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Can resource dilution explain differences in height by birth order and family size? A study of 389,287 male recruits in twentieth century Netherlands.

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Introduction

Although human heights have a strong genetic component (McEvoy & Visscher, 2009; Silventoinen, 2003; Silventoinen, Kaprio, Lahelma, Viken, & Rose, 2003), the impact of behavioral and environmental conditions on height is large. This is recognized by the current intervention strategies for improved health, nutrition, family planning, water, and sanitation supported by the World Health Organization to reduce the risk of childhood stunting (De Onis et al., 2013). The impact of the changing environment is also clear from the continuing secular increase in heights throughout the world, even in the most advanced societies (Silventoinen, 2003). Heights are therefore widely considered to be a useful indicator of the distribution of resources in human societies (Steckel, 2009).

In addition to the above conditions, growth delays or shorter stature could be due to specific medical factors, including endocrine disorders, abnormalities of bone growth, and chronic infections or cardio-vascular, pulmonary, or digestive diseases that affect overall nutrition (Behrman & Kliegman, 1990) . In general, height growth is gradual and regular except during the puberty period where a temporary rapid height increase is seen, also known as the 'growth spurt' (Tanner, 1978). The timing of exposure to any conditions that may affect growth is therefore important for their long term impact on height.

As noted in anthropometric studies, there is a close relation between body height and any differences in human resources that may exist between families. Such differences in part relate to gradients in education and parental occupation between families (Gyenis & Joubert, 2004; Heineck, 2006; Huang, Van Poppel, & Lumey, 2015; Jordan, Lim, Seubsman, Bain, & Sleigh, 2012; Komlos & Kriwy, 2002; Krzyzanowska & Umlawska, 2010; Meyer & Selmer, 1999; Peck & Lundberg, 1995; Silventoinen, Lahelma, Lundberg, & Rahkonen, 2001). This relation is reflected in height differences seen in many countries, including the Netherlands (Fredriks et al., 2000; Gyenis & Joubert, 2004; Heineck, 2006; Hiermeyer, 2009; Jordan et al., 2012; Komlos & Kriwy, 2002; Krzyzanowska & Umlawska, 2010; Schönbeck et al., 2013). Even within a household, however, when socio-economic status is fixed, an individual's height appears to be a powerful indicator of the availability of human resources. A clear indication of the latter is that sibling heights show a strong inverse relation with family size and with birth order. This relation is has been well established in 20th century European populations (Öberg, 2015). Heights tend to be lower in larger families (Öberg, 2015), but also among individuals with higher birth orders (Hatton & Martin, 2010). Since birth order is highly correlated with family size (as higher birth orders only occur in larger families) it is difficult however to separate the independent contributions of each factor to an individual's height. To date, this important question is largely unresolved.

The relation between personal characteristics and human resources has also been explored in the economic and demographic literature. In economics, their connection has been quantified with quantity-quality models that represent the competition by family members for scarce family resources (Becker & Lewis, 1973). In the demographic literature, the inverse relation between family size and education (years of schooling achieved by each child) has been described as a trade-off between quantity and quality (Blake, 1981). In this thinking, family resources will be diluted for children in larger families because for each sibling less resources will be available ('resource dilution') if parental resources are fixed. Children will then suffer if the specific resources needed for child achievement are compromised (Blake, 1981; Hertwig, Davis, & Sulloway, 2002; Jaeger, 2009). In these models, possible sibling interactions and economies of scale are largely ignored, and any resources are assumed only to go from parents to children.

In essence, resource dilution examines "the relation between family resources, parental allocation, and children outcomes" (Jaeger, 2009). Family resources can be financial and social, and relate to within family interactions or to activities outside the home. By their nature, some resources may be available equally to all siblings and not be subject to 'dilution', but others will not. For the models to hold, the family resources must drive the child outcomes; reduced investments therefore are assumed to result in reduced child achievements (Downey, 1995; Hertwig et al., 2002; Jaeger, 2009; Steelman, Powell, Werum, & Carter, 2002).

With regard to stature, 'resource dilution' has been invoked as a possible mechanism to explain the inverse relation between sibship size and sibling heights in European populations (Öberg, 2015). But alternative explanations include confounding of the relation by other (measured or unmeasured) family characteristics including socio-economic position or birth order. The inverse relation is subject to fertility changes over time that may affect the size and the birth order composition of studied families. It is also subject to secular height increases from improved childhood nutrition and protection from infectious diseases. These changes are concurrent with general improvements in sanitation, housing, and schooling, family incomes, and the potential confounding of family size effects by parental age effects (Barker & Record, 1967). It is difficult to quantify the contribution of any factor in isolation. Attempts have been made however using the instrumental variable (IV) approach to estimate family size effects using singleton vs. twin births and family composition effects using the sex composition of older siblings (Marteleto & de Souza, 2012; Millimet & Wang, 2011).

In this study, we propose to use height as an indicator of the within household distribution of human resources. We assume with Öberg (Öberg, 2015) that heights are a better measure of relative resource deficiencies than of abundance. With that in mind, we will examine its relation to family size, birth order, selected covariates, and potential confounders. This we hope will allow us to evaluate the explanatory power of 'resource dilution' to explain the observed patterns in the data. If so, it is plausible that the observed height patterns also apply to other outcomes related to health and development but this will need further exploration.

For our study, we will need a well-defined population to reliably assess the impact of family size and birth order on adult height, accounting for potential confounders. Our study group needs to include a sufficient number of high parity families, provide reliable information on both family size and birth order, and differentiate not only between first-born and later born children but between all birth orders. We need reliable information on height for all study subjects and measurements at a well-defined age. These can be found in historical data from the Netherlands.

After the economic crisis of the 1930s and the hardship of WWII, the Netherlands showed sustained economic growth starting in the late 1950s. This brought unprecedented prosperity in the Netherlands. Organizational and technical improvements helped restore Dutch agriculture after 1950 and also led to a significant growth of the industrial sector. Social services legislation of the expanding welfare state provided increased social security to Dutch society.

Social stability was assured by the close cooperation of labor unions and employers' associations and by consensus policies of the four dominant interest groups in Dutch society: Roman–Catholics, Protestants, Socialists, and Liberals. These political arrangements remained socially and economically important until the mid-1960s. Full employment, economic growth and social security enabled the development of extensive social services associated with the 'welfare state'. Far-reaching cultural changes were delayed until the middle of the 1960s (Blom, 1999).

Although life expectancy among males did not increase significantly in the period 1950-1970, mortality at younger ages strongly decreased after WWII. Deaths from infectious diseases during childhood and adolescence became exceptional. Nutritional conditions in the Netherlands were rapidly restored to normal after the Dutch 'Hunger Winter' famine that affected the Western part of the country in 1944-1945.

Quantitative data on heights in the Netherlands are available from the early nineteenth century. These show an impressive and sustained increase in heights starting in the last quarter of the nineteenth century that has continued to the present day. The Dutch are now among the tallest populations in the world (Schonbeck 2012). Within these overall trends, significant height differences remain however between geographical regions (with the tallest people living in the North and West provinces and the shortest in the South) and between urban and rural population (with the tallest people living in urban centres) (De Beer, 2001; Drukker & Tassenaar, 1997).

In this context, we accessed data from the national birth cohort of Dutch conscripts born in 1944-1947 and examined for military service at age 18. This source provides reliable information on our key variables of interest and on relevant socio-demographic variables. In the past, these data have been used to examine the relation between birth order, family size, and intelligence (Belmont & Marolla, 1973). The cohorts are cross-sectional and cover a narrow time–window of births. It is therefore not possible to look at birth order effects within completed families. It is possible however to examine the relation between family size, birth order, and height using ordinary least squares (OLS) regression models, and to adjust for information on potential socio-economic and demographic confounders as was collected during the military examinations. Some conscripts in the study population were born in the large cities in the Western Netherlands in 1944-1945 and could have been exposed to the Dutch famine during gestation or early childhood. As later discussed, this is not likely to have an effect on the study results however because exposure to the famine around the time of birth had no effect on recruits' heights (Z. Stein, Susser, Saenger, & Marolla, 1972; Van Wieringen, 1978) .

Our specific questions using these data are the following: are recruits from larger families shorter than recruits from smaller families?; how large are birth order effects in relation to family size effects?; are the observed effects linear? ; are the observed patterns broadly comparable in recruits from lower and higher socio-economic backgrounds?; and, are the observed data patterns robust to adjustment for covariates and potential confounders? We then review if our observations speak to resource dilution as a parsimonious explanation of the observed patterns.

Methods

Study Population

We studied anonymized military records provided by the Dutch Ministry of Defense in 1969 for a study of the relation between early nutrition and mental performance at Columbia University (Z. Stein et al., 1972). The records include all men of Dutch nationality born between January 1, 1944 and December 31, 1947 examined for military service in the Netherlands (n=408,015). Military examinations were based on yearly listings of all Dutch male citizens in the national population registers. All men were called to the military service induction exam at age 18, except those living in psychiatric institutions or in nursing institutes for the blind or for the deaf-mute after extraction of their medical records. Some (less than 5%) of prospective recruits could claim exemption from military service because three or more of their older brothers had served. It is not clear how many of these were absent from the medical examination. Re-examinations of recruits deemed temporarily unfit for service at previous examinations are included. The study population is especially suited for our purpose because it includes contemporary generations born at the end of World War II with significant numbers of high order births (7, 8, and 9+).

Information on family size and birth order and other demographic variables was collected from the questionnaire that was mailed out to each recruit prior to the medical examination. The questionnaire entries were discussed with the recruit and completed by the medical officer during the examination. The questionnaire included questions on recruits' family size (total number of male and female siblings), birth order, and number of older brothers.

The high number of large families reflects the much delayed historical fertility decline in the Netherlands compared to other European countries. The European fertility decline started in the 1880s but was so slow in the Netherlands that from around 1910 the Dutch fertility level stood well above other European countries. It was not until the mid-1960s that the proportion of high birth order families in the Netherlands had declined to the European average (Festy, 1971).

Available measures

Standing heights were measured for all men using the same military protocol with wall-mounted stadiometers. Measurements were taken without socks or shoes with the individuals' head positioned in the Frankfort plane. The recorded heights show no aberrations around the minimum height standard or digit preference.

From the military examination record we selected for further analysis subject's birth order and family size as the variables of primary interest for this study. In addition, we selected other relevant variables for which associations with adult height have been reported in the Netherlands (Fredriks et al., 2000; Huang et al., 2015), including place of birth in view of the North-South gradient in height, religion, subject education, and father's occupation. These variables also show a strong association with family size and this calls for their examination as potential confounders of the relation between birth order and family size.

Father's occupation was coded unknown for recruits who reported their father had no occupation, had an unknown occupation, had died more than 5 years prior to the examination, or was unknown. Fathers last known occupation was coded for fathers who had died 5 years or less prior to the examination. In all, father's occupation was coded unknown for 4.7% of recruits. No information was collected on mother's occupation or father's education.

Family size and birth order were ranked by number ranging from 1 to 9+. In view of the increasingly smaller number of families and birth orders in the range 10-20+, these groups were combined into the group 9+.

To evaluate the role of education, we defined six education categories, ordered by years of formal education in relation to primary school education from age 6-12. In the category 'less than primary school', we included individuals with special education for the handicapped. We then distinguished men who had received 2, 4, 6, or more than 6 years of formal education beyond primary school corresponding to 8-9, 10-11, 12, or 12+ years of education (Ekamper, van Poppel, Stein, & Lumey, 2013; Huang et al., 2015).

Father's occupation was ordered into five SES based categories, ranging from laborers and miners, service employees (including shop assistants), farmers and farm workers, to clerical workers and self-employed individuals and managerial and professional occupations. Father's occupation was also categorized in two groups of approximately equal size to analyze occupations with lower vs. higher socio-economic status. In the latter group, we included professional and managerial occupations, clerical employees, and farm owners (Ekamper et al., 2013; Huang et al., 2015; Ravelli, Stein, & Susser, 1976).

Place of birth was classified by geographic region and by urbanization status at birth and includes selected cities vs other places of birth in the North/East of the country, selected cities vs other places of birth in the West, selected cities vs. other municipalities in the South, and the agricultural province of Zeeland. Religion was defined as Roman Catholic, Protestant (Dutch reformed or Calvinist), no religion, and other religions, including unknown.

All available study subjects were included for analysis unless information was missing on either height (1.8%), birth order (2.1%), or family size (2.0%). Foreign births (2.5%) were also excluded. Because of partial overlap of missing variables, 95.4% (n=389,287) of the study population remained for analysis.

Statistical analysis

In brief, we evaluated differences in height by education, father's occupation, and other selected variables and carried out multiple linear regression analyses to evaluate the independent contribution of family size, birth order, and the other covariates to height at age 18. We first examined the mean heights of recruits cross-tabulated by family size and birth order. We then used linear regression models to estimate the height change associated with increasing family size and increasing birth order, examined singly or examined together, as discrete variables taking the values 1-9+ or as linear variables. We then examined the effect of adding covariates, singly or as a group, on the family size and birth order specific height changes estimated from the linear regression models. Selected covariates include religion, paternal occupation, and place of birth. All analyses were initially carried out using in the STATA statistical package and study results were confirmed in SPSS.

Results

Social and demographic characteristics of the study population with their corresponding heights are listed in Table 1. There is a monotone height decrease as the birth order increases from 1 to 9+ with a gradient of -2.4 cm (range from 177.8 to 175.4 cm). There is also a monotone decrease in height as the family size increases from 1 to 9+ with a gradient of -2.0 cm (range from 177.9 to 175.9 cm). In addition there are height differences by religion (average heights range from 176.4 cm among Roman- Catholics to 178.2 cm among Protestants), by place of birth (range from 175.2 cm for births in the rural South to 178.7 cm for births in North/East cities), by father's occupation (range from 176.1 cm among sons of manual laborers to 178.5 cm among sons of professionals and managers). Heights also varied by conscripts' education, with a range of 174.8 cm among those with the least education vs 179.9 cm among those with the most extended education.

In Table 2, conscript heights are shown by birth order and family size. In addition to the decrease in average heights as either family size or birth order increase, we see that the height differences are larger within rows than within columns, suggesting that family size has a stronger influence on height than birth order. This is clearly seen in Figures 1 and 2.

Conscripts' family size, religion, place of birth, and socio-economic background are highly related in the study population. Among Catholic conscripts, 15% came from families with nine or more children; this was only 6% among Protestant conscripts and 3% among non-religious conscripts. The overwhelming majority (90% or over) of recruits from the South was Catholic; this proportion was only 20% among recruits from the North. Mean family size (SD) by recruit's family background as defined by father's occupation was 4.0 (2.1) among non-manual families, 4.5 (2.3) among manual families, and 5.5 (2.4) among farming families. (Cross-tabulations not shown)

In Table 3, we show linear regression coefficients for the relation between height and family size and birth order (as discrete variables in nine categories with range 1-9+) from univariate, mutually adjusted, and multivariable models with additional covariates. We show separate entries for recruits from non-manual ('high SES') and manual ('low SES') backgrounds. Model A shows the decrease in recruits' heights for each unit increase in their family size; the estimates show that recruits from larger families are approximately 2 cm shorter compared to recruits from smaller families. Model B shows the decrease in recruits' heights for each unit increase in their birth order; these estimates show that elder children are also approximately 2 cm shorter than younger children in the families.

Model C in Table 3 shows the decreases with mutual adjustment for family size and birth order, and Model D shows results after additional adjustment for selected socio-economic covariates, including religion and place of birth. Model C shows that apparent birth order effects are driven by family size; the addition of the latter moves the coefficients for birth order closer to the null value. By contrast, the family size effects are largely unaffected by the addition of birth order to the model. The further addition of selected covariates (Model D) leads to a further reductions of family size effects.

In view of the monotone and approximately linear association of family size and birth order to height as seen in Table 3, we also estimated simpler models (see Table 4), with family size and birth order as continuous variables (with range 1-9), with and without the other covariates. Again, these models show that height decreases associated with higher birth orders are mostly driven by family size as addition of the latter renders the linear birth order effect indistinguishable from zero. As before, the family size effect is largely unaffected by adjustment for birth order. The further addition of selected covariates as a group (Table 4, model D) leads to a reduction of the negative family size effect on height of approximately -0.15 cm per added sibling, both in recruits from non-manual and manual backgrounds.

The overall height difference of men from manual vs. non-manual households (as defined by father's occupation) as represented by the regressions intercept was about 1.5 cm. After this is taken into account, the relative contribution of family size to recruits' height (-0.15 cm decrease in height for each added sibling) is similar in lower and higher SES populations. In both populations, the birth order contribution is significantly less.

Discussion

We used medical examination data from military conscriptions in the Netherlands to examine the relation of family size and birth order to height. In our study population, there are no sample selection issues because all 18-year old Dutch nationals at the time underwent a uniform medical examination to determine their fitness for military service. The study population is therefore not skewed by socio-economic background or by specific selection criteria for military service that may relate to socio-economic background, fitness, or height. All men were examined around the age of 18 years when their final height had been attained and subsequent siblings are unlikely. The national recruit population is large enough for accurate effect estimates of the relative impact of family size and birth order on height. It also includes the generations born at the end of World War II that were still characterized by significant numbers of higher order births (6, 7, 8, and 9+) in large families.

We used information on family size and birth order in this population to examine if in larger families the 'quality' of the children is affected because parental resources in larger families could be more diluted compared to smaller families. This phenomenon has been observed for several outcomes, initially for education but more recently also for height. There are remaining questions however, especially on the role of potential confounders, and on birth order effects on height after family size is taken into account.

If "Resource dilution" holds, we expect the following empirical findings:

1) That children in larger families are shorter than children in smaller families,

2) That this pattern holds after adjusting for potential confounders,

3) That the negative family size effect on height is larger in lower than in higher SES families,

4) That the later born children (because they share resources with more siblings growing up) are shorter than earlier born children. The form of the birth order effect on height (linear or non-linear) will need further determination however.

As set out below, our empirical findings are in broad agreement with resource dilution:

On the first point, we established that recruits from larger families are indeed shorter than recruits from smaller families and that height is driven by family size rather than birth order. Since the higher birth orders are only observed in the larger families there is a seemingly strong relationship between birth order and height when family size is not taken into account. After adjustment for family size the association with birth order is greatly diminished but still statistically significant. While parents who have larger families will have been aware that having more children means there is less to spend for each child, we think it is unlikely that the parents anticipated that this would affect the height of their offspring and adjusted their family size decisions accordingly.

In the literature (Öberg, 2015), the association between height and birth order is less consistent than the association with sibship size. Our findings suggest that the inconsistent birth order relation is likely to result from residual confounding by family size. Confounding by family size is also seen for child mortality, in the apparent association between high parity and child mortality (Kozuki & Walker, 2013). Our family size effects are similar in magnitude to the negative sibship size effect of approximately -0.3 cm per added child as estimated by Bailey et al. (2015) for the height of WWI servicemen in the British Army and the effects reported by Myrskala et al. (Myrskylä, Silventoinen, Jelenkovic, Tynelius, & Rasmussen, 2013) among Swedish recruits born in 1951-1983. The relative size of our mutually adjusted family size and birth order effects (Table 3, Model C) appears to be different however from the Swedish data as the latter appear to show birth order effects dominating over family size effects. This could in part be due to the fixed effects models used in Sweden to compare heights in recruits from the same family, controlling for maternal factors (Myrskylä et al., 2013). It is a limitation of our data that we have no family identifiers and cannot reconstitute families over a long observation period.

On the second point, we established that recruits in larger families are still shorter after adjusting for potential confounders, although the family size effect is somewhat diminished. This holds in lower and higher SES families. We carried out further adjustments for socio-demographic variables for two reasons. First, to take differences in resources available to the family into account. And second, to control for potential confounders of the associations of family size, birth order, and height. After adjustment for socio-economic covariates, there was a 50% decrease in the estimated family size effect on height. The decrease was seen in parallel models; one that estimated the relation of family size and height using categorical variables (Table 3; Figure 3, left panel) and a second that assumed a linear relation between family size, birth order, and height (Table 4; Figure 3, right panel). Both approaches show that confounding by measured characteristics is an unlikely explanation for the negative family size effect on height.

On the third point, our separate analyses among lower SES and higher SES families (as defined by father's occupation) show a similar functional relation between recruits heights, family size, and birth order (Tables 3 and 4, Figure 2). From Figure 2 we can also see however that the heights of recruits from lower SES backgrounds are systematically lower (by 1.3 cm or more) for all family size and birth order combinations compared to recruits from higher SES backgrounds. This raises the question what SES specific effects on height may not be subject to resource dilution such as access to medical care or dietary advice. Specific information on these matters is not available from the military examination but we expect that any such factors would be highly associated with social class. Our explanation for the baseline height differences in recruits by social class is that lower SES households have more budget restraints than higher SES households. These restraints most likely translate into differences in nutritional habits and health practices. In our study population no information is available however on family budgets or specific practices to further examine this question. Subgroup analyses by SES stratum show that the overall negative height effect of approximately -0.15 cm for each additional sibling (Table 4, model D) was similar for recruits who had fathers with manual occupations (lower SES) than for recruits from higher SES backgrounds. But the birth order effect is marginal, especially in the lower SES group. Our findings therefore differ somewhat with the third expectation in that the family size effect is similar across SES groups, although recruit's heights in absolute terms are significantly lower among lower SES recruits.

On the fourth point, there is indeed a suggestion that later born children are smaller than earlier born children, even after family size effects and other potential confounders have been taken into account. The birth order effects are small however in comparison to the family size effect and are essentially linear (Tables 3 and 4, Models C and D).

Comparing available studies of parental investment 'in terms of time, money, vaccination records, nutrition, etc.', Hertwig and colleagues (Hertwig et al., 2002) examined the relation of parental resource allocation with birth order in published studies. Their goal was to find empirical evidence that parents will spread resources evenly among all children. If this is true, the 'equity heuristic' in their view will produce unequal cumulative investments in siblings, depending on birth order. This is because the number of siblings competing for resources will be different at different time points, although the resources in the family are shared evenly. The ‘equity heuristic’ might thus produce seemingly contradictory (first, middle, and last) birth order effects. As illustrated for a three child family, ‘the middle child never has the opportunity to be the only child in the household at any point in its life’ (Hertwig et al., 2002). In our population, we see no suggestion for a non-linear association between birth order and height for birth orders 1-8, a much wider range than examined by Hertwig (Hertwig et al., 2002). It has to be borne in mind however that the impact of limited resourses at different stages in the life course will depend on the mechanism by which specific ‘resources’ may affect specific outcomes. As an example, adults heights may be especially affected after nutrition problems in critical growth periods for infant and child development (Tanner, 1978). These periods may be different for resources of time and money that for instance relate to psychological development. Our knowledge of these matters is still rudimentary.

Because of the large study population and the wide range of birth orders we were able in this study to establish with great precision that for height (taken as a marker of cumulative parental investment) there is an essentially monotone linear decrease with increasing birth order, even after adjustment for family size and other covariates. This finding is in agreement with expectations from a resource dilution mechanism.

Measurement error and residual confounding could be alternative explanations however why we see a negative association between sibship size and height, even after adjusting for potential confounders. In our study, we think significant measurement errors are extremely unlikely because heights were measured by standardized methods during the military examination. On further examination, we indeed found no digit preference of clumping of heights at the extremes of the height range.

With regard to residual confounding, we face the inferential problem from observational studies. It is hard to base causal inferences on the correlation between family size and offspring height alone. ‘Families who choose to have more children are different from families who don’t’ (Black, Devereux, & Salvanes, 2005) and this will be an analytic problem if they also differ in ways they rear and feed their children. It will then not be possible to separate the family size effect from the height effects of other important characteristics of parents who choose to have less or more children. We must therefore build our inferences on the plausibility of the picture that emerges from available data.

With regard to potential confounding by measured social or demographic characteristics, we see a substantial reduction of the family size effect across the SES spectrum after adjustment for place of birth, and religion. (Tables 3 and 4) These covariates are highly inter-correlated and also related to height in our study population; the reduction of the family size effect on height with the addition of covariates is therefore not additive.

With regard to men who were exempted from military service because they had three or more older brothers who had served, the number potentially absent at military examination is too small (less than 5%) to affect our study findings in any meaningful way. More important, such missing records will not bias study results of those examined as the validity of the available birth order and family size information of those examined is not affected.

Since the military data cover births 1944-1947, they include male twins and brothers with closely spaced dates of birth born in this period. The data contain no family identifyers however and brothers cannot be readily identified. We therefore estimated the number and impact of potential brothers in the data in two ways. We first identified potential male twins (and triplets) in the data by labelling recruits with the same place and date of birth, father's occupation, religion, and other family characteristics. Deletion of this group did not affect the results. By our criteria, 2.5% of recruits was identified. Not all recruits identified by this method will have been twins however because this number far exceeds the natural population twinning rate of 1 in approximately 80 births from Hellin's estimate (Allen, 1984) that applied to the Netherlands at the time. Many will have been misclassified as potential twins because the daily number of births in some cities was too large for this method to successfully identify multiple births in individual families. Second, we estimated the interpregnancy interval estimate in this birth period using data from the Historical Sample of the Netherlands (HSN), *Data Set Life Courses Release 2010.01* (n=37,137). Among the families in the sample, 36% had two births in 1944-1947, 7% had three, and one family had four. The sample includes boys and girls. Therefore the number of male siblings in our data is unlikely to exceed 10% assuming an even sex distribution at birth. This number is too small to bias our study findings in any meaningful way.

The most recent national growth studies of boys and girls age 0-20 years in the Netherlands (among individuals who were born two generations later than these recruits), still show similar and strong associations between height and geographical region, parent's education, and family size (Fredriks et al., 2000). The inter-correlation of these variables was not reported in the recent studies however but could have well diminished somewhat over time since nutrition and medical conditions have improved for the whole population and presumably inequality decreased. We also speculate that the increased mobility of the population may have contributed but have no empirical data on this question.

Another potential limitation of the study is that in this cross-sectional setting, individual heights are in essence only available for one sibling per family. Associations with family size and birth order could therefore be confounded by unmeasured within-family paternal and maternal characteristics because family size and birth order associations with height are estimated across and not within families. In this study, we are not able to compare our findings with family size and birth order 'fixed' effects from within families. In family size studies on child intelligence, the empirical estimates from between and within family models give similar results however (Black et al., 2005; Blake, 1981; Fredriks et al., 2000).

Completed families would also be helpful to address some other unresolved questions. Our study population includes many large families because fertility in the Netherlands was still high in the parental birth cohorts. Recruits' mothers born in the beginning of the twentieth century had 2.8-3.0 children on average. Mother's fertility decreased gradually to 2.5 for mothers born in 1935. The decline did not accelerate until after WWII when birth cohort fertility reached values below 2.0 (Frejka & Sardon, 2004; Sardon, 1990). But because of the gradual fertility decline, we do not think that changes in family size over time related to mother's date of birth could have biased the study results. The findings are robust to statistical adjustments for religion (Roman Catholic vs others) which at the time was closely related to fertility in the Netherlands. To address the question conclusively, complete families would be required again such that birth order and family size effects on offspring heights can be compared between and within families.

It could be argued that differences in adult heights of the parental birth cohorts may have been so large as to significantly affect the heights of their offspring. Our data provide no information on parental age that could be used to directly evaluate questions pertaining to potential parental cohort effects on the relation between family size and offspring height. Again using data from the Historical Sample of the Netherlands (Van Poppel, Reher, Sanz-Gimeno, Domingues, & Beekink, 2012), we estimate that there was a 10-year difference in parental year of birth (1904-1914) comparing first-born and last-born recruits in our data. We also infer based on historical data (Baten & Blum, 2012) that later born fathers were on average 1.4 cm taller than earlier born. This could indirectly lead to some differences in sons' heights, independent of birth order and family size. As parental heights are only partially predictive of offspring heights however (Galton), the effect on the next generation would be much less. Based on our estimates we do not think therefore that systematic differences in parental heights could have significantly biased our study results. But again, only family data could settle if theoretical reservations as described above should be of practical concern.

Specific to the outcome studied, we need to consider the potential impact of the secular trend. In the United Kingdom, childhood heights increased by 1 cm between members of the 1958 British birth cohort and their offspring (Li & Power, 2004). In the Netherlands, the average height of 18-year old men increased by approximately 3 cm comparing individuals examined in 1995 with those examined in 1965 in Dutch national growth studies (Schönbeck et al., 2013).

Could secular height trends for recruit birth cohorts therefore have biased our study findings? All men in the study population were born in a narrow time frame (1944-1947), too narrow to show a significant secular height trend, especially as heights were measured at age 18 for all men.

The relevance of birth characteristics and the prenatal period is highlighted by Danish and Norwegian conscript studies showing that their heights were related to birth weight, and especially with length at birth (Sørensen et al., 1999). Pregnancy outcomes, including birth weight and birth length, also tend to be more favorable in later-born vs first born outcomes and show a strong social gradient (Thomson, Billewicz, & Hytten, 1968). Analysis by SES group is therefore likely to reduce residual confounding by unmeasured birth characteristics but showed no SES related differences in family size and birth order effects.

On the role of short birth intervals and the possible associated maternal depletion of mothers epidemiologic studies show that these interval effects on height are very small in relation to other pregnancy characteristics that are highly related to social class and education (Weiss & Jackson, 1969). We believe therefore that in our study, adequate control of these factors was achieved by the adjustment for paternal occupation although information on specific maternal characteristics is missing.

The examined cohorts were born in 1944-1947, and at the time, the interpregnancy intervals were the shortest among the Catholic population and this group also had the largest families. This is a rationale why additional adjustments for religion are likely to address residual confounding by interpregnancy interval. In a study on intelligence scores in our study population, no relation was seen between birth interval and intellectual ability(Belmont, Stein, & Zybert, 1978), a characteristic closely related to height in these recruits (Huang et al., 2015).

For some outcomes, concerns have been raised that the Dutch data may not be appropriate for the analysis of only children or last children (Blake, 1981). For intelligence measures at age 18 for instance, the recruits in these specific groups show relatively low scores that have been characterized by Blake (1981) as 'demographically skewed', representing survivors among recruits born at the time of the Dutch famine of 1944-45, who were presumably most affected by starvation. Similarly, birth cohort fluctuations in fertility during World War II in the United States translate into changes in the birth order distribution of entering freshmen classes in the 1960s that may be important for the relation between birth order and achievement in this group (Folger & Bayer, 1966; Hooke, 1966).

Our results for heights in the overall study population do show some decrease in heights of only children, but inconsistent results for heights of last children, with effects only seen in large families. The changes are not large enough to affect the overall pattern of a resource dilution across the entire spectrum of family sizes and birth orders. To further examine the question raised by Blake (but to our knowledge not further examined by her with empirical data), we cross-tabulated the prevalence of only or last children in the study population by month and place of birth as indicators of famine exposure and found no specific patterns. The number of only or last recruits with potential famine exposure in our data is relatively small however as these groups are limited to recruits born in large cities in the Western Netherlands in the period November 1944- May 1945 (Z. A. Stein, Susser, Saenger, & Marolla, 1975) which reduces the cell counts of critical cells to very low counts, often not exceeding 100. This may explain the absence of demographic 'skew' detectable in the study population.

To examine the questions raised by the US experience, as these could potentially also be relevant for heights, we confirmed that our estimated birth order and family size effects (Tables 3 and 4) did not change by additional adjustment for 1944-1947 birth cohorts (Ravelli et al., 1976). Past analyses of heights of recruits born between 1944 and 1947 show no relation with height and exposure to the famine during gestation, infancy, or early childhood (Z. A. Stein et al., 1975).

Analyzing Dutch conscript heights from the 1850s onwards, van Wieringen reported that any inhibiting effects of WWII on secular trends in recruits' heights were limited to men from the 1950 draft (Van Wieringen, 1978). This shows that long term effects on height can be expected from acute nutritional changes during the rapid growth period in puberty. Although clearly deaths from infectious diseases during childhood and adolescence became exceptional with general access to antibiotics after WWII, less is known about the impact of more chronic deprivations in infancy and childhood.

In summary, based on accurate measures of height, we show that recruits from larger families are shorter than recruits from smaller families; that birth order effects are small in relation to family size effects; and that the effects are broadly comparable in recruits from higher and lower socio-economic backgrounds. Recruits from higher backgrounds are significantly taller however. Our findings are robust to control for available potential confounders. Although our study results are compatible with a 'resource dilution' hypothesis, our data cannot address the question what specific differences in the childhood environment in terms of nutrition, education, or other family behaviors could provide a mechanism for later differences in height. For this question, it would be necessary to identify what specific resources are diluted with an increase in the number of siblings and to establish that these resources could indeed generate height changes (Downey, 1995; Steelman et al., 2002). Although our study provides highly relevant empirical data on family size and height in a national population, other studies will be required to examine the long term impact of specific differences in the childhood environment that drive changes in height over time.

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