

# Adolescence and the next generation

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**Adolescent growth and social development shape the early development of offspring from preconception through to the post-partum period through distinct processes in males and females. At a time of great change in the forces shaping adolescence, including the timing of parenthood, investments in today's adolescents, the largest cohort in human history, will yield great dividends for future generations.**

Global megatrends are reshaping health and human development almost everywhere<sup>1,2</sup>. Rapid economic, technological, social and demographic changes have brought reductions in infectious diseases, infant and maternal mortality and refocused attention on the non-communicable diseases of later life<sup>3</sup>. These forces are also reshaping health and development across the second and third decades. In preindustrial societies, the time between the end of childhood, which is signalled in girls by the late pubertal event of menarche (onset of menstruation) and spermarche (first ejaculation) or breaking of the voice in boys, and transition to adulthood, typically marked by parenthood, was generally around two years in girls and four in boys<sup>4,5</sup>. Improved nutrition and fewer infectious diseases in childhood, have been accompanied by a fall of around four years in the age at puberty to between 12 and 13 years<sup>6</sup>, a fall that has been rapid in current middle- and lower-income countries<sup>7,8</sup>. Over the same period, an even bigger upward shift has occurred in the timing of parenthood, the result of extended education, changing social norms around marriage and parenthood, and the availability of effective contraception.

Puberty initiates a phase of growth and maturation of the reproductive, musculoskeletal, neurodevelopmental, endocrine, metabolic, immune and cardio-metabolic systems, that extends into the third decade<sup>9,10</sup>. For this reason, adolescence can be considered a sensitive phase, during which the quality of the physical, nutritional and social environments may change trajectories of health and development into later life<sup>11</sup>. Given the concept that growth continues into the twenties, together with the delays in adopting adult roles, the idea has been proposed that adolescence might best be considered as ranging from 10 to 24 years<sup>12</sup>. From this perspective, adolescence occupies a greater proportion of the life course with greater relevance for human development than ever before<sup>9</sup>. An extended adolescence creates an opportunity for this generation to acquire greater assets and capabilities. Equally, adolescence has been accompanied by shifts in the social milieu of development, with the emergence of distinct youth cultures, greater media and peer engagement, and marketing to future consumers, in turn shifting patterns of health and health risk<sup>13</sup>.

For example, the risk of sexually transmitted infections increases with multiple sexual partners before marriage; earlier initiation of substance use is associated with greater risk of later substance-use disorders; and a reduction in physical activity, alongside changes in diet, is associated with higher rates of obesity<sup>11,14</sup>.

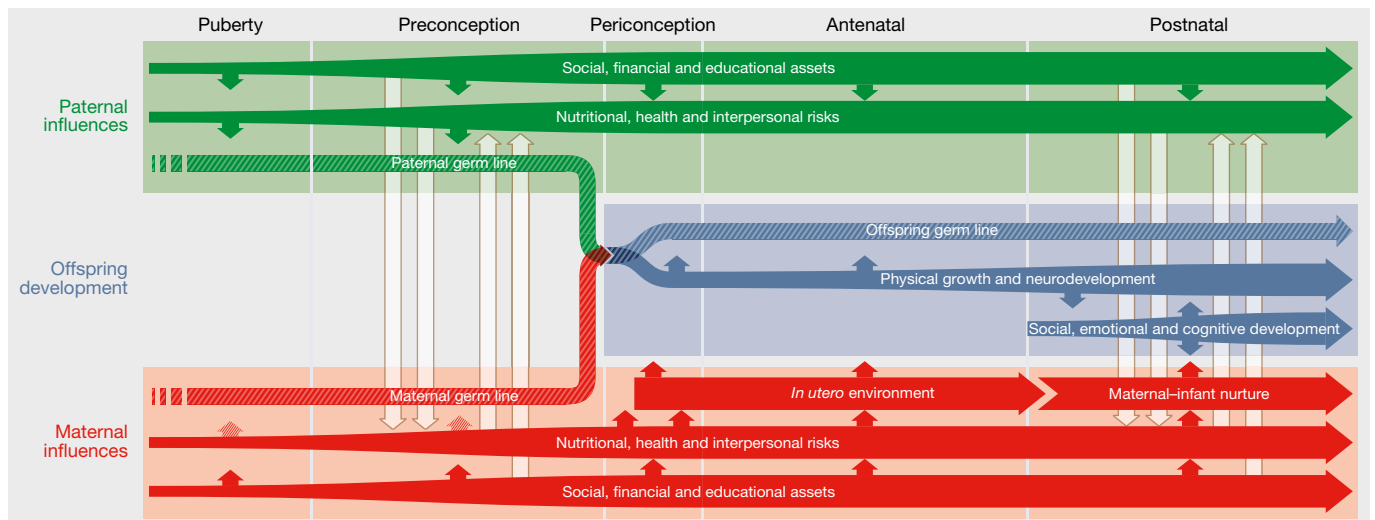
In contrast to the recognition of the significance of adolescence for later adult health, its relevance for the next generation has received less attention<sup>15</sup>. This is surprising, given that adolescents are the next generation to become a parent and we have known for decades that preconception maternal nutrition (for example, folate deficiency)<sup>16</sup> and infectious diseases<sup>17,18</sup> affect the early life health and development of offspring. Indeed, a failure to consider influences on growth during early life that emerge in adolescence before conception may explain why antenatal interventions have too often only led to small gains<sup>10,19</sup>.

Here we explore the range of adolescent processes—molecular, physiological, behavioural and sociocultural—that may affect the early growth, health and development of the next generation<sup>19–21</sup> (Fig. 1). Firstly, we consider time trends in the age of first parenthood and overall fertility across different country groups classified by level of economic development. Secondly, we explore the range of potentially modifiable processes that start during adolescence that may affect the early growth of offspring. Finally, we consider the shifting social determinants of health to illustrate the benefits for the next generation by investing in adolescents as the parents of tomorrow.

## The changing age of parenthood

Lower rates of giving birth during adolescence have led to a later transition to parenthood in most places. In all country income groups, birth rates in 15–19-year-old girls continue to fall with the most marked shifts in today's lower middle-income countries where rates in 2030 are anticipated to be a third of those in 1970 (Extended Data Fig. 1a). Marked falls are also taking place across all country groups for young women aged 20–24, with 2030 birth rates in today's high-income countries also predicted to be a third of the rates in 1970. As a result, adolescent parenthood

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**Figure 1 | Adolescence and the next generation: a model of processes underpinning intergenerational transmission.** Puberty marks a transition to adolescence and a life phase during which girls and boys acquire resources that are essential for becoming parents of the next generation. It also marks the beginning of reproductive life with a transition to functional gamete production. The preconceptional phase (that is, adolescence) varies markedly in length carrying implications for the acquisition of the social, financial and educational assets and nutritional, health and interpersonal risks that underlie intergenerational processes. The three months before conception is a time of male and female gamete maturation when parental exposures, including nutrition, obesity, substance use, stress, endocrine disruptors and physical activity

may influence gamete structure and function. Periconception includes fertilization of the maternal and paternal gametes as well as the zygote and embryonic phases that are sensitive to the maternal nutritional and hormonal environment. There continue to be direct maternal effects antenatally mediated through the *in utero* environment and postnatally through nutrition (for example, breastfeeding) and the maternal–infant relationship. Direct paternal influences grow in the postnatal phase through the paternal–infant relationship and potentially through risk exposures, such as paternal tobacco use. Maternal and paternal health, behaviour as well as social and economic circumstances continue to have an indirect effect on offspring development in both antenatal and postnatal phases.

is increasingly concentrated in specific geographic regions (South Asia, Latin-America and sub-Saharan Africa) and disadvantaged groups within countries<sup>22</sup>.

Decreases in birth rates during adolescence have led to parallel shifts in the duration of both adolescence and the preconception phase of reproductive life, defined as the time from reproductive maturity to first parenthood (Extended Data Fig. 1b). In high-income countries, only a quarter of girls now have a child by 25 years of age. As a result the gap between reproductive maturity, marked by menarche (on average between 12 and 13 years), and first parenthood is generally over a decade and often extends up to two. By contrast, over 80% of girls growing up in low-income countries become a parent by the age of 25, and 30% by the age of 18 years (Table 1). These differences have major implications for the acquisition of both assets and risks during the preconception window (Fig. 1).

Data on the timing of parenthood for males are scarcer and generally of poorer quality. France and Norway are among the few countries with data<sup>23</sup>. French men typically have children at around the age of 33 years, three years later than women. Males are also coming to parenthood later in life; 40% of Norwegian men born in the 1950s had become a parent by the age of 25 compared to less than 20% for those born in the 1970s, and just over 10% of those born in the 1990s. Therefore, the gap between reproductive maturity and parenthood has also lengthened for boys,

a result of effective contraception, extended education, higher costs to establish a family and changing social norms around family formation<sup>24</sup>.

### Early parenthood and its consequences

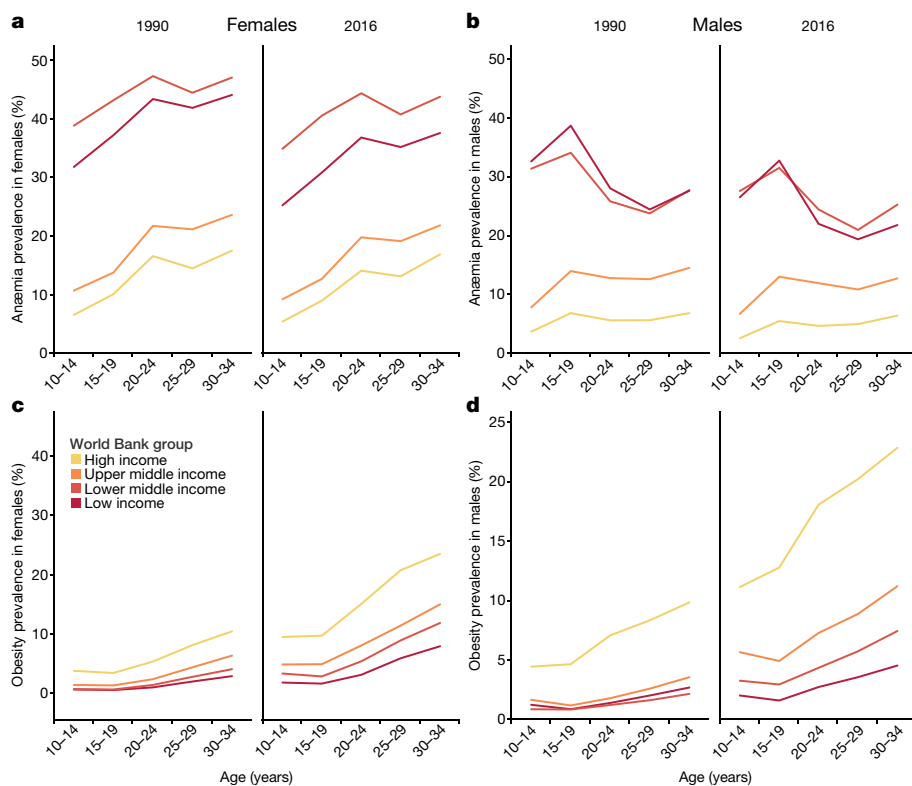
A longer adolescence leads to healthier growth, particularly for girls without the competing nutritional demands of early pregnancy, and greater opportunities for education and entry into the workforce<sup>25</sup>. For these reasons, age at first birth is a powerful determinant of long-term parental economic capacity, including income and housing<sup>26</sup>. Conversely adolescent parenthood predicts both poor maternal and infant health. In over 120,000 pregnancies in girls aged 10–24 in the Multicountry Survey of Maternal and Child Health of the World Health Organization (WHO), those giving birth before 15 years of age were at higher risk of eclampsia and puerperal infection<sup>27</sup>. Their babies had higher rates of low birth weight, preterm delivery and severe neonatal conditions<sup>27</sup>. Similarly, in pooled analyses of 19,403 offspring from birth cohorts in Brazil, Guatemala, India, the Philippines and South Africa, giving birth before the age of 19 predicted low birth weight, preterm birth and stunting of offspring and these associations were strongest in the youngest mothers<sup>28</sup>.

Nutritional needs increase markedly with rapid pubertal growth, making younger adolescents and their offspring vulnerable to undernutrition<sup>29</sup>. Studies of adolescents exposed to famine provide compelling evidence of the persisting effects on adult height of severe undernutrition during adolescence<sup>30</sup>. Equally, follow-up of the offspring of parents exposed to the Chinese (1959–1961) and Cambodian (1975–1979) famines suggest intergenerational risks, with rates of stunting greatest in those whose parents were exposed during adolescence<sup>31,32</sup>. Gestational undernutrition is particularly prominent in adolescence with maternal–fetal competition for energy and nutrients that remain essential for a girl’s own continued growth<sup>33</sup>. It is associated with increased risk of neonatal mortality, preterm birth, small for gestational age babies, and low birth weight<sup>34</sup>. The effects extend to the postnatal period with compromised antenatal breast development reducing breast milk quality and quantity<sup>35</sup> and the establishment of attachment bonds<sup>36,37</sup>.

**Table 1 | Percentage of mothers giving birth aged 15–24 years**

	15–24-year-old females	Percentage of females who gave birth before age:				Countries with data
		15	18	20	25	
	<i>n</i>					
Low income	63,744,000	5.5	30.1	53.2	84.1	28
Lower middle income	265,731,000	4.1	23.0	41.9	74.9	42
Upper middle income	179,542,000	1.7	15.7	32.6	65.7	26
High income	69,695,000	0.2	2.0	7.1	32.1	6

Percentage of women aged 25–29 who reported giving birth before specific ages from 15 to 24 years in household surveys over the past twenty years. The numbers of 15–24-year-old females are from ref. 140.



**Figure 2 | Nutrition risks across the years of transition to first pregnancy for 1990 and 2016. a, b, Prevalence of anaemia in females (a) and males (b). Prevalence of obesity in females (c) and males (d).**

Iron and other micronutrient requirements increase sharply at puberty, particularly for girls with the onset of menstruation, so that in younger adolescents anaemia is the leading cause of global disease burden<sup>14</sup>. Adolescent anaemia is commonly a result of iron and other micronutrient deficiencies and is therefore a useful indicator of nutritional status<sup>38,39</sup>. Figure 2a and Extended Data Figure 2 show rates of anaemia across the years of transition to first parenthood. Since 1990, rates of anaemia in low- and lower middle-income countries have fallen but only modestly. Consistent with rapid growth and the onset of menstruation, anaemia rates rise for young women from adolescence into the early twenties and then stabilize through the remaining reproductive years. It indicates that nutritional deficiencies remain common in young women in the transition to parenthood and policies to date have failed to address these major, modifiable determinants of early growth in the next generation.

In high-income countries, maternal and offspring outcomes are also poorer in those giving birth before 15 years of age with greater infant death, stillbirth, intrauterine growth restriction and preterm birth<sup>40</sup>. Teenage childbearing is often unplanned, and is associated with partnership instability, a greater likelihood of single parenthood, greater poverty and less parental education contributing to poorer child outcomes<sup>41,42</sup>. Even small delays of 6–18 months in the transition to motherhood independently predict offspring test scores for reading and mathematics that are in turn predictive of educational attainment and eventual earnings<sup>43</sup>.

Antenatal actions to promote maternal and fetal health generally occur after pregnancy recognition or a first antenatal visit. In high-income countries, such as the United States, women are generally unaware of pregnancy until six weeks of gestation or longer if the pregnancy was unintended<sup>44</sup>. Initiation of antenatal care is typically around three weeks later<sup>45</sup>. In resource poor settings, pregnancy confirmation and a first antenatal visit are generally much later. Less than half of pregnant women in sub-Saharan Africa have an antenatal visit in the first trimester, and rates are lower in adolescents<sup>46</sup>. Although undernutrition has been a major policy focus in maternal health<sup>47</sup>, antenatal interventions with maternal protein-energy or micronutrient supplements have generally brought minimal changes to birth weight<sup>10</sup>. One probable reason is that interventions are taking place too late in pregnancy<sup>48</sup>.

### Intergenerational risk processes

A range of parental adaptations have the potential to influence the growth and development of the next generation. These biological, interpersonal and social processes are outlined in the following sections.

### Mechanisms involving parental gametes

A possibility that the male germline captures information from a changing environment to pass on to subsequent generations has generated attention more recently<sup>49</sup>. It challenges an assumption that the sole function of gametes is to deliver half each of the maternal and paternal genomes to a common zygote. It was believed that this process did not include the transfer of environmental information. However, alternative theories, starting with Lamarck, and including Darwin in his theory of pangenesis, have suggested that some adaptations may be transmitted to the next generation. Recent studies have begun to describe these processes, revealing an interplay between environmental exposures and the parental reproductive milieu (Fig. 1). Potential mechanisms involve not only the protein and RNA cargo contained within gametes, but also factors, which are external to gametes, that are capable of influencing fertilization and early embryonic development. Gamete DNA also has a distinct, and modifiable, epigenetic profile, that is sensitive to environmental exposures, with some changes that are maintained during embryonic development, thus carrying information from one generation to the next<sup>50</sup>.

For both males and females, puberty initiates functional gamete production, a process that continues throughout adult reproductive life. There are likely to be sex differences in the timing and duration of sensitive exposure windows, given differences in gamete maturation. Gametogenesis begins early *in utero* with the specification of primordial germ cells. In males, this process is halted before meiosis, but in females, the process proceeds to the first meiotic division, where it then arrests until puberty. Thus, all primary oocytes produced throughout a female's lifetime exist before birth, or shortly thereafter. By contrast, the process of spermatogenesis commences at puberty. Sperm maturation takes between 70 and 100 days in humans, predominantly in the seminiferous tubules that are in constant contact with supporting Sertoli cells. This is followed by a 1–2 week transitional period in the epididymis, during which time

proteins and a small amount of RNA are selectively shuttled into the developing sperm<sup>51,52</sup>.

The paternal preconception environment modulates the RNA content of the developing sperm, with possible effects on post-fertilization development and offspring phenotypes<sup>53</sup>. In animal studies, paternal exposures to high-fat and high-sugar diets produce metabolic disturbances in offspring<sup>54</sup>, and both stress and exercise affect stress responses of the offspring<sup>55–57</sup>. Animal and some human studies have found effects of preconceptional tobacco, alcohol and illicit drug use on gamete epigenomes, with diverse effects on offspring development<sup>58,59</sup>. Although there are fewer human studies, alcohol consumption of more than two standard drinks per day is linked to morphological changes in sperm<sup>60</sup>. One report of a very large study has found effects of heavy (more than five standard drinks per day) paternal but not maternal preconception drinking on offspring head circumference and risk of microcephaly<sup>61</sup>. Paternal obesity generates risks of metabolic disturbance and obesity in offspring through the gamete epigenome, but diet and exercise appear to modify these risks<sup>62,63</sup>. In humans, bariatric surgery reverses obesity-induced epigenetic changes in spermatozoa<sup>64</sup>. Whether these paternal processes are ‘anticipatory adaptive responses’ to a likely postnatal environment or have other functions is currently under debate<sup>65–67</sup>.

Maternal gametes (oocytes) also have a unique epigenetic profile, as well as a cargo of RNA species and proteins that are mostly acquired over the four months of maturation before ovulation<sup>68</sup>. Both animal and human studies have shown that the preconception environment may alter oocyte maturation<sup>69</sup> with maternal obesity affecting the metabolism of the developing ova and early offspring growth<sup>70,71</sup>. Because mitochondrial DNA is only passed on through the maternal line, oocyte mitochondrial DNA may provide a further sex-specific intergenerational mechanism. In a mouse study, a high-fat and high-sugar diet beginning before conception altered insulin signalling in the skeletal muscle of the offspring due to mitochondrial dysfunction, an effect that passed through the maternal germ line to the third generation<sup>72</sup>.

### Periconceptional mechanisms

The time between fertilization and embryo implantation into the uterine decidua is marked by the emergence of distinct cell lineages, beginning with the specification of embryonic and extra-embryonic cells. There is extensive remodelling of parental gametic epigenetic profiles, a process that differs depending on the parent of origin. This re-organization initiates a shift from two distinct gametic epigenomes to a single embryonic epigenome with a capacity to form any cell type (see Fig. 1). This embryonic phase consists of two major epigenetic remodelling events: the first occurs immediately after fertilization; and the second induces the reestablishment of totipotency in primordial germ cells. These cells are the precursors of all offspring gametes, which is one of the reasons why periconceptional processes have implications for more than one generation<sup>73</sup>.

The epigenomic reorganization of early embryogenesis is sensitive to the maternal environment, with effects of protein-energy and micronutrient deficiencies as well as over-nutrition<sup>74,75</sup>. Observational studies, such as the Dutch Hunger Winter study, have implicated periconception as a sensitive time for epigenetic programming<sup>76</sup>. Of note are studies of metastable epialleles, epigenetically labile regions of the genome that are subject to large changes in response to environmental influences during very early embryogenesis. These regions were first described in mice, but subsequent human studies in Gambia have demonstrated epigenetic variation at metastable epialleles that are linked to periconceptional maternal nutrition<sup>77</sup>, findings that have later been replicated in a rural Bangladeshi cohort<sup>78</sup>. The methylation status of metastable epialleles has been linked to later obesity and metabolic function<sup>79</sup>.

Implantation is associated with further sensitivity to environmental influence. It initiates a functional interaction between the blastocyst (early embryo) and endometrium. The uterine microenvironment allows embryo–maternal crosstalk both pre- and post-implantation. Extracellular vesicles produced by the endometrium have been shown to

be mediators of maternal–embryo communication through their protein and RNA cargoes<sup>80</sup>. Secreted proteins from both the embryo (for example, human chorionic gonadotrophin from the trophoblast) and endometrium (for example, cytokines) guide successful implantation<sup>81</sup>. These processes are sensitive to maternal hormonal status and environmental influences, including stress and nutrition<sup>82</sup>.

### Persistence of adolescent assets and risks

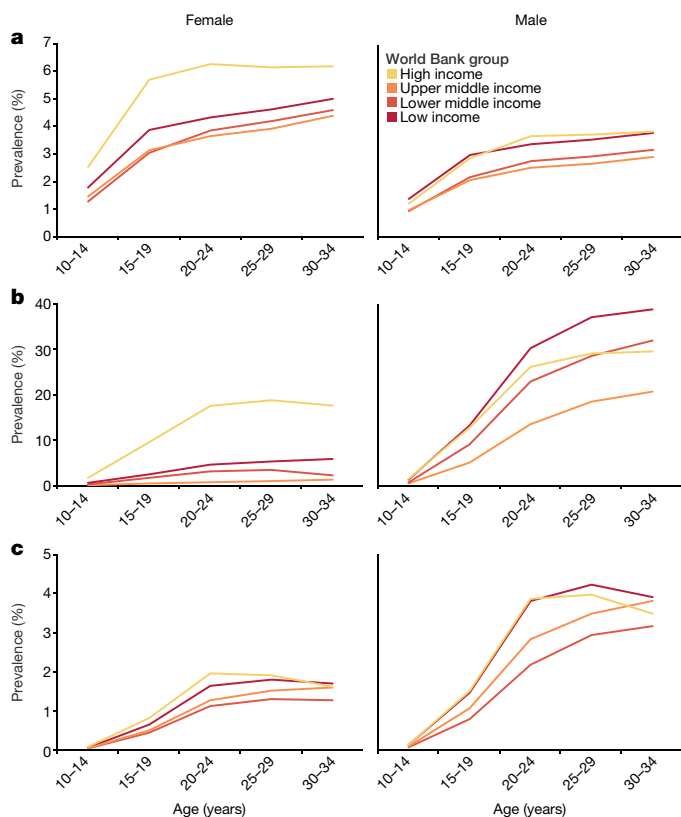
Assets derived from education, financial resources, family, social and cultural capital that are acquired during adolescence are essential for effective parenting and ultimately the growth and development of the next generation<sup>83</sup> (see Fig. 1). Similarly, risks related to undernutrition, obesity, substance abuse and mental disorders become prominent following puberty and tend to persist through the transition to parenthood even when this occurs decades later<sup>84</sup>.

**Stress and mental disorders.** Around one in four mothers experience symptoms of depression and anxiety in the perinatal period<sup>85</sup>. In contrast to earlier views that perinatal depression is a discrete disorder limited to the post-partum period, perinatal maternal depression more commonly seems to be a continuation of pre-pregnancy mental health problems into pregnancy and the post-partum period. A recent Australian study found that 86% of mothers with high perinatal depressive symptoms had a similar history before conception, predominantly dating back to adolescence<sup>86</sup>. Antenatal and postnatal exposures independently affect child cognitive and emotional development<sup>85,87</sup>. In low-resource settings, the effects extend to childhood stunting and physical illness with antenatal depressive symptoms predicting higher rates of pre-term birth, failure to thrive *in utero* and low birth weight<sup>88,89</sup>. Animal studies of maternal antenatal stress have shown effects on various hormonal and chemical mediators (glucocorticoids, oxygen and glucose) that are associated with reduced fetal weight, gender-specific metabolic changes in the offspring and long-term adverse metabolic and renal effects<sup>90,91</sup>. Persistence of preconception mental health risks into the postpartum affects mother–infant bonding with a greater likelihood of maternal over-intrusiveness, emotional withdrawal and failure to sensitively engage<sup>92</sup>.

Given recent secular trends to earlier onset, adolescent mental disorders have become more important as an intergenerational risk process<sup>93</sup>. In high-income settings, over half of young women have an episode of a common mental disorder before becoming a parent<sup>94</sup>. Figure 3a and Extended Data Figure 3 show prevalence estimates for DSM (Diagnostic and Statistical Manual of Mental Disorders) depressive disorders (major depression and dysthymia) in females and males aged 10–35 years, drawn from the Global Burden of Disease (2016) study<sup>95</sup>. Rates increase through to the mid-twenties and then plateau so that in high-income countries, women typically become parents at a time of high risk.

**Substance use.** Experimentation with tobacco, alcohol and other drugs typically begins in adolescence, with escalation to higher risk use and dependence in early adulthood<sup>96</sup>. Recent trends have generally been to earlier and heavier use with growing similarities in use in females and males<sup>97</sup>. Figure 3b, c and Extended Data Figures 4, 5 show patterns of daily smoking and alcohol-use disorders in females and males across the years of transition to parenthood. Daily smoking rates rise steeply during the period of adolescence and young adulthood for males in all country groupings. Rates of alcohol-use disorders are higher in males in all country strata, although in high-income countries, the gender gap is less. In high-income countries, the highest rates of substance use generally coincide with the peak in first parenthood for both sexes.

There is consistent and clear evidence that persisting maternal tobacco, alcohol, cannabis and other illicit drug use during pregnancy adversely affects growth and development of the offspring<sup>98</sup>. Maternal smoking has consistently been linked to adverse birth and child outcomes ranging from poor fetal growth, low birth weight, stillbirth, sudden unexpected death in infancy and a broad range of birth defects to later childhood



**Figure 3 | Mental health and substance use risks across the years of transition to first parenthood for 2016.** **a**, Prevalence of major depression and dysthymia in females and males. **b**, Prevalence of daily tobacco use in females and males. **c**, Prevalence of alcohol-use disorders in females and males.

behavioural problems, obesity and impaired lung function<sup>98,99</sup>. Heavier antenatal drinking (that is, more than three standard drinks per day) is also independently predictive of poor birth outcomes. What the risks of lower levels of consumption are remains debated<sup>100</sup>. Animal models indicate that alterations in fetal growth occur even with brief periconceptional alcohol exposure<sup>101</sup> and even low levels of alcohol consumption during the first trimester affect craniofacial development in humans<sup>102</sup>.

Women commonly modify their substance use during later pregnancy with modest benefits for fetal growth and development<sup>103</sup>. Heavy and dependent users, more common in countries with delayed parenthood, are less likely to cease use during pregnancy<sup>104</sup>. However, given that around 40% of pregnancies are unintended and recognition typically occurs around 6–8 weeks of gestation, pre- and periconceptional exposure is likely to be very high in countries in which substance use in adolescents is common<sup>105,106</sup>.

**Obesity and metabolic disruption.** Figure 2b and Extended Data Figure 2 illustrate the rapid increase in obesity during adolescence and young adulthood in females across all country income strata and for males in high-income and upper middle-income countries. The increase with age reflects obesity's strong tendency to persist once established<sup>107,108</sup>. Substantial increases in rates have occurred since 1990 across all country income groups. In high-income countries, prevalence rates of obesity for both females and males in the peak years for first parenthood are around one in five. Although rates are lower elsewhere, one in ten 25–29-year-old women in upper middle-income countries are obese.

Antenatal maternal obesity predicts macrosomic birth<sup>109</sup>, later childhood obesity and metabolic disturbance<sup>110,111</sup>, poorer cognitive skills and greater risk of behavioural problems during childhood<sup>112</sup>. Antenatal interventions to prevent these consequences appear to have

limited benefits. Exercise has the potential to promote greater maternal insulin sensitivity, but its benefits during pregnancy are debated<sup>113,114</sup>. A recent Cochrane review failed to demonstrate that dietary and lifestyle (including exercise) interventions for women with gestational diabetes mellitus restored glycaemic control or prevented adverse effects for women or their babies<sup>113,115</sup>. Although two reports have suggested some modest benefits of antenatal exercise in obese women, its late timing in those with no regular pattern of physical activity before pregnancy seems likely to bring limited benefits<sup>116,117</sup>. By contrast, exercise and diet before pregnancy may bring greater offspring benefits. Exercise initiated before and continued during pregnancy in female rats at risk of gestational diabetes prevents the development of glucose intolerance (gestational diabetes) by increasing  $\beta$ -cell mass and function<sup>118</sup>. Given rapidly rising rates of obesity in nearly all countries, primary prevention that starts in late childhood and continues during adolescence will be essential to avoid wide-ranging adverse intergenerational effects. Sharp drops in physical activity across the second decade, with only around 20% of adolescents globally achieving recommended levels, suggest that promoting physical activity should be a priority<sup>119,120</sup>.

### Adolescence and the next generation

Growth in the first thousand days predicts later-life health, human capability and resilience to adversity, which is why policies have focused on the promotion of optimal growth and human capital during the first thousand days. Increasingly it has also become a focus for the prevention of non-communicable diseases<sup>121</sup>. However, many of the processes that shape growth during early life originate well before conception or the first antenatal visit. Whether associated with early and high fertility, or with later and lower fertility, growth and development during adolescence provide a foundation for the start to life of the next generation.

The transition through education to employment typically occurs in adolescence, allowing the acquisition of assets that will be essential for being an effective parent, including financial resources and property, and extending to physical, cognitive, social and emotional capabilities (see Fig. 1). However, there are obstacles for many adolescents in achieving a secure foundation for parenthood. Early marriage is particularly noteworthy. Although rates are generally falling, more than half of girls continue to be married before the age of 18 years across many countries in sub-Saharan Africa<sup>122</sup>. Early marriage predicts early parenthood, overall fertility and poor maternal and child nutrition<sup>123–125</sup>. Its effects on the next generation are further mediated through curtailed education and exclusion of women from the formal workforce<sup>126</sup>. The annual benefits in 2030 from ending child marriage from reduced population growth and reductions in early childhood mortality and stunting have recently been estimated at US\$664 billion<sup>126</sup>. For proven interventions targeting social norms to delay early marriage, we estimated their benefit–cost ratios to be 8.9 in terms of improving education in the next generation (see Box 1).

Adolescent investments for the next generation will differ in different places. The education of girls is essential in countries with high and early fertility, and early marriage<sup>127</sup>. The education of boys also appears to be important, in that males without education are more likely to marry girls before the legal age and educated fathers have daughters who marry later<sup>125</sup>. Figure 4 illustrates progress in secondary school completion across country income groups in 1990 and 2010. Over 20 years, rates of secondary school completion for girls and boys have increased in all income groups, although much less so in low-income countries, in which only a small minority of girls complete secondary education. Despite gains in lower middle-income countries, rates of secondary school completion for both boys and girls remain under 50%, underlining the importance of continuing investments throughout the Sustainable Development Goal period. Ultimately, success in promoting education will also depend on tackling adolescent undernutrition, social norms favouring early marriage, exposure to hazardous social and physical environments, and adolescents' poor access to health services, including modern contraception.

## BOX 1

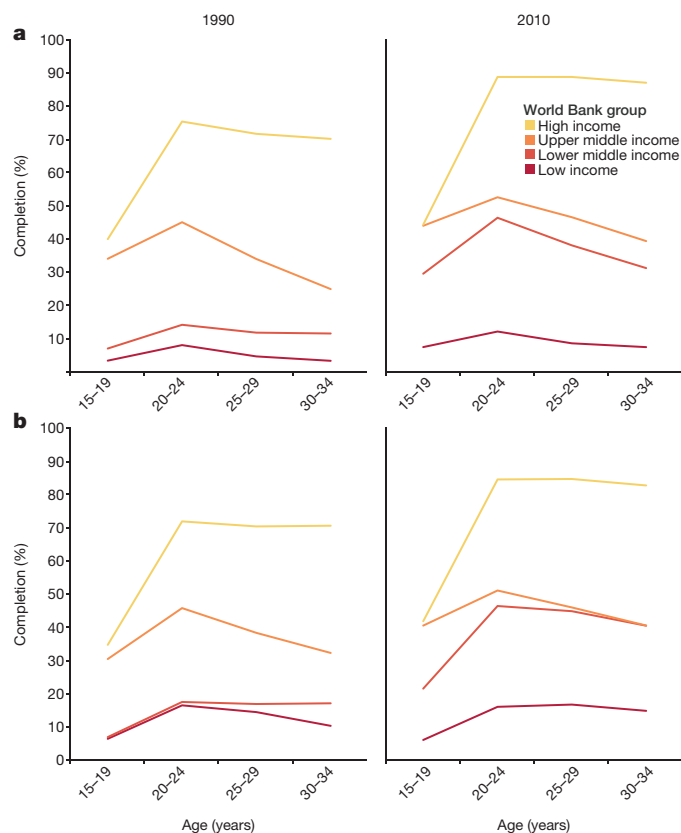
## Illustration of the benefits of delaying early marriage for the next generation

A recent investment case of adolescents showed that the promotion of education for girls and delaying marriage produced an almost sixfold increase in benefits across the course of life compared to costs<sup>15</sup>. That analysis excluded the intergenerational benefits for their children. Interventions to extend education and to delay marriage will improve a young woman's nutrition and growth as well as allow the acquisition of assets that extend her and her partner's parenting capabilities<sup>141</sup>. Conversely women who marry and parent at a young age are often trapped in a cycle of poverty with poorer life outcomes for their children through the many processes outlined here<sup>126</sup>.

One intergenerational benefit of delaying early marriage is greater education of the next generation<sup>142</sup>. This in turn is likely to have substantial health benefits for that next generation<sup>11</sup>. A recent report that was based on studies in 32 sub-Saharan African countries estimated that the children of girls that marry before the age of 18 years have, on average, 1.8 fewer years of schooling<sup>142</sup>. We used models developed for the recent global investment case for adolescence to estimate benefit–cost ratios for delaying marriage based on the effectiveness of a program targeting social norms in young women. This reduced rates of early marriage by 23.4% over four years<sup>143</sup>. We used estimates of the benefit for offspring, using an estimated 12.2% return per year of schooling for lifetime income, for economies in sub-Saharan Africa<sup>144</sup>. The value of an extra 1.8 years schooling for offspring, achieved by an intervention to defer early marriage, produced a benefit–cost ratio of 8.9 (95% uncertainty, 7.2–10.6). This illustrates the substantial intergenerational gains that are likely to arise from policies that emphasize education and delaying marriage in settings of high and early fertility.

In higher-income countries that have made a transition to low and late fertility, shifting the policy focus to health risks that emerge in adolescence and persist through to parenthood will be essential. Rates of adolescent mental disorders appear to be reaching historic highs and have a strong tendency to persist into the child-bearing years with consequences for maternal and child health, and family wellbeing. Similarly, adolescent and young adult alcohol use and other substance use continue to rise in many countries. Even more marked is the rise in obesity, particularly given that available antenatal interventions to reduce the metabolic consequences for both mothers and offspring are limited<sup>128</sup>.

Intergenerational epidemiological studies remain uncommon, and few have addressed risks during sensitive time periods<sup>129</sup>. However, it is becoming clear that different approaches to pregnancy and parenthood will be needed. Preparation for pregnancy and preconception care has been one recent focus<sup>48,75,130</sup>. Previously, the main preconception focus of health services has been on the prevention of unintended pregnancy through provision of contraception<sup>131</sup>. Nevertheless, in countries with high levels of primary care coverage, in which a majority of women make contact with health services at least annually, there would be scope to screen and intervene around intergenerational health risks<sup>132</sup>. The major barriers are the low current demand from future parents and a limited provision of more comprehensive healthcare, particularly for women at the greatest risk<sup>131</sup>. There is little doubt that a reorientation of service systems towards preconception would be of value<sup>133</sup>. However, given continuing high rates of unintended pregnancy<sup>134,135</sup> and the difficulty of modifying chronic health risks, addressing obesity, mental disorders and substance dependence earlier in adolescence will be essential. It



**Figure 4 | Secondary school completion (12 years and older) across age and income groups for 1990 and 2010. a, b, Secondary school completion for females (a) and males (b) in 1990 and 2010.**

requires a broadening of adolescent health beyond a traditional emphasis on sexual and reproductive health, extending the engagement of health service systems with adolescents and creating health-promoting environments in the families, schools, workplaces and communities in which adolescents are growing up<sup>11</sup>. Given the extent to which adolescents shape their own social and nutritional environments, this will require an active engagement with adolescents themselves.

The rapid rise in obesity in middle-income countries, even where undernutrition and food insecurity persist, will require multicomponent approaches with elements addressing healthy diets, physical activity and sedentary behaviour, as well as creating the opportunities for adolescents and their families to make healthy choices<sup>136</sup>. Similarly, high rates of mental disorders are likely to require not only early clinical intervention, but also the targeting of risk factors and the acquisition of protective social and emotional skills. For poor and socially marginalized adolescents in higher-income countries, who often have high and early fertility, responses may need to be similar to those for adolescents growing up in low-income countries<sup>19</sup>. Creating health-promoting environments for adolescents will ultimately require engagement well beyond the health sector, with education, local government, industry, religious leaders, civil society and young people themselves all essential actors.

Girls and young women should undoubtedly remain a priority. However boys and young men should also be brought into focus. They have important roles in parenting that are affected by health problems that commonly emerge before conception<sup>137</sup>. Their values and behaviours affect the capacities of young women to become effective mothers<sup>138</sup>. Increasingly we also understand that their influence on the next generation extends to distinct biological processes that directly affect the early development of the next generation.

Relative to other ages, the current generation of 10–24-year-olds is the largest cohort seen<sup>139</sup>. The potential demographic dividend from a large healthy and educated adolescent cohort entering the workforce has already captured policy attention<sup>25</sup>. We have largely overlooked the

fact that this will also be the largest generation to parent, promising an additional dividend in the health, growth and capabilities of the next generation<sup>43</sup>. In a world of competing policy priorities, there is no doubt that providing the resources for healthy adolescent growth, education and emotional development will yield large benefits for current and future generations.

**Online Content** Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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**Supplementary Information** is available in the online version of the paper.

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**Author Contributions** G.C.P. conceptualized the paper in conjunction with other authors. G.C.P. compiled the first draft with written contributions from S.M.S., C.A.O., V.S., R.S., M.E.W. and E.S. G.C.P., P.S.A., V.S., M.S., B.R., K.F. and K.S. contributed to the presented analyses. C.J.L.M., A.H.M. and N.J.K. provided estimates from Global Burden of Disease Study 2016. All authors reviewed first and subsequent versions of the paper and approved the final version.

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## METHODS

The analysis of risks included the 195 countries represented in the Institute for Health Metrics and Evaluation (IHME) Global Health Data Exchange database. The IHME provide population data for each country by year, sex and age group. We grouped countries according to World Bank income groups on gross national income per capita in US dollars: high income, upper middle income, lower middle income, and low income<sup>145</sup>. Estimates of prevalence are included as the percentage of people affected (for example, daily smokers) within each World Bank stratum. Estimates were generated for males and females; for the age groups (years): 10–14, 15–19, 20–24, 25–29 and 30–34; for the years: 1990, 1995, 2000, 2005, 2010 and 2016. The modelling of the data, including simulation of uncertainty bounds, is described elsewhere<sup>146–148</sup>.

The secondary school completion data were sourced from the database of ref. 149. Data are available for 146 countries. Completion of secondary education was defined as the sum of adolescents who had completed high school together with those currently in tertiary education.

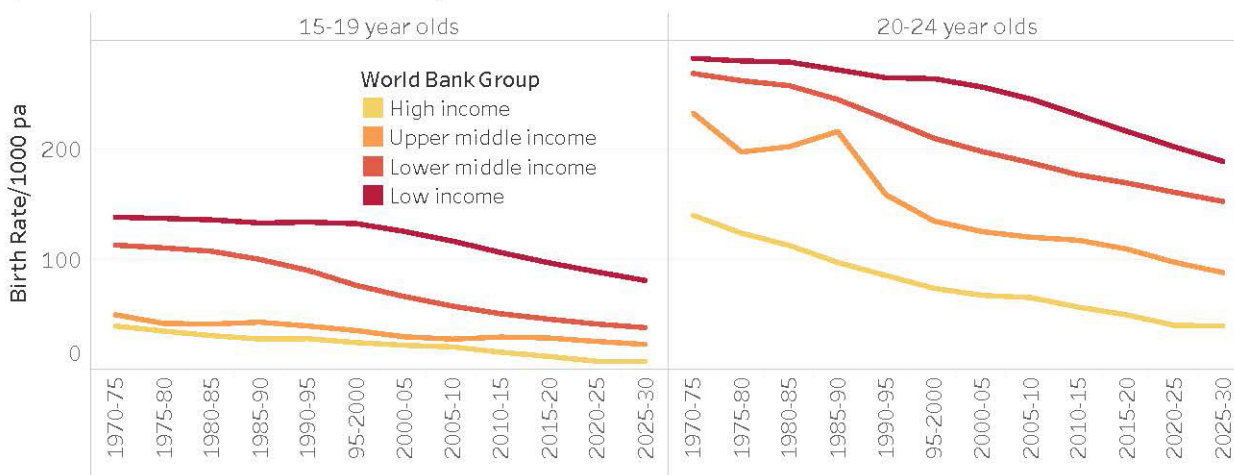
Data in Extended Data Fig. 1 derive from the United Nations Population Division (UNPD) beginning in 1970 and projecting through to 2030 for countries that are stratified by their World Bank income status in 2015. In Fig. 2b, the

estimates for 2030 are based on the level of education achieved in 2015 by girls in the respective country strata.

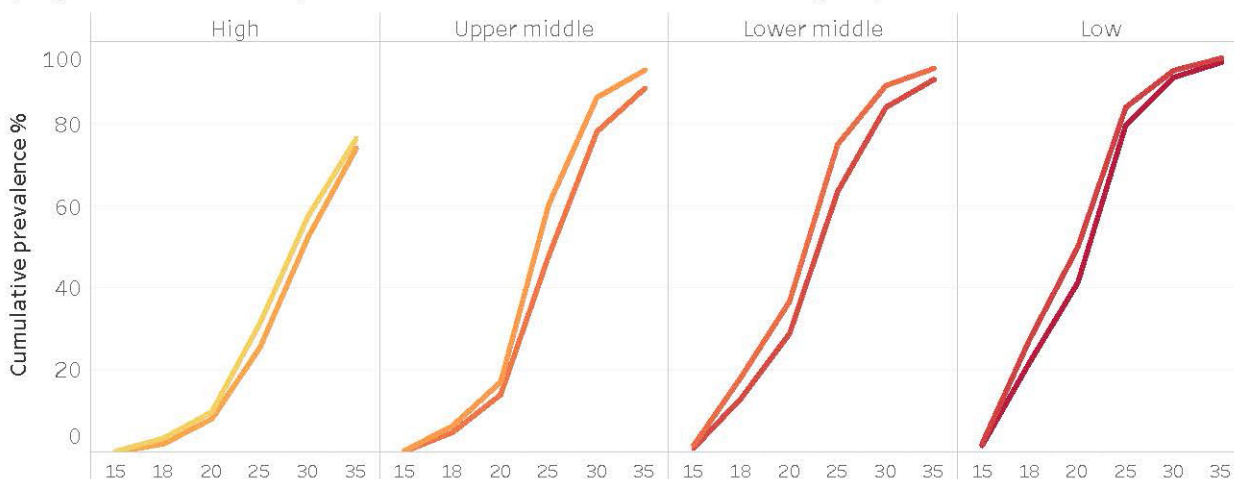
**Data availability.** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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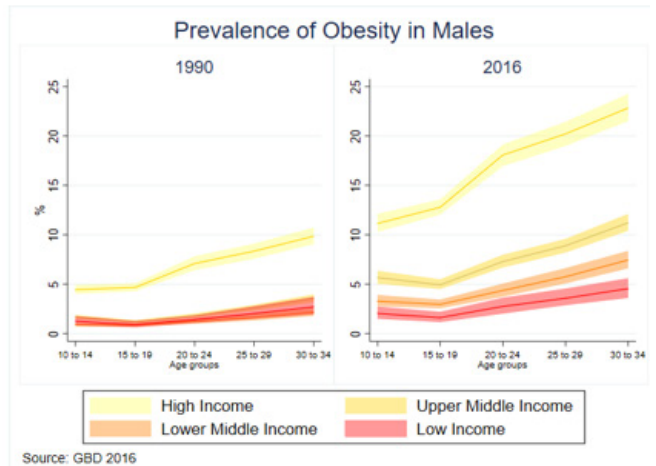
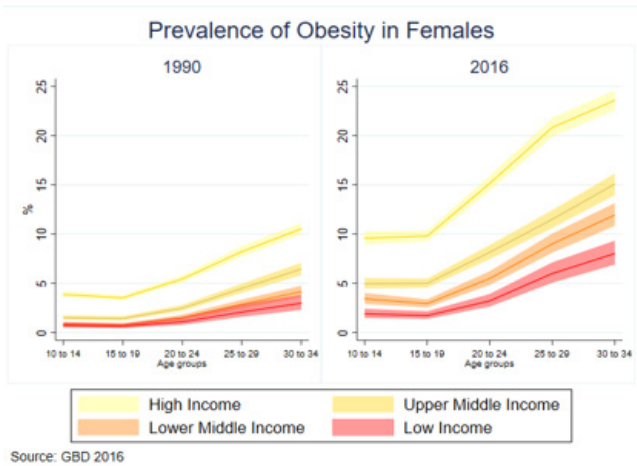
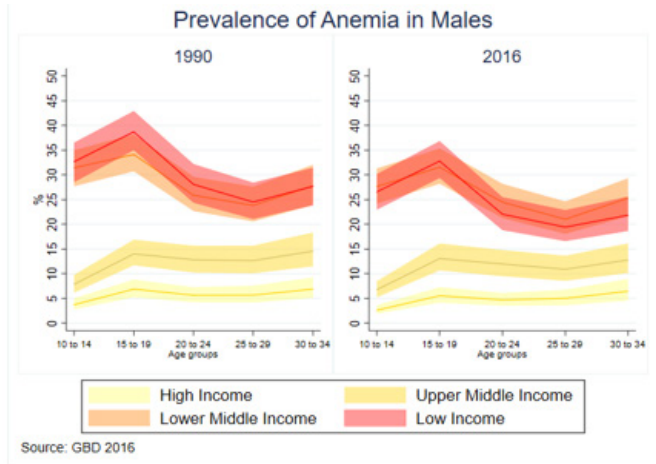
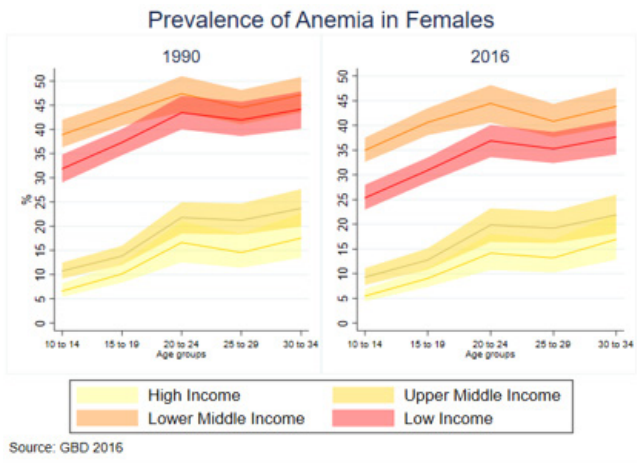
a) Birth rates in females 15 to 24 years: 1970 to 2030



b) Age of transition to parenthood across World Bank income groups: 2015 & 2030\*



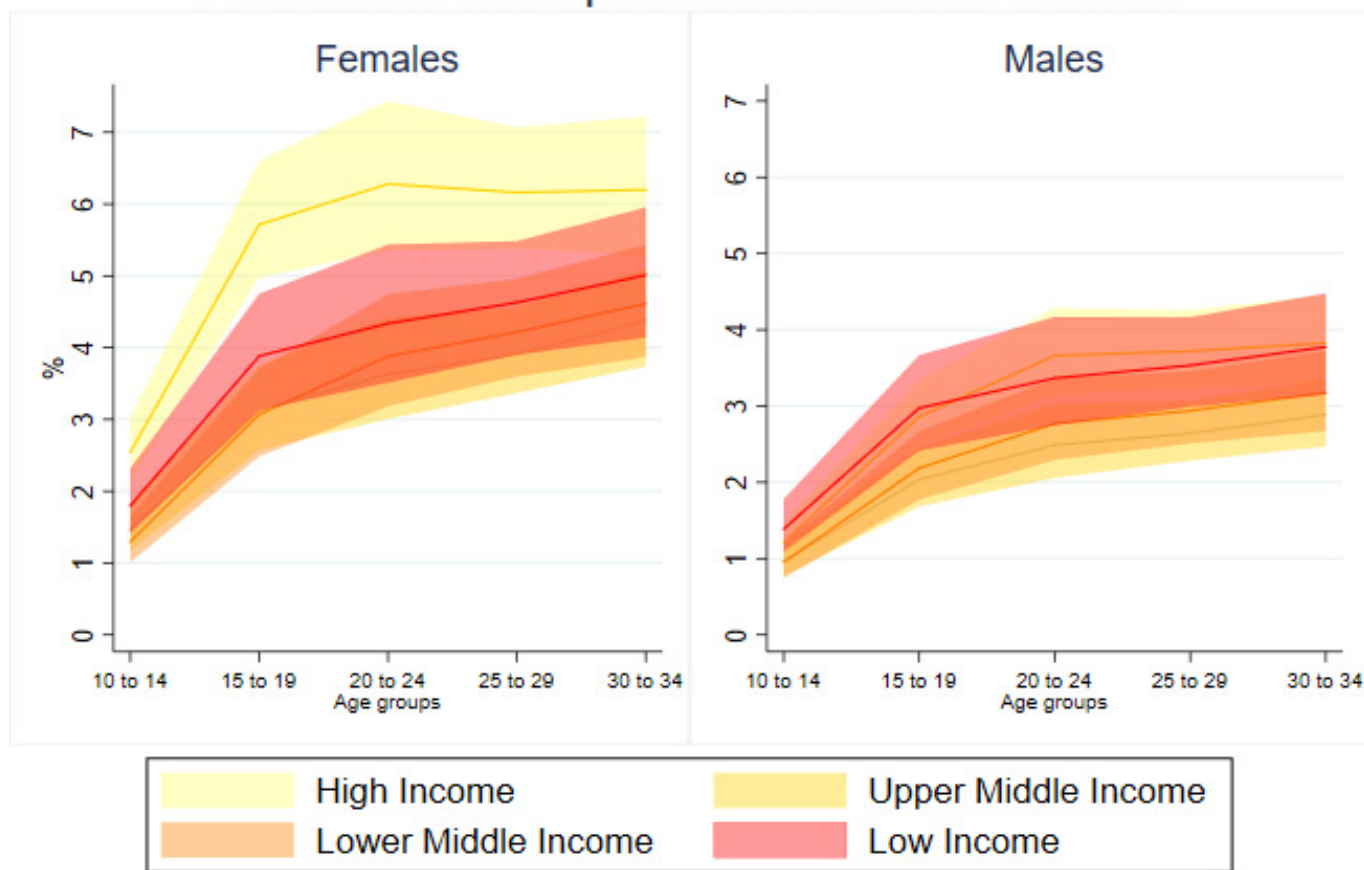
Extended Data Figure 1 | Birth rates and age of transition to parenthood in females across World Bank income groups. a, Trends in birth rates in 15–24 year olds for 1970–2030. b, Transition to parenthood in 2015 and 2030. \*Projections to 2030 are based on educational attainment of girls in 2015.



**Extended Data Figure 2 | Prevalence of anaemia and obesity in 10–34-year-old females and males in 1990 and 2016 for the four World Bank Country groupings in 2016.** Data are mean prevalence (line) and

95% uncertainty bounds (shading). Data were obtained from the Global Health Data Exchange (Global Burden of Disease Study 2016; <http://ghdx.healthdata.org/gbd-results-tool>).

## Prevalence of Depressive Disorders in 2016



Source: GBD 2016

Extended Data Figure 3 | Prevalence of depressive disorders in 10–34-year-old females and males in 2016 for the four World Bank Country groupings. Data are mean prevalence (line) and 95% uncertainty

bounds (shading). Data were obtained from the Global Health Data Exchange (Global Burden of Disease Study 2016; <http://ghdx.healthdata.org/gbd-results-tool>).

# Prevalence of Smoking in 2016

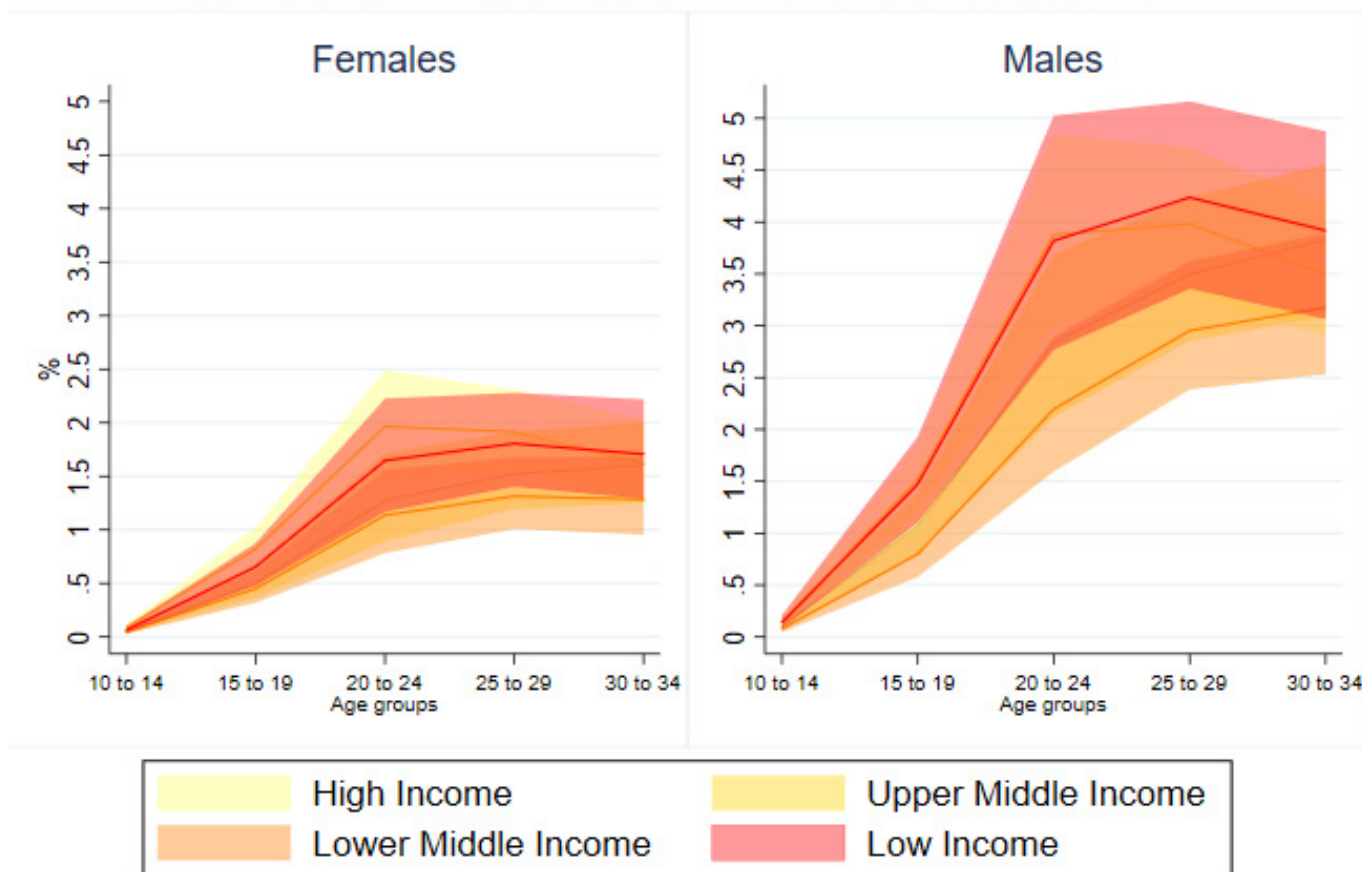


Source: GBD 2016

Extended Data Figure 4 | Prevalence of daily smoking in 10–34-year-old females and males in 2016 for the four World Bank Country groupings. Data are mean prevalence (line) and 95% uncertainty bounds (shading).

Data were obtained from the Global Health Data Exchange (Global Burden of Disease Study 2016; <http://ghdx.healthdata.org/gbd-results-tool>).

## Prevalence of Alcohol Use Disorders in 2016



Source: GBD 2016

Extended Data Figure 5 | Prevalence of alcohol-use disorders in 10–34-year-old females and males in 2016 for the four World Bank Country groupings. Data are mean prevalence (line) and 95% uncertainty

bounds (shading). Data were obtained from the Global Health Data Exchange (Global Burden of Disease Study 2016; <http://ghdx.healthdata.org/gbd-results-tool>).

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# CORRECTIONS & AMENDMENTS

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## CORRECTION

<https://doi.org/10.1038/s41586-018-0069-3>

## **Publisher Correction: Adolescence and the next generation**

George C. Patton, Craig A. Olsson, Vegard Skirbekk, Richard Saffery, Mary E. Wlodek, Peter S. Azzopardi, Marcin Stonawski, Bruce Rasmussen, Elizabeth Spry, Kate Francis, Zulfiqar A. Bhutta, Nicholas J. Kassebaum, Ali H. Mokdad, Christopher J. L. Murray, Andrew M. Prentice, Nicola Reavley, Peter Sheehan, Kim Sweeny, Russell M. Viner & Susan M. Sawyer

Correction to: *Nature* <https://doi.org/10.1038/nature25759>, published online 21 February 2018.

In Fig. 4a of this Analysis, owing to an error during the production process, the year in the header of the right column was '2016' rather than '2010'. In addition, in the HTML version of the Analysis, Table 1 was formatted incorrectly. These errors have been corrected online.