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The Influence of Health in Early Adulthood on Male Fertility

KIERON BARCLAY  AND MARTIN KOLK 

Despite the large literature examining predictors of fertility, previous research has not offered a population-level perspective on how health in early adulthood is related to male fertility. Using Swedish population and military conscription registers, we study how body mass index (BMI), physical fitness, and height are associated with total fertility and parity transitions by 2012 among 405,427 Swedish men born 1965–1972, meaning we observe fertility up to age 40 or older. Applying linear regression and sibling fixed effects, we find that these anthropometric measures are strong predictors of fertility, even after accounting for education and cumulative income. Men with a “normal” BMI and in the highest decile of physical fitness have the most children. Men who were obese at ages 17–20 had a relative probability of childlessness almost twice as high as men who had a “normal” BMI, and men in the bottom decile of physical fitness had a relatively probability of childlessness more than 50 percent higher than men in the top decile. In sibling comparison models the tallest men have the most children and men in the lowest two deciles of height have significantly lower fertility. Further analyses show that the strong associations persist even among men who married.

Introduction

Demographers have long been interested in the health–fertility nexus. In this study, we examine how several anthropometric measures recorded in early adulthood are associated with later childbearing outcomes, a topic that has received surprisingly little attention. Our measures include

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body mass index (BMI), physical fitness, and height, and as such capture dimensions of health that are strong predictors of health and mortality in later adulthood (e.g., see Blair et al. 1995; Stulp and Barrett 2016; Stokes and Preston 2016). BMI and physical fitness are strongly associated with aspects of male sexual and reproductive health, including sexual function (Cheng and Ng 2007), healthy endocrine balance (Kahn and Brannigan 2017), and various important semen parameters such as sperm count and sperm function (Jensen et al. 2004; Hammoud et al. 2008a). Likewise, our anthropometric measures have direct and indirect associations with the search for a sexual and childbearing partner. BMI, physical fitness, and height influence perceptions of physical attractiveness, stigma (Puhl and Heuer 2009; Pawlowski, Dunbar, and Lipowicz 2000), and are associated with socioeconomic attainment (Lundborg, Nystedt, and Rooth 2014).

Average levels of health and fitness measured in early adulthood have been decreasing over the past several decades, with an increasing prevalence of being overweight or obese, and lower rates of physical activity across almost all OECD countries. For example, in 1971 7.8 percent of men aged 17–18 in Sweden were obese or overweight, rising to 19.5 percent in 1995 (Rasmussen, Johansson, and Hansen 1999), and 25.3 percent in 2014 (Eriksson, Lingfors, and Golsäter 2018). At present, there is no detailed understanding of how the secular trends of rising overweight and obesity and declining physical fitness may influence future fertility in Sweden and other high-income countries. Although female cohort fertility in Sweden has remained stable at approximately two children per woman for the past century (Andersson et al. 2009; Jalovaara et al. 2019), recent data for men have shown a decrease in total number of children and an increase in the proportion that are childless at age 45 (Jalovaara et al. 2019). Of Swedish men born 1965–1969, 22 percent were childless at age 45, while only 4 percent had four or more children by that age. We therefore are particularly interested in how health in early adulthood is related to the probability of childlessness.

Part of the challenge of studying the relationship between health in early adulthood and later fertility is measuring health objectively, and doing so at a population scale. In this study, we exploit information from military conscription registers in Sweden to examine how height, physical fitness, and BMI, measured at ages 17–20, are related to later fertility for all men born in Sweden between 1965 and 1972. Using population registers, we are able to capture the full population of men born in the cohorts that we study, including institutionalized individuals who are typically missing from survey data. This large data also allow us to study less common dimensions of fertility, such as higher parity transitions, and the tails of the distribution of our anthropometric measures, for which it would not otherwise be possible to obtain stable estimates from survey data. We follow men up to age 40 or later in order to study how our measures of health are related to entry into

parenthood, parity transitions, and total number of children by the end of our follow-up period in 2012. Given previous research on how health influences socioeconomic attainment, we also take account of how educational attainment and cumulative income may mediate the relationship between health and fertility and examine the health–fertility association at different levels of income and education. We also take account of the importance of shared background factors by conducting sibling fixed-effects analyses using a subset of brothers. Furthermore, we examine how childlessness varies by whether the men that we study had ever been married by age 40, using ever-married status as an indicator of successful partnership formation independent of fertility.

To our knowledge, this study is the first to use population data to look at the relationship between height, BMI, and fertility. This study is also the first to take a demographic perspective on how physical fitness is related to fertility rather than a biomedical perspective. We believe that this study is also the first to account for how cumulative income or educational attainment moderates the relationship between these measures of health and fertility, and the first to use a sibling comparison design in order to adjust for all shared family background factors that might confound the relationship between health in early adulthood and later fertility outcomes.

Theoretical channels from health to male fertility

In this section, we consider the potential pathways by which health in early adulthood might be related to later childbearing, including the relationship between health and male fecundity, the influence of health on socioeconomic attainment and desirability as a potential romantic and childbearing partner, as well as the potential role of selection processes and confounding.

Physiological health and fecundity

Previous research has shown that being overweight or obese is linked to abnormal fluctuations in sex hormones, subnormal sperm counts, as well as sexual dysfunction (Hammoud et al. 2008b; Kolotkin, Zunker, and Østbye 2012). Overweight and obese men are at greater risk of suffering from impaired spermatogenesis, lower sperm count, lower sperm motility, lower circulating testosterone levels, poor libido, and erectile dysfunction (Feldman et al. 2000; Cabler et al. 2010; Stokes, Anderson, and George 2015). These various dimensions of male sexual physiology are directly related to the ability to conceive children, providing a potentially important explanation for any association between BMI and fertility. Although much less common among men, being underweight is also associated with lower sexual function (Cheng and Ng 2007). If a man's partner is also obese, subfertility

issues are typically worse (Ramlau-Hansen et al. 2007). Research suggests that men account for half of all infertility in couples (Gibson and Hammoud 2017). We expect that the link between health and fecundity should affect fertility even among men who have formed stable partnerships.

Cardiovascular fitness is also related to sexual function, including net of BMI. Higher levels of physical fitness are generally associated with healthy sexual hormone balance, higher sperm counts, higher sperm motility, and a lower likelihood of erectile dysfunction (Rosen, Friedman, and Kostis 2005; Agostini et al. 2011; Vaamonde et al. 2012; Józków and Rossato 2017). Sedentary behaviors are associated with lower sexual function on the aforementioned dimensions (Gaskins et al. 2015). Although experiments have shown that high intensity cardiovascular exercise continued over an extensive period of time can have a negative effect on various semen parameters and endocrine balance (Safarinejad, Azma, and Kolahi 2009), only a small proportion of the population consistently engage in such behaviors.

Net of genetic predispositions, adult height in low-income contexts is considered to be an important marker of health status as well as nutritional conditions and the disease environment during childhood, but this association is more ambiguous in high-income contexts (Deaton 2007; Stulp and Barrett 2016). We may presume that taller men in Western populations may have better than average health (Deaton 2007), since low height in adulthood is often associated with developmental disorders, and this may also be reflected in sexual function. Men at the very extreme top end of the height distribution may also have health problems (Stulp and Barrett 2016). However, height as a marker of sexual health has not received much attention in the literature and it does not obviously speak to sexual function beyond its correlation with general health status.

Desirability as a potential romantic and childbearing partner

BMI, physical fitness, and height have all been shown to be associated with partner choice. In contemporary Nordic countries, never partnering is the dominant pathway to childlessness for men (Jalovaara and Fasang 2017; Saarela and Skirbekk 2020). Men who are taller, stronger, and more physically fit are generally perceived as more physically attractive by women (Tovée et al. 1999; Pawlowski, Dunbar, and Lipowicz 2000; Sell, Lukazsweski, and Townsley 2017), and therefore men with those attributes are likely to have more partnering opportunities (Rhodes, Simmons, and Peters 2005). Overall, we expect most of our effects to be more pronounced at the extreme ends of our distributions (i.e., very low height, very low fitness, and very low or high BMI).

Beyond immediate physical attractiveness, a healthy lifestyle may in itself serve as an important dimension of male attractiveness and affect

female preferences for having children or forming a childbearing partnership. Buss and Barnes (1986) found that being “healthy” was considered one of the most highly desired traits in a partner, with women putting a higher priority on health than men, and women ranking health higher than both physical attractiveness and socioeconomic traits. Furthermore, a healthy lifestyle may be associated with both union stability and successful repartnering (Ortega et al. 2010). A literature in evolutionary human biology argues that female preferences for certain anthropometric characteristics in men are explained by these attributes serving as signals of higher reproductive potential (Fan et al. 2005; Hönekopp et al. 2007).

In modern Western societies, being overweight or obese can also carry stigma (Puhl and Heuer 2009). Population representative surveys find that people associate being overweight or obese with being lazy, having a lack of motivation and self-discipline, and being incompetent (Roehling 1999; Puhl and Brownell 2001). The perception that being overweight or obese is associated with “laziness,” whether true at the individual level or not, means that body mass is a readily available visual cue perceived as signaling something important about an individual’s underlying nature (Jutel 2005). Whether body mass or physical fitness are related to traits such as self-discipline or not, they will nevertheless serve as signals for these traits if there is a prevailing norm that there is a real association, and this is likely to influence one’s desirability as a potential childbearing partner.

Although there is relatively little research examining how health influences subsequent fertility, there is more research examining how entrance into cohabitation and marriage is influenced by antecedent health status. The influence of health on entry into partnership is important for understanding fertility because childbearing is more likely in stable unions. Studies using data from the United States have shown that men with higher levels of physical fitness are more likely to marry, though levels of cardiovascular fitness decrease after marriage (Ortega et al. 2010). Being overweight or obese, or having especially low stature, is also associated with a lower likelihood of entrance into marriage in the United States (Gortmaker et al. 1993; Fu and Goldman 1996; Murray 2000; Cai 2007). In Sweden, health is likely to be an important factor predicting entry into all forms of stable relationships, either marital or cohabiting. Childbearing outside of marriage is very common in Sweden, with over 50 percent of births occurring out of wedlock since the 1990s, primarily in stable cohabiting relationships (Kennedy and Thomson 2010). Although marriage is less common in Sweden than many other countries, 50 percent of men born in the cohorts that we study did marry by age 40, and most men who marry in Sweden have children. Among men born in the cohorts that we study, over 93 percent who ever-married also had children.

Pathways through socioeconomic status. Beyond direct effects of BMI, physical fitness, and height on perceptions of attractiveness, there is

evidence that these anthropometric measures influence socioeconomic achievement (Magnusson, Rasmussen, and Gyllenstein 2006; Case and Paxson 2008; Jæger 2011; Lundborg, Nystedt, and Rooth 2014). Socioeconomic status is an important mediator of partnership desirability for men, and this is particularly important in a Scandinavian context in which more socioeconomically successful men have higher fertility (e.g., Jalovaara et al. 2019; Kolk 2019). Although the income–fertility relationship varies across contexts (Jones, Schoonbroodt, and Tertilt 2010), higher levels of income and education are associated with higher fertility and a lower probability of being childless for men in Sweden (Chudnovskaya 2019; Jalovaara et al. 2019; Kolk 2019), consistent with the high costs of raising children in contemporary high-income societies. In our analyses, we consider the importance of educational attainment and cumulative income as potential mediators for the relationship between BMI, physical fitness, height and fertility, but also whether higher socioeconomic status may compensate for worse health.

Selection. A potentially important driver of a correlation between health and fertility is selection and confounding by factors jointly related to health status and health behaviors as well as fertility and partnership formation behaviors. Such factors include characteristics of the family of origin such as socioeconomic status (Case, Fertig, and Paxson 2005; Jalovaara et al. 2019; Kolk 2019), fertility (Murphy 2013; Kolk 2014), religiosity (Rønsen 2004), or inherited dimensions of parental health. For example, children raised in socioeconomically disadvantaged households are over-represented among those who are obese, among those who are childless, as well as among those who have four or more children in Sweden (Jalovaara et al. 2019). It is therefore critical to adjust for shared background factors that predict both our key independent variable as well as our outcome variable. The most powerful tool that we employ to try and minimize confounding by such factors is to compare brothers to brothers in a sibling fixed effects analysis.

Previous research on BMI, physical fitness, height, and male fertility

As reviewed above, most previous research on the relationship between health and male fertility is in the biomedical and reproductive health literature, with a particular focus on infertility. However, a small number of studies have examined how BMI is related to later male childbearing. A study by Jokela et al. (2007) on 1,298 Finnish men and women found that those who were underweight, overweight, and particularly those who were obese, had lower fertility than those with a “normal” BMI over a two-decade follow-up. A study using data on 12,073 American men and women from the National Longitudinal Survey of Youth (NLSY) also found that individuals

underweight or obese at ages 17–24 had lower overall fertility, and obese men were more likely to be childless by age 47, with part of these associations explained by the fact that underweight and obese men were less likely to have married (Jokela, Elovainio, and Kivimäki 2008). Although BMI changes with age, research using the same NLSY data has found that BMI changes are largely an additive effect of age, and individuals tend to stay in roughly the same rank order on BMI within their cohort (Malhotra et al. 2013). A study using data on Danish couples ($N = 47,835$) found that subfecundity, measured by a time-to-pregnancy of 12 months or longer, was more common if both the husband and wife were obese (Ramlau-Hansen et al. 2007). Several other studies that focus on BMI and fertility among women also show that underweight and obese women have lower fertility (Frisco and Weden 2013; Jacobsen et al. 2013; Jacobs et al. 2017; He et al. 2018).

There is also literature examining the relationship between height and fertility. A 2016 review of the literature found that in modern Western societies, men of average height had the highest fertility, and men in the tails of the height distribution had lower fertility (Stulp and Barrett 2016). This curvilinear relationship between male height and fertility has been consistently documented in both the United States and Finland (Clark and Spuhler 1959; Damon and Thomas 1967; Scott and Bajema 1981; Byars et al. 2010; Stulp et al. 2012, 2014; Silventoinen et al. 2013), though a study in Poland found a strong positive association (Pawlowski, Dunbar, and Lipowicz 2000), and a study using data from the UK found no association between height and reproductive success (Nettle 2002). However, it should be noted that these patterns differ across contexts that do not fit the Western, educated, industrialized, rich, and democratic mold (Sear 2006, 2010). We are not aware of any studies examining the relationship between physical fitness and fertility using representative survey data or a population-level perspective.

Data and methods

Data

We use Swedish population register data to examine the relationship between height, physical fitness, BMI, and different dimensions of male fertility. Register data with monthly event histories of vital events are available from 1968 to 2012. Using personal identification numbers, we combine data from military conscription, fertility, education, and tax registers. As the vital events are based on birth records, we can only link fathers to children that are known by the authorities, though these represent over 99 percent of all births (Statistics Sweden 2011). As such our data are superior to self-reported information, and particularly so for assessing male fertility. We use

the Swedish Multigenerational Register to link individuals to their parents, which allows us to link them to their siblings for our sibling fixed effects analyses. We also use this information on the sibling group to construct variables for sibling group size and birth order, both of which have been linked to the anthropometric measures that we study as well as fertility (Jelenkovic et al. 2013; Myrskylä et al. 2013; Barclay and Myrskylä 2014; Morosow and Kolk 2020). We define our population ($N = 405,427$) as all men born in Sweden from 1965 to 1972, who neither died nor emigrated from Sweden before the end of our follow-up period in 2012, and whose siblings were also born in Sweden. This also provides a subsample of 75,905 brothers in 36,512 families for our sibling comparison analyses. We define a sibling group through a shared biological mother and father.

Age at measurement of fertility

With data up to 2012, we are able to observe fertility for these cohorts up to age 40 or later. For example, for the 1972 cohort we observe fertility up to age 40, while for the 1965 cohort we observe fertility up to age 47 (see Figure A1 in the online Appendix). This assures that we have a highly complete count of fertility. We observe virtually all fertility for our 1965 cohort, whereas we miss more fertility for our 1972 cohort. In several robustness checks, we examine whether the relationship between our anthropometric measures and fertility varies when we examine those born 1965–1972, 1965–1967, and those born in 1965 alone.

Anthropometric measures

Each of the anthropometric measures that we use are taken from the military conscription registers. Sweden had universal military conscription for most of the 20th century, in which all men were obliged to spend approximately one year in the military, typically at ages 18–20. To assess eligibility, and more importantly to select people into various branches and jobs within the military, all men in Sweden had to participate in a one- to two-day examination before the beginning of their conscription. During these tests, men were subject to a battery of tests to assess their suitability for the armed forces and to determine their assignment. Although the military conscription was mandatory, there is missing data on BMI (11.2 percent), height (6.5 percent), and physical fitness (6.9 percent) for some men. Those who are missing information on these health measures were likely either excused from the evaluation because of a serious prediagnosed condition that would preclude military service (e.g., they were confined to a wheelchair or were blind), or were outside of Sweden during the ages at which they were required to conscript. These data are not missing at random, and therefore we do not impute missing values. We also have

information on education, income, and fertility for those men who are missing information on the three health measures that we examine, meaning that we are able to include them in our overall fertility analyses. We split the measures for height and physical fitness into deciles, and we also split our BMI variable into 10 categories. This approach towards categorizing our anthropometric measures allows us a flexible way of modeling the data that is consistent across all of our models and also allows us to capture potential nonlinearities in the relationship between health and fertility. All of our anthropometric measures were recorded at ages 17–20. Descriptive statistics on these three measures can be found in Table A1 in the Appendix.

Body mass index

We use measures of height and weight to calculate body mass index ($BMI = mass_{kg}/height_m^2$), at the time of conscription test. We categorize BMI into eleven different categories, and the distribution can be seen in Figure A2 in the Appendix. Of these cohorts, 11.2 percent are missing information on BMI. Although this categorization of BMI is not common in the literature, it allows us to discern differences in fertility within the major four categories of BMI that might otherwise be masked. We use the following 11 categories:

- Underweight (≤ 17.49)
- Underweight (17.50–18.49)
- Normal (18.50–19.99)
- Normal (20.00–21.99)
- Normal (22.00–22.99)
- Normal (23.00–23.99)
- Normal (24.00–24.99)
- Overweight (25.00–27.49)
- Overweight (27.50–29.99)
- Obese (≥ 30.00)
- Missing

Physical fitness

Our measure for physical fitness is based upon a measure of maximal working capacity, measured in watts (*fysisk arbetsförmåga i watt*). The distribution of the raw score in watts can be seen in Figure A3 in the Appendix. Of these cohorts, 6.9 percent are missing information on physical fitness. Maximal working capacity is measured as the maximum resistance attained in watts when riding on a stationary bike during a time period of 5–10 minutes and is correlated at approximately 0.9 with maximal oxygen uptake (VO_{2max}) (Patton, Vogel, and Mello 1982). We split this measure into deciles and

include a category for missing information. The vertical lines in Figure A3 mark the dividing line between each physical fitness decile.

Height

Height is measured in centimeters. For our analyses, we split height into deciles. We also include a category for missing information. The distribution of height can be seen in Figure A3 in the online Appendix. Of these cohorts, 6.5 percent are missing information on height. The mean height and range in centimeters in each decile can be found in Table A1 in the Online Appendix.

Mediating variables

Educational attainment. We use eight categories for education, based on highest educational attainment by 2012: primary (<9 years), primary (9 years), secondary (10–11 years), secondary (12 years), tertiary (13–15 years), tertiary, but not including postgraduate qualifications (15+ years), and postgraduate qualifications (approximately 16–20 years). The final, eighth, category indicates whether the variable for education has a missing value.

Cumulative income. The measure of income that we use takes into account gross salary, income from business activities, and work-related remuneration such as sickness benefit. After adjusting for the consumer price index measure of inflation provided by Statistics Sweden, we sum up the total income earned between the ages of 18 and 40 as a measure of cumulative income. We then split this measure of cumulative income into deciles.

Marital status. As part of our analyses, we examine whether the association between our various anthropometric measures and fertility persists among men who had ever-married by age 40. We use this variable as an indicator of whether the men had been able to form at least one serious partnership without conditioning on childbearing. Although over 50 percent of childbearing in Sweden occurs outside of marriage, 51 percent of men born 1965–1972 in Sweden did marry before age 40, and of that 51 percent 93.4 percent had at least one child. Due to the lack of a national dwelling register in Sweden over the period that we study fertility, we are not able to identify men in unmarried cohabiting relationships who do not have any children. This is the reason why we focus on ever-married men in these subanalyses. This measure of having ever-married ignores any subsequent change to marital status due to divorce or being widowed. We also conduct additional sensitivity analyses using a variable that indicates that an individual had been married for at least five years before any divorce or widowhood.

Statistical analyses

Descriptive analyses. We first present descriptive statistics for the level of fertility by BMI, physical fitness, and height. We decompose completed fertility into the contribution of men based on their eventual parity for different levels of BMI, physical fitness, and height. This is done by multiplying the proportion of men with a given parity, with the given parity (e.g., if 40 percent of all men with a BMI of 20.00–21.99 have two children, they contribute 0.8 to the completed fertility of men with BMI 20.00–21.99). This equals the average fertility of that group when summed up for all parities. We also report the percentage of men at each parity by the end of our follow-up period.

Regression analyses. We also conduct regression analyses to examine how our anthropometric measures are associated with total number of children as well as parity transitions. The populations of our models for parity transition n are the population with at least a final parity of $n - 1$. These models have a similar interpretation as the parity progression ratio, which is the proportion of men with a certain number of children who go on to have at least one more child. To study parity transitions, we apply linear probability models.

We present linear regressions where we use all men in the population, as well as fixed effects models in which we only analyze variance between full biological siblings. The latter class of models requires at least two brothers in each family, that they were both born in the 1967–1972 cohort window that we study, and that they differ on either our anthropometric measures or completed fertility. For each fertility outcome that we analyze, whether that is total number of children, or a given parity transition, we estimate four different models:

$$y_i = \beta_1 \text{Anthropometric}_i + \beta_2 \text{BirthYear}_i + \beta_3 \text{ConAge}_i + \alpha + \varepsilon \quad (1)$$

$$y_i = \beta_1 \text{Anthropometric}_i + \beta_2 \text{BirthYear}_i + \beta_3 \text{ConAge}_i + \beta_4 \text{BO}_i \\ + \beta_5 \text{Size}_i + \beta_6 \text{EDU}_i + \beta_7 \text{INC}_i + \alpha + \varepsilon \quad (2)$$

$$y_{ij} = \beta_1 \text{Anthropometric}_{ij} + \beta_2 \text{BirthYear}_{ij} + \beta_3 \text{ConAge}_{ij} + \alpha_j + \varepsilon \quad (3)$$

$$y_{ij} = \beta_1 \text{Anthropometric}_{ij} + \beta_2 \text{BirthYear}_{ij} + \beta_3 \text{ConAge}_{ij} + \beta_4 \text{BO}_{ij} \\ + \beta_5 \text{EDU}_{ij} + \beta_6 \text{INC}_{ij} + \alpha_j + \varepsilon \quad (4)$$

where y denotes our outcome variable, whether that is total number of children, or a binary variable for a parity transition, such as going from $1 \rightarrow 2$ children, for an individual i , with constant α and error term ε . We run separate models for each of our three anthropometric measures. In Model 1,

we control for birth cohort, *BirthYear*, using individual-year dummy variables (1965, 1966, ..., 1972), and *ConAge*, age at time of the conscription test (17, 18, 19, 20). In Model 2, we introduce additional control variables for birth order, *BO* (1, 2, ..., 6+), completed sibling group size, *Size* (1, 2, ..., 6+), as well as educational attainment, *Edu*, and cumulative income, *Inc*, described in greater detail above. Models 3 and 4 parallel Models 1 and 2, respectively, in terms of the control variables that are included, but introduce a sibling fixed effect, denoted by α_j , and the estimates are calculated for each individual i in a sibling group j .

Our sibling comparison models allow us to hold constant all factors that are shared by siblings, such as parental educational level and parental income, parental behavior and personality, and genetic similarity between brothers. These models therefore allow us to examine the importance of our anthropometric measures for fertility net of important shared genetic and environmental factors that influence body mass, physical fitness, and height as well as fertility preferences.

In further supplementary analyses, we examine entry into marriage at any point between ages 18 and 40 by BMI, physical fitness, and height. The models that we fit are the same as Models 1–4 above, with the exception that y denotes a binary variable for ever marrying between ages 18 and 40.

We also conduct complementary analyses examining the interaction between cumulative income and educational attainment with the three anthropometric measures:

$$y_i = \beta_1 SES \times Anthropometric_i + \beta_2 BirthYear_i + \beta_3 ConAge_i + \beta_4 BO_i + \beta_5 Size_i + \alpha + \varepsilon \quad (5)$$

$$y_{ij} = \beta_1 SES \times Anthropometric_{ij} + \beta_2 BirthYear_{ij} + \beta_3 ConAge_{ij} + \beta_4 BO_{ij} + \alpha_j + \varepsilon \quad (6)$$

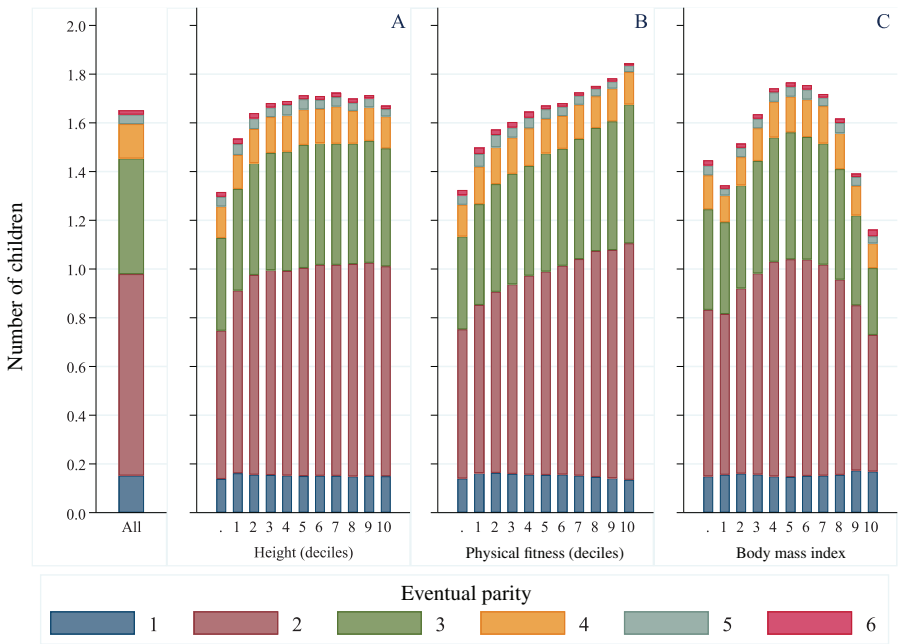
where we run separate models for the interactions between our two measures of socioeconomic attainment, *SES*, cumulative income and educational attainment, and each anthropometric measure, without (Model 5) and with (Model 6) sibling fixed effects.

Results

Descriptives

Figure 1 shows the average number of children that Swedish men born 1965–1972 have by 2012 by different levels of height, physical fitness, and BMI, and the contribution to fertility by men of different parities. The mean level of fertility for these men by 2012 was 1.65. Men who had two children contribute the largest single share to overall male fertility, followed by men

FIGURE 1 Contribution to fertility by parity by height, physical fitness, and BMI measured at ages 17–20 for men born in Sweden, 1965–1972. Fertility is measured up to 2012 and therefore age at fertility measurement varies by birth cohort—see Appendix Figure A1



who had three children. Detailed information on descriptive statistics for fertility, BMI, physical fitness, and height can be found in Appendix Tables A1, A2, A3, and A4.

Panel A of Figure 1 shows that men in the lowest decile for height had 1.53 children, while men in the top decile had 1.67 children. Men in height deciles from 4 to 9 had almost indistinguishable fertility, ranging from 1.69 to 1.72, so it is mainly men in the bottom two deciles who have lower fertility, and men who are missing information on height.

The pattern by levels of physical fitness shown in Panel B of Figure 1 demonstrates clearly higher fertility among men with higher levels of cardiovascular fitness. Men in the lowest decile of physical fitness have 1.50 children, while men in the top decile have 1.85 children, and there is a monotonic increase in fertility from the lowest to the highest decile.

Levels of fertility by BMI show that men with a “normal” BMI have the highest fertility, ranging from 1.64 to 1.77 across our five categories for “normal” BMI. Obese men had the lowest fertility, having an average of 1.16 children by the end of our follow-up period. Men who were in the lower category of overweight had 1.62 children, while men in the

higher category of overweight had 1.39 children. Men who were in the lower category of underweight had 1.34 children, while men in the higher category of underweight had 1.51 children.

In this population of men, 23 percent were childless by age 40 or older. A detailed figure showing the distribution of men by parity can be seen in Figure A4 in the Appendix. In terms of height, men in deciles 5–9 had the lowest probability of childlessness, at approximately 20 percent, while 27.7 percent of men in the bottom decile, and 21.7 percent of men in the top decile, were childless. The probability of childlessness decreases monotonically with increasing physical fitness; 30 percent of men in the bottom decile of physical fitness were childless, while only 15 percent of men in the top decile of physical fitness were childless. Men with a “normal” BMI had the lowest probability of childlessness, consistently less than 19 percent, while 35 percent of men in the lower category of being underweight were childless, and 42 percent of obese men were childless. This descriptive account of our data indicates very strong relationships between fertility and both physical fitness and BMI, while for height the main difference is between men in the shortest decile and all of the rest. Equivalent figures for the sibling subsample can be found in Figures A5 and A6 in the online Appendix.

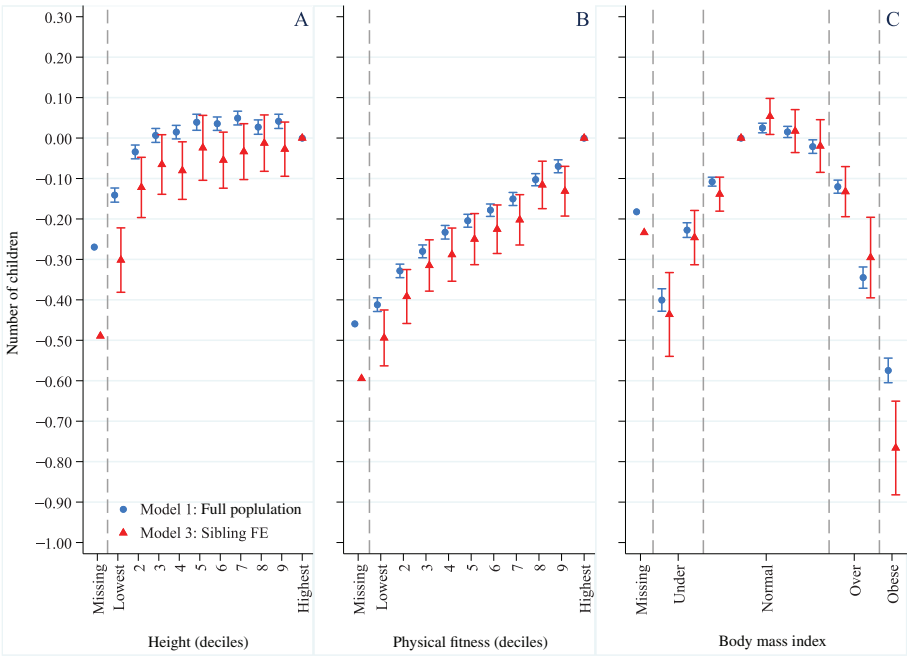
Total number of children

Figure 2 shows the results from regression models examining the relationship between different levels of height, physical fitness, and BMI and total number of children. In these analyses, the reference categories are a “normal” BMI (BMI = 20.00–21.99), and the highest deciles for physical fitness and height. Full results tables can be seen in the Tables A5 to A10 in the Appendix.

Model 1 is based on the full population of men born 1965–1972 and includes controls for birth year and age at time of conscription. Model 3 includes the same control variables as Model 1, but is estimated using sibling fixed effects upon a subsample of brothers. The confidence intervals are considerably wider in these sibling comparison analyses as these are based upon a subsample of 75,905 brothers. We omit confidence intervals for the estimates of the “missing” category, as these distort the scale of the graph and are not the focus of our study.

The results for height from Model 1 (Panel A of Figure 2) show that, relative to men in the tallest decile, men in deciles 5–9 had approximately 0.04 more children. Men in deciles 10 and 3 have similar fertility, while men in the shortest decile for height have the lowest fertility, at approximately 0.14 fewer children than the tallest decile. The point estimates from our sibling comparison model also show that fertility is lower among shorter men. However, this difference is only statistically significant among men

FIGURE 2 Total number of children by height, physical fitness, and BMI measured at ages 17–20 for men born in Sweden, 1965–1972. Linear regressions corresponding to Models 1 to 4



NOTE: Confidence intervals omitted for the “missing” categories for each variable.

in the lowest decile for height, who have 0.30 fewer children than men in the tallest decile.

Panel B of Figure 2 shows the results for physical fitness. Overall the patterns are very consistent across Models 1 and 3. The men with the highest levels of physical fitness at ages 17–20 have the highest fertility, and the least fit men have the lowest fertility. There is a monotonic decrease in fertility with each lower level of physical fitness. Compared to men in the top decile of physical fitness, men in the lowest decile are estimated to have 0.41 fewer children in the analysis of the full population (M1), and 0.49 fewer children in the sibling comparison (M3).

The results for BMI are shown in Panel C of Figure 2. Men in the upper range of a “normal” BMI have the highest fertility, while men who were underweight, overweight, or obese at ages 17–20 have statistically significantly and substantively lower fertility. In general, the results in Models 1 and 3 are very consistent with one another. Men who were in the lower category of underweight had 0.40 fewer children in Model 1 than men with a “normal” BMI of 20.00–21.99, while men in the higher category of overweight had 0.35 fewer children. The results are clearly strongest for men

who were obese at ages 17–20: in Model 1, these obese men are estimated to have had 0.57 fewer children than the reference category, while the estimated differences are even larger in our sibling comparison model, at 0.77 fewer children. This is a large difference given that the mean number of children for men in these cohorts by age 40 was 1.65—men who were obese in early adulthood have almost half as many children towards the end of their reproductive years.

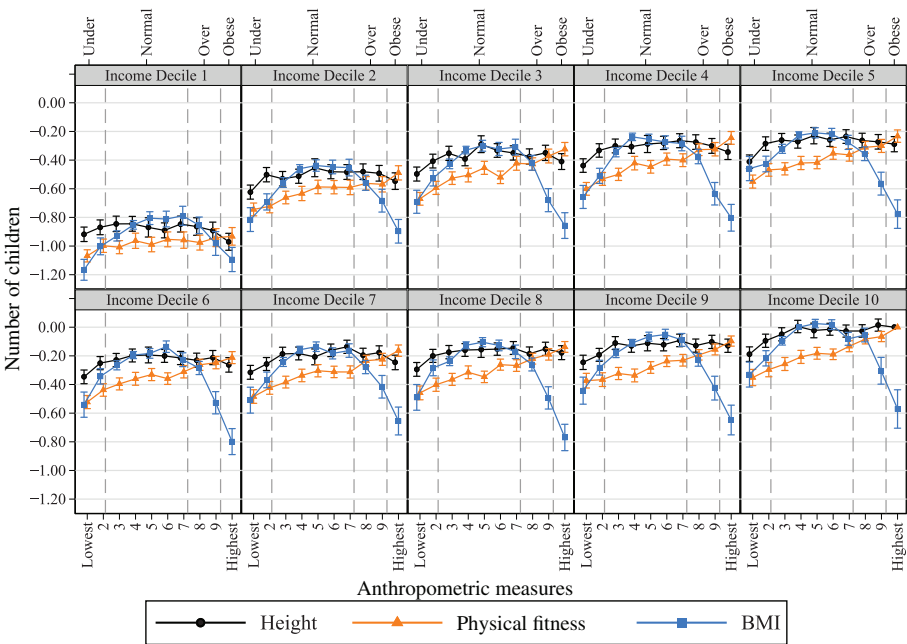
Controlling for factors expected to at least partially mediate the relationship between height and fertility, educational attainment and cumulative income, makes relatively little difference to the estimates, and the results from Models 2 and 4 can be found alongside Models 1 and 3 in Figure A7 in the Appendix. As a supplementary analysis, we also examine years of education and log income as outcome variables in relation to our anthropometric measures, and those results can be seen in in Figures A8 and A9 and Tables A11 to A16 in the Appendix.

Variation by socioeconomic attainment

Figure 3 shows the results from analyses corresponding to Model 5, examining the interaction between cumulative income by age 40, split into deciles, and the three anthropometric measures. Each panel of Figure 3 is a different decile of cumulative income (1 = lowest and 10 = highest). Figure 3 is based on three separate models for height, physical fitness, and BMI. For each analysis, there is a single common reference category: for height and physical fitness, it is the top decile of the anthropometric measure in the top decile of cumulative income, and for BMI it is a “normal” BMI (BMI = 20.00–21.99) in the highest decile of cumulative income. All other coefficients are relative to that single reference point for each anthropometric measure.

Figure 3 shows that the results seen in Figure 2 essentially persist regardless of the decile of cumulative income by age 40. Although we see a clear effect of income, where men with more money have more children, those who are underweight, overweight, obese, or with low physical fitness, have fewer children regardless of their cumulative income. One perspective on these results is that higher income does not compensate for poorer health. Alternatively, one might consider that better health can compensate for lower income: for example, men with a normal BMI in decile 2 of cumulative income have the same number of children as the most overweight or obese men in decile 10. Analyses by educational attainment can be seen in Figure A10 in the Appendix. As with cumulative income, the anthropometric–fertility pattern persists regardless of the level of educational attainment. These results are also consistent in fixed effects analyses, which can be seen in Figures A11 and A12.

FIGURE 3 Total number of children: interaction between deciles of cumulative income by age 40 and height, physical fitness, and BMI measured at ages 17–20 for men born in Sweden, 1965–1972. Linear regressions corresponding to Model 5



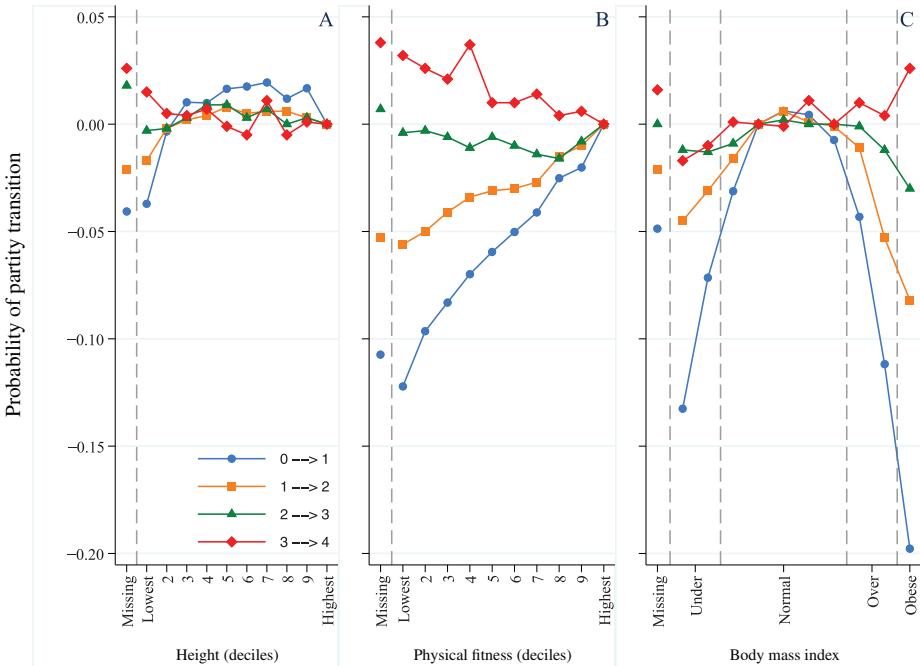
NOTE: See lower x-axis for deciles of height and physical fitness and upper x-axis for BMI.

Parity progression

Figure 4 shows results from regressions models on parity progressions. We show the results from models corresponding to Model 2, which control for birth year, age at conscription, birth order, sibling group size in the family of origin, educational attainment, and cumulative income by age 40, using the full population of men without sibling fixed effects. Full tables can be found in Tables A17 to A25 in the Appendix. We apply linear probability models where the estimates can be interpreted as percentage point differences in the probability of the outcome relative to the reference category, conditional on the other covariates. Estimates for parity transitions 4→5 and 5→6 are not shown in Figure 4, but can be found in Tables A19, A22, and A25 in the Appendix.

Our analyses show that the transition to fatherhood does seem to vary by height in men. Compared to the shortest and tallest deciles of men, men in deciles 3 to 9 are more likely to make the transition from 0→1 children. For example, the estimated difference in the probability of becoming a parent between men in height decile 10 and height decile 7 is 0.019, which

FIGURE 4 Parity progressions by height, physical fitness, and BMI measured at ages 17–20 for men born in Sweden, 1965–1972. Linear probability models corresponding to Model 2 for each parity progression



is a 2.5 percent difference relative to the baseline probability of 0.77. Men in the lowest decile have the lowest probability of making the transition to parenthood, and the estimated difference in the probability of becoming a parent between men in height decile 1 and 10 is -0.037 . Panel A shows that there is relatively little association between height and parity transitions among men who already have children, with the exception of men in the lowest decile of height; the shortest men are less likely to make the transition from $1 \rightarrow 2$ children, but more likely to make the transition from $3 \rightarrow 4$.

In panel B, Figure 4 shows that men with lower levels of physical fitness in early adulthood are monotonically less likely to become a parent or to make the transition from $1 \rightarrow 2$ children. Given that 23.0 percent of men born in Sweden between 1965 and 1972 were childless by 2012, the least physically fit men in early adulthood had a relative probability of being childless 53 percent higher than men who were the most physically fit in early adulthood (estimated probability difference: 0.122), even after adjusting for educational attainment and cumulative income. However, men in the lower deciles of physical fitness have a higher probability of higher parity transitions, such as $3 \rightarrow 4$.

The estimates for the association between BMI and parity transitions show relatively few differences between men at different levels of a “normal” BMI. Men who were underweight have a lower estimated probability of making almost all parity transitions, but the most striking difference is the lower probability of entering fatherhood. Men in the lower underweight category had an estimated probability of 0.133 of being childless relative to the reference category of men with a “normal” BMI, which is a 57.8 percent difference relative to the baseline. Men who were overweight at ages 17–20 were also less likely to become a father or to make the transition from 1→2 children. Men who were obese in early adulthood were by far the least likely to make the transition to parenthood, with an estimated probability of childlessness of 0.198 relative to the reference category, which is a 86.1 percent difference relative to the baseline. Obese men were also less likely to make the transition from 1→2 or from 2→3 children, but had a higher probability of making the transition from 3→4 children.

We also conduct these parity progression analyses using fixed effects, and those results can be seen in Tables A26 to A34 in the Appendix. Analyses focusing on childlessness (the inverse of the 0→1 transition) interacting the anthropometrics with cumulative income and educational attainment can be seen in Figures A13 to A16 in the Appendix.

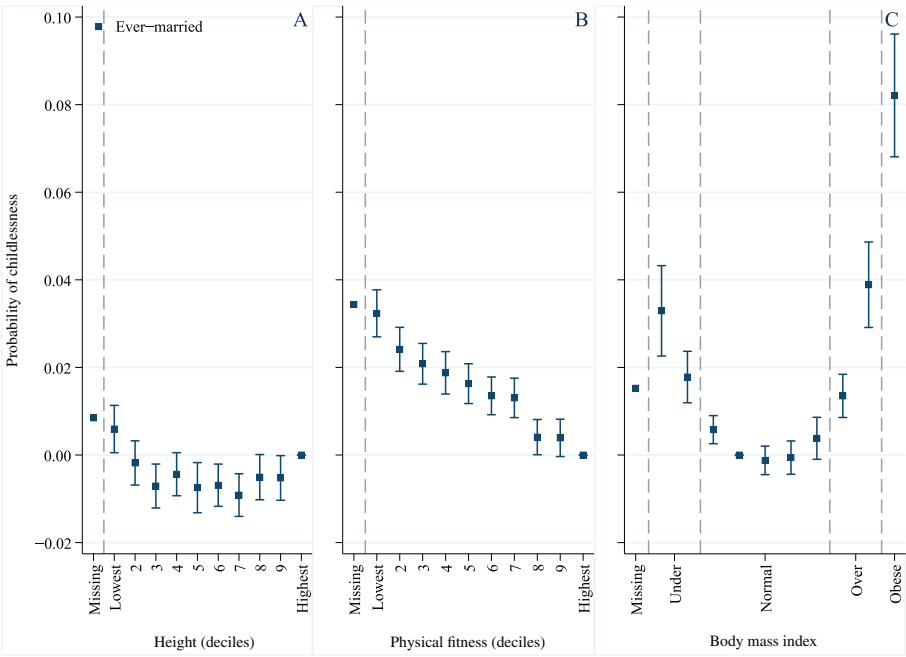
Childlessness among ever-married men

The results from the preceding analyses show that height, but particularly physical fitness and BMI, are all clearly associated with fertility among men in Sweden, but these patterns do not seem to be explained by socioeconomic attainment or socioeconomic background. In this section, we examine the relationship between our anthropometric measures and fertility by whether these men had ever-married by age 40. In our data, 51 percent of the men in the cohorts that we study had ever-married by age 40. Our results show that there are large differences in the probability of ever-marrying by height, BMI, and physical fitness, where men with lower stature, lower physical fitness, and those who are underweight, overweight, or obese, have a lower probability of ever-marrying. Those results can be seen in in Figure A17 and Tables A35 to A40 in the Appendix.

We focus on the probability of being childless by having ever-married. We focus on this particular parity transition (the inverse of 0→1), because entering parenthood is a fundamentally different life course transition from higher parity transitions. By conditioning on having married, we can to some extent examine whether the patterns that we observe are attributable to having entered into a stable partnership.

When analyzing ever-married men we study a population who have formed at least one stable partnership. We therefore assume that much of the remaining association between health and fertility among men who

FIGURE 5 Probability of childlessness among men born in Sweden, 1965–1972, who have ever-married by age 40. Linear probability models corresponding to Model 2



have ever-married may at least partially reflect relative differences in fecundity since most men who marry in Sweden do have children. In our data and cohorts, only 6.6 percent of men who ever-married were childless, while 40.1 percent of men who never-married were childless, showing that marriage is a strong mediator of childbearing even in Sweden where a high proportion of births occur outside of marriage.

Figure 5 shows the results from analyses using the full population, with the control variables included in Model 2. The results for height, shown in Panel A, indicate that there are only small differences in the probability of being childless among men who had ever-married by age 40. These estimates suggest that height is not related to fecundity.

Panel B shows the results for physical fitness. There is a clear gradient by physical fitness among those who ever-married by age 40. The estimated difference in the probability of childlessness is 0.032 among ever-married men in the bottom decile of physical fitness in comparison to men in the top decile, which translates into a difference over 50 percent higher relative to the baseline probability. This suggests that the relationship between physical fitness and childbearing may be related to fecundity.

The results for BMI are shown in Panel C. The probability of being childless is higher for men who were underweight, overweight, or obese at ages 17–20 even if they had ever-married by age 40. There are few if any differences among men with a “normal” BMI. However, men in the lower category of underweight who had ever-married had an estimated probability of childlessness 50 percent higher than men with a “normal” BMI relative to the baseline, and for men who were obese the difference was over 120 percent higher. These very large differences are consistent with the interpretation that body mass at ages 17–20 may be related to fecundity since we know that the higher probability of childlessness is not due to never-partnering in this population of men who had married.

Additional analyses looking at total number of children by height, physical fitness, and BMI among ever-married men can be seen in Figure A18 in the Appendix. We have also conducted these analyses using sibling fixed effects, and those estimates are shown in Figures A19 and A20. The results from the sibling comparison are qualitatively similar to the results shown in Figure 5. Full results tables can be found in Tables A41 to A52.

Robustness checks

We have also conducted additional analyses where we condition on men having been married for a continuous period of at least five years. Those results are qualitatively very similar to the patterns presented above and can be found in Tables A53 to A70 in the Appendix. In further robustness checks we examine whether the associations that we observe between our anthropometric measures and fertility would vary by birth cohort, since this determines our age at measurement of fertility. We focus on two groups, those born in 1965 and those born 1965–1967. Figures A21 to A25 of the Appendix show that the patterns documented above are extremely similar if we focus on fertility measured at ages 45 or older, where the fraction of unobserved fertility is approximately 2 percent. Figures A26 and A27 show the results from regression analyses corresponding to Models 1 and 2 using the full population for those born in 1965 and those born 1965–1967; in these graphs, the overall level of fertility is slightly higher, since it is measured at a later average age, but the patterns are otherwise very similar.

Discussion

Using population register data, we have examined how several anthropometric measures are associated with fertility for men in Sweden. We find remarkably strong patterns in our data. We observe a clear monotonic

pattern where men who were less physically fit have substantially lower fertility, with the least fit men having 0.31 fewer children and a relative probability to be childless over 50 percent higher than the most fit men. The results for BMI were even more striking: those underweight, overweight, or obese at ages 17–20 also have substantially lower fertility, and were more likely to be childless, with men who were obese having more than 0.5 fewer children and an estimated probability to be childless 86 percent higher than men with a “normal” BMI, even after adjusting for educational attainment and cumulative income. In the full population of Swedish men born 1965–1972, the results for the relationship between height and later fertility show a curvilinear pattern where both the tallest and shortest men have lower fertility, consistent with previous research (Stulp et al. 2012), though in our sibling comparison analyses only the shortest men have lower fertility.

We suggested that there are two primary channels by which height, physical fitness, and BMI should influence later fertility, which were fecundity and desirability as a potential partner, with the latter channel also allowing for indirect pathways such as the effects of health on socioeconomic attainment, which is itself strongly associated with fertility. To test whether the association was mediated by socioeconomic attainment, we both adjusted for educational attainment and cumulative income by age 40 and examined interactions, but this made very little difference to the results, despite the fact that educational attainment and cumulative income were independently strongly associated with the fertility outcomes in our results. Although height, physical fitness, and BMI have been shown to influence socioeconomic attainment, which is itself strongly associated with fertility (Jalovaara et al. 2019), our results suggest that our anthropometric measures influence fertility by a channel other than socioeconomic attainment, such as desirability for a healthy partner. This is particularly clear in our interaction analyses and sibling comparison analyses: even after comprehensively adjusting for all early life factors shared by brothers, and looking within levels of attained education and cumulative income, the relationship between our anthropometric measures and fertility persists in both direction and magnitude.

As an indirect way of examining whether the association between height, physical fitness, BMI, and fertility is related to how these anthropometric factors affect finding a stable romantic partner, we examined the associations between the anthropometric measures and fertility among men who had ever-married. Although our anthropometric measures are strongly associated with entrance into marriage, we also find that the relationship between physical fitness, BMI, and fertility persists even among ever-married men. These findings suggest that the observed relationship between BMI, physical fitness, height, and fertility is not simply attributable to never-partnering. Our findings indicate that height, physical fitness, and

BMI do influence desirability as a potential partner, but they also suggest that BMI and physical fitness influence fecundity because the probability of childlessness was much higher among those with worse health, even among the men who had ever-married.

Although the strong associations between these anthropometric measures and fertility among ever-married men are striking, we want to highlight several important limitations of these analyses. First, nonmarital fertility in Sweden has accounted for over 50 percent of childbearing since the 1990s, and most of this nonmarital fertility occurs in stable cohabiting relationships. Therefore, most childbearing in Sweden occurs outside of marriage today. Second, our analyses of fertility among men who ever-married do not condition on childbearing within marriage, they only condition on the men having become married at some point by age 40, and the childbirths could have occurred before or after marriage, or even after a subsequent divorce. Nevertheless, men who have ever-married have in some fundamental way demonstrated that they can develop a long-term relationship. Never partnering is the dominant pathway to childlessness in the Nordic region (Jalovaara and Fasang 2017; Saarela and Skirbekk 2020), and over 93 percent of men who ever-married in the cohorts that we study did have children at some point. We therefore believe that the results from these analyses of ever-married men allow some insights into the extent to which the relationship between the anthropometric measures that we study and fertility are attributable to never-partnering, and the extent to which they are attributable to physiological aspects of fecundity.

We believe that the results from this study may have important implications for understanding a large related literature examining how reproductive history affects the postreproductive health of mothers and fathers. Previous research has shown that childless men and women, as well as those with many children, tend to have higher mortality (see Högnäs et al. 2017, for a review and meta-analysis). Although previous research on the relationship between reproductive history and postreproductive health has included careful adjustment for socioeconomic confounding (Barclay et al. 2016), research on this topic has generally not controlled for health in early adulthood. Given the strong association between physical fitness, obesity, and mortality (Blair et al. 1995; Stokes and Preston 2016), our results suggest that health in early adulthood may be an important explanatory factor that explains why childless men and women, as well as those with many children, have higher postreproductive mortality. Indeed, in this study we observe that obese and overweight men, and men with the lowest aerobic fitness, are overrepresented both among the childless and those who have four or five children.

Although this study has many strengths, there are certainly limitations. First, it must be highlighted that we have measures of BMI, physical fitness, and height from ages 17 to 20, and we do not have dynamic

information on changes to these anthropometric measures over time. Although this does not matter for height, research shows that people tend to gain weight and to become less physically active as they age (Seefeldt, Malina, and Clark 2002; Malhotra et al. 2013). As such, we do not know the BMI or physical fitness of the men that we study at the time of partnership formation or childbearing, unless these transitions occur at a similar time to our measurements. Previous research indicates that although people tend to gain weight as they age, this is largely an additive effect of age where individuals stay in roughly the same rank order on BMI within their cohort (e.g., see figure 2 in Malhotra et al. 2013). In terms of physical fitness, interage correlations in dimensions of physical fitness tend to range from 0.3 to 0.6 (Seefeldt, Malina, and Clark. 2002). Although it would be very useful to have measures of BMI and physical fitness over the life course, a strength of having these measures at ages 17–20 is that we generally avoid potential concerns about reverse causality in the relationship between BMI, physical fitness, and fertility.

Another important limitation is that we only had data on height, physical fitness, and BMI for men, and it is difficult to know the extent to which these results could be generalized to women. The relationship between height and fertility would almost certainly be different for women, but it is possible that the patterns for physical fitness and BMI might be similar. A related limitation is that we did not have information on the anthropometric characteristics of the female partner of the men that we study. Due to assortative mating, it is very possible that part of the lower fertility of men who are less physically fit or who are overweight or obese could be attributable to having a partner with similar characteristics. As such, the lower fertility of these men might be attributable to having a partner with lower fecundity (Ramlau-Hansen et al. 2007), which we also know is more common than would be expected by chance due to assortative mating (Chen, Liu, and Wang 2014).

In this study we examine men born 1965–1972. The prevalence of being overweight or obese in childhood or early adulthood, and sedentary behavior, has become much more common in more recent birth cohorts in most high-income countries, and it is well established that the prevalence of obesity has increased dramatically across the world over the past several decades. Indeed, global obesity is estimated to have tripled between 1975 and 2016 (Jaacks et al. 2019). Given the research that demonstrates that being overweight or obese, or having a largely sedentary lifestyle, has a negative effect on fecundity (Hammoud et al. 2008a), it is plausible that rising obesity and decreasing fitness may depress fertility. Given secular trends in BMI and sedentary behavior, further research is needed to better understand how these developments are influencing fertility, and particularly childlessness, in Sweden as well as other countries.

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