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Thompson, Kristina; Lindeboom, Maarten; Portrait, France

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Adult body height as a mediator between early-life conditions and socio-economic status: the case of the Dutch Potato Famine, 1846–1847

Kristina Thompson[a], Maarten Lindeboom[b], France Portrait[a]

[a] Department of health sciences, Vrije Universiteit Amsterdam
[b] Department of economics, Vrije Universiteit Amsterdam; Tinbergen Institute Amsterdam; IZA Institute of Labor Economics

ABSTRACT

Adult body height appears to be a relatively accurate summary variable of early-life exposures' influence on health, and may be a useful indicator of health in populations where more traditional health-related indicators are lacking. In particular, previous studies have shown a strong, positive relationship between environmental conditions in early life (particularly nutritional availability and the disease environment) and adult height. Research has also demonstrated positive associations between height and socioeconomic status. We therefore hypothesize that height mediates the relationship between early-life conditions and later-life socio-economic outcomes. We also hypothesize that the period of exposure in early life matters, and that conditions during pregnancy or the first years of life and/or the years during puberty have the largest effects on height and socio-economic status. To test these relationships, we use a sample of 1817 Dutch military conscripts who were exposed during early life to the Dutch Potato Famine (1846–1847). We conduct mediation analyses using structural equation modelling, and test seven different time periods in early-life. We use potato prices and real wages to proxy early-life environmental conditions, and occupational status (using the HISCAM scale) to proxy socioeconomic status. We find no evidence of mediation, partial or full, in any models. However, there are significant relationships between potato prices in adolescence, height and socio-economic status. To determine causality in these relationships, further research is needed.

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1. Introduction

Research dating back to the nineteenth century has used adult body height as a rough barometer of living standards (e.g. Villermé, 1829; Engels, 1845). This is because height is the result of interactions between genes and environment. Genetic differences among individuals, although significant, tend to cancel out when looking across populations (Steckel, 1995). We therefore are able to view height as a reflection of environmental conditions from conception until the end of puberty. Such conditions include: stress load; the disease environment; sanitation; access to and quality of healthcare; and (arguably) most importantly, nutrition (e.g. Komlos and Baten, 1998; Hedges et al., 2017; Jacobs and Tassenaar, 2004). These inputs have been collectively termed the (or perhaps more generally, a) 'biological standard of living' (Floud et al., 1990). The more beneficial this biological standard of living, the taller individuals and populations have been shown to be (e.g. Deaton, 2007).

Increased height has also been shown to be positively associated with a host of later-life outcomes, including socio-economic status (SES) (Case and Paxson, 2008; Bozzoli et al., 2009). We define SES as a person's economic and social position in relation to others, often measured as a combination of income, education and occupation (Magnusson et al., 2006; Alderman et al., 2006). The taller people (particularly men) are, the more social respect they are afforded, and the more attractive they are on job and marriage markets. The mechanisms underlying this relationship are not yet agreed-upon. For instance, Bogin et al. (2015) argued that social dominance causes taller height: more socially dominant individuals grow taller during puberty, and it is therefore this dominance, rather than height, that is rewarded. Stulp et al. (2015) conceptualized the relationship moving in the other direction. They posited that taller individuals are more socially dominant because are more likely to win confrontations. Strauss and Thomas (1998) similarly saw height as the cause of social dominance, and theorized that height is associated with greater physical strength, and it is this strength that is rewarded on the labor market. Case and Paxson (2008) understood health as the cause of both increased height and intelligence, with increased intelligence rewarded on the labor market. It is therefore this

underlying endowment that results in a link between taller height and the social rewards with which it has been associated.

Finally, there is evidence that early-life conditions have a direct influence on later-life outcomes. Packard et al. (2011) found that those who grew up in socio-economically disadvantaged circumstances were more likely to be socio-economically disadvantaged in adulthood. They found worse physical and mental health and cognitive functions as a result of this deprivation. Other studies have shown that this relationship is borne out in the context of extreme nutritional shocks. De Rooij et al. (2010) found that people exposed to the Dutch Hunger Winter performed worse on cognitive tests in later life (aged late 50 s to early 60 s) than those not exposed. They argued that this is because early-life nutritional deprivation resulted in earlier cognitive decline. Alderman, Hoddinott & Kinsey (2006), in the context of twentieth century rural Zimbabwe, found that people exposed to various shocks (extreme malnutrition and drought) were shorter than expected and performed worse in school.

This large body of evidence demonstrates that early-life conditions influence height and later-life socio-economic status, and that height is related to later-life socio-economic outcomes. However, literature contending with these three relationships simultaneously is lacking. In this paper, we therefore are interested in further disentangling these relationships, and establishing with more certainty how they influence one another.

To do so, we understand height as a potential mediator between early-life environmental conditions and later-life SES. We see height as (at least partially) transmitting the effects of early-life conditions onto socio-economic status, although other factors explaining variations in SES are very likely at play (MacKinnon et al., 2007). This means we see adverse conditions in early-life as setting individuals on developmental trajectories, leading these individuals to have both shorter adult heights and lower SES in later-life. We therefore expect that height will (again, perhaps only partially) explain the relationship between early-life conditions and later-life SES. These relationships are illustrated in Fig. 1.

Better understanding how height is affected by environmental conditions, and in turn how height affects later-life outcomes is important for several reasons. First, height in historical populations can be viewed as a window into the past, giving us a better understanding of how the quality of life (or the biological standard of living) changed over time (Floud et al., 1990). Second, height among both historical and modern populations can serve as a rough measure of national health and wealth. This is particularly important among populations where more direct and precise measures of health are unavailable (Deaton, 2007). Better understanding what height represents about early life and what

it may confer in later life may help to illuminate height's usefulness as a health and wealth indicator.

1.1. Characterizing early-life

A fundamental aspect of understanding how early-life conditions affect both height and socio-economic status is determining what point(s) in early-life has the biggest effects on height and later-life outcomes. Here, there is a moderate amount of debate over which period is most important. Generally, the literature tends to emphasize the first years of life (pregnancy through year 2, when growth is fastest and about half of adult height is reached) as a 'critical period'(Barker et al., 1993). During this period, vital organs are developing, with insufficient or poor environmental conditions triggering epigenetic effects that can lead to life-long negative impacts on health (Barker et al., 1993; Lindeboom et al., 2010). This is widely known as the 'fetal origins of adult disease hypothesis' (or the Barker hypothesis). There is also evidence that one of the long-run effects of insufficient food may be stunted height: Gørgens et al. (2012) found that those who experienced China's 'Great Leap Forward' famine under the age of five were roughly 2 cm shorter than those who did not. After the first few years of life, it is rare for children to be able to grow fast enough to compensate for missed growth (Martorell and Habicht, 1986; Floud et al., 1990).

Yet, compensatory growth is possible. Puberty is accompanied by the second-fastest growth period in development, and is extremely plastic: it can occur earlier or later, depending on the amount of food and resources available (Depauw and Oxley, 2017). The mechanism of 'catch-up growth' may enable stunted children to ultimately reach a normal height in adulthood. More specifically, catch-up growth " . . . describes the much faster rate of growth which occurs (assuming an adequate diet) after a period of restricted growth, whether the latter was caused by lack of food, illness or other factors" (Tanner, 1978, p. 154). Catch-up growth is thought to be possible until the terminus of puberty, and was likely more prevalent in pre-industrial and industrializing populations in Western Europe, as well as in low-income countries today, where environmental conditions are more likely to vary (Floud et al., 1990). For instance, Steckel (1986) showed that children born into slavery in the United States were often stunted in childhood until the age of 11, but then experienced much more rapid pubertal growth spurts when their diets improved. Therefore, environmental factors immediately before the end of puberty may be critical in determining adult height.

Complicating matters further is that the pubertal growth spurt changed in timing, tempo and velocity over time: Schneider and
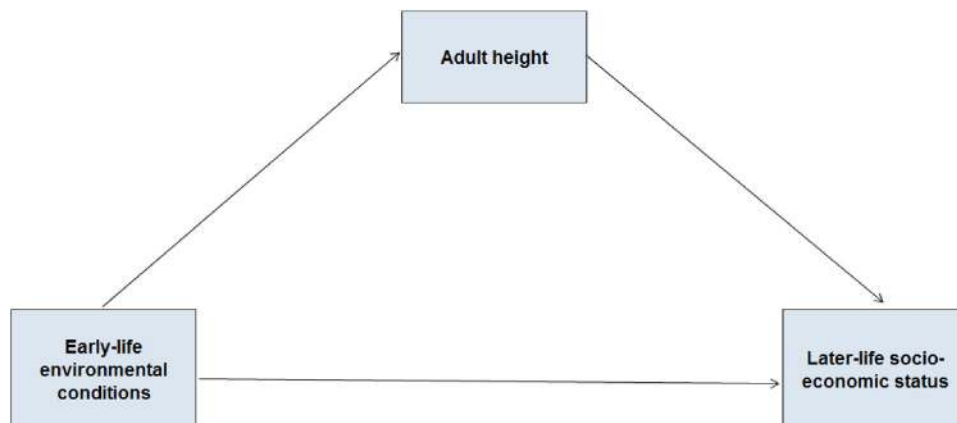
Fig. 1. Theoretical pathways.

Ogasawara (2018) discussed that in early twentieth century Japan, the pubertal growth spurt was much less steep than it is today. They instead point to an influence of conditions across the developmental trajectory (Schneider and Ogasawara, 2018). It may be that conditions at various points in childhood in the past had a more pronounced effect than during a critical period (discussed more fully below).

While there is a debate surrounding what timing of exposure to early-life conditions has the biggest influence on height, this does not appear to be the case in relation to early-life conditions' influence on SES. The existing literature on the latter subject has largely concentrated on the first few years of life. For instance, Kim et al. (2017) found that with the famine that resulted from Great Leap Forward, children exposed in utero or infancy had lower educational and socio-economic outcomes than those not exposed. Alderman et al. (2006) also focused on conditions from conception until age three.

Taken together, there appears to be a debate on what period in development has the biggest influence on height, and a lacuna in the literature regarding different periods in development's influence on SES. It would therefore be informative to test what period(s) in development – including very early-life and the period before the end of puberty – have the biggest effect on height and SES. Therefore, in this paper, we are not only interested in exploring adult height as a mediator between early-life conditions and later-life socioeconomic outcomes, but also in determining at what point(s) these conditions are most critical.

1.2. In context

1.2.1. The Dutch potato famine (1846–1847)

Famine may be an important backdrop against which to study the relationships among early-life nutrition, height and SES. Famines have several key features that make them especially suited for this purpose: there is a great deal of variation in available nutrition in a short period of time; they have a defined beginning and end; and they are (relatively) randomly-occurring (Scholte et al., 2015). In this way, famines are 'natural experiments', with the famine serving as exogenous variation, and unexposed and exposed groups (designated either by geography or timing of exposure) assigned relatively randomly. Testing the influence of famines on height and later-life outcomes may therefore help to add certainty to our conclusions about the relationships between early-life nutrition, height and later-life outcomes (Gørgens et al., 2012).

The Dutch Potato Famine of 1846 and 1847 has these key features, in that it was a period of acute, unpredicted and widespread nutritional deprivation (Lindeboom et al., 2010). Moreover, it was the first famine for which more granular, individual-level data is available, and has already been illustrative in testing the relationships between early-life nutrition and later-life outcomes (Lindeboom et al., 2010).

In the eighteenth and nineteenth centuries, the Dutch, relative to other Europeans, had a high standard of living and balanced diets (Knibbe, 2007). However, the typical Dutch diet became increasingly concentrated on a few staples in the first half of the nineteenth century. In particular, the potato formed a larger and larger share of the Dutch diet, initially for lower income households, but increasingly across all social strata. By mid-century, the Dutch consumed the most potatoes in Europe, after the Irish (Knibbe, 2007).

The Europe-wide failure of potato crops in the 1840s therefore placed the Netherlands in a precarious position (Mokyr and O'Gráda, 2002). In the Netherlands, roughly three-quarters and then half of potato crops died in 1845 and 1846, respectively. In 1845, famine was initially staved off thanks to reserves and effective government interventions, including financial aids, and increased imports alongside decreased exports. However, the already-troubled situation worsened when in 1846, the rye and wheat crops also failed (Lindeboom et al., 2010). While similar measures as those in 1845 were implemented, they proved inadequate. As with other 'modern' famines, it appears that this food shortage resulted in famine because of human involvement (or a lack thereof) (Sen, 1981). In 1846, about a third of potatoes were available per individual as they were in 1844, with the worst months of the Dutch famine occurring between September 1846 and September 1847 (Paping et al., 2007). Around this period, there were extremely high prices of potatoes and all other substitute sources of food. This resulted in increased mortality rates, disproportionately affecting young children and the elderly (Lindeboom et al., 2010). Fig. 2 illustrates the dramatic increase in the infant mortality rates and the decrease in birth rates in the period immediately surrounding the Famine. The lower birth rate suggests that the Famine contributed to lower fertility rates and/or increases in miscarriages.

1.2.2. Changing height and SES dynamics

Because we are applying theory about early-life conditions, height and socio-economic status formulated in different geographies and time periods, it is worth briefly exploring these relationships in our study's context. First, research indicates that, before and during industrialization, there was greater variability in environmental conditions (e.g. Floud et al., 1990). This likely means that the environment's influence on height was even greater during the mid-nineteenth century Netherlands, and that the influence of genetics was lesser relative to the Netherlands today.

Second, the ability for individual attributes (such as height) to influence SES may be different in a nineteenth century population versus a post-industrial one. Social mobility was certainly more limited in the mid-nineteenth century Netherlands than it was in the twentieth or twenty-first centuries: Looking at the Hague from 1859 to 1902, van Poppel et al. (2003) found that the likelihood of men inheriting their fathers' occupation was persistently high, 'reflecting a historical class structure that slowly evolved during the Dutch Golden Age and that had hardly changed since' (p. 264).

Still, it appears that in the years surrounding the Famine in the Netherlands, some degree of social mobility was present and was on the increase. For instance, van Leeuwen and Maas (1997) demonstrated that in the province of Utrecht, three types of social mobility (in their terms, intergenerational, career and connubial) increased significantly in the period 1850 to 1940. Knigge et al. (2014) similarly found that fathers' influence on son's occupations lessened over the course of the nineteenth century.
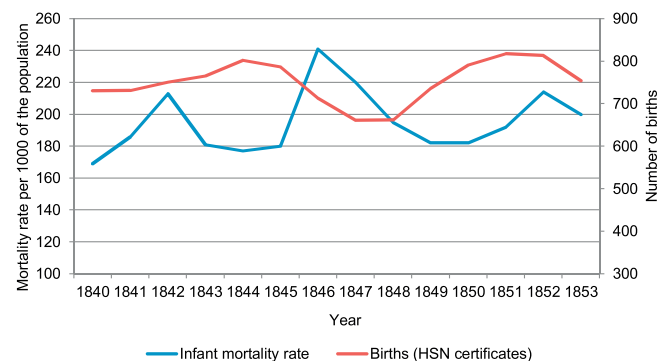

Fig. 2. Infant mortality and birth rates.
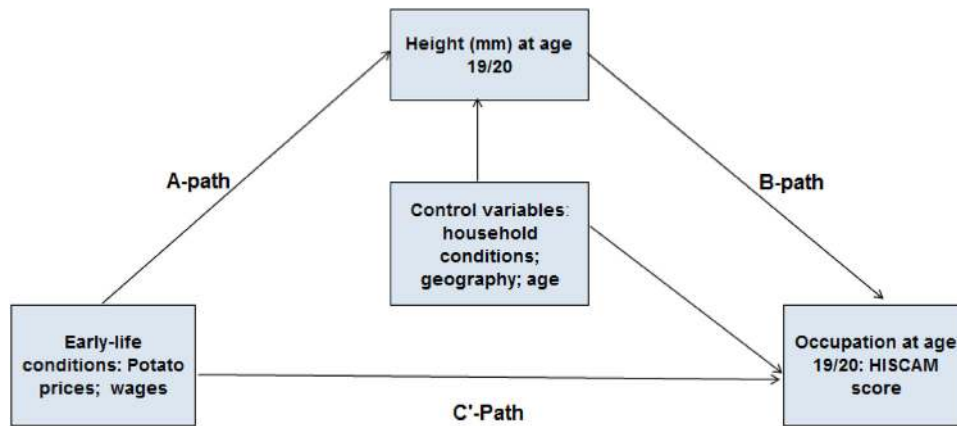Data from van der Bie and Smits (2001) and the Historical Sample of the Netherlands certificates release (2010).

Fig. 3. Mediation analysis pathways.

Hastening these shifts were the nineteenth century's various demographic transitions, which were largely wrought by industrialization. Van Leeuwen and Maas (2007) pointed to changes in occupational structure as the source of middle class growth. They found that occupations deemed to be 'middle class' expanded from about a fifth of the workforce to a third over the course of the nineteenth century. These trends likely helped facilitate upward mobility: in the city of Groningen, research has shown that class shifts were largely upward (from lower to middle, or middle to upper) in the period 1870 to 1910 (Kooij, 1987).

Against this backdrop, we pose the research question: what is the interplay between early life conditions, height and later-life outcomes and, more specifically, to what extent (if any) did adult body height mediate the relationship between early-life conditions and later-life socio-economic outcomes in the context of the Dutch Potato Famine? A secondary research question is: what timing of exposure has the greatest effect on height and SES?

We hypothesize that height mediates the relationship between early-life conditions and later-life socio-economic outcomes; and that the most important periods are very early life (i.e. pregnancy through age 2) and the period toward the end of puberty (i.e. ages 15–18). Because environmental conditions' influence on height is thought to be stronger in pre-industrial and industrializing populations, we expect to see a relatively large association between early-life conditions and height. Because social mobility – while present in the latter half of the nineteenth century Netherlands – was much less common than it is today, we expect that there will be significant relationships between height and SES and early-life conditions and SES, but that these relationships will be more muted.

2. Methods

In this study, we use a combination of individual level-data, drawn from primarily military conscription records, and population-level data to perform mediation analyses on early-life nutrition, height and SES. Fig. 3 demonstrates how these concepts are operationalized.

2.1. Data sources

2.1.1. Individual-level data
The present study exploits individual-level data predominantly from the Height and Life Courses (HLC) database. This dataset contains information on 8598 unique research persons (RPs), with birth years from 1812 through 1922. The HLC is drawn from Dutch conscription records, and contains information on, inter alia, birth place, height, occupation and any reason for exemption from

military service (including health problems and being too short). The present sample contains RPs measured in Friesland, Drenthe, Limburg, Noord-Holland, Noord-Brabant, Utrecht and Zuid-Holland. These provinces are thought to be representative of the key types of economies in nineteenth-century Netherlands (coastal urban; coastal rural; inland rural) (Drukker and Tassenaar, 1997). Because the HLC is based on military conscription data, all RPs are necessarily male. A particularly compelling aspect of this dataset is that conscription was universal (although some minor selection issues, for instance, whereby the higher SES RPs are underrepresented, are present). All (or nearly all) Dutch males who were drawn by lottery to be conscripted, even those who were obviously unsuitable for military services, were required to be examined (and therefore measured). Our database therefore stands out among other anthropometric data sources, the majority of which are subject to much more pronounced selection biases (e.g. Baten and Murray, 2000; Mokyr and O'Gráda, 1996).

Further, HLC RPs have been sampled from the Historical Sample of the Netherlands (HSN), and is representative of HSN boys who reached the age of conscription (19 or 20), were born between 1812 and 1922, and who were born in the selected provinces. The HSN itself is a representative sample (0.5%) of Dutch people born in this window. The HSN contains information from civil certificates regarding birth, death and marriage. In the present study, information from the HSN certificates are linked to the HLC RPs to give us a fuller understanding of individuals' life courses and their families circumstances.

As noted above, the current release of the HLC contains 8598 RPs with height and occupation information. RPs whose heights were thought to be recorded incorrectly were excluded (n = 16).[1] Further, since the present study focused predominantly on the Dutch Potato Famine, the sample was narrowed to RPs who would have experienced the Famine during early-life (between conception and the end of puberty), and those born in the years immediately around this. Because the Famine occurred in 1846 and 1847, we include RPs with birth years 1825 through 1853, resulting in a study sample of 1817 RPs.

2.1.2. Population-level data
In order to proxy early-life conditions, the combined dataset from the HLC and HSN was supplemented with population-level time series data. Based on Jacobs and Tassenaar (2004), we use

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[1] A number of RPs were not exempted for being too short, but were under 1200mm. We assume that these were the result of transcription errors (The one RP who was under 1200mm but who was exempted for being too short is included in our study).

annual average national-level wages (van der Bie and Smits, 2001) and annual provincial-level potato prices (van Riel, 2017) in order to proxy the biological standard of living in early-life. Real wages help to give an understanding of economic conditions at a particular point in time, and are thought to be preferable to other economic measures (e.g. GNP) because they are more directly reflective of consumption (Jacobs and Tassenaar, 2004). We also use potato prices because they characterize specifically nutritional availability. Potato prices, versus other available food prices, are particularly informative, because as previously mentioned, potatoes were consumed relatively evenly across social strata. Wheat and rye, in contrast, formed larger or smaller shares of Dutch diets based on social class (Jacobs and Tassenaar, 2004).

2.2. Variables

2.2.1. Early-life conditions

We use several measures of early-life conditions to measure exposure to the famine.

2.2.1.1. Potato prices. We assume that lower potato prices represented more food available, and therefore a more positive early-life environment. We use raw potato prices as explanatory variables in the mediation analyses.

Fig. 4 displays annual average potato prices by province. Here, we can see that, following volatility in the 1820s, prices broadly stabilized in the 1830s and the first half of the 1840s. Around the Famine, prices spiked dramatically, before once again falling around 1848.

Because we are interested in exploring what timing of exposures have the largest influence on height and SES, we use early-life condition variables measured at different periods in RPs' lives. We therefore measure potato prices at the following seven time periods in early-life: pregnancy; the first year of life; birth through age 2; years 3 through 6; years 7 through 10; years 11 through 14; and years 15 through 18. These characterizations of early-life are based on Depauw and Oxley (2017)'s (although we do not include ages after 18, because our RPs were measured at age 19 or 20). We also include pregnancy and the first year of life, due to the large body of evidence pointing to an influence of pre- and immediately post-natal conditions on later-life (e.g. Barker et al., 1993; Stein et al., 2007; Portrait et al., 2017; Karimi and Basu, 2018).

To compute these variables, we weight potato prices based on birth month, in an attempt to more accurately reflect the early-life

condition during the specified ages of the RPs, using Yeung et al. (2014)'s methods. For ease, we assume that all RPs were born on the first of the month, and that all pregnancies lasted nine months. For instance, an RP born in December of 1840 would have potato prices in their first year of life represented by 1/12 the average annual potato price of 1840, plus 11/12 the average annual potato price of 1841.

2.2.1.2. Real wages. We assume that higher real wages indicate a more positive early-life environment. To calculate real wages, we use the nominal annual wages in van der Bie and Smits (2001), and divide these based on the annual population (van der Bie and Smits, 2001). Then, we use a consumer price index to deflate the wages, yielding real wages (van der Bie and Smits, 2001). The consumer price index treats 1913 as the benchmark year (100). We also use the same time characterizations of early-life (e.g. pregnancy) and weighting method as potato prices. In Fig. 5, we see that after a period of relative prosperity in the 1830s, real wages decline in the years around the Famine.

2.2.2. Height

In the HLC, height is measured at age 19 (before 1862, when boys were conscripted at this age) or 20 (after 1862), and is recorded in millimeters. In cases where the millimeter digit is missing from the database, we code the digit as '0': although this is an extremely rough estimate, including these RPs increases the power of our study. Still, to exclude heights that are too imprecisely recorded, we exclude heights from which centimeters, decimeters and/or meters are missing. Fig. 6 demonstrates average height based on the year of birth. Here we see that in the 1840s, average heights began to increase, a trend that, after the 1850s, continued apace.

2.2.3. Socio-economic status

We use occupational status to measure SES. In the nineteenth century Netherlands, occupation is the best-available measure of SES: individual-level income information is not available, and education was much more limited than the present day and not recorded in military records until 1895. In the HLC, occupation is measured at age 19 or 20. We convert these occupations into HISCAM scores. The HISCAM scale, or the Historical CAMSIS scale (CAMSIS itself stands for 'Cambridge Social Interaction and Stratification'), ranges from 40 (very low SES) to 99 (very high SES) (Lambert et al., 2013). It is also a social interaction distance scale, which assumes an occupational hierarchy that is based on the frequency of which a combination of occupations occurs in social relationships. The greater frequency that people with these
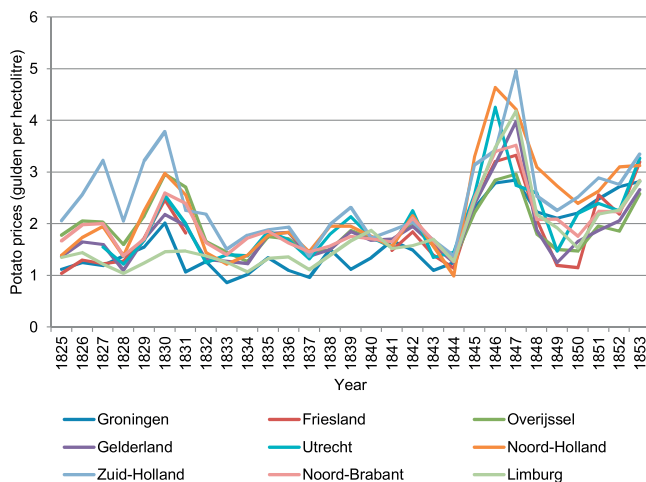

Fig. 4. Potato prices per year, based on province.
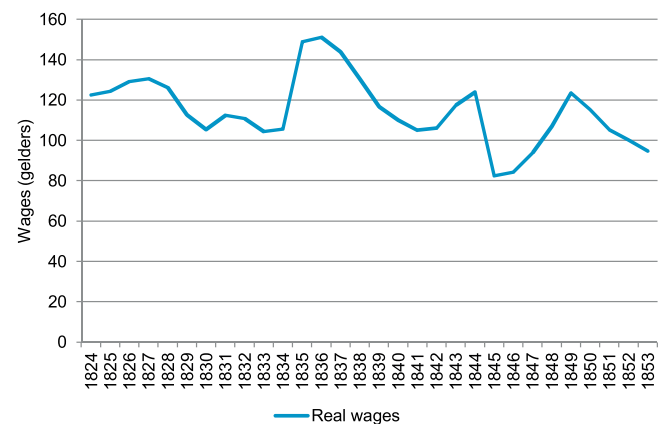Source: van Riel (2017).

Fig. 5. Annual average real wages.
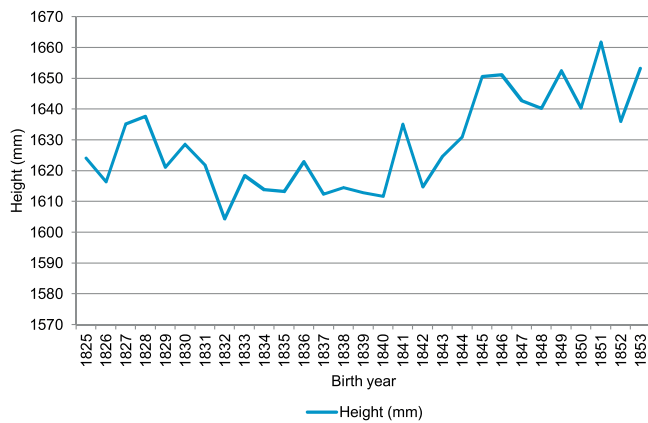Source: van der Bie and Smits (2001).

Fig. 6. Mean height of conscripts based on year of birth.

occupations form social relationships, the closer they are scored (Lambert et al., 2013). HISCAM applies validated CAMSIS methodology to historical occupations across seven countries, based on intergenerational occupational pairings (Lambert et al., 2013). In this study, we use the Netherlands-specific version of HISCAM (Lambert et al., 2013). Fig. 7 shows the average HISCAM score based on RPs' year of birth. It appears that there are dramatic shifts in the average HISCAM score in the 1830s, but this is because there are only 45 to 68 RPs per birth year, and several HISCAM scores are outliers.

2.2.4. Additional covariates

We control for age of measurement (in days). This is because RPs are measured at age 19 (pre-1862 conscription year) or at age 20 (post-1862 conscription year), meaning some RPs are nearly two years apart in age. This is particularly important for our study, as boys in this period likely continued growing well into their twenties (Jacobs and Tassenaar, 2004).

Additionally, we control for factors concerning individual household circumstances. This includes father's occupation (also using HISCAM scores), as this has been shown to have large effects on both the resources available in the childhood household, and the ultimate socio-economic status of adult children (e.g. Currie, 2009). We also control for the father being involved in a farming occupation. Being a farmer's son likely increases an RP's proximity to food, which also likely would increase the quantity and quality of his food intake (e.g. Baten and Blum, 2014).

Finally, we control for variables related to RPs' geographies. Because growing up in urban or rural environments has been shown to have an impact on both height and SES (Baten and Blum,
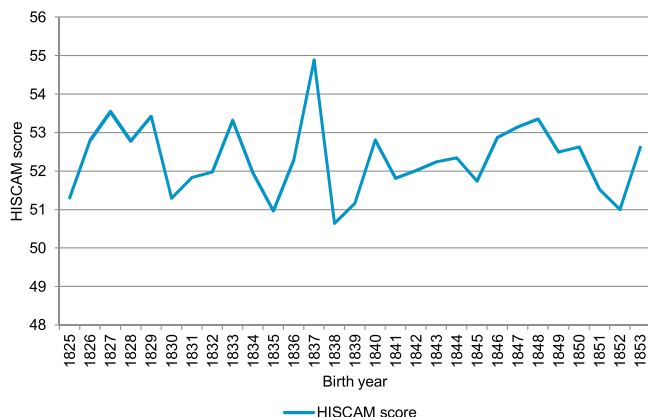

Fig. 7. Average HISCAM score based on year of birth.

2014), we control for town size using the number of residents per municipality from the 1840 Dutch census (Centraal Bureau voor de Statistiek, 2011). Also, for real wages, which are national-level, we include province of birth, as occupations and heights have been shown to vary widely by province, particularly after the mid-nineteenth century (Drukker and Tassenaar, 1997). Because potato prices are provincial-level, including dummies for province of birth may over-control for provincial differences, and so in these mediation analyses we exclude them. Rather than controlling for all eleven of the nineteenth century Dutch provinces, we condense these into economic and geographical categories, loosely based on Drukker and Tassenaar (1997)'s categorizations. These include: Northern (Friesland and Groningen); Coastal (Zuid-Holland and Noord-Holland); Middle (Drenthe, Overijssel, Gelderland and Utrecht); and South (Zeeland, Limburg and Noord-Brabant). It is worth noting that our sample includes RPs born in provinces outside of those in which they were measured (and in which our data was collected): this means that RPs' parents (and very likely, the RPs themselves) moved at some point between birth and RPs' conscription.

2.3. Analysis

Data are analyzed in STATA version 14. First, we run descriptive statistics. Then, we run separate mediation analyses for each of the seven characterizations of early-life, using the two early-life variables, totaling 14 separate mediation analyses. We employ Hayes's (2013) methods using structural equation modelling (SEM), which is a general multivariate technique. SEM "uses a conceptual model, path diagram and system of linked regression-style equations to capture complex and dynamic relationships within a web of observed and unobserved variables" (Gunzler et al., 2013). SEM is very similar to regression, but it differs in that there is less of a clear division between predictor and outcome variables: a predictor in one part of a SEM system can be an outcome in another (Gunzler et al., 2013).

We test whether height mediates the relationship between early-life conditions and later-life SES by decomposing the total effects of early-life conditions on SES into direct and indirect effects. To do so, we fit two models: a first ordinary least squares regression model, which regresses height on each early-life conditions variables (A-path) and a second ordinary least squares model regressing SES on the early-life variables (C'-path, or the direct effect) and height (B-path). The models are specified below:

$$Y = a_1 + b_1 ELC + c_1 X + e_1, \tag{1}$$

$$Y = a_2 + b_2 ELC + c_2 M + d_2 X + e_2, \tag{2}$$

$$M = a_3 + b_3 ELC + c_3 X + e_3, \tag{3}$$

where Y refers to the outcome of interest 'later-life SES,' M refers to the potential mediator 'height,' ELC refers to variables characterizing early life conditions, and X refers to additional covariates; a_1, a_2 and a_3 are constants; b_{1-3}, c_{1-3} and d_2 are coefficients, and e_1, e_2 and e_3 are residuals.

Then, we calculate the indirect effect as a product of the A-path and B-path regression coefficients for the early-life nutrition variables and height, respectively. We do so in order to measure the effect of early-life conditions that are mediated by height. We next calculate the total effect by summing the direct effect (C'-path coefficient) and the indirect effect (the product of the A-path and B-path coefficients). This is written:

Total effect: $b_1 = b_2 + (b_3 * c_2)$

Finally, we use bootstrapping with 5000 replications to calculate 95% confidence intervals for each indirect effect. Bootstrapping increases the accuracy of the estimation of the indirect effect, because indirect effects tend to be skewed, and because our sample size is relatively small (Hayes, 2013).

In order to gauge whether or not mediation has occurred, several criteria have to be met: (1) the confidence interval of the indirect effect does not contain zero, as this ensures that the indirect effect is different from zero; (2) the p-values of the A-path and B-path must be significant; and (3) the p-value of the C'-path should be insignificant (Kenney, 2018). If the first two criteria are met, but the C'-path is significant, then partial mediation has occurred (Kenney, 2018). Partial mediation is defined "as the path from X to Y is reduced in absolute size but is still different from zero when the mediator is introduced" (Kenney, 2018). If all three criteria are met, then the path from X to Y should be reduced to zero, and full mediation has occurred.

3. Results

3.1. Descriptive statistics

Table 1 reports the descriptive statistics for all variables used in the mediation analyses. The data source, as well as the role of the variable in the analyses, are also included.

Potato prices have averages that range from 0.63 (pregnancy) through 4.96 (also during pregnancy) guilders per hectoliter. Real wages range from 82.57 (the first two years of life) to 201.65 (ages 15 through 18) 1913 guilders.

In terms of individual-level data from the HLC and the HSN, the average height was 1630 mm, with a range of 1196 to 1890. HISCAM scores range from 40.24 to 99.00. Despite this relatively large range, HISCAM scores are concentrated at the lower end of the spectrum, with a mean of 52.26.

Regarding additional covariates, the average age at measurement is 6986 days old (or 19 years of age). In terms of geography, the largest share of RPs (39%) are born in southern provinces (Limburg and Noord-Brabant), followed by 29% in coastal provinces (Noord and Zuid Holland), 21% in middle provinces (Drenthe, Gelderland, Overijssel and Utrecht) and 11% in northern provinces (Friesland and Groningen). In terms of family conditions, 11% of RPs have fathers involved in farming occupations. The average HISCAM score of fathers is 52.81.

3.2. Mediation analyses

3.2.1. Potato prices

In all mediation analyses, the B-path (the relationship between height and SES) is positive and highly significant (p-value = 0.01), although with small effect sizes (b = 0.01). The influence of potato prices on height and SES is less straightforward, and varies based on the time characterization of potato price.

The mediation analyse using potato prices as the early-life conditions are presented in Table 2. First, looking at potato prices during pregnancy, the criteria for mediation are not met. The A-path (the influence of potato prices on height) is insignificant (p-value = 0.992). The C'-path (the influence of potato prices on SES, holding height constant) is significant (p-value = 0.029), indicating that height does not fully explain the relationship between potato prices and SES. Finally, the confidence interval of the indirect effect (-0.03; 0.04) contains zero.

Results for the first year of life and the first two years of life present similar pictures, with criteria for mediation not met in both. The A-paths are insignificant (p-value = 0.220 in the first year of life; p-value = 0.358 in the first two years of life). The confidence intervals of both indirect effects also contain zero.

Potato prices during years 3 through 6 and 7 through 10 also do not meet the criteria for mediation. The A-paths for both were insignificant (p-values = 0.198 in years 3 through 6; 0.560 in years 7 through 10), and the indirect effect's confidence interval all contained zero.

Prices during years 11 through 14 presents a somewhat murkier picture. The A-path in is significant at α = 10%, with p = 0.077, and has a negative beta coefficient (b = -6.39), in line with our

Table 1
Descriptive statistics.

Source	Type	Variable	N	Mean	Std. Dev	Min.	Max.
Van Riel (2017)	Explanatory: early-life condition	Potato: Pregnancy	1790	2.01	0.66	0.63	4.96
		Potato: Year 1	1785	2.09	0.68	0.74	4.83
		Potato: Birth through 2	1780	2.13	0.67	1.13	4.43
		Potato: 3 through 6	1783	2.27	0.62	1.22	3.78
		Potato: 7 through 10	1790	2.37	0.63	1.22	3.83
		Potato: 11 through 14	1789	2.46	0.57	1.31	3.83
		Potato: 15 through 18	1796	2.59	0.53	1.52	3.83
van der Bie and Smits (2001)	Explanatory: early-life condition	Real wages: Pregnancy	1760	113.12	15.14	82.57	151.23
		Real wages: Year 1	1760	111.46	15.83	82.57	151.23
		Real wages: Birth through 2	1760	110.50	15.30	83.43	150.13
		Real wages: 3 through 6	1760	106.69	14.19	87.69	143.69
		Real wages: 7 through 10	1760	105.57	14.56	87.69	143.69
		Real wages: 11 through 14	1760	103.98	12.43	87.69	144.94
		Real wages: 15 through 18	1760	119.81	35.55	87.69	201.65
HLC	Explanatory: time	Age at measurement (days)	1817	6985.7	213.43	6620.00	8286.00
	Explanatory: geography	Municipality size (no. of residents, 1840)	1801	42687.04	74258.08	125	211349
		Born in the North	1817	0.11	0.31	0.00	1.00
		Born in the Coast	1817	0.29	0.45	0.00	1.00
		Born in the South	1817	0.39	0.49	0.00	1.00
		Born in the Middle	1817	0.21	0.40	0.00	1.00
HSN	Explanatory: family life	Father's HISCAM score	1672	52.81	7.75	40.24	99.00
		Father in a farming occupation	1672	0.11	0.314	0.00	1.00
HLC	Outcome	RP's HISCAM score	1817	52.26	7.09	40.24	97.09
	Mediator	Height (mm)	1816	1631.45	81.54	1196.00	1945.00

Table 2
Mediation results: The relationships among potato prices, height and SES.

Early-life variable	Time period	Path	Coefficient (p-value; CI)
Potato prices	Pregnancy	**Total effect** (A-path*B-path + C'path)	0.55 (0.034)
		A-path (early-life variable's influence on height)	−0.03 (0.992)
		B-path (height's influence on HISCAM score, controlling for early-life nutrition variable)	0.01 (0.008)
		C'-path/Direct effect (early-life variable's influence on HISCAM score, controlling for height)	0.55 (0.029)
		Indirect effect (A-path*B-path)	−0.0002 (−0.034; 0.035)
	First year of life	Total effect	0.24 (0.28)
		A-path	3.84 (0.220)
		B-path	0.01 (0.011)
		C'-path/Direct effect	0.22 (0.396)
		Indirect effect	0.02 (−0.011; 0.061)
	The first two years of life	Total effect	0.05 (0.854)
		A-path	3.07 (0.358)
		B-path	0.01 (0.011)
		C'-path/Direct effect	0.04 (0.893)
		Indirect effect	0.02 (−0.020; 0.060)
	Years 3 through 6	Total effect	0.46 (0.161)
		A-path	−4.87 (0.198)
		B-path	0.01 (0.013)
		C'-path/Direct effect	0.48 (0.121)
		Indirect effect	0.46 (−0.180; 1.097)
	Years 7 through 10	Total effect	0.23 (0.461)
		A-path	−2.06 (0.560)
		B-path	0.05 (0.024)
		C'-path/Direct effect	0.238 (0.411)
		Indirect effect	−0.01 (−0.054; 0.026)
	Years 11 through 14	Total effect	0.75 (0.009)
		A-path	−6.39 (0.077)
		B-path	0.01 (0.017)
		C'-path/Direct effect	0.78 (0.008)
		Indirect effect	−0.03 (−0.080; 0.002)
	Years 15 through 18	Total effect	0.606 (0.043)
		A-path	−11.50 (0.002)
		B-path	0.01 (0.019)
		C'-path/Direct effect	0.64 (0.038)
		Indirect effect	−0.03 (−0.097; 0.005)

expectations that higher potato prices are associated with shorter heights. Still, no full or partial mediation is present, as the indirect effect's confidence interval contains zero. The C'-path is also significant (p-value = 0.008). Contrary to our expectations, the C'-path's beta coefficient is positive (b = 0.78), meaning that higher prices in early adolescence are associated with higher occupational status at age 19 or 20.

Potato prices during years 15 through 18 mirror those during years 11 through 14. First, the A-path is highly significant (p-value = 0.002), and its beta coefficient (b = -11.50) is negative. Again, contrary to our expectations, the C'-path is significant at α = 5%, (p-value = 0.038) but with a positive beta coefficient (b = 0.64). Because the C'-path is significant and the indirect effect's confidence intervals contain zero, we again do not find mediation present.

3.2.2. Real wages

Table 3 reports the mediation results for real wages. As with potato prices, the B-path had a positive beta coefficient (0.01) that was highly significant (p-value = 0.01) in all models. For pregnancy, we find no mediating effect. The A-path is insignificant (p-value = 0.607), and the indirect effect's confidence intervals contain zero, although the C'-path is insignificant (p-value = 0.727).

With real wages during the first year of life and the first two years of life, the A-paths are insignificant (p-value = 0.506 and p-value = 0.590, respectively), and the indirect effect's confidence intervals contain zero. However, the C'-path in both case are insignificant (p-values = 0.492 in the first year of life and 0.137 in the first two years of life).

Real wages during years 3 through 6 and 7 through 10 exhibit similar relationships. The A-paths are both insignificant (p-value = 0.866 in years 3 through 6 and 0.440 at ages 7 through 10, and the confidence intervals both contain zero. However, the C'-paths are both insignificant (p-value = 0.508 in years 3 through 6 and 0.298 in years 7 through 10).

Real wages during ages 11 through 14 and ages 15 through 18 similarly have A-paths that are not significant (p-values = 0.240 and 0.176, respectively), although they are more so than other characterizations of real wages. The A-path's beta coefficients are positive, in line with our expectations: (0.184 during ages 11 through 14 and 0.082 during ages 15 through 18). In the case of ages 11 through 14, the C'-path is insignificant (p-value = 0.416), in line with our hypotheses. Yet, in the case of potato prices at age 15 through 18, the beta coefficient is negative (-0.01) and significant (p-value = 0.065), contrary to our expectations.

3.2.3. Additional covariates

We include all covariates in the two regressions underlying each mediation analysis (excepting the provincial dummies, which were only included in the real wages mediation analyses). In each model, the covariates yield similar results. Age at measurement is positively and significantly associated with height, although it is not significantly associated with HISCAM score. Being born in a municipality with a higher population is significantly associated with shorter height, but higher HISCAM score. In terms of family characteristics, having a father involved in a farming-related occupation is significantly associated with taller height, but lower HISCAM score. Fathers' HISCAM scores are positively and significantly correlated with height and RPs' HISCAM

Table 3
Mediation results: The relationships among real wages, height and SES.

Early-life variable	Time period	Path	Coefficient (p-value; CI)
Real wages	Pregnancy	**Total effect**	−0.004 (0.690)
		A-path	−0.07 (0.607)
		B-path	0.01 (0.018)
		C'-path/Direct effect	−0.004 (0.727)
		Indirect effect	−0.0003 (−0.002; 0.001)
	First year of life	**Total effect**	0.01 (0.518)
		A-path	−0.09 (0.506)
		B-path	0.05 (0.017)
		C'-path/Direct effect	0.01 (0.492)
		Indirect effect	−0.0004 (−0.002; 0.001)
	The first two years of life	**Total effect**	0.02 (0.158)
		A-path	−0.08 (0.590)
		B-path	0.01 (0.017)
		C'-path/Direct effect	0.02 (0.137)
		Indirect effect	−0.0003 (−0.002; 0.001)
	Years 3 through 6	**Total effect**	0.01 (0.876)
		A-path	−,03 (0.866)
		B-path	0.01 (0.018)
		C'-path/Direct effect	0.01 (0.508)
		Indirect effect	−0.0001 (−0.002; 0.002)
	Years 7 through 10	**Total effect**	0.015 (0.287)
		A-path	0.13 (0.440)
		B-path	0.01 (0.019)
		C'-path/Direct effect	0.01 (0.298)
		Indirect effect	0.0006 (−0.001; 0.002)
	Years 11 through 14	**Total effect**	−0.009 (0.460)
		A-path	0.184 (0.240)
		B-path	0.01 (0.017)
		C'-path/Direct effect	−0.01 (0.416)
		Indirect effect	0.0009 (−0.0006; 0.0029)
	Years 15 through 18	**Total effect**	−0.007 (0.155)
		A-path	0l.082 (0.176)
		B-path	0.001 (0.013)
		C'-path/Direct effect	−0.008 (0.065)
		Indirect effect	0.0002 (−0.0002; 0.0008)

scores. For the mediation models using real wages as a proxy for early-life conditions, being born in the north, south and middle had a significant, positive effect on heights relative to the coastal reference group.

3.3. Sensitivity analysis

In order to assess the robustness of our findings, we also conduct mediation analyses using different provincial-level food prices (wheat and rye prices, also from van Riel, 2017), and national-level average calcium and protein intake (Knibbe, 2007). We find similar results: while mediation is not present, there are stronger relationships at ages 11 through 14 and 15 through 18 than in the first years of life. Also, in case there are trends present in our early-life conditions variables affecting our results, we conduct the same analyses using potato prices and real wages, but use deviations from the trend instead of the raw figures. Again, we find similar results.

Overall, out of all 14 mediation models in the main analyses, we do not find evidence of height as a mediator between early-life conditions and SES. However, we do find significant, positive relationships between height and SES in all models, in line with our hypotheses. At ages 11 through 14 and 15 through 18, we find significant (or nearly significant) negative relationships between potato prices and height, in line with our expectations. At these time points, as well as pregnancy, we find significant, positive relationships between potato prices and SES, contrary to our expectations.

4. Discussion

With this study, we seek to add to the understanding of the relationships between early-life conditions and later-life

outcomes, and how height can summarize these relationships. Height is a well-established indicator of well-being up until the end of puberty, and it may be an important predictor of later-life outcomes. Yet, its usefulness and interpretation in part depend on a better understanding of what (early-adult) height represents, both about early-life and later-life. We conduct mediation analyses to add to this understanding: while this type of analysis does not give us insight into causal chains, it allows us to simultaneously study how predictor, mediator and outcome variables impact one another. While we do not find evidence of mediation in any of the 14 models, we do find noteworthy relationships in several of the models that are worth exploring further.

4.1. Interpretation of findings

4.1.1. Early-life conditions' influence on height

Our study joins an emerging body of literature finding a larger effect of environmental conditions during puberty than during early-life. This aligns with several recent studies (e.g. Depauw and Oxley, 2017, looking at the heights of Flemish prisoners in the nineteenth century and Schneider and Ogasawara, 2018, looking at the heights of Japanese school children in the early twentieth century). Depauw and Oxley (2017) cautioned against viewing height as a reflection of conditions in the first few years of life, especially in periods of large fluctuations in environmental and economic conditions (in periods of more stability, conditions in adolescence are likely similar to those in early-life). Our findings seem to directly reflect this, and point to the human body's ability to adapt after longer periods of deprivation earlier in childhood.

The coefficients of the variables characterizing the early life conditions are also relatively large: at ages 11 through 14, a 1

guilder increase in potato prices is associated with RPs being 6.39 mm shorter. This is in line with our expectations that early-life environmental conditions will have a sizeable impact on height. Yet, these findings are not as significant as we initially expected: at age 15 through 18 with potato prices, for instance, the p-value is 0.176. This may be due to the fact that RPs are measured at ages 19 or 20: in pre-industrial and industrializing populations, growth occurred well into boys' 20s, as environmental conditions, particularly food quantity and quality, were more variable. As noted earlier, puberty is plastic, particularly for boys: during periods of deprivation, puberty will be delayed (Floud and Harris, 1996). Particularly because our RPs were measured at ages 19 or 20, they may simply not have been done growing, impacting the significance of the relationship between early-life conditions and height.

Further, it may be somewhat artificial to declare the first years of life or later puberty the most influential on height: the fetal origins of adult disease hypothesis (or the Barker hypothesis) and catch-up growth are in many ways complementary theories. Barker et al. (2002) discussed catch-up growth, and argued that children who are deprived in the first few years of life may experience more rapid, delayed growth later on in development. This growth acceleration may incur a "health penalty" in older age, helping to explain the links between deprivation during early-life and its effects on longer-run mortality (Barker et al., 2002). Adult height may therefore not be an exact reflection of the biological standard of living in early life.

Also, it is noteworthy that we find similar effects of potato prices and real wages, with the adolescent years having the greatest effects on height. Still, the results with potato prices are more significant than those with real wages. This may be because potato prices are more granular than real wages, as they are measured on a provincial level, versus a national one. Also, potato prices more directly measure the nutritional environment than wages, with nutrition thought to be the biggest environmental influence on both health and height (e.g. Komlos and Baten, 1998). Real wages, in contrast, broadly reflect the economic conditions and consumption patterns in households (Jacobs and Tassenaar, 2004). While we had initially expected potato prices to better proxy early-life conditions, these broadly similar results with different proxies of early-life conditions gives further credence to our findings.

4.1.2. Early-life conditions' influence on SES

The relationship between early-life conditions and SES is more surprising. With potato prices measured during pregnancy and ages 11 through 14 and 15 through 18 and real wages measured at ages 15 through 18, there is a significant relationship that indicates adverse early-life conditions lead to higher SES (although not to taller height). In terms of our mediation models, mediation does not occur, meaning that height is not fully able to explain the relationship between the early-life condition variable and SES. Several of the beta coefficients of the early-life condition variables also move contrary to our expectations: we initially assumed that beneficial conditions in adolescence would lead to RPs having higher SES.

In the case of pregnancy, it may be that, when there are very adverse conditions and survival is most precarious, the weakest die rather than bear scars of these exposures (Bozzoli et al., 2009). Those who survive tend to be stronger and healthier (Blum et al., 2017). Therefore, survivors entering the labor market are in some way 'fitter' and better able to succeed on it. As survivors of a period of high mortality, they also may be competing with a smaller cohort of new labor market entrees. With adolescence, it may be that macroeconomic fluctuations in the years prior to entering the labor market have a beneficial effect on their opportunities: when

they enter the market after a period of stagnation, job opportunities may be on the increase.

However, it may be that there are unaccounted-for confounders affecting our results. As noted elsewhere, we attempt to control for all pertinent confounding variables, when possible. Still, there are myriad factors that affect the relationship between early-life conditions and SES. It may simply be that, despite using the best-available sources, we have not been able to reduce the 'noise' in our models.

4.1.3. The influence of height on SES

We find a highly significant correlation between height and SES. However, the effect size is modest: at age 15 through 18, using potato prices as the early-life condition, a 1 mm increase in height is associated with a 0.005 increase in HISCAM score. This is in line with our expectations: while we anticipate that height may facilitate social mobility, this mobility was likely much more muted in the nineteenth century Netherlands than among post-industrial, high-income populations.

This strong correlation (p-value = 0.01) also may be in part due to the choice to measure height and occupation at the same point in time. We do so for practical reasons: the next available recorded occupation through the HSN certificates release (2010) is at marriage. However, we only have marriage records for roughly half of RPs included in our sample (either RPs were unmarried, or their certificates are not able to be found). In contrast, nearly all RPs had an occupation listed in the HLC (at the point of measurement/ conscription, at age 19/20). For the RPs with both HLC and marriage certificate occupations available, nearly all had the same occupation. Because our sample is already relatively small, with only a few hundred RPs measured per year across the Netherlands, we elect to increase power by using the HLC occupations.

Still, we may now have difficulty discerning the direction of the relationship between height and occupation. Indeed, as mentioned, boys in the nineteenth century Netherlands were not finished growing. Their occupations therefore may have had a direct influence on their heights. For instance, the environmental conditions of some occupations, such as industrial jobs, may have stunted boys. It therefore may not have been that RPs with certain 'endowments' were both taller and able to access better occupations. Based on our study, it is therefore impossible to conclude why and how there is such a tight correlation between height and SES.

4.2. Strengths

Our study adds value to the literature about the interplay of early-life conditions, height and later-life outcomes. First, we use a new, unique dataset of Dutch military conscripts, the Historical Life Courses (HLC) database, that is a (nearly) representative random sample of Dutch men in the nineteenth century. This dataset, with its broad geographical and temporal scope, should help to answer more definitively how and why the Dutch grew so quickly. The HLC is uniquely informative, both because we have a non-truncated sample of heights, and because we are able to link RPs to those in the HSN, allowing us to follow them from birth to death.

Second, we exploit a mix of individual- and population- level data. On the one hand, individual-level data gives us a level of granularity that is important to understand different life course trajectories and avoid ecological fallacy issues. On the other hand, population-level data tend to be more exogenous, and therefore help to reduce bias in our models. Using population-level data also allows us to proxy environmental conditions that are generally not available at an individual level in the nineteenth century Netherlands. With our data choices, we have the best of both worlds.

Third, fluctuations in broader environmental conditions affect individuals' early-life conditions but are much less likely to be confounded by individual characteristics. The Dutch Potato Famine (1846–1847) was an exogenous (mostly unanticipated) shock, in a period with substantial variations in wages and potato prices. Therefore, using these sources of exogenous variation helps to reduce bias in our models. This allows us to more thoroughly identify the long-run effects of early-life conditions on early-adult height and SES. Doing so also helps add to the body of literature attempting to disentangle the relationships between early-life nutritional shocks, growth and development (e.g. Lindeboom et al., 2010; Schneider and Ogasawara, 2018).

Fourth, we test 'early-life' in a number of different ways, helping to assess which point is most critical (specifically in the nineteenth century Netherlands, although this is likely generalizable to other northern European populations at similar points in time). This is a departure from most other studies on the subject. Our choice to test multiple characterizations of early-life helped us to better articulate what point(s) in development have the largest influence on height and SES. Ultimately, this may help us better understand what height represents about early-life, and what it predicts about later-life.

4.3. Limitations

Our study also has several limitations. First, as mentioned, we use occupation at age 19 or 20, which may not be an accurate representation of socio-economic status in later life. It also may be that, because height and occupation are measured at similar times, the direction of this relationship is not clear-cut: occupation may have an influence on height. However, as noted above, we elect to measure them at the same time due to data availability. Sensitivity analyses using occupations in later life yield similar results.

Second, the way in which we characterize early-life conditions may be somewhat problematic. We link population-level variables in an effort to measure individual-level household conditions. While this has been done successfully in other studies (e.g. van den Berg et al., 2010), it may be that there is not enough precision to reflect household characteristics on an individual level. We are, rather, working with best estimates.

Third, and perhaps more importantly, our models do not take into account all possible confounders, and therefore are providing us with evidence of associations, rather than causal relationships. There are myriad factors that affect height, and we attempt to control for those that we have available. However, because we are using the HSN release of birth, marriage and death certificates (the more elaborated HSN release based on population registers begins only in 1860), we do not have access to information such as religion and family size, both of which have been shown to have an influence on long-run outcomes (e.g. Öberg, 2015).

This third point has significant implications for the way in which our findings should be interpreted. On the one hand, the literature states that mediation analysis relies "on the assumption that there are no confounders that influence both the mediator, M, and the outcome" (Coffman, 2011, p. 1). Yet, mediation rests on the same assumptions as normal regression: while a more nuanced, less certain interpretation is warranted, it does not mean that mediation analyses are ipso facto not worth undertaking. Our findings provide insight into associations that require further research, versus demonstrating causal chains.

In future, using multi-generational data (including fathers, sons, grandsons, and brothers) could be useful. This would help us to control for within-family characteristics that may be over- or under-estimating the effects of the Famine on height and socio-economic status in early adulthood. We anticipate that they may be causing us to over-estimate their effects, as family-level circumstances are currently unaccounted-for in our present models. A future release of the HLC is set to contain these data, which will allow us to conduct similar analyses with more certainty. With this release, we would expect that, even when controlling for within-family circumstances, we would find smaller (but no less significant) impact.

5. Conclusion

With this study, we seek to better understand the relationships between early-life conditions, height and later-life SES, and attempted to disentangle them via mediation analysis. While we do not gain insight into causal chains with mediation analysis, we do get a unique glimpse into these relationships in concert with one another. We do so using a uniquely representative sample of Dutch military conscripts, supplemented by time series data of real wages and potato prices. We find that early-life conditions are significantly and positively associated with early-adult heights, and that this relationship is strongest when characterizing 'early life' as adolescence (ages 11 through 14 and 15 through 18). The relationship with SES is more complex: in adolescence and pregnancy, worse environmental conditions (when proxied with higher potato prices) predict better labor market outcomes. This may be due to selection effects. Height is also a significant but modestly-sized predictor of SES. These findings add to an emerging body of literature that indicates that adult height is most reflective of environmental conditions in puberty. However, to establish these relationships more definitively, future research, ideally using data that are better able to control for intra-family conditions, is needed.

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