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Is paternal height related to fertility outcomes? Evidence from the Netherlands during the secular growth trend

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ABSTRACT

Over the past two centuries, the Dutch experienced a tremendous secular trend in height, and ultimately became the tallest nation in the world. Improving environmental conditions likely played the largest role in explaining these developments. But it is not yet precisely clear what factor set the Dutch head and shoulders above other nations, who were also experiencing improving environmental conditions. Could fertility also have played a role? To understand this, we would first need to know whether height and fertility were related during the secular growth trend. In this study, we investigated whether this was the case. A sample of Dutch men, birth years 1850–1900 (n = 3396), was examined. We tested the extents to which height was associated with having a certain number of children, and with having a certain number of children survive infancy. Multinomial logistic regressions were used. In terms of findings, height's relationship to fertility outcomes was curvilinear: being shorter-than-average (0.75–0.5 standard deviations below the mean height) was associated with a higher probability of being married and having five to seven children, while being moderately tall (0.5 standard deviations above the mean height) was associated with the lowest probability of being unmarried. There was no relationship between paternal height and children surviving infancy in the sample overall, but taller height was associated with a decreased risk of being in a high-mortality family among men born between 1880 and 1900. If paternal fertility played a role in the secular growth trend, we would expect to see very tall men have the most children, and clearly have the most children surviving infancy. Given this study's findings, it is unlikely that this was the case.

1. Introduction

With an average male of height of 182.4 centimeters (cm), the Dutch are the tallest nation in the world (Baten and Blum, 2012). But this was not always the case: in the mid-nineteenth century, the Dutch were relatively short compared to their European peers. In 1840, the average Dutchman's height was 164.5 cm, which was 0.2 cm taller than the average Frenchman, 2.1 cm shorter than the average German, and 7.7 cm shorter than the average American (*ibid.*). Over the late nineteenth and early twentieth centuries, the Dutch experienced a remarkable secular growth trend. By 1930, the Dutch, then with a mean height of 174.1 cm, had narrowly become the tallest nation, with the gap between them and other countries widening over the following decades (*ibid.*).

What factors contributed to this tremendous rise, and set the Dutch head and shoulders above other nations? Improving environmental conditions in early-life likely explain the majority of the Dutch secular growth trend, whereby better nutrition and a less virulent disease environment resulted in a taller population (e.g. Floud et al., 2011). Accordingly, sons were generally successively taller than their fathers. Despite a large body of literature dedicated to studying improving environmental conditions, it is still not clear what gave the Dutch an edge over other nations. To that end, Stulp et al. (2015) suggested that fertility outcomes may have played a complementary role in accelerating the velocity of the Dutch secular growth trend, whereby taller men were more likely to become fathers, to have more children, and to have more children surviving infancy. This may be via an evolutionary

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pathway: a greater share of 'tall genes' in the population may have helped give the Dutch a height advantage over other nations. Alternatively, improving living standards may have had a compounding effect across generations. Taller men, who were perhaps healthier by virtue of exposure to more hospitable environmental conditions, may have had more children, who were in turn taller and healthier than their peers. Before these pathways can be disentangled, it is important to determine whether height and fertility outcomes were in fact related during the Dutch secular growth trend. This would be the first step to determine whether fertility outcomes may have helped to augment the secular growth trend's speed. In this study, we investigated whether this was the case.

While height's relationships to fertility outcomes are relatively well-researched, findings are somewhat conflicting. For women, the majority of studies have found that height and fertility outcomes (odds of being a mother, number of children, number of surviving children) are positively related, e.g. tallness was associated with a greater number of children (Martorell et al., 1981; Brush et al., 1983; Devi et al., 1985; Fielding et al., 2008). However, there is no such consensus whether men's height is associated with fertility outcomes. Several studies using samples from modern middle- and low-resource settings found no relationship between men's height and fertility outcomes (Sear, 2006, 1984). However, Pawlowski (2003), found a positive relationship between height and the likelihood of becoming a father among a sample of Polish men. Kirchengast (2000), using a Namibian sample, similarly a found positive relationship between father's height and the number of surviving offspring. Finally, Mueller (1979) found a curvilinear relationship between height and the number of surviving children, whereby being above-average height (but not the tallest) was associated with increased fertility success in rural Colombia.

Most relevantly, Stulp et al. (2015) found that being taller was associated with improved fertility outcomes among a Dutch sample. Particularly, this study found that moderately tall Dutch men were more likely to become fathers, to have a greater number of children, and to have a greater number of surviving children (*ibid.*). The authors suggested that height may have been transmitted via natural selection, and therefore may have contributed to the secular growth trend (*ibid.*). However, this study's sample was born well into the twentieth century, with birth years from 1935 to 1967 (*ibid.*). During this period, the velocity of the Dutch secular growth trend was already beginning to decelerate (Fredriks et al., 2000). It is not yet known if height was related to fertility outcomes during the peak of the Dutch secular growth trend, in the late nineteenth and early twentieth centuries.

More generally, evidence of height's relationship to fertility among historical (pre-1915) populations is lacking. To our knowledge, no study has examined this relationship among historical men. Studying height's relationships to fertility outcomes in different contexts may ultimately help shed light on the mechanisms underpinning them. By examining when study findings converge and diverge, we may gain better insight as to why these relationships are present in some contexts but not in others.

To that end, we exploited a unique life-course dataset of men born in the latter half of the nineteenth century, and explored whether paternal height was associated with fertility outcomes. More specifically, we examined the relationship of paternal height to fertility success (being unmarried; being married and childless; being married and having a certain number of children). This study also examined paternal height's relationship to infant survival.

1.1. Theoretical concepts

Height is determined by both genetic and environmental factors. On an individual level, the majority of variation in height can be explained by genetic differences (Silventoinen et al., 2003). However, as mentioned, variation in human height on a population level is largely due to variation in environmental conditions. Environmental conditions can be better-specified as the components of net nutrition, or the quantity and quality of food an individual consumes, minus claims on their diet (Steckel, 2009). These claims include physical activity, basal metabolism, disease, and stress responses (*ibid.*). In general, the taller populations are, the better their environmental conditions during development tend to have been.

In turn, height may influence fertility outcomes. These outcomes are determined by a variety of factors, including culture, economics, socialization, genetics, and the interplay among these factors (Bras et al., 2013). Paternal height may play a role in this complex process. Several studies have found evidence that height specifically, and physical characteristics more generally, are related to fertility outcomes (Jokela, 2009; Pflüger et al., 2012).

First, paternal height may be associated with fertility because height is associated with a number of characteristics that are preferred on marriage markets. Already, a large body of research has shown that height is related to the probability of finding partners in both historical (Manfredini et al., 2013; Murray, 2000; Thompson et al., 2021) and modern (Sohn, 2015; Yamamura and Tsutsui, 2017) contexts. In our research population, being married meant having a partner, as couples generally did not live together without marrying. Thompson et al. (2021), using the same dataset as this study, found that shorter men were less likely to be married, although height was not associated with the timing of marriage.

Why exactly potential partners may prefer taller men is up for debate. It may be that tallness is associated with one or several psychosocial characteristics in adulthood that are rewarded with fertility success. One such characteristic is intelligence: Case and Paxson (2008) found that height was related to labor market outcomes because it was associated with cognitive ability. Increased intelligence may also make taller men more attractive partners (Kolk and Barclay, 2021). Height may also be related to fertility outcomes via other psychosocial characteristics, such as social skills (Persico et al., 2004); self-esteem and emotional well-being (Prieto and Robbins, 1975); and risk appetite (Kasielska-Trojan et al., 2017). Additionally, it is possible that labor market successes mediate the relationship between these psychosocial characteristics and fertility outcomes: taller men may have more labor market success because they possess more of these characteristics and to greater extents than their peers (Thompson, 2022; Thompson et al., 2019). In turn, men who are more successful on labor markets may have greater chances of finding partners (Yamamura and Tsutsui, 2017).

Second, taller height may be associated with better health. As mentioned, being taller is an indication that an individual was exposed to better environmental conditions in early-life. This means that height is a partial reflection of health in early-life (Alter, 2004). Perhaps as a result, height has been shown to be linked to later-life health outcomes, with taller individuals, up until a certain point of tallness, generally found to live longer, particularly in contemporary, high-income settings (e.g. Davey Smith et al., 2000). However, there is evidence that this is not the case in historical and contemporary lower-resource settings (e.g. Thompson et al., 2022; Sear, 2010; Thompson et al., 2020).

In turn, paternal height may be associated with children's health outcomes. This may occur directly, by a healthier father transmitting a health advantage to his children. This may also occur via an indirect, more material pathway, in which taller men, who tended to be exposed to better environmental conditions during their own childhoods, would be more likely to raise children in more hospitable environments. For instance, sons of farmers would likely grow up close to food sources, and in areas with low population densities. These men would be less likely to be exposed to infectious diseases, and to experience food scarcity (Groote and Tassenaar, 2020). These men may have been more likely to become farmers themselves, and to raise their children in similarly healthier environments. However, evidence for paternal height's relationship to the survival outcomes of their children is lacking. There is evidence for this relationship among women: several studies set in modern, low-income contexts have found a positive relationship between maternal height and childhood survival (e.g. Monden and Smits, 2009; Pollet and Nettle, 2008; Sear et al., 2004), although the mechanisms underpinning this relationship likely differ based on parental gender.

Third, height may be associated with paternal fertility because taller men are more fecund. Tallness may be indicative of a man's increased biological ability to have more children. In the literature, there is very little exploration as to whether and why this may be the case for men (Sear, 2010). For women, tallness is thought to be associated with greater energy reserves, and so taller women may be better-able to produce more children, although Sear (2010) argued that this energy requirement may not be the same for men. Nonetheless, it is possible that height and paternal fertility outcomes are related via fecundity.

When using observational data, fecundity is virtually impossible to disentangle from fertility behavior. In other words, does a taller man have more children because he is more fecund, or because he is more fertile (i.e. more sexually active) (Smarr et al., 2017)? As with fecundity, there is no convincing evidence of height's relationship to fertility behavior. However, Frederick and Jenkins (2015) found that taller men were more sexually active than shorter men, but the authors posited that this was because taller men simply had 'more mating opportunities' (p. 2). Likewise, Mueller and Mazur (2001) found that taller men had more children because they were more likely to have second marriages after divorce. The authors argued that this was because taller men were perceived as more attractive, and therefore had more partners (*ibid.*).

To summarize, we identified several potential mechanisms explaining why height and fertility may be related: psycho-social characteristics, health, and fecundity and/or fertility. These mechanisms may be intertwined. Additionally, it is possible that taller individuals may actually possess these characteristics, but also may be more likely to be perceived as having them. Here, height may function as a signal of a beneficial characteristic. For instance, taller men may be perceived as more attractive by virtue of their tallness, perhaps by signalling a mix of health, intelligence, dominance, social skills, et cetera. Although it is outside of the scope of this study to explicitly test these mechanisms, they nonetheless were used to orient and interpret this study's findings.

1.2. Study setting

In our research period, the Netherlands was experiencing a demographic transition, and was moving from having higher birth and death rates to having lower ones (Omran, 1971). As mentioned, this was likely due to improving environmental conditions, e.g. fewer outbreaks of infectious diseases, improved sanitation and/or greater food quantity and quality. This is particularly visible with the infant death rate, which is more sensitive to environmental shifts. Over the course of the 1870 s and 1880 s, the infant mortality rate in the Netherlands began to decline (van der Bie, 2001).

According to classical demographic transition theory, fertility declines are spurred by mortality declines. This appears to have been the case in the Netherlands (van Poppel et al., 2012). As more children survived until adulthood, having many children became less common. The average family size shifted from eight in the period 1871–1875 to just above three in the period 1931–1950 (van Poppel et al., 2012). This may have been part of a conscious attempt to regulate family size, or may have occurred unconsciously, via biological mechanisms (Engelen and Hsieh, 2007).

In addition to temporal trends, there were also apparent regional trends in marriage practices and fertility. Buissink (1971) argued that, because of uneven sex ratios across the Netherlands, marital fertility rates varied widely. For example, in 1899, the fertility rate in Zuid-Holland was 7 % higher than in Drenthe. Similarly, the infant mortality rate has been found to vary by province, particularly toward the beginning of our research period. Using a relatively small sample, van Poppel et al. (2005) found that, between 1850 and 1859, the infant survival rate was 94.4 % in Utrecht, but 70.6 % in Zeeland. However, between 1890 and 1899, these figures were 98.1 % and 94.7 %, respectively (*ibid.*).

Some of these regional differences may be explained by religion, with the south of the country more Catholic, and the north more Protestant, albeit with considerable overlap throughout the country. There were also significant differences between liberal and the more conservative Neo-Calvinist Protestants. Neo-Calvinist Protestants and Catholics were less likely to engage in stopping and spacing practices than liberal Protestants (van Bavel and Kok, 2004). Perhaps as a result, liberal Protestants ultimately had fewer children than either Catholics or Neo-Calvinist Protestants (Engelen and Hillebrand, 1986). Additionally, there is strong evidence that Catholics experienced much higher infant mortality rates than members of other religions (Walhout, 2019). This is likely because Catholic mothers breastfed for shorter durations. This may have had two consequences. First, when weaned, babies would generally have been fed diets consisting of cows' milk and porridge, and were therefore more greatly exposed to water- and food-borne pathogens (*ibid.*). This may have contributed to higher rates of infectious disease-related deaths. Second, mothers perhaps had shorter birth intervals as a consequence of shorter breastfeeding (*ibid.*). According to the maternal depletion hypothesis, mothers who have children in shorter intervals are less able to recover from one pregnancy/birth to the next, and are less likely to have healthy children (Winkvist et al., 1992). As a result, these children have a greater chance of dying in early childhood (*ibid.*).

Finally, in nineteenth-century Europe, fertility outcomes may have been influenced by social class (Dribe et al., 2017). White-collar and elite workers tended to experience the transition to having fewer children first, with unskilled workers trailing behind (*ibid.*). However, there is evidence that infant mortality rates did not vary strongly by social class during this period (Ekamper and van Poppel, 2019).

2. Methods

2.1. Data and variables

The starting point of this study was the Historical Sample of the Netherlands (HSN). The HSN is a ~0.25 % representative sample of Dutch people born between the years of 1812 and 1922, and contains, at a minimum, birth certificates for these individuals (Mandemakers, 2000). Where available and/or applicable, death and marriage certificates were also included in the HSN. In 1850, population registers, which contain much more detailed information on household composition, were implemented. Between 1910 and 1939, this was followed by family cards, which contain information similar to population registers, and are based around the household as the unit of observation (*ibid.*). From 1939 onward, family cards were replaced with personal cards, so that individuals became the unit of observation.

Information on research persons' (RPs') children was gleaned from the population registers and family cards. To appear in this dataset, children had to be born alive, and to survive long enough to be registered in households (generally a few days after birth). van den Berg et al. (2021) noted that 'RPs' children were identified very accurately in the HSN because RPs were, in principle, followed for their entire life course' (p. 97). We considered a child to have died when they exited the household.

Next, a sample of necessarily male HSN RPs was linked to their conscription records in the Heights and Life Courses database, as only men were conscripted in the Netherlands. This database contains conscription information from nine of the eleven nineteenth-century Dutch provinces (Mandemakers, 2019; Kok et al., 2016). Although the Heights and Life Courses database includes RPs born until 1922, few RPs in this dataset were born after 1900. For the sake of data sufficiency, only RPs born between 1850 and 1900 were included. We also excluded RPs who died before age 40 so that RPs in this study would have had sufficient time to become fathers and have children, and excluded those without complete covariate information. This yielded a sample of 3396

RPs. This full sample was used in this study's fertility success analyses. In the infant mortality analyses, only RPs who had children were included (n = 2290).

In terms of outcomes, two categorical variables were used. The first measured fertility success, and included the following categories: unmarried and childless; married and childless; married with one child; married with two to four children; married with five to seven children; and married with eight or more children. It is worth noting that, in this period, a man had to be married to the mother of his child for him to be registered as the father. This means that all unmarried men were considered to be childless in this study. In most cases, this was true, although between 2 % and 5 % of births in the Netherlands during this study's research period were found to be out-of-wedlock (Gates et al., 2006).

The second outcome variable measured RPs' children's survival in infancy, and included the following categories: low, medium and high risk of experiencing infant death. We elected to use survival until age one as our outcome, because infants are the most vulnerable to infectious disease and death. Any health and/or care advantage that paternal height might confer would therefore perhaps be strongest among infants (Abernethy and Yip, 1990). To create these categories, we borrowed from Edvinsson et al. (2005). 'High risk' was defined as having fewer than six births, and two or more deaths; having seven to ten births, and three or more infant deaths; or having eleven or more births and five or more infant deaths. 'Medium risk' was defined as having fewer than six children and one infant death; having seven to ten births and two infant deaths; or having eleven or more births and three or four infant deaths. All other RPs with children were defined as 'low risk'.

The key predictor variable was height. Because RPs in this study were successively taller over time, height was categorized as z-scores weighted by ten-year birth cohorts. Further, based on Stulp et al. (2015) and Mueller (1979), we initially expected to find a curvilinear relationship between height and fertility outcomes. We therefore tested whether including higher-order polynomials resulted in better-fitting models with likelihood-ratio tests. For the fertility success analyses, the model including a quadratic height term was the best fit. For infant survival analyses, the model not including any higher-order polynomials was the best fit.

In adjusted analyses, relevant factors that likely confounded the relationships between height and fertility outcomes were also controlled for. First, we controlled for RP's birth cohort. Categorical variables were used.

The father of the RP's occupational class was also included as a covariate. We used the highest occupation available for fathers in the HSN, and characterized these using the HISCLASS5 score. HISCLASS is a widely-used and validated historical occupational classification system, with its condensed, five-category version most appropriate for inclusion in quantitative analyses of relatively small samples (van Leeuwen and Maas, 2011). Six occupational categories were included: elite; middle class; skilled workers; farmers; unskilled workers, and those with unknown occupations.

Region of birth was also controlled for. Given the rather small geographic size of the Netherlands, we categorized the eleven nineteenth-century Dutch provinces into four regions, based on geography and economy type: north (Friesland, Groningen, Drenthe); middle (Utrecht; Overijssel; Gelderland); coastal (Noord and Zuid-Holland); south (Noord-Brabant, Zeeland, Limburg) (e.g. Thompson et al., 2022).

Additionally, whether an RP was born in a large city was included as a covariate. This was defined as being from a city of over 100,000 residents (Amsterdam, Rotterdam, and the Hague), based on the 1889 census (Centraal Bureau voor de Statistiek, 2011). We also controlled for religion (Catholic; Liberal Protestant; Neo-Calvinist; Jewish; unknown/no religion).

Factors relating to family circumstances in childhood were also adjusted for. We controlled for the number of siblings the RP had at age 10, whether or not the RP experienced parental death before the age of 16, and whether or not the RP was illegitimate.

Finally, because the infant survival analyses only included RPs who were married and had children, characteristics related to their marriages and children could be included in these analyses. These covariates included: age at marriage, characterized by standard deviations from the mean; age gap with spouse, characterized by standard deviations from the mean; and whether or not the RP's wife had, on average, short birth intervals, defined as an average birth interval of 33 months or fewer (de Jonge et al., 2014).

2.2. Analyses

All analyses were performed in Stata version 16. First, sample characteristics were computed. Next, because we were interested in modelling more than two discrete outcomes, multinomial logistic regressions were used, with fertility success and infant survival as the two outcome variables. These equations were specified:

$$Probability\quad \left(Y^{a,b} = j|X\right) = \frac{\exp(X\beta_J^{a,b})}{1+\sum_{J=1}^{J}\exp(X\beta_J^{a,b})}, \tag{1}$$

whereby $Y^{a,b}$ = categories with "a" referring to the model for fertility success and "b" referring to the model for infant survival; $\beta_J^{a,b}$ = parameters of the independent variables (height and confounding variables); X = independent variables (height and confounding variables); and j = Total number of independent variables "j".

For brevity's sake, we only reported the results of adjusted regressions, without covariate information. The full results, including complete covariate information, are reported in the Appendix. For the fertility results, restricted F-tests were performed, to test the joint significance of the height terms. These are reported at the bottom of each equation's results. Relative risk ratios (RRRs) were reported, whereby a RRR greater than one indicates the risk of the outcome falling into a comparison group increases as the variable increases, relative to falling into the reference group. The full-sample regression results are reported, alongside results stratified by birth cohort (1850-1879 and 1880-1900).

We also performed several robustness checks, which are reported in the Appendix. First, the main analyses were performed using height in centimeters instead of height as z-scores (tables B.1 and B.2), to assess whether the characterization of height influenced this study's results. Similarly, to understand whether paternal height's relationship to children's survival varied based on children's ages, we examined height's relationship to children surviving until age five, instead of age one (table B.3). To check whether using multinomial logistic regression impacted the results of the infant survival analyses, which are somewhat ordered, we performed these analyses using ordinal logistic regressions (table B.4). These analyses' results aligned with those of our main results.

We also performed several additional analyses to better-understand height's relationship to fertility outcomes. We examined height's relationship to the timing of first birth, using survival analyses. When examining height and height^2's relationship to the hazard (timing) of first birth using the full sample of 3396 RPs (table B.5), we found a strongly curvilinear relationship (p = 0.000), with RPs around the mean height having the highest hazards of first birth. However, when only including married RPs (n = 2759), we found that this relationship was no longer significant, particularly when including the timing of marriage as a covariate (table B.6).

Further, it is possible that including men who were married at later ages has polluted this study's fertility results. These men likely had less opportunity to have children as a consequence of being married later. We found some evidence of this: men who were married but had no children were on average married later (31.8 years) than other men (27.2 years). To test whether this impacted our findings, the fertility analyses were performed when excluding men who were married at age 45 and later (table B.7). These results aligned with those reported in the main results.

Table 1
Sample characteristics.

	Obs.	%/Mean (SE)
Fertility outcomes		
Unmarried + childless	637	18.8 %
Married + childless	469	13.8 %
Married + 1 child	256	7.5 %
Married + 2–4 children	967	28.5 %
Married + 5–7 children	581	17.1 %
Married + 8 or more children	486	14.3 %
Children's mortality outcomes		
Married + low risk	1781	77.8 %
Married + medium risk	384	16.8 %
Married + high risk	125	5.5 %
Height (cm)	3396	168.104 (6.929)
Birth cohort		
1850–1859	278	8.2 %
1860–1869	717	21.1 %
1870–1879	803	23.6 %
1880–1889	1019	30.0 %
1890–1900	579	17.0 %
Father's highest occupational class		
Elite	97	2.9 %
Middle class	697	20.5 %
Skilled workers	1124	33.1 %
Farmers	659	19.4 %
Unskilled workers	789	23.2 %
Unknown/no occupation	30	0.9 %
Birth region		
North (Groningen, Friesland, Drenthe)	828	24.4 %
Middle (Utrecht, Overijssel, Gelderland)	1204	35.2 %
Coastal (Noord-Holland, Zuid-Holland)	720	21.2 %
South (Limburg, Noord-Brabant, Zeeland)	644	19.0 %
Born in a city with a 100,000 + population		
Yes	1312	38.6 %
No	2084	61.4 %
Religion		
Catholic	1130	33.3 %
Liberal Protestant	1631	48.0 %
Neo-Calvinist Protestant	284	8.4 %
Jewish	88	2.6 %
No/unknown religion	263	7.7 %
Number of siblings at age 10		
Only child	68	2.0 %
One sibling	214	6.3 %
2–4 siblings	1233	36.3 %
5–7 siblings	1280	37.7 %
8 or more siblings	601	17.7 %
Experienced parental death?		
No	2620	77.2 %
Maternal death	338	10.0 %
Paternal death	385	11.3 %
Total orphan	53	1.6 %
Illegitimate?		
Yes	22	99.4 %
No	3374	0.7 %
Age gap with wife		
More than 1 SD below mean (17.9–1.9 years younger)	246	8.9 %
Within 1 SD of mean (1.9 years younger to 7.3 years older)	1670	60.5 %
More than 1 SD above mean (7.3 years to 31.4 years older)	276	10.0 %
Unknown	567	20.6 %
Age at first marriage		
More than 1 SD below mean (18.1–22.0 years)	191	6.2 %
Within 1 SD of mean (22.0–34.1 years)	2105	76.3 %
More than 1 SD above mean (34.1–74.8 years)	309	11.2 %
Unknown	154	5.6 %
Average birth interval under 33 months?		
Yes	868	37.9 %
No	1422	62.1 %

3. Results

3.1. Sample characteristics

Table 1 presents the sample characteristics. Average height was 168.1 cm. Average age of first marriage was 28.0 years, and average age of first birth was 28.9 years. In terms of fertility outcomes, 18.8 % of RPs were unmarried and childless, while 13.8 % were married and childless. Further, 7.5 % were married with one child; 28.5 % were married with between two and four children; 17.1 % were married with five to seven children; and 14.3 % had eight or more children. Fig. 1 illustrates height's relationship to fertility outcomes. RPs who were unmarried and childless had a median height of 167.9 cm. Those who were married but childless had a median height of 168.3 cm. Those had one child had a median height of 169.2 cm. RPs with two to four children had a median height of 169.0 cm. RPs with five to seven children had a median height of 167.3 cm. Finally, those with eight or more children had a median height of 167.8 cm.

In terms of infant survival outcomes, 77.8 % were married and had a low-risk family (and 64.0 % experienced no infant death); 16.8 % were married and had a medium-risk family; and 5.5 % were married in a high-risk family. Fig. 2 illustrates height's relationship to infant survival outcomes. RPs in low-risk families had a median height of 168.5 cm. Those in medium-risk families had a median height of 167.7 cm, and those in high-risk families had a median height of 167.8 cm.

3.2. Height's relationship to fertility outcomes

The results of height's relationship to fertility outcomes, adjusted for relevant covariates and a second-order height term, are presented in Table 2. The full results, including complete covariate information, are included in the Appendix. The predicted probabilities of the regression results are illustrated in Fig. 3. Height z-score was significantly related to the risk of being unmarried (restricted F-test $p = 0.030$) in the full-sample analysis. This relationship was curvilinear, with those 0.5 standard deviations above the mean height having the lowest predicted probability of being unmarried (Pr=0.174). The shortest RPs, those who were two standard deviations below the mean height, had the highest predicted probability of being unmarried (Pr=0.248). RPs who were more than two standard deviations above the mean height also had a higher predicted probability of being unmarried (Pr=0.197). Additionally, there was a significant relationship between height and the risks of having five to seven children (restricted F-test $p = 0.068$), relative to the reference group. Height's relationships to these outcomes was also curvilinear. RPs 0.5 standard deviations below the mean height had the highest predicted probabilities of having five to seven children (Pr=0.188). RPs who were two standard deviations below (Pr=0.165) and above (Pr=0.111) the mean height also had lower predicted probabilities of having five to seven children.

Also in the full-sample analysis, height z-score did not play a significant role in the risks of being married and childless, married and having one child, or of being married and having eight or more children, relative to the reference group of being married and having two to four children. It is, however, worth noting that the functional forms of these relationships differed: RPs 0.5 standard deviations below the mean height had the lowest probabilities of being married and childless. In contrast, RPs who were 0.5 standard deviations below the mean height also had the highest probabilities of having eight or more children. There was a linear relationship between height z-score and the relative risks of having one child, and of having two to four children, whereby being taller was associated with higher probabilities of these outcomes.

In the analyses stratified by birth cohort, we observed similar findings to those of our main results for RPs born between 1850 and 1879, and RPs born between 1880 and 1900.

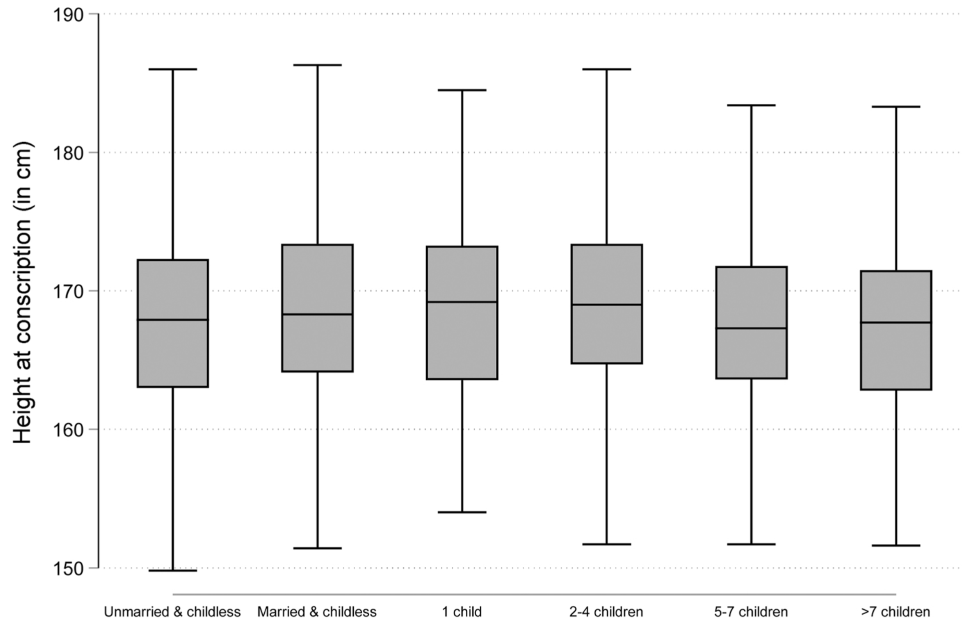

Fig. 1. Median height, over number of children.

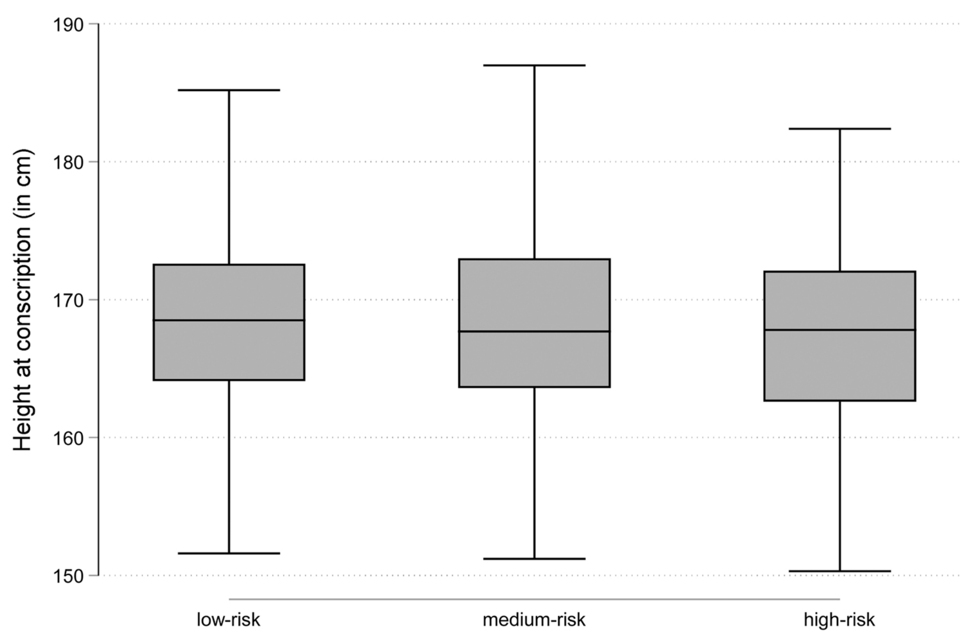

Fig. 2. Median height, over infant mortality risk.

3.3. Height's relationship to infant survival outcomes

The results of height's relationship to infant survival outcomes, adjusted for covariates, are presented in Table 3. The predicted probabilities of the regression results are presented in Fig. 4. No significant relationships between height and infant survival outcomes were found in the full-sample analysis. RPs had the highest probabilities of being in low-risk families, with no or few infant deaths, followed by the risks of being in medium risk and high risk families.

When examining the results stratified by birth cohort, we found no significant relationships among RPs born between 1850 and 1879, in line with the findings for the full sample. However, among RPs born between 1880 and 1900, a one standard deviation increase in height was associated with 0.701 times the risk of being in a high-risk family (95 % CI: 0.474–1.036; p-value: 0.074), relative to being in a low-risk family.

4. Discussion

In this study, we examined height's relationship to fertility outcomes among a sample of Dutch men. This study added to the literature on height and fertility in several ways. First, a historical sample, from more than 100 years ago, was used. To our knowledge, this study was among the first to do so. This is important, because paternal height's relationships to fertility outcomes appears to vary by context (Sear, 2010; Stulp and Barrett, 2016). By comparing settings in which these relationships are present to those in which they are not, it may ultimately be possible to shed light on the mechanisms underlying height's relationships to fertility outcomes. Further, the present study was the first to examine height's relationship to fertility in the nineteenth and early-twentieth centuries Netherlands, when the secular growth trend was in full swing. Examining men born in the latter half of the nineteenth century

Table 2
Height's relationship to fertility, full sample, and stratified by birth cohort, adjusted multinomial logistic regressions.

	Full sample (n = 3396)				Birth years 1850–1879 (n = 1798)				Birth years 1880–1900 (n = 1598)			
Fertility outcomes	RRR	P-value	95 % Conf. Interval		RRR	P-value	95 % Conf. Interval		RRR	P-value	95 % Conf. Interval	
Unmarried + childless												
Height (cm)	0.848	0.002	0.766	0.939	0.830	0.011	0.720	0.958	0.871	0.072	0.749	1.012
Height (cm)^2	1.068	0.030	1.007	1.133	1.041	0.322	0.961	1.127	1.105	0.029	1.010	1.209
Height terms F-test (chi^2 and p-value)	4.74	0.030			0.98	0.322			4.74	0.029		
Married + childless												
Height (cm)	0.925	0.172	0.828	1.034	0.956	0.583	0.814	1.123	0.874	0.092	0.747	1.022
Height (cm)^2	1.052	0.126	0.986	1.123	1.064	0.173	0.973	1.162	1.037	0.469	0.940	1.144
Height terms F-test (chi^2 and p-value)	2.34	0.126			1.86	0.173			0.52	0.470		
Married + 1 child												
Height (cm)	0.911	0.208	0.788	1.053	0.821	0.088	0.655	1.030	0.973	0.787	0.798	1.187
Height (cm)^2	0.996	0.929	0.907	1.093	0.964	0.600	0.840	1.106	1.012	0.852	0.889	1.153
Height terms F-test (chi^2 and p-value)	0.01	0.929			0.27	0.600			0.03	0.852		
Married + 2–4 children	**Base outcome**				**Base outcome**				**Base outcome**			
Married + 5–7 children												
Height (cm)	0.814	0.000	0.725	0.914	0.795	0.006	0.676	0.936	0.830	0.030	0.702	0.982
Height (cm)^2	0.935	0.085	0.866	1.009	0.908	0.068	0.818	1.007	0.968	0.575	0.865	1.084
Height terms F-test (chi^2 and p-value)	2.96	0.085			3.33	0.068			0.31	0.575		
Married + 8 or more children												
Height (cm)	0.861	0.016	0.763	0.973	0.936	0.404	0.800	1.094	0.726	0.003	0.588	0.896
Height (cm)^2	0.977	0.563	0.905	1.056	0.971	0.553	0.882	1.070	0.974	0.699	0.852	1.113
Height terms F-test (chi^2 and p-value)	0.33	0.563			0.35	0.554			0.15	0.699		

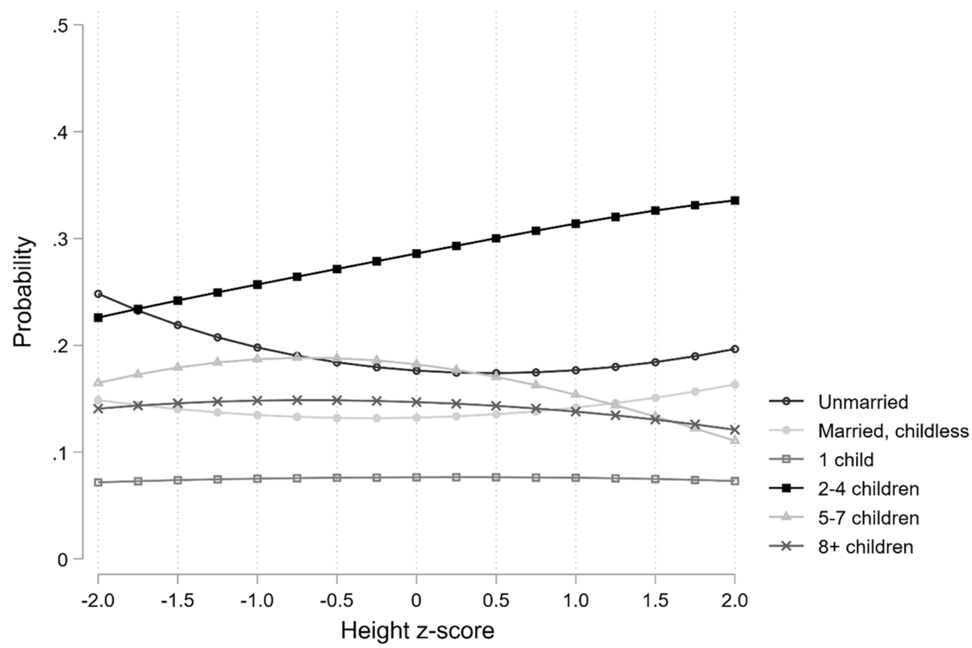

Fig. 3. Height's relationship to fertility outcomes.

Table 3
Height's relationship to infant survival, full sample and stratified by birth cohort, adjusted multinomial logistic regression.

Infant mortality outcomes	Full sample (n = 3396)				Birth years 1850–1879 (n = 1798)				Birth years 1880–1900 (n = 1598)			
	RRR	P-value	95 % Conf. Interval		RRR	P-value	95 % Conf. Interval		RRR	P-value	95 % Conf. Interval	
Low risk	**Base outcome**				**Base outcome**				**Base outcome**			
Medium risk												
Height (cm)	1.002	0.969	0.887	1.135	0.982	0.823	0.835	1.154	1.082	0.438	0.887	1.319
High risk												
Height (cm)	0.928	0.489	0.750	1.147	1.069	0.615	0.825	1.384	0.701	0.074	0.474	1.036

enabled us to more explicitly study whether fertility played a role in the secular growth trend.

Second, this study focused on men's fertility outcomes. Much of what is known about parental height's relationship to fertility concerns maternal height (e.g. Sear, 2010; Subramanian et al., 2009). This is logical: women's bodies play a much more immediate role in

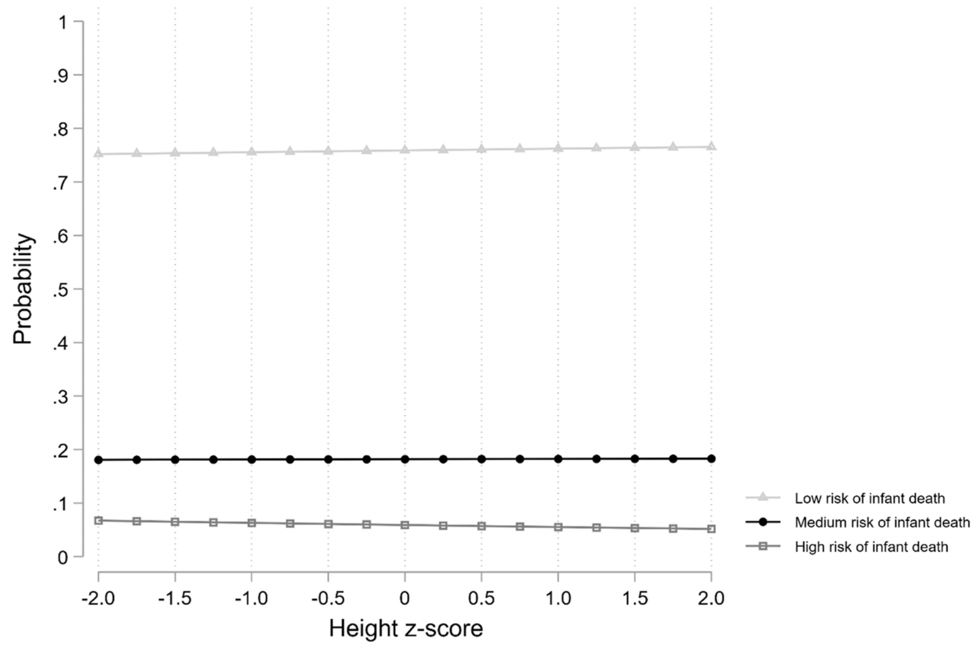

Fig. 4. Height's relationship to infant survival outcomes.

childbearing and rearing. But there is evidence that drivers of fertility differ for men and women, and should be considered separately to fully understand fertility behavior (Schoumaker, 2019). The present study helped to address this gap.

Third, this study stood out for its dataset. This study's sample contains relatively untruncated heights. The Dutch, in theory, measured all men during conscription (Quanjer and Kok, 2020). Even men who were set to be exempted from military service, e.g. for being under the minimum height requirement, were measured. Of course, some comparatively minor selection issues, such as an underrepresentation of higher socio-economic status RPs, are present in the data (*ibid.*). Even so, this sample, relative to other anthropometric samples from the nineteenth century (as described by Komlos, 2003), more accurately reflects the height of its research population.

Fourth, this study's analytic strategy enabled better specification of the relationship between height and fertility, compared to existing studies on the topic. As mentioned, Stulp et al. (2015) examined similar relationships in a large (N = ~90,000) twentieth-century sample, and found evidence of improved fertility outcomes for moderately tall men. This study considered each outcome (e.g. the likelihood of being married and the number of children) separately. This may not accurately reflect reality. For instance, the likelihood of finding a partner is connected to the likelihood of having children. The present study helped to address this issue by using multinomial logistic regressions, in which several outcomes were considered together.

Overall, this study provided evidence that height was related to fertility outcomes during the secular growth trend in the Netherlands, although tallness was not always beneficial. We found that being around average height was significantly related to a higher probability of having five to seven children, and to a lower probability of being unmarried, relative to the reference group of having two to four children. This finding conflicts with some existing studies, which have shown that tallness is unequivocally rewarded on dating and marriage markets (e.g. Shepperd and Strathman, 1989; Mueller and Mazur, 2001). However, other studies have found that average-height men have the highest probabilities of success on marriage and dating markets, which Stulp and Barrett (2016) term 'a puzzle'. It is not clear why average-height men would have greater success finding a partner than shorter ones. One possibility is that because height is normally distributed, the largest share of people within a given population tend to be around the average height. If an individual prefers partners around the average height, they have the largest pool of potential partners (Pawlowski et al., 2000). This, in turn, would give that individual the largest chance of reproductive success (*ibid.*).

Additionally, the particularities of this study's research population may explain why being around average height was associated with higher probabilities of fertility success. A possibility is that average height and/or somewhat short men were more likely to be married at younger ages, to have longer fertility careers, and to ultimately have more children. In this study's research period, lower socio-economic status men tended to be both shorter, and to get married at younger ages than their peers (Quanjer and Kok, 2019; Engelen and Kok, 2003). This was likely due to lower socio-economic status individuals being subject to fewer financial constraints on marriage (Engelen and Kok, 2003). This effect may have been larger in this study than in those set in contemporary contexts, due to the absence of modern birth control.

The uneven pace of the demographic transition throughout the Netherlands may also explain this study's somewhat surprising findings. As mentioned, the decline in fertility rates in the Netherlands was preceded by a decline in mortality rates, and this process occurred at different times throughout the country (Boonstra and van der Woude, 1984). We also know that individuals exposed to more virulent disease environments (generally proxied by infant mortality rates) during development tend to be shorter (Bozzoli et al., 2009). Perhaps men exposed to worse environmental conditions were both shorter, and had more children due to later experiences of the demographic transition. These men may have been less likely to regulate their family sizes than their contemporaries, who may have encountered falling mortality rates, and who were perhaps consequently more likely to limit their family sizes.

This study also found that height did not play a role in infant survival in the full sample analyses (birth years 1850–1900), and among men born between 1850 and 1879. However, we found that, among men born between 1880 and 1900, taller height was related to a decreased risk of being in a family with a high rate of infant death. This indicates that context may matter for height's relationship to infant mortality outcomes. In the nineteenth and early twentieth century Netherlands, infant death was both largely caused by infectious disease and was more widespread, with rates declining over this study's research period (Walhout, 2019). There is also existing evidence that infant death was more random in the nineteenth century, with better environmental exposures, proxied by parental socio-economic status, only weakly related to childhood survival (Ekamper and van Poppel, 2019). Any protection, either health or material, that paternal height may have conferred would perhaps have mattered less at the beginning of this study's research period, and more at its end. It follows that if we observed later cohorts, we could expect a stronger relationship between height and infant survival. This finding also aligns with research showing that a social gradient in mortality did not emerge until well into the twentieth century, largely due to the more random nature and increased likelihood of infectious disease death (Bengtsson et al., 2020).

The importance of the disease environment to paternal height's relationship to infant mortality may also help to explain variations in findings among existing studies. For instance, while Sear (2006), examining a Gambian sample, did not find a significant relationship, Stulp et al. (2015), examining a contemporary Dutch sample, found a curvilinear relationship between paternal height and infant survival.

A final question: what does this mean for fertility's role in the secular growth trend? Stulp et al. (2015) concluded that fertility outcomes may have augmented the secular growth trend. For this to have been true for paternal fertility, the tallest men would have clearly had the most children, and have had the most children surviving infancy. We found that shorter-than-average men had the highest probabilities of having many children. We also found no relationship between height and infant survival at the beginning of this study's research period. Although possible, it seems unlikely that paternal fertility outcomes would have accelerated the velocity of the secular growth trend.

4.1. Limitations

Our study had several limitations that are important to bear in mind. First, this study could not explicitly identify the mechanisms through which height may be related to fertility. This limited the extent to which we were able to understand why height was related to fertility outcomes.

Second, only children who survived long enough to be recorded in the population registers and/or family cards were included in this study. Generally speaking, stillborn children, or children who died within the first day of life were not recorded. This may have downwardly biased our estimates for both the fertility success and infant mortality analyses, particularly among short men, who were more likely to be living in deprived conditions. These men may have had more children, but also more deaths among those children.

Third, this study only examined fertility success from one generation to another. Studies examining fertility outcomes are often able to explore these relationships across several generations (e.g. Goodman and Koupil, 2009; Dillon et al., 2020). We were unable to do so, based on the way in which information on fertility outcomes was collected: information on the children an RP had was gleaned from the Dutch population registers and family cards, which recorded information on that RP's household. Because grandchildren would generally not be part of the same household, we have no useful information on three generations. Future Dutch studies, based on data linked across grandfathers, fathers and grandsons could perhaps shed more lightly on the transmission of height, health and fertility across generations.

Fourth, this study did not include women. This was due to using historical data, in which information about women is often lacking (Mackinnon, 1995). This is especially the case with representative height data (e.g. Meredith and Oxley, 2015). This also limited the extent to which fertility's role in the secular growth trend could be understood.

Finally, it was assumed that, for all men in our sample, marrying, becoming a father and having children were desired outcomes (Thompson et al., 2020). While it was certainly the norm to both find a wife and have children, this was likely not universally the case.

5. Conclusions

In this study, whether height was related to fertility outcomes during the Dutch secular growth trend was examined. Height appeared to have played a role in some fertility outcomes. Being around the average height was associated with a higher probability of being married and having five or more children, relative to being married and childless. Perhaps this is due to a more universal preference for average-height men, or because shorter men were married at younger ages.

Further, there was only a relationship between height and mortality among men born in the nineteenth and early twentieth centuries. This was perhaps because, in this later cohort, infectious disease death was less common, and infant mortality less random. Positive factors with which taller paternal height may be associated, e.g. better health and improved environmental conditions, may therefore have played a greater role in determining infant survival outcomes.

Returning to the question posed in this paper's introduction, what does this result mean for fertility's contribution to the secular growth trend? Based on this study's findings, it appears unlikely that paternal fertility outcomes played a meaningful role in the Dutch's tremendous growth.

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CRediT authorship contribution statement

Kristina Thompson: Conceptualization, Data curation, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Maarten Lindeboom:** Funding acquisition, Methodology, Supervision, Writing – review & editing. **France Portrait:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Disclosure statement

The authors report there are no competing interests to declare.

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Appendix A and B. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ehb.2022.101172.

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