Sukarno, the Indonesian nationalist leader, proclaimed Indonesian independence from the Netherlands in August, 1945. However, as the Netherlands tried to re-establish their rule, a clash between the Netherlands and Indonesian nationalists ensued. Thus, until the Netherlands formally recognized Indonesian independence in December 1949, the Indonesian economy was largely in disarray, and poverty was widespread.

An immense amount of rehabilitation of war-torn plant and infrastructure temporarily boosted economic growth up to 1957. However, the country had difficulty in stabilizing its political conditions. In the confusion, in the name of "Guided Democracy," Sukarno overthrew the government. His government failed to industrialize the economy and the country experienced a rapid deterioration in terms of trade after 1959 and hyperinflation by the mid-1960s. The unusually dry years in 1961–1967 adversely affected many parts of the country. Eventually, the weakened Sukarno was replaced by Suharto, then head of the armed forces in 1967. The economy saw industrialization in earnest, boosted by the oil boom in the 1970s. Although economic growth slowed in 1982–1987, it was a brief downturn in the medium-term rapid growth—until the Asian financial crisis in 1997.

The percentage of the primary sector suggests that this take-off is due to modernization rather than the expansion of agriculture. Before 1967, the ratio of the primary sector grew, indicating that the period (particularly after the Second World War) witnessed not only the failure of industrialization but also the retrogression of the economic structure. However, after 1967, the percentage started to plummet, coinciding with the take-off of GDP per capita. This historical background suggests that our results would be similar to those of the Negative Group.

MATERIALS AND METHODS

Sources of data

The main source of our data is the Indonesian Family Life Survey (IFLS), an on-going longitudinal survey in Indonesia. The survey was initiated in 1993 and covered over 22,000 individuals from 7,224 households in 13 of the 27 provinces in Indonesia (IFLS1). Provinces were selected to maximize representation of the population, reflect the cultural and socioeconomic diversity, and be cost-effective given the size and the terrain of Indonesia. The resulting sample is representative of 83% of the population in the year. Follow-up surveys were conducted in 1997 (IFLS2), 1998 (IFLS2+), 2000 (IFLS3), and 2007 (IFLS4).

Rothman et al. (2013) argued that the scientific goal of understanding a phenomenon is not enhanced by representativeness but by tightly controlled comparisons drawn over a variety of relevant settings; thus, they warned against favoring representative over nonrepresentative samples for a scientific study. However, they acknowledged that the application of scientific knowledge to specific populations may require representativeness. As this article aims to apply the knowledge of the positive relationship between early life conditions and leg length to the Indonesian population, the representativeness of the sample is appealing.

Sample

As is typically done in the literature, trunk length is represented by sitting height, and leg length is represented by the difference between height and sitting height (i.e., subischial leg length). However, sitting height is available only for respondents aged 40+ in IFLS4. Thus, the analysis inevitably focuses on this group in cross-sectional data. The target households for IFLS4 were the original IFLS1 households, excluding those whose members had died by 2000, but including all of the split-off households from 1997, 1998, and 2000 (excluding those whose members had died). Of the 10,994 target households, ILFS4 recontacted 90.6% (6,596 original IFLS1 households and 3,366 old split-off households) and an additional 4,033 new split-off households were contacted. As the recontact rates are high, attrition bias or sample selection bias does not pose a serious concern. However, survival bias can be concerning if too old respondents are included in the sample. Conversely, excluding too many respondents would result in low statistical power and imprecise estimation. Considering these trade-offs, the age range is restricted to 40–70, which results in the range of birth years 1936–1968. The sample size is 4,193 for men and 4,684 for women.

Variables

The dependent variables of interest are leg length, trunk length, and height. Because the IFLS is a general social science survey, no detailed measurement procedures are provided in the user's guide. However, the guide assures that specially trained nurses measured all anthropometrics, visiting households even word multiple times. Therefore, measurement error and bias are likely to be small (Sohn, 2014a, in press b, c, for details). In addition, all the anthropometrics are measured to the nearest millimeter.

Bogin and Varela-Silva (2008) argued that fatness biased the use of estimated leg length as an epidemiological marker. Specifically, if leg length is represented by the difference between height and sitting height, as in our case, fatness may lead to greater gluteofemoral fat mass, which, in turn, artificially increases sitting height and decreases leg length. To remove this bias, hip size-adjusted leg length and hip size-adjusted trunk length are also considered. Hip size-adjusted leg length is represented by the residual of a regression of leg length on hip size and a constant; hip size-adjusted trunk length is similarly estimated. Although it is of interest to adjust hip size, most studies in the literature have not done so. Thus, for comparison purposes, hip size-unadjusted leg length and trunk length are considered along with the adjusted ones.

The follow-up period of the IFLS is not long enough to trace the early life conditions of respondents, and few questions were retrospectively asked regarding their early life conditions in IFLS4. Thus, the variable of years of schooling is the only reliable measure of early life conditions in IFLS4. This variable differs from that of other studies in that it is constructed using two variables: the highest education level completed and the highest grade completed at that school. This combination of the two variables is important particularly for the developing world because of grade repetition. A small number of respondents—who reported adult education, open university, Islamic school, and school for the disabled as their highest education levels—are excluded because these types of school are not comparable to regular school, and it is difficult to determine years of schooling.

Although this is a single variable, we argue that it accurately reflects early life conditions for the following reasons. When respondents in the sample grew up, they were barely influenced by industrialization. In contrast, they experienced colonization by two countries (the Netherlands and Japan), independence wars, independence, regional rebellions, changes in the government system, and economic underdevelopment. As a result, the demand for education arose only from parents who could afford costs of education for their children—that is, directs costs such as tuitions and indirect costs such as money that the children could have earned if they had worked for pay rather than going to school (Booth, 1998; Van Zanden and Marks, 2012). If the availability of education had been large, even children from poor families could have attended school. However, this was not the case; a palpable growth in availability started only in 1973 (Duflo, 2001; Sohn, 2013).

In the following multivariate analysis, we also control for age and being Javanese (the majority ethnic group), both of which were self-reported.

Statistical analysis

Ordinary least squares are used to assess the relationship between early life conditions and anthropometrics. The specification is as follows.

$$y_i = \beta_1 \mathrm{Edu}_i + x_i \beta_2 + u_i, \quad (1)$$

where y_i refers to individual i's anthropometric, Edu to years of schooling, x to a set of age, a dummy for being Javanese, and a constant, u to an error term, and β_1 and β_2 to a coefficient and a coefficient vector, respectively, to estimate. Sampling weights are applied to make the estimation representative of the age population. Standard errors are clustered at the household level, but this adjustment is inconsequential since, in almost all cases, a single man or woman was interviewed for each household: 4,193 men in 4,142 households and 4,684 women in 4,537 households. A priori, there is no reason to assume that men and women exhibit the same relationship between

TABLE 1. Descriptive statistics

	Men	Women
Continuous Variable	Mean (SD)	Mean (SD)
Height (cm)	160.5 (6.1)	149.4 (5.7)
Shrinkage Adjusted Height (cm)	160.9 (6.0)	149.8 (5.6)
Leg Length (cm)	78.0 (5.3)	72.4 (5.4)
Hip Size-Adjusted Leg Length (cm)	0.0 (5.3)	0.0 (5.4)
Trunk Length (cm)	82.5 (5.1)	77.0 (5.3)
Hip Size-Adjusted Trunk Length (cm)	0.0 (4.8)	0.0 (5.1)
Hip Size (cm)	89.3 (8.0)	92.2 (9.7)
Years of Schooling	6.9 (4.7)	5.0 (4.5)
Age	51.8 (8.5)	51.9 (8.5)
Discrete Variable	%	%
Non-Javanese	54.64	56.06
Javanese	45.36	43.94
N	4,193	4,684

early life conditions and anthropometrics. The sensitivity of long bones to environmental changes may differ between the two sexes (Jantz and Jantz, 1999), and the son preference in Indonesia, particularly in the past, could produce different relationships for the two sexes. Thus, we estimate specification (1) separately by sex. However, for illustrative purposes, after documenting the results of specification (1), we test whether the relationship differs between the two sexes by pooling the two samples and adding a dummy for being female and its interaction term with years of schooling.

Our sample may suffer from shrinkage, and therefore, it is instructive to understand potential bias in $\hat{\beta}_1$ (i.e., the estimate of β_1) when shrinkage is unaccounted for. This bias is essentially omitted variable bias, so it can be considered in this setting. Suppose that u can be decomposed into $\beta_s s$ (a coefficient times shrinkage) and ε (random error): $u=\beta_s s+\varepsilon$. Then, ignoring x for simplicity without losing the substance, $E[\hat{\beta}_1|\text{Edu},\ \text{s}]=\beta_1+\frac{Cov(\text{Edu},\ \text{s})}{Var(\text{Edu})}\beta_s$. In general, high socioeconomic status (SES) individuals exhibit longer anthropometrics (i.e., $\beta_1 > 0$) and experience less shrinkage (i.e., $Cov(\text{Edu},\ \text{s}) < 0$). In addition, shrinkage mainly affects trunk length. Then, $\beta_s \approx 0$ for leg length (= (height - s) - (trunk length - s)) and $\beta_s < 0$ for trunk length and height, and $\hat{\beta}_1$ is biased little for leg length and upward for trunk length and height.

Survival bias can be considered in a similar manner. Suppose that u can be decomposed into $\beta_{sv} sv$ (a coefficient times survival indicator) and ε (random error): $u = \beta_{sv} sv + \varepsilon$. Then, for the stated reasons, $Cov(\text{Edu},\ \text{sv}) > 0$, $\beta_{sv} \approx 0$ for leg length and $\beta_{sv} > 0$ for trunk length and height, and $\hat{\beta}_1$ is biased little for leg length and upward for trunk length and height.

When bias stemming from shrinkage and survival is considered together, $\hat{\beta}_1$ for leg length is considered unbiased and $\hat{\beta}_1$ for trunk length and height upper bounds. However, shrinkage is typically small (Cline et al., 1989). In any event, we also adjust shrinkage as proposed by Cline et al. (1989) and run the same specification; the adjustment is inconsequential. Furthermore, we show below that survival bias is negligible. Therefore, these types of bias should not pose a great concern for our results.

RESULTS

Descriptive statistics

Table 1 presents descriptive statistics by sex. To save space, only some variables of importance are briefly explained. The shortness of Indonesians is striking: the mean height is 160.5 cm (5 feet 3 inches) for men and 149.4 cm (4 feet 11 inches) for women. Shrinkage adjustment hardly makes any difference. When ages are restricted to 40–49, the mean height remains short: 161.5 cm for men and 150.6 cm for women. Thus, there is some indication that the improvement in material conditions resulted in an increase in height, but only slightly. The mean leg length is 78.0 cm for men and 72.4 cm for women.

Because the sample consists of rather old individuals, their education levels are low. The mean years of schooling are 6.9 years for men and 5.0 for women. The sex difference reflects the lower status of women in Indonesia in the past. Although the means are low, the SDs are sufficiently great. Thus, there is little concern that a small variation in the variable would cause severe estimation imprecision, and consequently, statistically insignificant β_1—if this happens, it would be difficult to understand whether the statistical insignificance indicates truly no effect or a false negative. The mean age is about 52 years for both sexes, while the age range is 40–70. Thus, the majority of the sample is not too old to cause large survival bias.

Trends in height and leg length

Before proceeding to the formal results, Figure 2 provides an intuition of the formal results. Height is adjusted for shrinkage, as proposed by Cline et al. (1989). However, as expected from Table 1, unadjusted height produces almost identical results (not shown). Lines are weighted by the number of observations for each sex-by-age cell.

Height (solid line) indicates that younger men and women are taller than older men and women, which is consistent with the fact that living conditions in Indonesia improved over time (Fig. 1). Trunk length (dashed line) exhibits similar trends for both sexes. The trends in leg length (dotted line) for both sexes are the same as those in height and trunk length as far as the direction is concerned. However, for both sexes, the slope of the trend in leg length is flatter than those of height and trunk length. These differences anticipate that leg length is less sensitive to living conditions than height and trunk length, at least in Indonesia. Table A1 in the appendix presents formal results after regressing each anthropometric on age and a constant.

Early life conditions and height components

Table 2 presents the results of specification (1). Age and a dummy variable for being Javanese are controlled for but not listed for brevity. However, Table A2 in the appendix lists all coefficients for leg length for illustrative purposes. The patterns of the coefficients for the other dependent variables are similar and not listed for brevity.

The results for leg length indicate that an additional year of schooling is associated with 0.080 cm longer leg length for men and 0.078 cm for women (Row 1). When hip size is adjusted (Row 2), the corresponding figures decrease to 0.045 cm for men and 0.068 cm for women. This decrease in the coefficient for both men and women indicates that schooling is positively correlated with hip size, which is consistent with the fact that SES is, in general, positively related to obesity in Indonesia (Sohn, 2014b) and in the developing world (Hruschka and

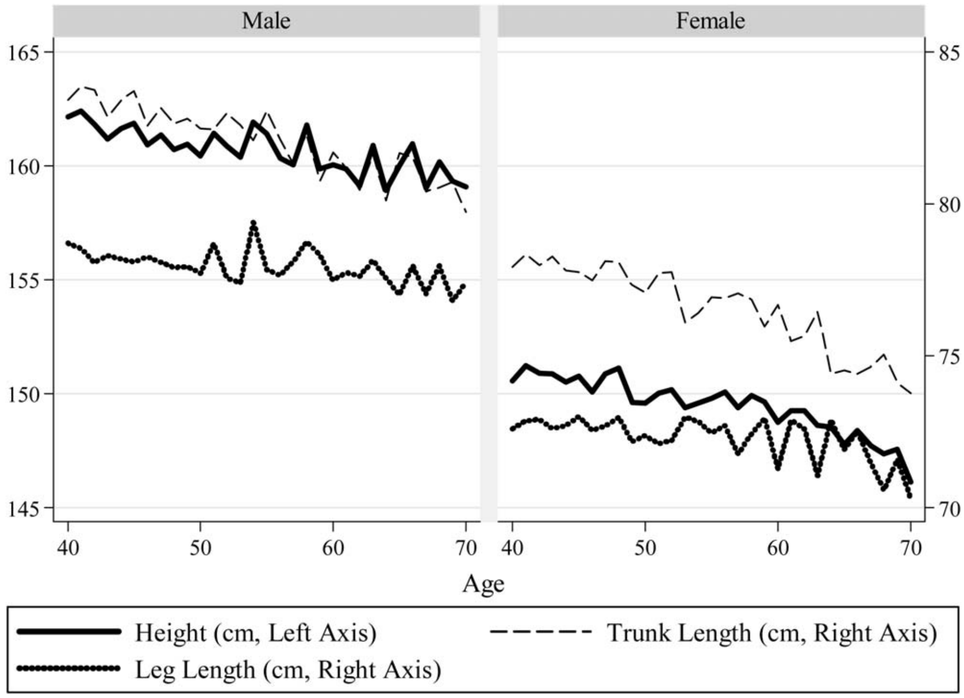

Fig. 2. Anthropometrics by age. Height is adjusted for shrinkage, as proposed by Cline et al. (1989). Lines are weighted by the number of observations for each sex-by-age cell.

TABLE 2. Early life conditions and height components for individuals aged 40–70

	Anthropometric	Men	Women
1	Leg Length (cm)	0.080 (0.020)[b]	0.078 (0.020)[b]
2	Hip Size-Adjusted Leg Length (cm)	0.045 (0.020)[a]	0.068 (0.021)[b]
3	Trunk Length (cm)	0.180 (0.019)[b]	0.123 (0.019)[b]
4	Hip Size-Adjusted Trunk Length (cm)	0.060 (0.018)[b]	0.054 (0.018)[b]
5	Height (cm)	0.260 (0.022)[b]	0.201 (0.020)[b]
6	Shrinkage-Adjusted Height (cm)	0.261 (0.022)[b]	0.202 (0.020)[b]

The listed number refers to the coefficient on years of schooling. Age, a dummy for being Javanese, and a constant are controlled for but not listed. The sample size is 4,193 for men and 4,684 for women. Standard errors are clustered at the household level.
[a]*P*-value$<$0.05
[b]*P*-value$<$0.01

Brewis, 2013). In addition, the smaller decrease for women than for men suggests that women's hip size is less influenced by SES than men's. This is consistent with the fact that women deposit more (essential) fat in the gluteofemoral region than men for pregnancy and lactation (in addition to survival) and that fat utilization from this region is much lower than from any other part of the body, including the mammary glands (Singh, 1993); it is utilized primarily during late pregnancy and lactation.

The results for trunk length show that an additional year of schooling is associated with 0.180 cm longer trunk length for men and 0.123 cm for women (Row 3). These figures are greater than those for leg length. However, when hip size is adjusted, the corresponding figures decrease to 0.060 cm for men and 0.054 cm for women. In relative and absolute terms, this decrease is much greater than that for leg length. This indicates that hip size influences trunk length more than leg length, which makes sense in that, while leg length is mediated by standing height, trunk length is not mediated by any factor. In addition, consistent with the results for leg length, hip size adjustment influences $\hat{\beta}_1$ for men more than for women. When hip size is unadjusted (Row 4), trunk length appears a better indicator of early conditions than leg length. However, when hip size is adjusted, this argument is no longer compelling.

Regarding height (Row 5), an additional year of schooling is associated with 0.260 cm taller height for men and 0.201 cm taller height for women. This size is much greater than those for leg length and trunk length, irrespective of hip size adjustment. Specifically, when hip size is unadjusted, $\hat{\beta}_1$ for male height is 225% greater than that for leg length and 44% greater than that for trunk length. The corresponding figures for women are 158% and 63%. In addition, in all cases (except for Row 2), $\hat{\beta}_1$ is greater for men than for women. This finding is consistent with Jantz and Jantz's (1999) argument that male long bones are more sensitive to environmental changes than female ones. However, we hastily add that, when formally tested, evidence of the statistically significant difference between the sexes is not compelling (Table 3). Shrinkage adjustment is inconsequential (Row 6). In addition, the degree of potential survival bias can be assessed by restricting ages to 40–59; the results are almost the same as those in Table 2 (Table A3 in the appendix).

Relative size

The coefficients listed in Table 2 measure the relationship between education and height components in

TABLE 3. Testing for differences in association by sex for individuals aged 40–70

	Anthropometric	Sex Dummy × Years of Schooling
1	Leg Length (cm)	Not Significant
2	Hip Size-Adjusted Leg Length (cm)	Not Significant
3	Trunk Length (cm)	Significant [b]
4	Hip Size-Adjusted Trunk Length (cm)	Not Significant
5	Height (cm)	Significant [a]
6	Shrinkage-Adjusted Height (cm)	Significant [a]

The male and female samples are pooled. Age, a dummy for being Javanese, a dummy for being female, and a constant are controlled for but not listed. The sample size is 8,877.
[a] *P*-value<0.10
[b] *P*-value<0.05

TABLE 4. Coefficient divided by its anthropometric mean

	Anthropometric	Men (%)	Women (%)
1	Leg Length	0.103	0.108
2	Trunk Length	0.218	0.160
3	Height	0.162	0.135

TABLE 5. Coefficient divided by its anthropometric mean for Webb et al.'s (2008) study

	Anthropometric	Men (%)	Women (%)
1	Leg Length	0.70	0.50
2	Trunk Length	0.39	0.31
3	Height	0.53	0.40

The selected group is men in Poland, and an early life measure is father's education. The mean is used for normalization.

absolute terms. However, leg length is shorter than height, and therefore, the smaller size of the relationship for leg length than that for height does not mean that the former is smaller than the latter in relative terms. For example, suppose that the mean leg length is half of the mean of height. Then, if an additional year of schooling has a relationship with leg length as half as that with height, in relative terms (relative to their means), the size of the relationship is the same for both leg length and height. Hence, although the coefficients in Table 2 are of interest in themselves, if our aim is to estimate the relative strength of the relationship, it is necessary to normalize the coefficients.

Li et al. (2007) and Webb et al. (2008) normalized using SD. However, the mean of the dependent variable critically influences the size of the coefficient, while the SD influences the estimation precision of the coefficient. Thus, each coefficient is divided by the mean of its corresponding anthropometric; hip size-adjusted anthropometrics are not normalized because their means are, by construction, zero. Table 4 shows that leg length continues to have the smallest relationship with years of schooling even in relative terms. When Tables 2 and 4 are considered together, it is evident that leg length is not an accurate biomarker of early life conditions in Indonesia. Height in absolute terms and leg length in relative terms are better qualified.

DISCUSSION AND CONCLUSIONS

Our results are more consistent with those of the Negative Group than those of the Positive Group, but some differences are noteworthy. We do find a statistically significant relationship between early life conditions (proxied by years of schooling) and leg length, which differs from the findings of Schooling et al. (2008a, b). Schooling et al. (2008b) found that the relationship between early life conditions and leg length for women in Guangzhou, China was not statistically significant when age at menarche was not controlled for. It became statistically significant only when age at menarche was controlled for (their Table 2). In addition, when Schooling et al. (2008a) analyzed the same sample separately by sex, they found that leg length was not statistically significantly related to early life conditions for both men and women in Guangzhou, China. However, they found a statistically significant relationship for trunk length and standing height among individuals with relatively high SES family backgrounds.

Their explanation of this finding was based on animal experiments that showed that maternal nutrition could impact growth and health over several generations. Thus, they speculated that the socioeconomic development in China was too recent to exhibit a statistically significant relationship between early life conditions and leg length. However, our results indicate that this relationship can be statistically significant even among a population in a long-term poor country. Despite the sustained economic growth for a long time, as documented in Figure 1, Indonesian GDP per capita on a purchasing power parity basis was US$ 5,200 as late as 2013, ranking at 158 of 228 countries. In fact, the Indonesian population is an extreme case (more than the Chinese population) in long-term poverty, because Indonesia belonged to the region that exhibited the shortest height in the world at least during the past two centuries (Baten and Blum, 2012). At present, they are short even compared with individuals in other developing countries. For example, the mean height was 163.9 cm for men aged 50+ in Guangzhou, China whose parents were illiterate (implying low SES status) and 153.5 cm for the corresponding women (Schooling et al., 2008a). This argument suggests that Schooling et al.'s explanation in its current form may not easily apply to other developing countries.

Webb et al.'s (2008) study differs from Schooling et al.'s (2008a, b) in that they concerned the Czech Republic, Russia, and Poland, which are more developed than China. They generally found a statistically significant relationship between early life conditions and leg length for the Czech Republic, Russia, and Poland (in their Table 4). However, when they calculated the ratio of the age-adjusted regression coefficient to the SD of the given anthropometric, the relationship between early life conditions and leg length was smaller than that between early life conditions and height. Therefore, they concluded that height was the most useful summary measure of the effects of early life conditions on growth. However, as explained above, the SD normalization is not appropriate. When the mean is used for normalization for their results, the relationship for leg length, on average, is not small compared with that for height, as argued in their study. For illustration purposes, we select a group and an early life measure that exhibited the greatest relationship: father's education for men in Poland. Then, we use the mean for normalization and present the results in Table 5. They interpreted their results as consistent with those of the Negative Group, but, in substance, their results are consistent with those of the Positive Group.

Padez et al. (2009) shed slightly different light on the issue as they considered children instead of adults, and sitting height ratio ((= sitting height / height) × 100) instead of leg length. When they compared children in a low SES area with those in a high SES area in Mozambique, height in the high SES area was taller than that in the low SES area for boys and girls aged 9–11, 12–14, and 15+. The difference was statistically significant for five of the six groups (in their Fig. 2). The exception was girls aged 15+, but the sign of the difference was as expected. Conversely, the difference in sitting height ratio between the two areas was not statistically significant for five of the six groups (in their Fig. 4). The exception was boys aged 9–11, and in this case, the sign of the difference was not as expected, particularly for girls. For girls aged 12–14 and girls aged 15+, the high SES area exhibited a *higher* sitting height ratio than the low SES area. Nevertheless, it is evident that height is a more accurate biomarker of early life conditions.

Kinra et al. (2011) also considered children—in 29 villages near Hyderabad city in South India. A notable feature of this study is the use of random assignment to estimate the effect of supplemental nutrition on leg length. Using this experimental scheme, they could estimate the treatment effect of supplemental nutrition, relatively free of major concerns that have plagued most studies in the literature, such as endogeneity and sample selection bias. In the treatment villages during 1987–1990, all pregnant and lactating women daily received 2.09 MJ and 20–25 g protein, and all children under 6 daily received 1.25 MJ and 8–10 g protein. Then, children born during the trial were traced in 2002–2005 and were invited to undergo examination. Kinra et al. (2011) used relative leg length (= leg length / height) × 100) instead of leg length. After controlling for age, they found that the treatment was statistically significantly related to height, but not to relative leg length. They explained this discrepancy between their results and those in other studies using the intergenerational influence on which Schooling et al. (2008a, b) also relied. In addition, they added that the effect of early life conditions on leg length might not appear among people living in uniformly deprived conditions. This explanation is not consistent with our results as we estimate a statistically significant relationship between early life conditions and leg length even in a long-term poor country. Nevertheless, their main message is consistent with ours since we find that height is more greatly related to early life conditions than leg length.

Some differences notwithstanding, our results are consistent with those of the Negative Group in finding that leg length is not a more accurate biomarker of early life conditions than height. It is worth highlighting that the Positive Group's samples have concerned developed countries, while the Negative Group's samples (including ours) have concerned countries much less developed than the Positive Group's countries (including Webb et al.'s). This relatively neat separation of the concerned countries can salvage Schooling et al.'s (2008a, b) explanation. Our results suggest that it does not take several generations for early life conditions to influence leg length. It seems that early life conditions influence leg length regardless of economic development stages; however, the size of the influence seems greater in developed countries than in developing countries. Hence, the explanation amounts not to a "yes" or "no" question but to a "how much" question. If our reasoning is correct, we anticipate that future research for other developing countries would report results similar to ours as long as they have large sample sizes and variables with small measurement error, thereby increasing statistical power.

We acknowledge some potential limitations. First, like other studies that calculated leg length by subtracting sitting height from height, leg length suffers from attenuation bias stemming from measurement error. This could make its relationship with early life conditions smaller than otherwise. However, given the large relative difference between the relationship for leg length and for height, this concern should be small. Second, only one variable (years of schooling) is used as a measure of early life conditions, although it is an important one. This limitation directly results from the cross-sectional nature of the data. If this variable captures a sufficient amount of early life conditions, our results would not lose much. Otherwise, more variables would be required because other variables, such as father's occupation and education, could have a greater relationship with leg length than with height. Albeit minor, we add that we do not know any details about the procedure of measuring heights.

APPENDIX :

TABLE A1. Slope of the Trend in Anthropometrics

	Anthropometric	Men	Women
1	Leg Length (cm)	−0.033 (0.010)[a]	−0.041 (0.010)[a]
2	Trunk Length (cm)	−0.114 (0.010)[a]	−0.136 (0.011)[a]
3	Shrinkage-Adjusted Height (cm)	−0.087 (0.012)[a]	−0.117 (0.010)[a]

The slope refers to the coefficient on age in a regression of each anthropometric on age and a constant. The sample size is 31 for each sex. The regression is weighted by the number of observations for each sex-by-age cell.
[a]*P*-value<0.01.

TABLE A2. Early Life Conditions and Leg Length for Men and Women Aged 40–70

Variable	Men	Women
Years of Schooling	0.080 (0.020)[b]	0.078 (0.020)[b]
Age	−0.023 (0.010)[a]	−0.032 (0.010)[b]
Javanese	−1.206 (0.178)[b]	−1.453 (0.173)[b]
Constant	79.42 (0.59)[b]	74.57 (0.58)[b]
N	4,193	4,684
R Squared	0.019	0.026

Standard errors are clustered at the household level.
[a]*P*-value<0.05
[b]*P*-value<0.01.

TABLE A3. Early Life Conditions and Height Components for Individuals Aged 40–59

	Anthropometric	Men	Women
1	Leg Length (cm)	0.078 (0.023)[c]	0.077 (0.023)[c]
2	Hip Size-Adjusted Leg Length (cm)	0.043 (0.023)[a]	0.067 (0.023)[c]
3	Trunk Length (cm)	0.180 (0.021)[c]	0.119 (0.021)[c]
4	Hip Size-Adjusted Trunk Length (cm)	0.061 (0.020)[c]	0.051 (0.020)[b]
5	Height (cm)	0.258 (0.024)[c]	0.196 (0.022)[c]
6	Shrinkage-Adjusted Height (cm)	0.258 (0.024)[c]	0.197 (0.022)[c]

The listed number refers to the coefficient on years of schooling. Age, a dummy for being Javanese, and a constant are controlled for but not listed. The sample size is 3307 for men and 3654 for women. Standard errors are clustered at the household level.
[a]*P*-value<0.10
[b]*P*-value<0.05
[c]*P*-value<0.01

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