Life history theory and the social clustering of adolescent behaviour

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I, Abram Joachim van Leeuwen, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

Humans – foragers and megacity dwellers alike – inhabit complex social worlds. Many behavioural and non-behavioural traits show distinct patterns of social clustering: members of social groupings are more similar to each other than to random individuals.

This thesis uses social clustering as an entry point for the study of behavioural variation, exploiting the fact that different causal mechanisms will produce different clustering patterns. I combine this with a focus on evolutionary explanations of behavioural variation, particularly those derived from life history theory, and apply this approach to contemporary adolescents in the United Kingdom. Adolescents are a key demographic from a life history theoretical perspective: transitioning from the pre-reproductive to the reproductive phase of life, adolescents start displaying many of the behaviours and traits of interest to life history theorists. Moreover, paths taken during adolescence may have long-term implications for an individual's life history trajectory.

I quantify social clustering of sexual experience and cooperativeness in neighbourhoods, schools and friendship networks and investigate whether life history predictors, such as socioeconomic deprivation and father absence, explain behavioural variation or their social clustering. I further examine the social clustering patterns across a range of behavioural and non-behavioural traits, in order to assess the explanatory scope of different evolutionary models. Finally, I examine whether measures of the quality of the childhood environment affect a range of measures of pubertal development in girls and boys, in line with theoretical predictions.

Overall, results indicate that adolescent behaviours tend to cluster in friendship networks but barely in neighbourhoods or schools. This suggests limited scope for explanatory theories centred on contextual influences on behaviour in this population. While life history predictors do not explain much social clustering of adolescent behaviour, they are associated with sexual experience, cooperativeness, and pubertal development in ways broadly consistent with life history theoretical predictions.

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Chapter 1: Introduction and background

1.1 Introduction

Homo sapiens owes much of its remarkable evolutionary success to its social nature. Humans build extensive networks of cooperative relationships, which allow us to achieve things, through collective action and division of labour, unattainable to the solitary individual, however strong or smart (Nowak & Highfield 2011). We can also use cooperative social relationships to buffer ourselves against environmental risk, for example, when hunter-gatherers share food to even out variance in foraging and hunting returns (Kaplan et al. 2009). And crucially, our 'hypersociality', in combination with large brains, allows us to share ideas widely, the basis of the process of cumulative cultural evolution responsible for taking humanity from the Stone Age to the Space Age (Richerson & Boyd 2005; Powell et al. 2009). Social groups and social networks are central to the human way of life.

When we consider behavioural variation in humans, we find – regardless of whether we are surveying a population of modern hunter-gatherers or the inhabitants of a mega-city – that many behavioural characteristics are neither randomly scattered across the social world nor universal. Instead, many behaviours, as well as non-behavioural traits, show distinct patterns of *social clustering*, which, as I use the term in this thesis, simply means that members of some social grouping, like members of a friendship network or residents of the same village or neighbourhood, are more similar to each other than random members of a wider reference population.

Social clustering provides a possible avenue for the study of the origins of behavioural variation, the central topic of the human evolutionary behavioural sciences (Sear et al. 2007). The empirical finding that a behaviour clusters at a particular social level can be used as the entry point for an investigation into its causes. Indeed, unless one understands why said behaviour exhibits social clustering, one cannot be considered to have a complete understanding of why it varies between individuals. By approaching the problem from a social clustering angle, one also acknowledges the fact that, as members of a highly social species, humans are very responsive to their social environments and recognizes that much behavioural variation may be attributable to social sources.

In this thesis, I adopt a social clustering angle to explaining behavioural variation and apply it to the study of behavioural variation in a contemporary population of adolescents in the United Kingdom.

A second major theme of the current thesis is life history theory, arguably the dominant evolutionary framework for understanding behavioural variation in adolescents (Ellis et al. 2012). From a social clustering perspective, one would ask to what extent observed social clustering in a particular behaviour, such as experience with sexual intercourse (chapter 2), is due to similarities among social group members in life history variables, such as supposed cues to local mortality rates that individuals are exposed to.

From an evolutionary perspective, adolescents are a very interesting demographic in which to study behavioural variation. During adolescence, individuals go through major changes as they transition from the pre-reproductive to the reproductive phase of life, and many of the changes of adolescence – physical/physiological, behavioural, social – can be understood in light of this evolutionary-functional perspective. Because many traits of interest to life history theorists (e.g., those relating to sexual and reproductive behaviour) appear for the first time during adolescence and, moreover, reproductive strategic 'decisions' made during adolescence may have large and long-lasting consequences on an individual's life trajectory, adolescence is a pivotal life stage rom a life history perspective.

In the remainder of this introductory chapter, I first put human adolescence in an evolutionary perspective, focusing on its ultimate reproductive function, and I discuss evolutionary thinking about sex differences and its implications for adolescent behaviour (1.2: Adolescence: an evolutionary perspective). Next, I look at life history theory and its application to adolescent behavioural and physical development (1.3: Life history theory). This is followed by a section that derives predictions about adolescent behavioural and physical development based on the previous two sections, in particular as they relate to the outcomes investigated in later empirical chapters (1.4). I then provide a theoretical context for thinking about social clustering and its origins (1.5: Social clustering). The distinction between social influence and social selection is introduced; a cultural evolutionary perspective on social clustering is briefly developed;

and friendship and a preference for similarity are considered from an adaptationist perspective. Finally, a chapter-by-chapter outline of the rest of this thesis is presented.

1.2 Adolescence: an evolutionary theoretical perspective

1.2.1 What is adolescence?

Before bringing an evolutionary perspective to bear on adolescence, I will start by giving a more descriptive view of adolescence (although occasional interpretative or functional statements about adolescence are unavoidable here). Adolescence is a cross-culturally recognized life stage that bridges the period between childhood and adulthood (Schlegel & Barry 1991)[1]. During adolescence, individuals undergo a process of physical growth and development, known as puberty, culminating in sexual maturity; develop socially, cognitively and emotionally towards adult functioning; their role in society is redefined in preparation of full adulthood (Schlegel & Barry 1991). These dramatic changes combine to transform dependent children into more or less self-reliant adults able to raise offspring.

1.2.1.1 Social adolescence

A useful conceptual distinction can be made between *social* and *biological* adolescence, although the two are clearly intertwined. Social adolescence encompasses systematic shifts in the social lives of adolescents and their communally recognized role in society. Cross-culturally, these include a gradual lessening of dependence on parents and concomitant increase in autonomy, an emphasis on learning skills and acquiring knowledge required for assuming the social roles and responsibilities of adulthood, and a growing importance of the (same-sex) peer group as a socialization agent (Schlegel & Barry 1991).

The beginning of social adolescence usually coincides roughly with the start of biological adolescence and in many cultures is marked by some kind of ritual or 'puberty rite' (Schlegel & Barry 1991). The end of social adolescence tends to be less well-defined. In many traditional societies, people are considered adults from marriage. In modern Britain, the end of adolescence is often associated with the setting up of one's

[1] Sometimes an additional *juvenile* stage is recognized between childhood and adolescence, wherein someone is no longer dependent on their parent(s) for survival but is still pre-pubertal (Bogin 1994). Here I am using a 'childhood' in a broad sense to include this juvenile period.

own household and a large measure of, if not complete, financial independence from parents.

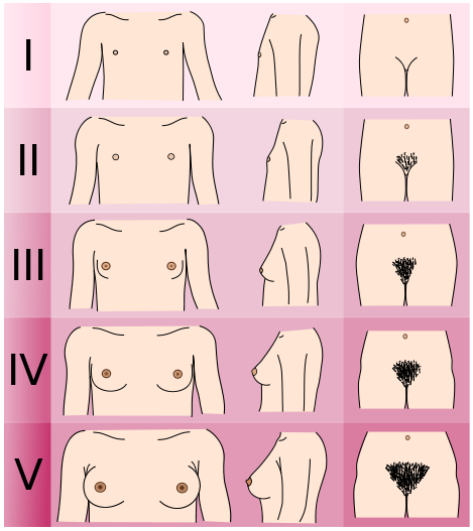
1.2.1.2 Biological adolescence

Biological adolescence largely comprises the hormonally regulated physical and physiological changes associated with puberty. The first sign of puberty in girls is usually the onset of breast development, while in boys puberty usually starts with enlargement of the testes (Wheeler 1991). Puberty ends with the closing of the epiphyseal plates of the long bones, the physiological end of (height) growth (Roenneberg et al. 2004). Some biological changes associated with adolescence, such as changes in sleeping patterns, continue to occur for several years after the end of puberty (ibid.).

1.2.1.2.1 Female biological adolescence

The physical changes of female pubertal development in girls include the pubertal growth spurt, menarche (first menstruation), the onset and progression of pubic and armpit hair growth, and breast development (Marshall & Tanner 1969). Pubic hair growth and breast development can be tracked using Tanner stages (Tanner 1962; Fig. 1.1), which cover development from the pre-pubertal state (stage I) to the adult state (stage V).

Figure 1. Tanner stages for breast development and pubic hair growth



A typical sequence of pubertal events in girls is as follows (Marshall & Tanner 1969). The start of puberty is usually marked by the onset of breast development, i.e., when a girl enters Tanner stage II (an event referred to as B2). This is followed by the start of pubic hair growth (PH2). In an ALSPAC-based-study, the median age at B2 was 10.2 and the median age at PH2 was 11.0 (Christensen et al. 2010). Next, the pubertal growth spurt reaches its point of fastest growth (or *peak height velocity*). Menarche occurs around half-way through puberty. Mean age at menarche in the ALSPAC sample is approximately 12 years and 6 months (Culpin, Heron, Araya, Melotti, et al. 2014a). The final physical changes of puberty are reaching of the adult breast stage (Tanner V) and closing of the epiphyseal plates of the long bones, marking the end of height growth. Body composition also changes markedly during adolescence. Girls gain a modest amount of (height-adjusted) lean mass during puberty but far more fat mass (Wells 2007).

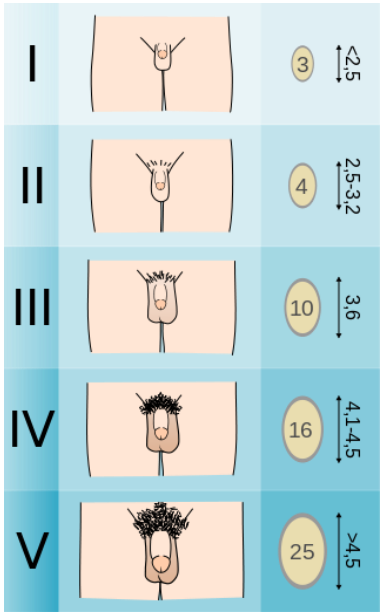
While the ordering of these events appears to be quite uniform across human societies (Bogin 1994), their timing does show substantial variation between societies, with girls in contemporary industrial societies progressing through puberty comparatively early (Weisfeld 1999; Hochberg & Gawlik 2011).

1.2.1.2.2 Male biological adolescence

Male puberty includes the pubertal growth spurt, maturing of the genitalia (penis and scrotum), spermarche (first seminal emission), and the onset and progression of pubic and armpit hair growth (Marshall & Tanner 1970). Again, Tanner stages can be used to track pubic hair growth and, in the case of boys, development of genitalia (Tanner 1962; Fig. 1.2).

The first event of male pubertal development is usually enlargement of the scrotum and testes (Marshall & Tanner 1970). Pubic hair growth is the next noticeable change. Age at peak height velocity is a relatively late event. The final events of male puberty are the reaching of Tanner stages V of genital development and pubic hair growth and the closing of the epiphyseal plates. In marked contrast to the body composition changes in girls, boys gain a lot of (height-adjusted) lean mass (>50% as muscle) but no fat mass during adolescence (Wells 2007).

Figure 2. Tanner stages of male genitalia (Figure by Michal Komorniczak, licensed under CC BY-SA 3.0)



1.2.1.3 Human adolescence in a comparative perspective

Among mammalian life histories, including those of the great apes, human adolescence is remarkable due to its sheer length. Biological adolescence lasts around 8 or 9 years in our species, several years more than in chimpanzees (Bogin 2009). Social adolescence may also be a protracted affair, especially for boys. In some societies (e.g., polygynous ones), males do not reach adult status until they are ~25 (Weisfeld 1999), in which case (social) adolescence will have taken up over a decade.

A rapid adolescent skeletal growth spurt, following slow growth during a protracted juvenile period, may be unique to humans (Bogin 1994; Hamada & Udono 2002). This unusual growth pattern has been argued to have evolved to allow for additional brain rather than somatic growth during the juvenile period, which facilitates the acquisition of complex behaviour (Weisfeld 1999; Gurven & Walker 2006). Additionally, a longer juvenile period followed by a rapid adolescent growth spurt may have allowed for increased fertility in our species by reducing the energetic demands of offspring on provisioning parents (Gurven & Walker 2006).

1.2.2 The evolutionary function of adolescence

Scientists working on human adolescence do not have a shared, core theory of human adolescence. The view taken here is that an evolutionary approach offers the best hope

of formulating such a theory (Weisfeld 1999; Ellis et al. 2012). The reason is the functional perspective that evolutionary biology brings to the table, which allows one to anchor theorizing about adolescence in ideas about *why* human adolescence and its specific features evolved, which may have a heuristic function when thinking about mechanisms. The core idea of such an approach is that adolescence is a transitional period between the pre-reproductive and the reproductive phase of life and thus serves to prepare an individual for reproduction. The changes of adolescence can all be understood in this light.

The comparatively long duration of human adolescence requires an explanation, since postponing reproduction for many years would seem like a losing strategy in the inclusive fitness game. And yet, the mean age at first reproduction of women in foraging societies is just under 20 years (Kaplan et al. 2000), while for men it is often higher still (Weisfeld 1999).

The commonly accepted explanation is that the knowledge and skills required to be able to function as a (reproductively) successful adult in human society require a particularly long learning period (Bogin 1994; Kaplan et al. 2000; Weisfeld 1999). Adolescence, then, can be seen as a training period for adulthood – its evolutionary function is to prepare individuals for performing the tasks required of them as adults with the ultimate goal of ensuring reproductive success (Bogin 1994; Weisfeld 1999).

During their 'apprenticeship', girls acquire knowledge on how to deal with pregnancies, learn the ins and outs of and practice child care, and are trained in (society-specific) female economic behaviour, while boys are introduced to the world of male-male competition and (society-specific) male economic behaviour; at the same time, both sexes learn sex-appropriate norms of adult social and sexual relationship behaviour (Bogin 1994; Weisfeld 1999). Meanwhile, adolescents' bodies similarly prepare for reproduction, puberty transforming them into sexually mature individuals.

1.2.3 Evolution and sex differences

1.2.3.1 Evolved sex differences stem from asymmetries in parental investment

Evolutionary theorists frame many behavioural sex differences in terms of differences between male and female reproductive strategies, which reflect differing sets of selection pressures during a species' evolutionary history. Robert Trivers' ideas about parental investment and sexual selection have been particularly influential (Trivers 1972). The central argument is that differences in selection pressures on males and females can ultimately be traced back to asymmetries between the sexes in minimum parental investment requirements.

In human reproduction, the minimum amount of parental investment required of females – in gestation, lactation, and the like – is far greater than what is strictly demanded of males, for whom, in some cases, their sole contribution consists of a single ejaculate.

Because of obvious physiological limitations, a pregnant woman cannot increase her reproductive success by pursuing additional fertilizations. Even after giving birth, she will remain in a state of infertility while breastfeeding (lactational amenorrhea), before once again being able to conceive. Upon fertilization, women are effectively committed to a large investment, spanning several years, in a single offspring (ignoring rare multiple births). The upshot of this is that a woman's reproductive success is usually limited by her access to food resources. By contrast, men can increase their reproductive success, potentially drastically, by impregnating multiple women, whose pregnancies plus periods of lactational amenorrhoea may overlap. A man's reproductive success is therefore limited by his sexual access to fertile women willing and able to carry and care for his offspring.

One important consequence of these asymmetries is the greater (potential) variance in men's reproductive success compared to women's (a.k.a. the Batemen effect).

1.2.3.2 Female and male reproductive strategies

As a result of the sex difference in minimum parental investment, females should, as a general rule, be the choosier sex when it comes to picking sexual partners. A poor choice

of sexual partner by a female may result in her having to invest heavily in low-quality offspring. A male should be less concerned with the quality or reproductive value of any particular sexual partner, since he can simply walk away after fertilization. (For the sake of argument, I am, for now, ignoring pair-bonding behaviour and all sorts of cultural restrictions on mating behaviour in our species.). Thus, males should have evolved to be less choosy when selecting sexual partners.

Because of the Bateman effect, males run a greater risk of not reproducing at all, but also have the opportunity to reap extraordinary rewards, from an evolutionary fitness perspective, by fathering many offspring with multiple women. Combined with female mate choice, this sets up conditions for intense male-male (intrasexual) competition for access to fertile females.

Pair-bonding and (often) substantial male parental care requirements temper the Bateman effect because fewer men will be left out of the mating game (as polygyny dilutes the amount of resources a man is able to direct at individual women). This may have reduced the intensity of male-male competition in our species. Another important consequence is that – unlike males willing and able to impregnate a female, which are abundant – males willing and able to provide large amounts of parental investments *are* a contestable resource that can affect a female's reproductive success. This means that females also compete for males and males may be able to exercise mate choice in the sphere of long-term reproductive partnerships.

Both men and women may have multiple reproductive strategies to their disposal (Gangestad & Simpson 2000).

What characteristics should females value in a potential mate (and what sort of traits should males therefore compete on)? In foraging cultures, which arguably provide the best model for ancestral human societies, biparental care is the norm (Marlowe 2000), although male care in particular shows substantial variation (Geary 2000), and a sexual division of labour exists between men and women within pair-bonds (Marlowe 2007). In such societies, we might expect women to choose males who display indicators of resource acquisition skills and a willingness to provide continued investment in them and their shared offspring. We might therefore expect a man's abilities as a hunter and protector to be highly valued. Thus, women may also have been selected to value (i.e.,

be sexually attracted to) bodily features associated with physical prowess (strength, agility, robustness) and men to compete on indicators thereof.

In situations where paternal investment is unlikely to be forthcoming, she may emphasize traits of male dominance like, again, physical prowess and attractiveness, which help him gain access to fertile females, in the hope that any male offspring that result will inherit those traits and be able to reap the reproductive rewards. If paternal investment is a more likely prospect, women should pay more attention to indicators of resource acquisition skills and fidelity.

Men meanwhile can opt for a strategy centred on parental effort (the 'dad' strategy), investing a lot of time and other resources in a particular pair-bond (mate and children). Alternatively, they can adopt a strategy aimed at maximizing the number of fertilizations they achieve, expending reproductive effort largely as mating rather than parental effort. Perhaps these choices are best imagined as extremes on a spectrum. The optimal strategy for a particular male may depend on his personal characteristics (e.g., physical attractiveness) and local socioecological conditions (e.g., operational sex ratio).

In sum, while the reproductive interests of males and females in a pair-bonding species with biparental care like our own will often show substantial overlap, human males and females are not subject to identical reproductive considerations. These differences may be reflected in cross-cultural sex differences. Of course, there are numerous cultural influences on human behaviour, including behavioural sex differences, which have little to do with selection pressures faced by ancestral humans. Moreover, sex differences are often modest, behavioural, psychological, and other traits of men and women showing marked overlap (e.g., mate preferences: Buss 1989).

1.2.3.3 Implications for adolescent behaviour

Based on the evolutionary ideas just reviewed, what sort of behavioural differences might we expect between male and female adolescents?

1.2.3.3.1 Boys are more prone to risky behaviour than girls

One critical prediction derived from the Trivers (1972) model of sex differences, when applied to humans, is that adolescent boys will be more prone to risky behaviour their

female counterparts (Ellis et al. 2011; Weisfeld 1999; Wilson & Daly 1985). A large body of empirical evidence attests to a clear gender gap in risk-taking propensity (e.g., Byrnes et al. 1999).

Boys should be more inclined to take risks of various kinds to improve their social status, because the stakes are higher for them. As explained above, through evolutionary history males have been in greater danger of complete reproductive failure, while also having much higher potential reproductive success. This should have put a selective premium, within limits, on greater risk-taking propensity in human males. This appetite for risks should peak during adolescence that is when individuals are competing for mating opportunities while many of their competitors and potential mates are still unmated, leading to fierce competition for the best available mates.

Risky, norm-breaking behaviour during adolescence may thus be a form of male-male status competition, which, ultimately, functions to improve a participant's sexual access to fertile females (Weisfeld 1999; Ellis et al. 2011; Wilson & Daly 1985). In this vein, it has been argued that "[d]elinquent and risky behaviours (e.g., crime, rule breaking, fighting, risky driving, drinking games) often have signalling functions that enhance reputations for bravery and toughness and can leverage position in dominance hierarchies, especially for males" (Ellis et al. 2011: 4).

1.2.3.3.2 The nature of intrasexual competition in girls and boys differs

Male intrasexual competition is expected to be more physical, aggressive, and intense for reasons outlined above. Adolescent boys' status and self-esteem will be related to physical traits such as height, muscularity and agility, which all feed into physical attractiveness, and to (markers of) economic success, and perhaps, in some cultural contexts, intellectual abilities or academic achievements (Weisfeld 1999; Vannatta et al. 2009). For girls, physical attractiveness – as possible proxies of youth, health and fertility – would be expected to affect their popularity among peers and especially with the opposite sex (Weisfeld 1999).

Evidence suggests that physical attractiveness is a key determinant of social status or dominance rank in both male and female adolescents, predicting (leadership) popularity and peer acceptance (Weisfeld et al. 1984; Vannatta et al. 2009). Athleticism

appears to be more important in determining boys' rather than girls' dominance position (Vannatta et al. 2009), in line with evolutionary considerations with regard to sex differences in attractiveness features.

While a cooperative interpersonal strategy would seem to be beneficial to both sexes, girls may have evolved a stronger inclination to towards acting cooperatively as a result of these sex differences in the nature of intrasexual competition, since they did not evolve the same physical tools as male to use in situations of conflict, nor perhaps their psychological inclination (Weisfeld 1999).

1.2.4 Changes of adolescence in the light of evolution

I will now discuss some of the many profound changes – psychological, behavioural, physical, physiological, social – taking place during adolescence and discuss out their possible relationship to the evolutionary function of adolescence. The following remarks should be taken as applying cross-culturally (Schlegel & Barry 1991; Weisfeld 1999). Some atypical features of adolescence in contemporary Britain will be highlighted.

1.2.4.1 Puberty leads to (biological) sexual maturity

Firstly, there are the physical changes of puberty (1.2.1.2), i.e., the development of primary and secondary sexual characteristics and pubertal growth spurt. The physical characteristics acquired during puberty serve to make individuals physically capable of reproduction (reproductive capacity) and able to successfully compete for mates (intrasexual competitive ability). For example, males boys become more physically imposing – more muscular, broad-shouldered, larger, deeper-voiced, and so on – during puberty.

1.2.4.2 Puberty rites

In many cultures, adolescents undergo some kind of puberty rite as part of their transition to adulthood and incorporation into adult society (Schlegel & Barry 1991), which tend to take place just before the onset of fertility (e.g., typically at menarche in girls) (Weisfeld 1999). In addition to marking and signalling a status change for the initiate, puberty rites tend to involve explicit instruction in sex-specific adult social and

economic behaviour – "a crash course in adulthood" (Weisfeld 1999: 110) – a process that often continues after the rite of passage proper. A puberty rite, and the following process of socialization, is a "cultural analogue of biological puberty" (ibid.: 109) in that it serves to promote behavioural maturity, similar to the way that biological puberty transforms pre-reproductive youngsters into biologically – sexually and reproductively – mature individuals.

1.2.4.3 Emotional distancing from parents, turn towards peers

Emotional closeness between parents and their offspring decreases during adolescence and is positively correlated with pubertal maturation (Steinberg 1987). This presumably forms part of a larger process of reducing dependence of parents in preparation of adulthood (Weisfeld 1999). At the same time, adolescents become markedly more peer-oriented (Schlegel & Barry 1991). This makes evolutionary sense, since – for typical heterosexual adolescents – opposite-sex peers in the local area (apart from close kin) make up an individual's mating pool, while same-sex peers are one's competitors in the mating arena (as well as likely cooperative partners) (Weisfeld 1999).

1.2.4.4 Appearance of sex drive and romantic feelings

During adolescence, individuals become preoccupied with sexual and romantic feelings and relationships, that is, they acquire pair-bonding motivations (Weisfeld 1999). In light of the evolutionary function of adolescence, this makes sense, since the pair-bond between a male and female who provide parental care to their shared offspring is the typical (core) unit of reproduction in our species, although male parental care is more variable (Geary 2000).

1.2.4.5 Intrasexual competition

Like other group-living primates, humans are often preoccupied by and trying to improve their place in the dominance hierarchy of salient reference groups, i.e., they care intensely about their social status. In this context, pride and shame may function as status emotions – low or loss of status leads to shame, while high or increase of status engenders a feeling of pride – that motivate us to strive to increase our status (Weisfeld

1999). The importance of status may also be inferred from its apparent impact on primate health, including humans (Sapolsky 2004). In general, status matters because individuals higher up in the dominance hierarchy have increased access to resources.

For male primates arguably the most important resource is sexual access to females, preferably females of high reproductive value. Indeed, high social status seems to benefit the reproductive success of human males in a variety of societies (e.g., von Rueden et al. 2011). Evidence from foraging societies suggests that successful hunters enjoy more prestige and reproductive success (Smith 2004).

Competition for sexual and romantic partners starts during adolescence – which ultimately serves a reproductive function – so it is not surprising that adolescents tend to be pre-occupied by their status among peers (Ellis et al. 2012). In peer groups of adolescent boys, dominance hierarchies are often identifiable and seem to be based largely on physical prowess (Weisfeld 1999). During adolescence, boys become physically larger as a result of the growth spurt, although the final size difference with girls is somewhat also for a sizable part due to relatively prolonged skeletal growth in the juvenile period (Weisfeld 1999), and become more muscular relative to girls (Wells 2007). Human females also compete for mates, although perhaps less overtly. Girls and women are expected to compete on attractiveness (Fisher 2004) and, as mentioned, physical appearance of female adolescents predicts social standing and popularity among girls and with the opposite sex (Vannatta et al. 2009).

1.2.4.6 Possible functional significance of ordering

The species-typical ordering of events during human adolescence has been suggested to have functional significance (Bogin 1994). In girls, pubertal development has been ongoing for several years before they become fertile and even more before they reach adult levels of fertility. Because the adolescent girl physically looks like and starts behaving more like an adult female, to some extent, she is included in the sphere of women rather than girls and may start to get involved in romantic and sexual relationships. Her subfertility ensures actual pregnancy is unlikely to occur before she is ready to take on such a responsibility. In boys, behavioural changes and spermarche occur well ahead of physical developments like the skeletal growth spurt and muscular development responsible for the adult male's physique. Thus, while the adolescent boy

may start behaving, to some extent, like a man in terms of sexual and social behaviour, he does not yet look like one and is therefore not perceived as a threat to older males, which allows him to practice adult behaviour while reducing the risk of physical repercussions from older males. By remaining physically underdeveloped, they also prevent being perceived as father material even though they are physiologically capable of siring offspring.

1.2.5 Some unusual features of adolescence in modern Britain

Some features of adolescence in modern Britain, the setting for the empirical studies reported in this thesis, appear unusual from a cross-cultural perspective and are also likely to be uncharacteristic of our species' evolutionary history.

In contemporary Industrial societies like the United Kingdom, many adolescents do not contribute much (if anything) economically to the household, in sharp contrast to foragers (Kaplan et al. 2000) and traditional societies (Weisfeld 1999). Related to this, British adolescents tend to stay in full-time education for many years and often delay having their first child until they are well into their twenties, late twenties or even their thirties (Office for National Statistics 2013). The jobs available in the complex economies of Industrial societies may require so much training that investments in acquiring the required knowledge and skills necessitate postponing reproduction and also lead to relatively late economic independence. In line with this, adult status is attained substantially later than in traditional societies (Weisfeld 1999).

Other species-atypical features of adolescence in contemporary Britain include relatively little contact with kin (including parents who are often the primary socializer in traditional societies), weaker ties with the local community, strong age segregation (through the schooling system), and the general absence of a puberty rite (Schlegel & Barry 1991).

Certain issues and problems we associate with adolescence may be directly related to such unusual characteristics of modern adolescence rather than cross-cultural, intrinsic features of adolescence. The emergence of a youth subculture, for example, has been suggested to be the result of the high degree of age segregation characterizing

adolescence in modern society, which is related to the modern schooling system and late incorporation of adolescents in adult society (Weisfeld 1999).

As another example, consider that teenage, unmarried pregnancy is not typically an issue in traditional cultures since girls tend to marry around the time of fertility. By contrast, in contemporary Industrial societies like Britain, the mean age at female fertility lies around 14 – given an age at menarche of 12.5 (Culpin, Heron, Araya, Melotti, et al. 2014a) and a short period of adolescent infertility – while age at first marriage has long been over 25 and is currently around 30 for women (Office for National Statistics 2016), giving a large "window of vulnerability between the onset of fertility and the age of marriage" (Weisfeld 1999: 269) during which women are at risk of becoming pregnant while unmarried. Obviously, shifting cultural norms and personal values affect how we interpret such a 'risk'.

1.2.6 Why adolescents are interesting to life history theorists

Adolescents are of particular interest to life history theorists for at least two reasons: 1) many of the traits and behaviours of interest to life history theorists, especially those relating to reproduction, arise first during adolescence; and 2) decisions made during adolescence may have a large impact on the type of reproductive strategy an individual takes.

1.2.6.1 Many behaviours of interest arise first during adolescence

Life history theorists are interested in the timing of key life history events, such as age at sexual maturity and age at first birth (1.3). Clearly, adolescence is a pivotal life stage in this regard. It is the period during which individuals reach sexual maturity and enter the mating arena; when striving for and competing over social status and resource control reach a new level of salience (Ellis et al. 2011). Humans show substantial variation in life history traits, many of which are systematically correlated. Adolescence gives us perhaps our first clear view of an individual's life history trajectory. Is puberty relatively early or late? What about sexual debut? Does someone have few or many sexual partners?

1.2.6.2 Decisions made and paths taken during adolescence have downstream effects

Life history decisions made and paths taken during adolescence (not necessarily consciously), e.g., early pregnancy, may have important consequences in terms of the kind of reproductive strategy open to one. As such, adolescence is "an inflection point (i.e., a sensitive period for change) in developmental trajectories of (…) fitness relevant outcomes" (Ellis et al. 2011: 4). For instance, getting pregnant soon after gaining reproductive capacity implies a very different life history strategy than postponing reproduction in favour of investing in resource-acquisition skills. Over the past three decades or so, a sizeable body of literature has emerged devoted to the application of life history theory to the problem of explaining variation in adolescent behavioural and physical development (1.3.3).

1.3 Life history theory

1.3.1 General theory

1.3.1.1 Resource allocation and inclusive fitness

Life history theory addresses how organisms should allocate resources to life's key activities of growth, development, maintenance, and reproduction (Stearns 1992). During its life, an organism has to its disposal a finite amount of resources – fundamentally, time and energy – that can be used for a multitude of purposes. The particular ways in which the individual organism uses those resources, and how it manages the inevitable trade-offs, affect how well it succeeds in projecting copies of its genes into the future. Over evolutionary time, genes that produce more effective solutions (phenotypes) to this allocation problem, compared to their competitors in the gene pool, are favoured by natural selection and become more numerous.

A life history is the life course of an organism viewed through the lens of resource allocation and genetic fitness. Life history theory analyses and attempts to explain variation in life history traits – such as age and size at sexual maturity and amount of parental care provided – both between and within species, guided by the principle of (inclusive) fitness maximization (Stearns 1992). Both fixed phenotypic traits and phenotypic plasticity in response to adaptively relevant circumstances, such as individual condition or environmental variation, fall under the purview of life history theory.

1.3.1.2 Trade-offs

Resources allocated to one task are unavailable for other activities. For example, food-derived building blocks used to 'build' new offspring cannot also be directed toward individual growth that would aid survival. When making a 'decision' about where to invest its resources, an organism has to make trade-offs between investments in maintenance, growth and reproduction. Investments in organismal maintenance and growth are referred to as somatic effort; investments directly aimed at increasing reproductive success comprise an organism's reproductive effort (Williams 1966;

Voland 1998). Two trade-offs are considered particularly important, namely, those between 1) current and future reproduction and 2) offspring quantity and quality.

1.3.1.2.1 Current versus future reproduction

Firstly, organisms face the choice of either investing in bodily maintenance and growth now, in a bid to increase reproductive opportunities in the future (e.g., through higher survivorship or investments in improving traits important in intrasexual competition), *or* investing in reproduction now, at the cost of fewer reproductive opportunities in the future. In short, organisms face a trade-off between current and future reproduction.

According to life history theory, the main determinant of the optimal timing of reproduction (age at maturity) is extrinsic mortality. Extrinsic mortality consists of mortality risk that an organism cannot affect by its actions and investment decisions. Where extrinsic mortality is higher, earlier reproduction is favoured because the organism is less likely to be around to reap the potential benefits of investments in future reproduction (Michod 1979; Stearns 1992; Gasser et al. 2000).

1.3.1.2.2 Offspring quantity versus quality

A second critical trade-off occurs between offspring quantity and quality (Lack 1947; Stearns 1992). Organisms can produce fewer offspring of higher quality (higher offspring fitness) or more offspring of lower quality (lower offspring fitness). Socioecological factors (and individual condition) determine which compromise between quantity and quality maximizes inclusive fitness, by altering the shape of the relationships between investments and outcomes (Hill & Kaplan 1999).

1.3.1.3 The fast-slow continuum; two axes of co-variation of life history traits

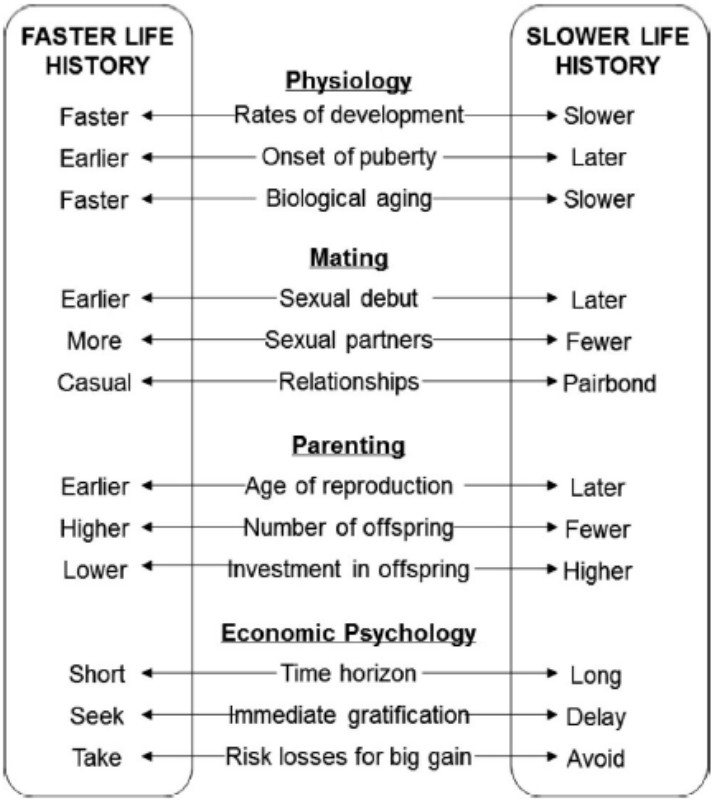
Variation in life histories, both within and between species, is sometimes expressed in terms of positions on a fast-slow continuum. In the simplest, one-axis version, taxonomic units are placed somewhere between the fast end, characterized by high mortality, quick maturation, and large litters of small neonates, and the slow end, characterized by the opposite suite of traits. Over the years, several factor analyses, using large data sets covering several orders, have shown that at least two axes are

needed to adequately capture systematic correlations between life history traits (Stearns 1983; Bielby et al. 2007).

One major study analysed patterns co-variation of life history traits in 267 mammalian species, focusing on female body mass, gestation length, litter size, neonatal mass, interbirth interval, weaning age, and age at sexual maturity (Bielby et al. 2007). After removing body size effects, factor analysis revealed two axes of variation. The first factor corresponded to the timing of reproduction, with significant loadings for weaning age, interbirth interval and age at sexual maturity. Being fast on this axis means early weaning, short interbirth intervals and early sexual maturity. The second factor was interpreted as reproductive output. Being fast on this axis means low neonatal body mass, short gestation length and large litter size. Together, the timing and output axes explained 69.3% of the variation in life history traits in mammals.

Figure 3 characterizes variation associated with fast and slow life history strategies in a range of traits, as conceptualized by human evolutionary behavioural scientists.

Figure 3. Faster versus slower life history strategies (reproduced from Ellis et al. 2012)



1.3.2 Human life histories

1.3.2.1 The human life history in comparative perspective

Comparatively speaking, humans are on the slow end of the fast-slow continuum, or slow on both the reproductive output and reproductive timing axes in the two-axis model. As such, we develop slowly, with a long period of offspring dependence, reach sexual maturity relatively late, produce few offspring (low fertility), reach a large adult size, and have long life spans.

Even relative to the other great apes, human life histories are, in many respects, slow (Harvey & Clutton-Brock 1985). Compared to chimpanzees, for instance, humans have a much later age at sexual maturity (198 versus 118 months), a later age at first reproduction (232 versus 138 months), and longer life spans (70 versus 44.5 for chimpanzees) (Harvey & Clutton-Brock 1985). However, some features of the human life history contrast sharply with this slow pattern. Humans wean their children much earlier (after 720 days) than chimpanzees (1,756 days), orangutans (1,728 days) or gorillas (2,110 days) and have substantially shorter interbirth intervals than chimpanzees (1,440 versus 1,825 days) (ibid.).

1.3.2.2 Adaptive life history variation in humans

Life histories also vary substantially within our species, within and between societies and through historical time. Some of this variation might represent adaptive responses to adaptively relevant environmental features or individual condition, in line with predictions from life history theory.

Consider, for example, the relationship between women's age at first birth and local mortality rates (Low et al. 2008). Women's age at first birth shows a lot of variation within and between countries. In England and Wales, 4.2% of all live births in 2013 were to women under 20, but the average age at first birth was much later, at 28.3 years (Office for National Statistics 2013). Around the world, mother's mean age at first birth varies from about 18 in countries like Angola and Bangladesh to 30-31 years in place like South Korea, Australia and Greece (Central Intelligence Agency 2015).

One of the most basic predictions of life history theory, reflecting the trade-off between current and future reproduction, is that mortality rates should be inversely correlated with age at first reproduction – a prediction well-supported by the empirical evidence (Harvey & Zammuto 1985). Natural selection appears to have shaped species-typical life histories in such a way that age at first reproduction takes into account species-typical mortality rates in order to maximize the inclusive fitness of individuals. In addition, species facing varying mortality rates over time may have evolved the ability to facultatively adjust their reproductive timing to prevailing or predicted mortality rates. Given the large variation in women's age at first birth, it makes sense to ask whether humans display such phenotypic plasticity.

Cross-cultural comparisons have shown that mortality rates do indeed predict women's age at first birth, in a way that is consistent with adaptive phenotypic plasticity. Researchers comparing more than 170 countries found that age at first birth, at the country-level, is strongly positively associated with life expectancy at birth (e_0) – women who can expect to live longer, reproduce later (Low et al. 2008). In addition, age-specific fertility was higher, at all ages, where mortality rates were higher. In the terminology of life history theory, mothers in high-mortality environments appear to be pursuing a reproductive strategy favouring current over future reproduction and quantity over quality of offspring, while mothers in low-mortality environments might be pursuing a reproductive strategy which puts more weight on future reproduction and emphasises quality over quantity of offspring.

1.3.3 Evolutionary models of adolescent development

A number of evolutionary models of adolescent development have been proposed over the years. They are generally concerned with the timing of sexual maturity, reproductive behaviour, and the propensity to engage in risky behaviours. In general, the proposed models identify adaptively relevant circumstances (e.g., local mortality rates), cues to those circumstances (e.g., father presence or absence), and specify appropriate – that is, (once) adaptive – responses (e.g., early sexual maturation and transition to the reproductive phase of life).

1.3.3.1 Paternal investment theory

In a classic paper, Draper and Harpending (1982) offered a novel, evolutionary interpretation of some associations repeatedly found between father absence experienced during childhood and a number of developmental outcomes observed in girls and boys, such as an early interest in sexuality in girls and increased verbal ability in boys. Their key proposal was that children from father-absent and father-present families respond to their differing situations by adopting different reproductive strategies. They further suggested that the first five (or so) years of life constitute a sensitive period for learning about reproductive strategies.

While remaining agnostic about proximate mechanisms, Draper and Harpending argued that a father-absent childhood signals an environment in which males provide little parental investment and pair-bonds are weak and unstable. Under such conditions, females should forgo investing time and energy into finding a mate willing and able to provide substantial parental care over an extended period, as such investments are likely to go to waste, but instead should start their reproductive career early.

Where men are low-investors, their reproductive success depends on their position in the local male dominance hierarchy because this translates into sexual access to females. Boys growing up in father-absent households are predicted to exhibit an opportunistic mating strategy and not invest heavily in pair-bonding or parental care, and they should be more interested in manipulating the social rather than the physical environment, reflecting an emphasis on dominance striving rather than resource extraction for provisioning purposes.

In sum, paternal investment theory states that father absence acts as a cue to a low paternal investment socio-ecology in which females should start reproducing early because time spent looking for high-investing males is wasted time; and in which males should pursue a mating- rather than parenting-oriented strategy.

Ellis and colleagues are responsible for more recent formulations of paternal investment theory (Ellis 2004). The central claim is that fathers have an independent effect on (female) reproductive development that is not simply due to correlations with, and so cannot be subsumed under, sources of stress or general childhood adversity (e.g., low SES). In addition to actual father absence, low levels of paternal investment,

stressful father-daughter relationships, low paternal warmth and the like are hypothesised to have an accelerating influence on female pubertal timing, for the reasons outlined by Draper and Harpending (1982).

1.3.3.2 Psychosocial acceleration theory

Belsky, Steinberg and Draper's (1991) influential "evolutionary theory of socialization and lifespan interpersonal development" (649; henceforth: psychosocial acceleration theory) builds on Draper and Harpending's model. Like its predecessor, psychosocial acceleration theory assumes that, during our species' evolutionary past, certain features of the family environment were predictive of the kind of environment likely to be encountered when the time came for offspring to start reproducing, and we have evolved the capacity to adaptively exploit this information through developmental flexibility in the 'choice' of a reproductive strategy. The concept of a critical period, identified as the first 5-7 years, is reiterated.

Psychosocial acceleration theory expands on Draper and Harpending's (1982) effort in a number of directions. Firstly, it is more explicit about proximate mechanisms. Parenting behaviour is suggested to act as a mediator between "contextual stress" and child development, which is channelled towards the adoption of an appropriate reproductive strategy. Harsh, insensitive, unaffectionate parenting signals an environment characterized by resource scarcity, untrustworthiness of other people, and unstable relationships. In such an environment, an opportunistic mating strategy and interpersonal style are most appropriate. Individuals reared in such an environment will tend to start having sexual relations at an earlier age and be involved in less stable and more pair-bonds. By contrast, sensitive, responsive, affectionate parenting indicates an environment in which resources are plentiful and predictably available, people are generally trustworthy and cooperative, and relationships are durable. Later sexual debut and stronger pair-bonds are expected for children reared in this type of situation. Financial difficulties and parental relationship quality are also included in psychosocial acceleration theory as features of the family environment that influence child development, either directly or through their effects on parenting behaviour.

Secondly, psychosocial acceleration theory explicitly incorporates physical development. The same features of the family environment implicated in channelling

behavioural development – parenting behaviour, parental relationship quality, and financial hardship – are predicted to also influence pubertal timing. Specifically, a stressful family environment should be associated with early puberty.

Chisholm (1993) devised a synthesis of the psychosocial acceleration theory and the so-called bet-hedging model from general life history theory. Promislow and Harvey (1990) proposed a bet-hedging model for the evolution of life history traits, arguing that selection will favour traits that minimize transgenerational variance in reproductive success over traits that simply maximize offspring number in each generation. Which reproductive strategy produces this result, they argued, depends fundamentally on mortality rates. As a general rule, species facing high mortality rates should adopt a quantity-oriented strategy, producing many offspring in a bid to maximize the chances that at least some will survive to reproductive age and produce grand-offspring. By contrast, low mortality rates may favour a quality-oriented strategy. When mortality rates are low, parents have the resource of time, which gives them the option to invest heavily in a few offspring. These high-quality offspring are more likely to succeed in reproducing and leaving high-quality offspring themselves. In a low-mortality environment, this strategy minimizes the transgenerational variance in reproductive success.

Chisholm's (1993) main contribution consists in the suggestion that the stressors identified by psychosocial acceleration theory act as cues to the local mortality rate and affect human reproductive development according to the logic of the bet-hedging model. Following Belsky et al. (1991), Chisholm suggested a causal model in which correlates of mortality rates, such as poverty and disease, affect parental behaviour, which in turn affects offspring attachment style (Bowlby 1969), which then affects the 'choice' of reproductive strategy.

1.3.3.3 Child development theory

Both paternal investment theory and psychosocial acceleration theory assume that family-level factors, such as father absence, serve as cues to a broader socio-ecological context and humans have evolved the ability to utilize these cues by adjusting their developmental processes towards the adoption of an appropriate reproductive strategy for the socio-ecology they find themselves in.

Ellis's (2004) child development theory, by contrast, does not assume this link between family and wider context. It holds that pubertal timing is phenotypically plastic and is calibrated to the quality of the family environment during childhood. A high-quality rearing environment causes an extension of the pre-reproductive phase so as to maximize the benefits gained from growing up in such a nurturing environment, whereas a low-quality environment induces an early transition to the reproductive phase because little is to be gained, and time is lost, by extending childhood when investments are not forthcoming.

According to child development theory, the family environment does not, however, serve as a cue to the kind of reproductive strategy that would be most appropriate for offspring to adopt. While a low-quality family environment will be associated with early puberty and early sexual activity, individuals who grew up in such an environment are not predicted to have less stable pair-bonds, have more sexual partners, have a less restricted sociosexual orientation, or provide less parental investment as adults.

1.3.3.4 Intergenerational conflicts about reproductive opportunities

Intergenerational conflict provides an alternative explanation of the effects of father absence on reproductive development (Moya & Sear 2014). If individuals support the reproductive efforts of their parent(s), then it matters – from an inclusive fitness perspective – how related they are to the offspring thus produced. When a biological parent leaves, any subsequent offspring of the remaining biological parent and a new partner will be less related to already existing offspring than offspring produced by the original pair ($r = 0.25$ rather $r = 0.5$). This changes the expected fitness costs and benefits associated with supporting one's parents' reproduction versus starting one's own reproductive career (which always produces $r = 0.5$ offspring), making the latter more attractive in terms of inclusive fitness consequences. Thus, parental absences may speed up offspring reproductive development, one manifestation of which is earlier puberty.

1.3.3.5 Early life adversity as an internal predictive adaptive response

In an *external* predictive adaptive response, such as those proposed by psychosocial acceleration theory, the cue affecting development is used to predict future

environmental circumstances the developing organism is likely to face (Nettle et al. 2013). By contrast, early life adversity may lead, through decreased energy availability, to "reduced investment in somatic tissues [which] reduces the chances of survival, and hence favours earlier reproduction" (Wells 2012: 262). Because, in this case, individuals predict their own future bodily state and their consequent ability to survive and reproduce as they age, this has been referred to as an *internal* predictive adaptive response (Nettle et al. 2013).

1.3.3.6 Other models

A number of other models of adolescent development have been proposed, mostly as alternatives to the psychosocial acceleration theory in the context of the father absence and age at menarche literature. For example, according to the male shortage model (Hoier 2003), the effect of father absence on age at menarche represents a facultative adaptive response to a female-biased sex ratio. Where men are in short supply and therefore the sex in demand, they have little incentive, from a fitness perspective, to practice a reproductive strategy emphasising parental investment, but rather should opt for an opportunistic mating strategy. In such a situation, women incur fitness costs if they delay reproduction in order to search for a high-investing male. Others have suggested that inbreeding avoidance might be the ultimate reason for the observed links between growing up in a father-absent household and age at menarche and sexual debut (Matchock & Susman 2006). The presence of a related adult male delays female reproductive development because this prevents inbreeding and, thereby, associated fitness costs.

1.3.4 Evolution and the Big Five personality factors

The evolution and maintenance of personality differences in humans and other animals have recently become a focus of evolutionary theorizing and modelling (Dall et al. 2004; Wolf et al. 2007) and spawned a sizeable body of empirical research. While personality traits may vary randomly, perhaps around some optimal value, several models explain the evolution of personality differences and their maintenance in evolving populations in adaptive terms, for example, as a consequence of some form of balancing selection

(Penke et al. 2007). Different personalities could thus represent alternative, but in the long run equally fit, life history strategies (Nettle 2006; MacDonald 1995).

In the human literature, the focus is often on the so-called Big Five personality factors: extraversion, agreeableness, conscientiousness, emotional stability (or its opposite neuroticism), and openness (Digman 1990; Costa & McCrae 1992).

Nettle (2006) argues that each of these represent different evolutionary trade-offs. On his account, *extraversion* – which covers such traits as sociability, assertiveness, and a tendency to experience positive emotions – represents a life history strategy that emphasizes mating effort and exploratory and social behaviour at the cost of increased exposure to risk (Nettle 2005).

Conscientiousness – that is, a tendency to be organized and a preference for planning over spontaneity – might represent a life history strategy that emphasizes long-term investments rather than short-term rewards. In line with this, conscientiousness is associated with healthy behavioural habits which actually results in more conscientious individuals living longer (Kern & Friedman 2008). However, foregoing short-term rewards can also be costly.

Agreeableness – a disposition to trustfulness and friendliness, as opposed to suspiciousness and hostility toward others – might benefit individuals because of the potential cooperation partners gained through their positive interactions with others. There is ample evidence that more agreeable individuals tend to have higher-quality social relationships (e.g., Asendorpf & Wilpers 1998; Jensen-Campbell et al. 2002). Their trusting nature may, however, make agreeable vulnerable to exploitation.

Neuroticism – an individual's tendency to experience psychological distress – may have provided fitness benefits in ancestral environments because of its association with vigilance. It is also associated with competitiveness, which, Nettle suggests, may sometimes translate into fitness benefits, given the right environment and competitive ability of the neurotic individual. On the cost side, highly neurotic individuals are also far more likely to suffer from a range of psychiatric disorders (Lahey 2009).

Finally, *openness* refers to an individual's behavioural flexibility and openness to new ideas and experiences (and is sometimes called intellect/imagination). Open individuals

may gain benefits from being creative but may also have an increased risk of psychotic disorder.

1.4 Predictions derived from an evolutionary perspective on adolescence and life history theory

What predictions can we derive from the previous two sections with regard to predictors of variation in the measures investigated in the empirical chapters that follow, viz., experience with sexual intercourse (around 17.5 years; Chapter 3), cooperative behaviour (Chapter 4), sex differences in the Big Five personality traits, substance use (alcohol, cannabis, cigarettes), (Chapter 5), and timing of pubertal developmental (Chapter 6)? Here I will discuss predictions derived from the evolutionary theorizing in the previous two chapters, in turn for each of the following empirical chapters.

1.4.1 Predictions for chapter 3: experience with sexual intercourse

In Chapter 3 I look at predictors of experience with sexual intercourse. Both evolutionary arguments relating to sex differences (1.2.3) and life history models of adolescent development (1.3.3) may be relevant here.

In the section on evolution and sex differences, I highlighted two key points. The first was that males, and perhaps in particular adolescent males, should be more willing to engage in risky behaviour. This may include bids to improve status among peers through norm violations; it may include physically risky, criminal or unhealthy behaviour considered undesirable by wider society. To the extent that having sexual intercourse falls in this category, one would therefore predict that boys are more likely to have had sex. Note, however, that in this chapter I look at experience with sexual intercourse by ~17.5 years, which arguably should not be considered a norm violation or a form of risky behaviour in the population under consideration.

The second point I emphasised with regard to evolution and sex differences is that while evolved male and female reproductive strategies may overlap to a large extent, they are certainly not identical (while also acknowledging the availability of various strategies within each sex). One implication of sex differences in minimum parental investment and reproductive variance was that males should be less choosy and more opportunistic where it comes to the pursuit and selection of sexual partners. For this reason, one would, again, predict that adolescent boys might be more likely to have had

sex. That said, the fact that heterosexual intercourse, by definition, involves a female party obviously limits the extent to which sex differences in preferences, if present, can be realized. Of course, the existence of affordable, readily available and effective birth control methods is relevant here, modifying the risk of unplanned pregnancy and its associated high level of female investment (although evolved preferences may manifest themselves regardless of such technical innovations).

Based on the life history models of adolescent development, one would predict that (cues to) a harsh local socio-ecology will speed up reproductive and sexual-behavioural development. For this reason, low socioeconomic status and neighbourhood deprivation are therefore predicted to be associated with an increased probability of having had sex at a particular time point during adolescence. I elaborate on these predictions in Chapter 3.

Father absence has been argued to switch developing individuals onto a faster life history trajectory, for a variety of possible reasons discussed in 1.3.3. Based on this, one would predict that adolescents growing up without a father in the household are more likely to have started having sex. Similarly, low parental care may be associated with a higher probability of having had sex, if it acts as a cue to a harsh environment in which mating effort is emphasised over parenting effort. Alternatively, according to Ellis's child development theory (1.3.3.3), low levels of parental care might precipitate an early transition to the reproductive phase of life simply to cut short a pre-reproductive phase characterized by low parental investment. Finally, lower levels of parental investment might produce individuals with a lower life expectation, who need to speed up reproductive development in order to maximize reproductive success in the relatively limited time available (1.3.3.5).

In Chapter 3, I also test whether the Big Five personality traits predict experience with sexual intercourse. Based on an evolutionary interpretation of the Big Five (1.3.4), the clearest predictions seem to follow for extraversion and conscientiousness. Extraversion may represent a life history strategy characterized by high mating effort and a strong tendency to engage in exploratory and social behaviour. With such behavioural tendencies, extraverts may be expected to have had sex. By contrast, highly conscientious individuals were argued to display a slow life history, emphasising long-

term investments. Hence, one would expect them to be less likely to have had sex than less conscientious adolescents of the same age.

Table 1 lists these 'evolutionary predictions' for experience with sexual intercourse.

Table 1. Evolutionary predictions for experience with sexual intercourse (Ch. 3)

Prediction	Why?
Adolescent boys are more likely to have had sexual intercourse than girls of the same age	Boys are more risk-prone because of greater reproductive variance; boys more promiscuous because of lower minimum level of parental investment
Adolescents who experience father absence are more likely to have had sexual intercourse	Harsh environments favour faster life history; low paternal investment socio-ecology favours earlier transition to reproductive phase
Adolescents who received less (direct) parental care	Harsh environments favour faster life history; low parental investment socio-ecology favours earlier transition to reproductive phase
Adolescents living in more deprived areas are more likely to have had sexual intercourse	Harsh environments favour faster life history
Adolescents from socioeconomically more deprived households are more likely to have had sexual intercourse	Harsh environments favour faster life history
More extraverted adolescents are more likely to have had sexual intercourse	Extraversion represents a life history strategy focussed on mating and exploration and social behaviour
More conscientious adolescents are less likely to have had sexual intercourse	Conscientiousness represents a slow life history with long time horizons

1.4.2 Predictions for chapter 4: cooperation

In chapter 4 I investigate predictors of cooperative or prosocial behaviour, specifically predictors implicated by evolutionary reasoning.

As mentioned (1.2.3.3.2), girls may me be more predisposed to acting cooperatively as a result of sex differences in the nature of intrasexual competition, which is typically less physical and confrontational intense in women than men, as well as, perhaps, less intense, leaving women less physically and perhaps psychologically prepared for using physical force, or the threat thereof, to settle disputes or achieve their ends more generally.

A harsh environment may lead to a less cooperative, more exploitative interpersonal style (Belsky et al. 1991; McCullough et al. 2012). One's time horizon may be shorter in such an environment, curtailing one's willingness or ability to invest in long-term cooperative relationships while foregoing immediate benefits associated with exploitative behaviour. Cues to living in a harsh environment, such as neighbourhood deprivation, low socioeconomic status, and father absence, may therefore lead someone

to be less likely to cooperate. (Note that I discuss the possible relationship between socio-ecology and cooperation in more detail in Chapter 4.)

With regard to the Big Five personality traits and their possible associations with cooperation, the most obvious prediction is that more agreeable individuals will be more cooperative. Agreeableness has been argued to represent a life history strategy geared towards cultivating cooperative relationships (1.3.4). More conscientious individuals, due to their long time horizons, may also be more willing to invest in (potential) long-term cooperative relationships.

Table 2 lists the 'evolutionary predictions' for measures of cooperation.

Table 2. Evolutionary predictions for cooperation (Ch. 4)

Prediction	Evolutionary reasoning
Adolescents from socioeconomically more deprived households are less likely to be cooperative	Harsh environments favour more opportunistic interpersonal style
Adolescents who experienced father absence during childhood are less likely be cooperative	Harsh environments favour more opportunistic interpersonal style
Adolescents living in more deprived areas are less likely to be cooperative	Harsh environments favour more opportunistic interpersonal style
Girls are more cooperative than boys	Intrasexual competition is less physical and confrontational in females
More agreeable individuals are more cooperative	Agreeableness represents a strategy geared towards cultivating cooperative relationships
More conscientious individuals are more cooperative	Longer time horizons make investments in (potential) long-term cooperative relationships more attractive

1.4.3 Predictions for chapter 5: sex differences in substance use and personality traits

Chapter 5 compares the social clustering of a range of behavioural and non-behavioural measures, such as various measures of substance use and personality traits (as well as experience with sexual intercourse and cooperative behaviour, which have already been discussed). The only substantive predictor I examine in this chapter is sex, hence the relevant predictions all relate to sex differences that may have an evolved basis (as reiterated above, in 1.4.1).

Based on the suggestion of an evolved sex difference in risk-taking propensity (1.2.3.3.1), one would predict that boys are more likely to have engaged in various kinds of substance use that violate societal norms of appropriate behaviour of young people, such as smoking cigarettes, drinking alcohol, and trying cannabis.

Based on life history strategic interpretations of the Big Five personality traits and evolutionary ideas about evolved sex differences, one might expect girls on average to be more agreeable (cf., 1.4.2 on why girls are expected to be more cooperative) and boys to be more extraverted, since being an extravert requires a higher tolerance of risks related to mating and exploratory behaviour.

Table 3 lists the predictions discussed in the current section.

Table 3. Evolutionary predictions for sex differences in substance use and personality traits (Ch. 5)

Prediction	Evolutionary reasoning
Boys are more likely to have ever smoked a cigarette	Boys are more risk-prone because of greater reproductive variance
Boys are more likely to have ever tried cannabis	Boys are more risk-prone because of greater reproductive variance
Boys are more likely to have ever had whole drink	Boys are more risk-prone because of greater reproductive variance
Boys are more likely to have ever had 4 drinks in 24 hours	Boys are more risk-prone because of greater reproductive variance
Extraversion	Boys are more tolerant of risks associated with extraversion
Agreeableness	Intrasexual competition is less physical and confrontational in females

1.4.4 Predictions for chapter 6 (pubertal development)

In chapter 6 I look at predictors of the timing of pubertal development, as assessed by a wide range of measures, in both girls and boys. For the same reasons outlined for 1.4.1 in relation to experience with sexual intercourse, higher neighbourhood deprivation, lower socioeconomic status, and father absence are expected to earlier puberty or a more advanced stage of puberty at any particular time point.

1.5 Social clustering

1.5.1 Examples of social clustering: adolescent substance use and sexual behaviour

Many behaviours, beliefs and attitudes are widely believed or known to cluster at different levels of the social world of adolescents, be it at the level of schools, neighbourhoods, friendship networks, or elsewhere in the social structures they are embedded in. Where this occurs, individuals in the same social group are more similar to each other, in terms of the clustering trait, than they are to others randomly plucked from the population. (Note that this definition of social clustering is neutral with regard to the actual mechanism responsible for said clustering.) For example, adolescents tend to have more friends of the same rather than opposite sex (e.g., Mercken et al. 2009). Thus, members of the same friendship networks will tend to be more similar to each other in terms of the trait 'sex' than they are to random others in the wider population – sex can be said to *cluster in* friendship networks. A lot of attention has been devoted to the clustering among adolescent friends of behaviours that are considered undesirable or 'deviant' by parents and policy makers, clustering that is usually ascribed to peer pressure or conformism to peer group norms. Schools and neighbourhoods have also received considerable attention as potentially important social contexts for understanding variation in adolescent behaviour and potential foci of social clustering.

Here I will not review the literature on social-environmental (contextual) influences on adolescent behaviour, which is far too large to review here with any degree of comprehensiveness. Instead, I focus specifically on studies that quantify social clustering of adolescent sexual behaviour and substance use, two of the most thoroughly researched adolescent behaviours, in social (friendship) networks, neighbourhoods and schools. Few studies try to explicitly quantify behavioural clustering at multiple levels of the social world of adolescents at the same time, the way I do in following chapters. Often, the focus is on specific predictors at a particular level and nesting of individuals in social groups is treated as a nuisance rather than a point of interest in its own right. This presents challenges when reviewing the literature for estimates of the extent of social clustering. In many cases, such estimates are not provided or derivable from the available statistical output. While many studies try to get

a handle on the reasons for clustering (e.g., peer influence), here I focus just on the empirical fact of clustering. A discussion of clustering mechanisms follows later in the chapter.

1.5.1.1 Clustering in social networks

Work on clustering of adolescent behaviour in social networks is usually about friendship networks. Numerous studies have confirmed that adolescents tend to be similar to their friends in terms of a range of attitudes, beliefs and behaviour (e.g., Kandel 1978; Eiser et al. 1991).

1.5.1.1.1 Substance use

Much empirical evidence convincingly shows that substance use clusters in friendship networks. Friends tend to be more similar to each other than to random age peers when it comes to whether they smoke or not, (binge) drinking patterns, whether they have ever tried cannabis, and other measures of substance use (Kandel 1978; Eiser et al. 1991; Urberg et al. 1997; Alexander et al. 2001; Jaccard et al. 2005; Clark & Lohéac 2007; Ali & Dwyer 2010). Note that all the studies just cited are based on self-reported behaviour, not reports on friends' behaviour, which may suffer from projection bias (Bauman & Fisher 1986).

The easiest way to get a sense of the extent of clustering is to look at behavioural correlations between members of the social grouping of interest (which, unfortunately, are often not reported or easy to calculate from provided information). Consider, for example, the following school-based study (Eiser et al. 1991), in which a sample of British adolescents (aged 11-16) was asked about smoking and alcohol use, and respondents were also asked to list one or more friends in their school. Incidentally, this study was conducted in the English city of Bristol, where the study sample for this thesis is also from (2.1), but involved an earlier generation of adolescents. When the researchers looked at the median correlation between respondent and friend behaviour – as reported by those friends themselves, who are also respondents – across three friends for smoking status (non-smoker, ex-smoker or trier, current smoker) and alcohol use ("never been really drunk", "only once", "more than once"), they found them to be around 0.2 to 0.4 for smoking and 0.2 to 0.3 for alcohol use, differing slightly by

age-and-sex group. These results suggest a fair amount of clustering of substance use behaviours in friendship networks (adjusted for age and sex). Similar respondent-friends correlations were reported for a range of other measures, including spending behaviour, self-judged school performance, health locus of control (external vs. internal), and occupation-based parental SES. Note, though, that nesting of the respondents in 10 secondary schools (or neighbourhoods) was not taken into account in the correlational analyses, so it cannot be ruled out that some of the clustering at the level of friendship networks is actually school-level clustering (cf., Ali & Dwyer 2010).

Other studies suggest comparable levels of similarity in substance use among friends, e.g., Kandel (1978) reported a Kendall's tau of about 0.5 for stable pairs of friends in the US, while correlations between individual and (perceived) friend smoking behaviour for adolescents across six European countries were around 0.3 for best friends and 0.4 for friends in general (de Vries et al. 2003).

1.5.1.1.2 Sexual behaviour

A recent meta-analysis, based on 57 studies, of the association between adolescent sexual behaviour and descriptive peer norms – that is, actual or perceived peer sexual behaviour – found a mean effect size, expressed as a correlation coefficient, of 0.40 (Van de Bongardt et al. 2015). Measures of sexual behaviour included experience with sexual intercourse, age at first intercourse, number of lifetime sexual partners, among others. Close friends appeared to be more similar ($r = 0.45$) than school peers ($r = 0.29$). Note that all but three of the studies included in this meta-analysis used perceived rather than actual peer behaviour.

1.5.1.2 Clustering in neighbourhoods

Clustering of adolescent behaviour at the level of neighbourhoods has received considerably less attention than clustering in friendship networks. Studies tend to look for evidence of neighbourhood effects after controlling for individual, family and peer influences (Leventhal & Brooks-Gunn 2000). Explicit (unadjusted) quantification of neighbourhood clustering is rare.

1.5.1.2.1 Substance use

The few studies that explicitly quantify neighbourhood-level clustering suggest that substance use does not, in general, cluster very strongly, if at all, in neighbourhoods. A study of 65 Los Angeles neighbourhoods reported the following intraclass correlations (ICCs; 2.3.1.1.2) for adolescent substance use: 1% for smoking (not significant) and 5% and 2% for, respectively, alcohol and drug use (both significant) (Musick et al. 2008). An Add Health-based study of adolescent smoking, which looked at neighbourhood- and school-level clustering simultaneously using cross-classified multilevel modelling (2.3.1.2), found an (unadjusted) ICC for its 2,111 neighbourhoods of only 0.5% (Dunn et al. 2015). Notably, the latter study also found that the neighbourhood ICC was about 10 times higher in a multilevel model without schools, indicating that clustering estimates can be highly misleading if social structure, such as nesting of adolescents in neighbourhoods *and* schools, is not properly accounted for.

1.5.1.2.2 Sexual behaviour

Similar to the findings of Dunn et al. (2015) with regard to substance use, a study conducted in Philadelphia (USA) found that when both schools and neighbourhoods were included as classifications in a cross-classified model looking at whether someone had ever had sexual intercourse, neighbourhoods came out as relatively unimportant (Teitler & Weiss 2000). Based on the reported neighbourhood and school variances, I have calculated the neighbourhood ICC as 2.9%, compared to an ICC of 10% for schools (for calculation method, see 2.3.1.1.2).

A more recent study on the impact of the neighbourhood normative climate, operationalized as a neighbourhood-aggregated measure of sexual attitudes among adolescents, found that, unlike neighbourhood disadvantage, the normative climate was predictive of individual sexual behaviour (sexual debut, casual sex, number of sexual partners), even after controlling for individual characteristics and household SES (Warner et al. 2011). This implies some level of neighbourhood clustering. Moreover, a model with just the normative climate variable suggests a neighbourhood ICC of 7.7% (ignoring the explained variance due to the normative climate variable, which is not calculable from the available information). This study's multilevel models do not,

however, include a school level, which may have led to a misattribution of school-level variance to neighbourhoods.

1.5.1.3 Clustering in schools

1.5.1.3.1 Substance use

Adolescent substance use appears to cluster modestly but reliably in schools. The school-level ICC for the Add Health-based study using a cross-classified model mentioned above was 5.4% in a model that also included neighbourhoods as a level (Dunn et al. 2015). A different study from the US reported even higher school null ICCs of 12% for a composite scale of alcohol and marijuana use and 18% for a measure of frequency and intensity of cigarette smoking (Mayberry et al. 2009), while a study from Iceland found school ICCs of 9.6% for daily smoking, 4.7% for lifetime drunkenness, and 5.3% for lifetime cannabis use (Kristjansson et al. 2013). The latter two studies did not include neighbourhoods as levels.

1.5.1.3.2 Sexual behaviour

Very few studies have explicitly quantified school-level clustering of adolescent sexual behaviour, although a number of studies have found that average school- or class-level sexual behaviour is predictive of individual sexual behaviour (Fletcher 2007; Ali & Dwyer 2011), which implies clustering. Based on the school and neighbourhood variances reported by Teitler and Weiss (2000), I have calculated the ICC for experience with sexual intercourse for schools across Philadelphia as 10%.

1.5.2 Clustering mechanisms

Mechanisms that can generate social clustering fall into two basic categories: *social influence* (socialization) and *social selection* (Kandel 1978). Social selection can be further separated into *assortment resulting from similarities* and *similar responses to a shared ecology*.

1.5.2.1 Social influence

In a social influence process, someone changes his or her behaviour as a result of interacting with or observing others. Some such processes may cause individuals in the

same social group to become more similar to each other, thereby giving rise to social clustering. Similarity through social influence may come about, for instance, if individuals have a tendency to copy the most frequent behaviour in a reference group; or if people are inclined to adopt the behaviour of prestigious individuals in their society or some more narrowly defined social group. Individuals can also be influenced by others through the communication of ideas – they might copy the beliefs or attitudes of others, which then give rise to particular kinds of behaviours.

In fact, numerous academic and folk theories – often, but not always, focusing specifically on children and adolescents – propose that observed behaviours are, to a large extent if not entirely, the result of the social transmission of behaviour and norms of appropriate behaviour (relative to some group) – that is, socialization (Oetting & Donnermeyer 1998; Harris 1995; Christakis & Fowler 2013). Potential socialization sources include parents, siblings, schools, peers, religious communities and other groups, online communities (virtual social networks), and a variety of media (e.g., music videos and television).

1.5.2.2 Social selection

In social selection, by contrast, more similar individuals are more likely to become (or stay) affiliated with each other. If, for example, teenagers who smoke are more likely to become (or stay) friends with teenagers who also smoke, then smoking behaviour will cluster in friendship networks (Mercken et al. 2009). Two important avenues for affiliation with similar others are *assortment resulting from pre-existing similarities* and *similar responses to shared ecology*.

1.5.2.2.1 Assortment resulting from similarities

Affiliates might be more similar because pre-existing similarities make them more likely to associate with each other. This can come about in several ways.

1.5.2.2.1.1 A preference for similarity

People might actively *prefer* to associate with others *because* they resemble them in certain respects. If people are able to satisfy this preference for similarity to some degree, social clustering will result. For example, teenagers might actively prefer to

hang out and then become friends with age peers who exhibit similar smoking behaviour (Mercken et al. 2009).

1.5.2.2.1.2 A restricted pool of potential affiliates

Another form of social selection occurs when the pool of others one can or is likely to affiliate with is restricted to individuals who are more similar to oneself than members of the wider population.

Fans of a particular sports team might count many fans of the same team among their friends, not because they prefer fellow fans (although that is obviously conceivable as well), but because they spend a significant portion of their spare time at games and events associated with their preferred team, which causes their pool of potential friends and acquaintances to be skewed towards fellow supporters. For similar reasons, swimmers would be more likely to be friends with other swimmers, engineers with engineers, etc., even if they have no active preference for similarity on these or associated traits.

An important real-world example of this mechanism is selection into neighbourhoods based on socioeconomic status. As a result of this process, people are more likely to form associations with others of similar socioeconomic status, who, as a by-product, may also be similar in all sorts of characteristics associated with socioeconomic status.

1.5.2.2.2 Similar responses to shared ecology

If particular kinds of environmental conditions have a statistical tendency to induce particular kinds of responses, then environments and behaviours will end up being correlated. A corollary of this is that if different social groups in a wider reference population inhabit different environments, behaviours evoked by those varying environments will display social clustering. When social clustering is a result of similar responses to a shared ecology, the level of the social structure at which a behavioural outcome clusters depends on the scale at which the responsible environmental feature varies and the magnitude of that variation.

Behavioural scientists working from an evolutionary perspective, such as human behavioural ecologists and evolutionary psychologists, are often especially interested in explaining behavioural variation in terms of adaptive responses to a person's

socioecological environment. Thus, their most significant contributions in accounting for social clustering is likely take the form of explanations in terms of similar, possibly adaptive, responses to a shared ecology.

For example, age at first birth is strongly related to life expectancy at birth across countries (Low et al. 2008). If one were to inspect individual mothers' age at first birth around the world, one would find that these cluster in countries: first time mothers from the same country are more similar in their age at first birth than randomly chosen women from around the world. In this case, this appears to be driven by a shared ecology characterized by a particular mortality rate (see section 3 below for a life history theoretical interpretation).

A more deep-historical form of clustering due to similar responses to a shared ecology would be the clustering of adaptations (e.g., adult lactase persistence) in certain groups because of a shared evolutionary history (Holden & Mace 1997).

1.5.2.3 Homophily

A term that one frequently encounters in the literature about social clustering and explaining similarities between friends is 'homophily'. Different authors may use the term in subtly different ways. Usually, what is intended is the fact that individuals are more likely to form social ties or come into contact with others who are more similar to them (McPherson et al. 2001), which makes it an alternative explanation to social influence when explaining similarity of associates. One classic paper, however, uses it simply to mean manifest similarity of associates, which could be due to social influence (Kandel 1978). It also tempting to use the term in its literal sense to refer to an active *preference* for similar others. Because of these different usages and the resulting potential for confusion, I have chosen to avoid the term altogether in this thesis (except for 1.5.4.2.2 below, where it was impossible to avoid but carefully defined).

1.5.3 Cultural evolution and social clustering

While human behavioural ecology and evolutionary psychology are mainly concerned with evolutionary explanations of individual variation and, by extension, social clustering due to shared socioecological circumstances, the third of the evolutionary behavioural sciences (Sear et al. 2007), viz., cultural evolutionary studies (Richerson &

Boyd 2005; Henrich & McElreath 2003), brings an evolutionary perspective to bear on social clustering due to *social influence*.

Cultural evolution theorists are interested in the social transmission of ideas and behaviours. The mere fact that ideas and behaviours are transmitted from person to person can give rise to social clustering of said ideas and behaviours as people will tend to share ideas with those in closer social proximity. In many real-world cases of social clustering, however, a lack of exposure to certain ideas is not a likely reason for clustering. Clusters of non-smoking teenagers are not made up of non-smokers because the idea of smoking has not reached their corner of the social world yet. More likely, transmission biases are at work.

Cultural evolutionists argue that humans have certain evolved biases when it comes to adopting socially transmitted traits (behaviours, attitudes, beliefs, etc.). Several of these biases appear to be operating in the adolescent peer group context, in particular, prestige bias, which might be better called popularity bias in this context, and conformist bias. Cultural evolutionists argue that such biases evolved because they allow individuals, in situations where the optimal behaviour is not obvious, to adopt more successful solutions to problems through copying rather than the usually more costly approach of individual learning (Henrich & Boyd 1998; Henrich & Gil-White 2001; Richerson & Boyd 2005).

The most straightforward bias, which is perhaps least relevant to the context of clustering in modern adolescent behaviour, is success bias, i.e., the preferential copying of cultural models who are more skilled, where the link between skill and results is clear enough to discern (Richerson & Boyd 2005). Prestige bias and conformist bias gain in importance when it is more difficult to establish what explains the problem-solving success of some individuals relative to others.

Prestige bias means that people are more likely to copy individuals of high social status or standing in a group. The evolutionary rationale behind this, the reason it was favoured by natural selection, is that prestigious individuals are often prestigious for a reason. They do or know something that has made them more successful than others. Because it is often unclear what exactly explains their success, less successful individuals may be better off simply copying a range of behaviours displayed by

prestigious individuals (Henrich & Gil-White 2001; Chudek et al. 2012). Part of what we see happening in adolescent peer groups, in terms of cultural transmission dynamics, may simply be prestige bias playing out in a social context that is particularly salient to adolescents: copy the popular kid and you might attain his or her level of popularity as well.

Conformist bias is adaptive because it allows people to pool information about the costs and benefits associated with different behaviours based on the experiences of a large number of individuals, making it more likely that the most beneficial behaviour is adopted (Henrich & McElreath 2003; Henrich & Boyd 1998). Conformist bias can lead to social clustering if reference groups differ in terms of the most frequent behavioural variant.

It is also possible that similarity provides benefits in the context of cooperative interactions, as discussed below (1.5.4.2.2), which could also provide an adaptive rationale not just for forming associations with similar others, but also for changing one's attitudes, norms and behaviours to more closely fit with those of others after such associations have been formed.

1.5.4 Evolutionary perspectives on friendship and a preference for similarity

Friends are important players in most human social lives, perhaps especially during adolescence (Schlegel & Barry 1991; Harris 1995). Friendship networks are also prominent sites of social clustering. From an evolutionary perspective, this raises two interesting (evolutionary) why-questions. Why do people have friends? And why are friends often similar to each other?

1.5.4.1 The evolution of friendship

1.5.4.1.1 Friendship is a human universal, occurs in other animals and confer fitness benefits

Friendship appears to be a human universal (Hruschka 2010) and is found, in modified form, in many other species, including dolphins, elephants, and closer relatives such as chimpanzees and baboons (Seyfarth & Cheney 2012; Massen et al. 2010). Even though the typical characteristics of friendships vary between cultures, they are always

strongly tied to helping behaviour. Indeed, an expectation or norm of mutual aid is the most consistently described feature of friendships cross-culturally (Hruschka 2010) and may be considered a defining feature of this social relationship. People are willing to incur immediate costs for friends in need, whether in terms of material wealth, labour or time. Similarly, some non-human animals form long-term, close social bonds between non-kin, often characterized by cooperative interactions that may involve asynchronous exchanges of help (Seyfarth & Cheney 2012; Massen et al. 2010).

The appearance of friendships on several branches of the evolutionary tree and their association with costly helping behaviour suggest they may have fitness benefits which ultimately outweigh the costs and explain their repeated evolution and retention in multiple species. And the available evidence does suggest that friendships in humans and non-human animals confer a wide range of benefits that plausibly translate into fitness benefits (reviewed in Massen et al. 2010). In humans, for example, having high-quality social relations is associated with better health and lower mortality (House et al. 1988); and women who receive more social support during pregnancy have been shown to give birth to heavier babies with higher Apgar scores (indicating better infant health) and to be less likely to experience post-partum depression (Collins et al. 1993).

1.5.4.1.2 Hruschka's model of the evolution of human friendship

The most elaborate model of the evolution of friendship in humans was proposed by Daniel Hruschka, based on his cross-cultural study of friendships and mathematical modelling exercises (Hruschka 2010). I summarize it here to give an impression of recent evolutionary theorizing about human friendships.

One of the most interesting features of human friendships, which any evolutionary model needs to account for, is the fact that friendships do not, in general, operate on a tit-for-tat or balanced accounting basis (Hruschka 2010). Quite large imbalances in the balance of favours are allowed to arise and not considered a reason to end the relationship. How could this state of affairs have evolved?

Like all organisms, humans occupy environments containing myriad sources of uncertainty. In a foraging context, for example, these include unpredictable variation in day-to-day hunting success and the vagaries of political life. Faced with such

uncertainty, all individuals in a population are likely to be in need of some kind of assistance (e.g., food sharing or coalitional support) at some point in time, and likely repeatedly. But why would one assent to a request for help when this is costly to oneself and directly benefits someone else? One possible answer is that one helps someone because they are friends who will provide aid when you are in need in the future. Given the potential benefits of cooperation in an uncertain environment and the risk of being exploited by unscrupulous individuals (i.e., cheaters), it makes adaptive sense to form enduring cooperative relationships with trusted partners rather than call on random others in times of need.

The lack of synchronicity of helping behaviour leaves intact the temptation to cheat (i.e., receiving help now but failing to provide it in the future). Hruschka (2010) proposes a game-theoretical model of friendship that solves this issue. His model is based on a game called the favour game. In the favour game, players need either a small or a large favour from another player at random time points. They are allowed free partner choice. It is assumed that both players will be better off if they agree to help each other when in need compared to the situation in which neither helps the other.

The threat of free-riding is dealt with in two ways in this model. Firstly, friendship formation involves a costly courtship period, in the form of things like gift-giving and spending time together. As Hruschka (2010) points out, it is important that these gifts are (and are required to be) "intrinsically worthless" so that they cannot be used to cover the courtship costs of a different potential friendship. If individuals require such courtship investments before being willing to provide favours, then these start-up costs render ending one friendship and starting another a costly action to take. This makes it more likely that the benefits of the current friendship (favours to be received in the future) are greater than the benefits of refusing to provide a favour now (which might end the friendship and necessitate paying for a new courtship period).

The second anti-free-riding mechanism players can employ in the favour game is a ratcheting up of the size of the favours they are willing to perform for their partner based on whether said partner reciprocates the favours one performs for them. In this way, a friendship becomes more valuable over time, reducing the temptation to defect. Traditional models treat cooperation as a binary phenomenon: individuals can either

defect or cooperate. Evolutionary simulations had already shown that, when investments in (repeated) cooperative interactions can take on any value on a (bounded) continuous scale, a 'raise the stakes' strategy – which consists in investing little in a cooperative interaction to start with and slowly escalating investment over time if the interaction partner follows suit – outcompetes obvious alternative strategies: it spread to fixation in a population of evenly mixed strategies and can, like tit-for-tat in the classic models, invade a population of non-cooperators in a small cluster playing the same strategy (Roberts & Sherratt 1998).

Hruschka's (2010) modelling exercises show that the most successful strategy in the favour game is one where friends go through a costly courtship period and ratchet up the size of the favour they are willing to perform for their partner. As a final element in this model, he argues, in line with the cross-cultural evidence of balanced accounting in friendship contexts, that in established friendships of sufficient value to the involved parties, deliberate calculation of costs and benefits is replaced by a simple friendship judgment and "knee-jerk altruism" towards those judged to be friends.

In sum, according to this evolutionary model, human friendships are cooperation vehicles aimed at coping with unpredictable, varying environments.

1.5.4.2 Why are friends often similar? Fitness benefits of similarity

1.5.4.2.1 Friends are often similar

I have already highlighted the well-documented similarity of human friends (1.5.1), but similarity of close associates has also been reported for other species, for example, for age and sex in bottlenose dolphins (Lusseau & Newman 2004) and many primate societies (Brent et al. 2011) and personality in chimpanzees (Massen & Koski 2014). In the latter study, dyads were identified as friends based on their frequency of sitting in close contact and similarity in personality of friends versus non-friends was assessed for six previously validated personality traits, for three of which – sociability, boldness, and grooming equity – friends were found to be more similar. It is interesting to note that the chimpanzee-based personality construct of sociability bears a clear resemblance to gregariousness, a facet of the Big Five factor extraversion, which human

studies have similarly found extraversion to be a trait in which adolescent friends tend to be more similar than non-friends (Selfhout et al. 2010; Burgess et al. 2011).

1.5.4.2.2 Similarity may improve coordination in cooperation

Why should humans and other animals be more likely to form close social ties with individuals who resemble them in certain ways? At a proximate level, part of this may be due to people *preferring* to form and maintain social ties with similar individuals, a phenomenon often referred to as 'similarity attraction' (Byrne 1997). The fact that similarity of friends is widespread in humans and is also exhibited by other social species, suggests that a preference for similarity, whether conscious or unconscious, may have been favoured by natural selection and thus have an evolutionary (i.e., selected-for) function.

A popular view for why a preference for similarity, whether consciously held or not, evolved by natural selection is because it facilitates coordination among collaborators engaged in (complex) task performance (Cole & Bruno Teboul 2004; Fu et al. 2012). Our ancestors would have been able to increase their inclusive fitness if they managed to perform certain relatively complex tasks, such as organized defence against predators and hunting difficult-to-catch prey, which require coordinated collaboration. Those individuals better able to coordinate their actions with their collaborators would be more successful in performing such complex tasks. The key idea is that coordination might be easier achieved between individuals who share ways of thinking and feeling – collaborators with interests or affective states or holding similar assumptions will find it easier to agree on what needs to be done in order to achieve a particular goal and will also find it easier to predict each other's behaviour. (It should be remarked that empirical research into the coordination benefits gained from similarity is remarkably sparse.)

There are also traits for which it is beneficial, from a reproductive fitness perspective, to have a preference for *dissimilar* social partners. In general, the benefit from heterophily will lie in some form of complementarity of the interaction partners.

Fu et al. (2012) constructed a mathematical model to address the evolution of homophily (here: a tendency to interact with similar others) and heterophily. In the

model's world, individuals have observable phenotypes and varying degrees of homophilous or heterophilous preferences for interaction partners. Individuals go through three stages in each time period of this dynamical model. First, they *choose* whether or not to interact with a similar other (with probability p) or with a dissimilar other (with probability $1 - p$). Next, each individual randomly *meets* another and then, depending on both individuals' choices and whether their phenotypes are similar or not, they finally *interact* (or not) and receive the payoff associated with the type of interaction they've engaged in. The payoff from a homophilous interaction is termed the *payoff to synergy* and that from a heterophilous interaction, the *payoff to specialization*. The payoffs from these interactions determine an individual's fitness, and the preferences for (dis)similarity of the fitter individuals will spread in the population (in a way that can be thought of as natural selection or learning). The model also includes the possibility of random mutation and both phenotypic traits and preferences are allowed to evolve.

While perhaps hard to grasp at an intuitive level, the results of this modelling exercise indicate that a preference for interacting with similar others is the dominant strategy under a wide range of circumstances, even, strikingly, in parts of the parameter space where the payoff to specialization is (much) larger than the payoff to synergy. Model variations also showed that if the chances of meeting similar others was higher to begin with, for instance, because similar individuals tend to occupy similar environments, homophily was even more likely to evolve.

Similarity of collaborative partners cannot only be achieved by putting already-similar individuals together through a process of preferential assortment, but can also be the result, for modifiable traits, of changing trait values to fit with those of one's interaction partners. Thus, coordination benefits also provide an evolutionary rationale for being susceptible to some forms of social influence (e.g., a tendency to conform to group norms) (Koski & Burkart 2015).

One of the few studies to look at possible coordination benefits of similarity looked at the behaviour of matched pairs of players in two coordination games, viz., a stag hunt game and an entry game (Chierchia & Coricelli 2015). Both games were similar in that participants had to decide, individually, whether to go for a safe payoff or a higher but

uncertain payoff. In the stag hunt game, the uncertain payoff would only be paid out if both players chose the uncertain payoff. In the entry game, only one player could get the uncertain payoff, when he or she was the only player to pick the uncertain payoff; if both players chose the uncertain payoff, neither would receive anything.

It was found that pairs of participants who were under the impression of being similar to each other (in some kind of dispositional trait, such as 'organized' or 'romantic'), were more likely achieve coordination by choosing the same payoff and also more likely to take the financial risk of going for the uncertain payoff *and* be successful in doing so because the other player did the same. By contrast, in the entry game, where participants needed to "decouple" their choices to achieve coordination, similar players were less likely to take risks and more likely to go for the safe payoff. In both games, the expected payoffs were higher for players who thought they were similar to their counterpart than for dissimilar players. Interestingly, similarity was *perceived* rather than actual, since players were not actually matched based on similarity but provided with artificial information about the similarity of the other player, manipulated so as indicate either similarity or dissimilarity (in a personality trait the participant receiving the information identified with and liked).

1.6 Thesis outline

In **Chapter 2: General methods: data source, recurring variables, recurring methods**, I cover data and methodological matters relevant to all or several of the analysis chapters: I introduce my main data source, the Avon Longitudinal Study of Parents and Children; discuss variables appearing in more than one chapter; and set out my statistical approach, which uses multiple classification models to incorporate social structure and quantify social clustering, and discuss my missing data strategy.

Chapter 3: Life history factors, personality and the social clustering of sexual experience is the first analysis chapter. It establishes whether and how, in our sample of British adolescents, experience with sexual intercourse at 17.5 years clusters in neighbourhoods, schools and friendship networks, and goes on to examine if the Big Five personality factors and predictors implicated by life history theorists as potential modifiers of life history pace can explain variation in sexual experience and, additionally, account for any social clustering of this behavioural trait. It is found that sexual experience clusters in friendship networks but hardly at all in schools or neighbourhoods. The clustering in friendship networks cannot be explained by similarity in life history predictors but appears to be partly due to personality similarities of friends. Life history predictors, such as father absence, account for some of the individual variation in sexual experience.

In **Chapter 4: Social clustering of cooperativeness and its relation to life history predictors** I first aim to find out whether cooperativeness (five measures) shows social clustering, as predicted by evolutionary models of cooperation. Cooperativeness has been argued to be a life history trait – individuals with a slower life history strategy are supposedly more cooperative. I therefore add life history predictors to the multiple classification null (clustering) models to assess whether they explain any differences in cooperativeness or social clustering of cooperativeness. The relationship between personality and cooperativeness is also examined. It is found that cooperativeness clusters in friendship networks. Some minor school and neighbourhood clustering, evident in the null clustering models, disappears upon adding life history predictors. While life history predictors and personality factors both account for some variation in

cooperativeness, they do not explain the clustering of cooperativeness in friendship networks.

Next, in **Chapter 5**: **Comparing the social clustering of multiple behavioural and non-behavioural traits**, I quantify and compare the social clustering in neighbourhoods, schools and friendship networks for a wide range of behavioural and non-behavioural measures, including sexual experience, substance use, personality traits, household socioeconomic status, academic performance, sex, and body mass index. The goal of this chapter is to establish whether there are instructive patterns of clustering across outcomes in order to determine the scope for different kinds of evolutionary explanations in accounting for behavioural variation that manifests itself as social clustering. It is found that behavioural variables, in this population, only show clear clustering in friendship networks, not in neighbourhoods or schools. In terms of evolutionary explanatory models, these results suggest little scope for adaptive flexibility to environmental variation in explaining social clustering, but more room for coordination benefits from similarity or cultural evolutionary processes operating in friendship networks. Evolutionary predictions about sex differences in substance use and personality traits are also tested.

In **Chapter 6: Quality of the childhood environment and pubertal development**, the focus is on physical development. I examine whether measures of the quality of the childhood environment, such as household socioeconomic status and father absence, affect a range of measures of pubertal development in boys and girls, and, if so, whether they follow predictions derived from life history theory. In addition to using measures of pubertal progression at particular time points as dependent variables, I apply a recently proposed statistical approach which summarizes developmental trajectories in a small number of parameters (age at peak velocity and peak velocity), and investigate those as dependent variables as well. It is found that socioeconomic deprivation predicts earlier puberty in both girls and boys, as does father absence. However, the statistical associations between life history predictors and measures of pubertal development are inconsistent.

Finally, in **Chapter 7: Conclusions**, I formulate general conclusions based on the foregoing and propose future research directions.

Chapter 2: General methods: data source, recurring variables, recurring methods

2.1 The Avon Longitudinal Study of Parents and Children

2.1.1 ALSPAC in brief

The Avon Longitudinal Study of Parents and Children – also known as 'Children of the 90s' – is a large, ongoing prospective birth cohort study following children and their parents, centred on the city of Bristol in England (Golding et al. 2001; Boyd et al. 2013; Fraser et al. 2013). It started life as the Avon Longitudinal Study of Pregnancy and Childhood as part of the European Longitudinal Study of Pregnancy and Childhood (ELSPAC) and was set up in order to "determine how the individual's genotype combines with environmental pressures to influence health and development" (Golding et al. 2001: 75). Perhaps ALSPAC's greatest strength is the wide variety of data that were and are being collected as part of the study, from the wide range of topics covered by its frequent and wide-ranging postal questionnaires to anthropometrics, biological samples, and genetic and epigenetic data. Data linkages, for example, to the National Pupil Database and neighbourhood statistics produced by the Office for National Statistics (ONS), further extend the range of questions researchers can address with ALSPAC.

2.1.2 Recruitment and participation

Original recruitment occurred in 1990-1992 and was aimed at enrolling all pregnant women with an expected delivery between April 1991 and December 1992 residing in the Avon area in and around the English city of Bristol (Boyd et al. 2013).

Several avenues were used to recruit as many eligible women into the study as possible, including posters in strategic locations (e.g., antenatal clinics, chemist shops), press coverage raising the public profile of the study, dissemination of information about ALSPAC by midwives and hospitals, and requests for participation by ALSPAC staff (for instance, at routine ultrasound examinations) (Golding et al. 2001).

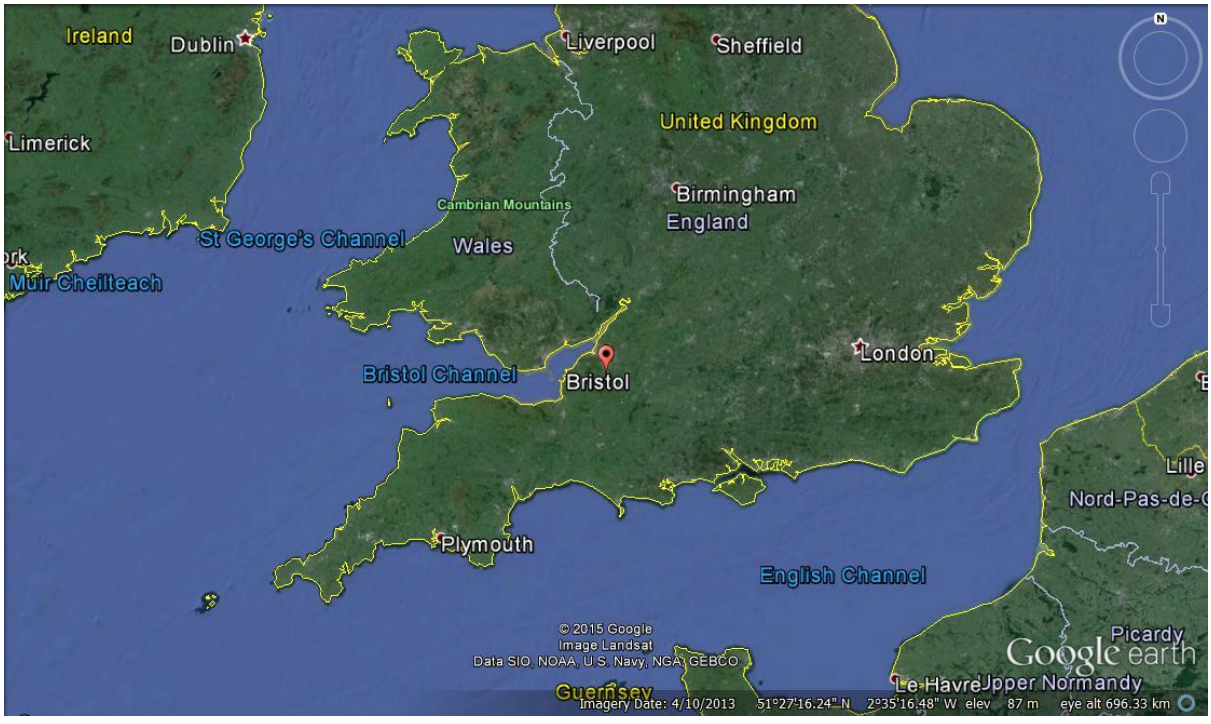
The eligible sample was retrospectively determined at 20,248 pregnancies. The initial study sample, made up of all index pregnancies of women who returned at least one

questionnaire, consisted of 14,541 pregnancies (~72% of the eligible sample), resulting in 14,062 live-births. The samples featured in the analyses in this thesis all take the core sample of 14,541 pregnancies as their starting point.

2.1.3 Catchment area

The catchment area comprised the District Health Authorities (DHAs) Southmead, Frenchay, and Bristol and Weston, which in 1991 were combined into as single DHA known as Bristol & District, which covers both the city of Bristol itself and urban and rural areas around Bristol (Boyd et al. 2013). Bristol is a city in the South West of England (Figure 4), located on the river Avon. The Office for National Statistics estimated the city's population at 442,474 as of mid-2014. Within the United Kingdom, Bristol is a comparatively prosperous city, as indicated, for instance, by a relatively high median income after tax: £20,900 in 2012-13, compared to the UK median of £18,700 (HMRC 2015).

Figure 4. Map showing geographical location of Bristol



2.1.4 Representativeness

Comparisons based on the 1991 census indicate that mothers of infants in the ALSPAC catchment area, compared to Great Britain, were on average slightly more affluent – e.g.,

more likely to be an owner-occupier (68.7% versus 63.4%) or have a household car (83.7% versus 75.6%) – and also more likely to be white (95.9%% versus 92.4%) (ALSPAC website 2015). This pattern was repeated for mothers who participated in ALSPAC, as indicated by completing a questionnaire 8 months post-partum, compared to the wider group of mothers of infants in the study area (ibid.).

Compared to a national sample of pupils, children from families who returned at least one questionnaire or attended at least one clinic, had higher levels of academic attainment at the age of 16 (Key Stage 4), are more likely to be white, and less likely to be eligible for free school meals (an indicator of low household income) (Boyd et al. 2013). Overall, the study sample in ALSPAC's early stages was to a large extent representative of the population of Great Britain in terms of socioeconomic and medical markers, although there was some underrepresentation of non-white and less affluent Britons (Boyd et al. 2012; Golding et al. 2001).

2.1.5 Attrition

Like all longitudinal studies of this kind, ALSPAC suffers from attrition, that is, the dropping out of participants with time. For example, the response rate for the child-based questionnaires roughly halved between early infancy (~12,000 returned questionnaires) and when the study children were about 16.5 years old (~6,000 returned questionnaires) (Boyd et al. 2013).

Attrition is not random with regard to respondent characteristics. Mothers who attended the 'Focus on Mothers 1' clinic, between November 2008 and March 2011, were on average older and of higher SES – for instance, roughly twice as likely to have a university degree – than invited non-attendees (Fraser et al. 2013). Compared to all enrolled study adolescents, those who have recently participated (when aged 16-17), had higher average academic attainment scores, were more likely to be female and white, and less likely to be eligible for free school meals (Boyd et al. 2013).

In the appendices to chapters 3 and 4, I also provide demonstrations of the fact that attrition is biased by comparing baseline characteristics of the analysis and attrition sample.

2.1.6 Data sources for thesis

The data used in this thesis were gathered in a number of ways. Table 4 lists all the variables with their respective sources and approximate time points (measured from the study child's birth).

The first major source were ALSPAC's postal questionnaires. I used data from ALSPAC's carer-completed questionnaires, which were usually filled out by the study child's mother; child-based questionnaires, usually filled in by the mother; child-completed questionnaires; teacher-completed questionnaires; and puberty questionnaires, typically filled in by parents, the study child, or both (depending on age at questionnaire).

At several time points, ALSPAC has invited participants to clinical assessment sessions ('clinics'), largely in order to perform a variety of physical assessments but also to administer questionnaires with sensitive topics, such as adolescent sexual behaviour and substance use. Four such clinics provided data used in the current thesis: Focus@7 (target age = 7y6m), Teen Focus 2 (target age = 13y6m), Teen Focus 3 (target age = 15y6m), and Teen Focus 4 (target age = 17y6m).

Neighbourhood deprivation data produced by the Office for National Statistics of the UK government were linked to the ALSPAC database by the ALSPAC team. Data linkage with the National Pupil Database provided pupil performance data and school identifiers at Key Stage 4.

Table 4. All variables used in this thesis with their sources and approximate time points

Variable	Source(s)	Time point(s)
Sex of study child	Birth notifications	Birth
Maternal age at menarche	Carer-completed questionnaire	12 weeks gestation
Paternal age at index pregnancy	Carer-completed questionnaire	12 weeks gestation
Maternal age at first pregnancy	Carer-completed questionnaire	18 weeks gestation
Mother's highest educational qualification	Carer-completed questionnaire	32 weeks gestation
Mother's partner's highest educational qualification	Carer-completed questionnaire	32 weeks gestation
Mother had sex with boyfriend when <16	Carer-completed questionnaire	32 weeks gestation
Female parental care	Carer-completed questionnaire	1y6m
Male parental care	Carer-completed questionnaire	1y6m
Home ownership status	Carer-completed questionnaire	Pregnancy, 1y9m, 7y1m, 10y2m
Financial difficulties	Carer-completed questionnaire	2y9m, 7y1m
Father absence	Carer-completed questionnaire	Pregnancy, 1y9m, 2y9m, 3y11m, 7y1m, 8y1m, 10y2m
Index of Multiple Deprivation	Office for National Statistics	~6y, ~16y
BMI at Focus@7	Clinic	7y6m
Teacher-rated prosociality	Year 3 schools questionnaire	7-8 years
Pubic hair growth	Puberty questionnaire	8y1m, 9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Armpit hair growth	Puberty questionnaire	9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Age at menarche	Puberty questionnaire	8y1m, 9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Had period	Puberty questionnaire	8y1m, 9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Male genital development	Puberty questionnaire	8y1m, 9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Breast development	Puberty questionnaire	8y1m, 9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Voice breaking	Puberty questionnaire	9y7m, 10y8m, 11y8m, 13y1m, 14y7m, 15y6m, 16y
Ever smoked a cigarette	Teen Focus 2 clinic	13y6m
Extraversion	Teen Focus 2 clinic	13y6m
Agreeableness	Teen Focus 2 clinic	13y6m
Conscientiousness	Teen Focus 2 clinic	13y6m
Emotional stability	Teen Focus 2 clinic	13y6m
Openness	Teen Focus 2 clinic	13y6m
BMI	Teen Focus 3 clinic	15y6m
Ever tried cannabis	Teen Focus 3 clinic	15y6m
Ever had a whole alcoholic drink	Teen Focus 3 clinic	15y6m
Ever had 4 alcoholic drinks in 24 hours	Teen Focus 3 clinic	15y6m
Adolescent has had sexual intercourse	Teen Focus 3 clinic	15y6m
School ID (KS4)	National Pupil Database	~16y
Adolescent education: GCSE results	National Pupil Database	~16y
LSOA ID	Supplied directly by ALSPAC	~16y
Friendship network ID	Child-completed questionnaire	~16y
Returned Friends questionnaire	Child-completed questionnaire	~16y
Times nominated as friend	Child-completed questionnaire	~16y
Mother-rated prosociality	Child-based questionnaire	16y6m
Mother-rated conduct problems	Child-based questionnaire	16y6m
Adolescent has had sexual intercourse	Teen Focus 4 clinic	17y6m
Age at TF4	Teen Focus 4 clinic	17y6m
Attended TF4	Teen Focus 4 clinic	17y6m

2.2 Recurring variables

Many of the variables used in the following analyses appear in multiple chapters. To avoid repetition, some of these recurring variables are discussed in some detail here and therefore receive minimal elaboration in the analysis chapters.

2.2.1 Household socioeconomic status and adolescent education

2.2.1.1 Parental education at pregnancy

Two parental education variables were used, prepared by the ALSPAC team based on information provided by the study child's mother around 32 weeks into their pregnancy. One indicated the highest educational qualification obtained by the mother (maternal education), the other the highest educational qualification obtained by the mother's partner. Because the mother's partner during pregnancy was nearly always the natural father of the child (> 99% of mothers with partners), I refer to mother's partner's educational level as paternal education throughout.

Mothers' answers to a set of 16 questions about their own and their partner's educational qualifications were used to create ordinal categorical maternal and paternal education variables with five categories. Parents in the highest educational category education are those who, after completing secondary education (ages 11-18), went on to obtain a degree at university. Those who did not can be further subdivided. The lowest category contains those who did not obtain any educational qualification beyond a primary school diploma or Certificate of Secondary Education. Between 1965 and 1988, the so-called Certificate of Secondary Education (CSE) was the least advanced qualification awarded in secondary education in the United Kingdom (bar Scotland). Typically, these pupils left the educational systems by the age of 15. At the next level are those parents with additional vocational qualifications. The next category comprises those parents whose highest educational qualification is an Ordinary or O-level. O-levels are secondary school qualifications in specific subjects (awarded between the fifties and 1988). O-levels were usually obtained when pupils were 16 years old. After O-levels, some pupils continued for another two years of secondary education, working towards Advanced or A-levels, which are more advanced, pre-university qualifications in specific subjects (still in use today).

Table 5 shows the distribution of educational qualifications for the mother and fathers of the study child, as reported by mothers during the index pregnancy.

Table 5. Highest educational qualification at pregnancy of study child's parents (n = 12,441)

	Mothers	Fathers
CSE/none	20.7%	25.7%
Vocational	9.7%	8.0%
O level	34.1%	20.0%
A level	22.1%	24.6%
Degree	12.7%	17.2%
Missing	0.6%	4.4%

2.2.1.2 Home ownership status

Home ownership status is another variable intended to capture the socioeconomic status of the household in which the study child grows up.

At multiple time points, starting during the index pregnancy, mothers were asked whether their home was "being bought/mortgaged", "owned – with not mortgage to pay", "rented" (various forms, e.g., "rented from council"), or "other (please describe)". From their answers, a three-category home ownership status variable was derived with "owned", "mortgaged" and "rented" as its categories.

2.2.1.3 Financial difficulties

At various time points, mothers were asked to indicate how difficult – 'very', 'fairly', 'slightly', or 'not difficult' – they were finding it to afford each of a list of items, such as 'food', 'clothing', 'heating', 'rent or mortgage', and 'things you need for your children'. A financial difficulties score was calculated based by adding 3 points for every 'very difficult', 2 for 'fairly difficult', etc. From this, a three-category variable was derived, indicating 'no financial difficulties', 'some financial difficulties' or no 'financial difficulties'. For example, at 2 years and 9 months, a financial difficulties score of 0 was categorized as 'no financial difficulties', a score between 1 and 5 as 'some financial difficulties', and a score between 6 and 15 as 'many financial difficulties'.

2.2.2 Neighbourhood deprivation

A neighbourhood is considered deprived if it lacks fundamental resources such as educational and employment opportunities and good-quality health care facilities. The

households in ALSPAC have been linked, using post codes, to indices of local deprivation produced by the UK government.

2.2.1 Index of Multiple Deprivation 2000

The Indices of Deprivation 2000 are ward-level measures of deprivation in six domains: income; employment; health deprivation and disability; education, skills and training; housing; and geographical access to services (DETR 2000). The domain-specific scores are combined in a summary measure known as the Index of Multiple Deprivation 2000 (IMD 2000). The indices use the ward boundaries of 1998 and are available for all 8,414 wards in England. According to the Office of National Statistics, the average ward has about 5,500 inhabitants.

Briefly, the domain-specific indices measure the proportion of the population on a low income (income), involuntary unemployment (employment), poor health outcomes (health deprivation and disability), lack of educational achievement (education), low-quality housing and homelessness (housing), and access to essential services (post office, food shops and GP) for individuals on benefits and access to primary schools for 5-8 year olds (geographical access to services). More details on the deprivation indicators can be found in the government report "Indices of Deprivation 2000" (DETR 2000) and the appendix to chapter 2 (section 1). Unfortunately, a crime domain was not included for lack of suitable data.

The main steps in constructing the IMD 2000 were as follows. The deprivation scores for the different domains were first standardized by ranking the wards from least to most deprived. The most deprived ward received a score of 1 (= 8,414/8,414), while the least deprived ward was assigned a score of 1/8,414 (≈ 0.000119). The resulting scores were transformed to an exponential distribution. This distribution was chosen to reduce the risk that a lack of deprivation in one domain would mask deprivation in another. Finally, the domain scores were combined into a single measure (the IMD 2000), to which they contributed according to the following weights:

- Income 25%
- Employment 25%
- Health Deprivation and Disability 15%

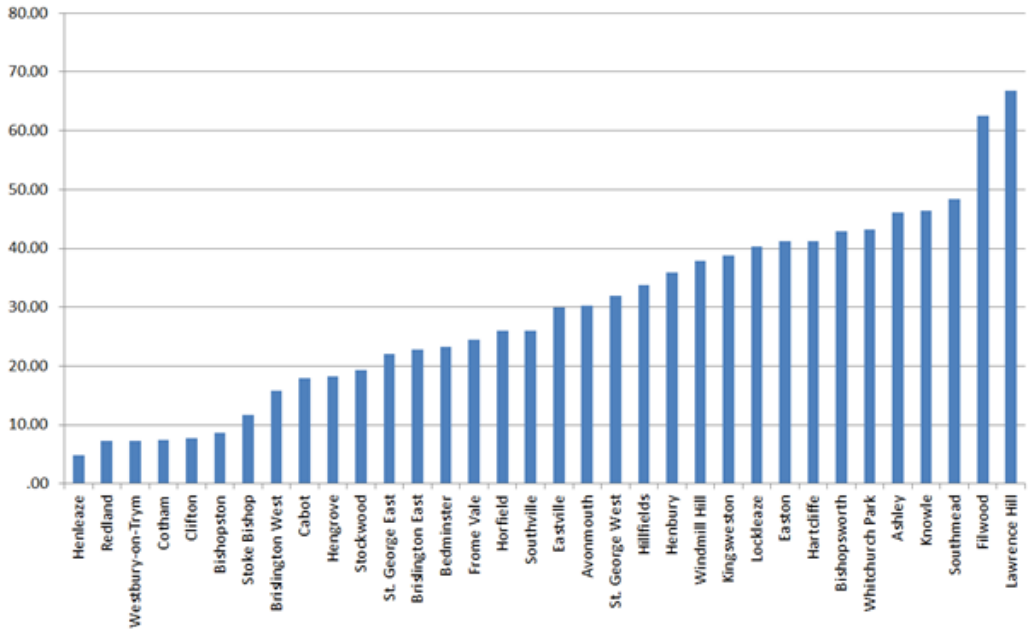
- Education, Skills and Training 15%
- Geographical Access to Services 10%
- Housing 10%.

Table 6 lists the wards of Bristol and gives the IMD score and national rank for each. Figure 5 graphically displays the IMD scores for wards in Bristol, showing the wide variation that exists between wards.

Table 6. Index of Multiple Deprivation 2000 scores with national ranks for wards of Bristol

	IMD score	National rank
Ashley	46.05	756
Avonmouth	30.23	1955
Bedminster	23.31	2951
Bishopston	8.58	6897
Bishopsworth	42.90	935
Brislington East	22.79	3040
Brislington West	15.84	4485
Cabot	17.99	3970
Clifton	7.78	7172
Cotham	7.47	7295
Easton	41.20	1043
Eastville	29.90	1998
Filwood	62.50	221
Frome Vale	24.40	2765
Hartcliffe	41.23	1036
Henbury	35.91	1423
Hengrove	18.29	3911
Henleaze	4.89	8065
Hillfields	33.75	1596
Horfield	26.03	2504
Kingsweston	38.86	1207
Knowle	46.45	733
Lawrence Hill	66.80	133
Lockleaze	40.31	1095
Redland	7.25	7367
St. George East	22.06	3168
St. George West	31.94	1783
Southmead	48.42	628
Southville	26.06	2496
Stockwood	19.22	3713
Stoke Bishop	11.63	5819
Westbury-on-Trym	7.26	7363
Whitchurch Park	43.22	921
Windmill Hill	37.83	1278

Figure 5. Index of Multiple Deprivation 2000 scores for wards of Bristol



2.2.2 Index of Multiple Deprivation 2010

The Index of Multiple Deprivation 2010 is based on the English Indices of Deprivation 2010 (McLennan et al. 2011). The Indices of Deprivation 2010 are measures of deprivation for so-called Lower layer Super Output Areas (LSOAs; Office for National Statistics n.d.). LSOAs are geographical areas defined by the ONS for statistical purposes, with populations numbering between 1,000 and 3,000 (or 400 and 1,200 households). Thus, the Indices of Deprivation and IMD 2010 have a somewhat higher spatial resolution than the ward-level Indices of Deprivation 2000 and IMD 2000. Another difference is the inclusion of a crime domain in the IMD 2010.

The English Indices of Deprivation 2010 comprise indices of deprivation in seven domains, which form the basis of the Index of Multiple Deprivation 2010. The seven domains (with their weights in the IMD) are: Income (22.5%), Employment (22.5%), Health and Disability (13.5%), Education, Skills and Training (13.5%), Barriers to Housing and Other Services (9.3%), Crime (9.3%), and Living Environment (9.3%). The domain indices roughly correspond to the proportion of the population on a low income; involuntary unemployment; poor health outcomes; lack of educational achievement; access to essential services (primary school, Post Office, supermarket/convenience store and GP) and housing; crime levels; and the quality of

housing and the living environment (see McLennan et al. 2011 for a full description). The IMD 2010 mainly uses data from 2008.

2.2.3 Parental life history pace

Life history strategies may be inherited, whether genetically, culturally or both. I included indicators of parental life history pace as independent variables in models in chapters 3, 4, and 6 in order, firstly, to control for them while evaluating other predictors of interest, and, secondly, to get an indication of the extent to which adolescent behaviour is a function of parental life history pace.

Three indicators of maternal life history pace are used in the following chapters. They are: 1) the study mother's age at first pregnancy, ascertained by questionnaire at approximately 18 weeks gestation; 2) a binary variable indicating whether the mother had had sexual intercourse with a boyfriend before the age of 16, based on data from a questionnaire at 32 weeks gestation; and 3) the mother's age at menarche, also reported on the questionnaire administered around 32 weeks gestation.

Unfortunately, appropriate measures of paternal life history pace were not available. I do include the paternal age at index pregnancy in some of the analyses in the following chapters, but this is unlikely to be a particularly good indicator of the paternal life history trajectory, as the study fathers may already have had children from the same or another relationship.

2.2.4 Big Five personality factors

Personality, which has a strong genetic basis in humans (Bouchard & Loehlin 2001), is one differentiating factor that appears to be key to understanding behavioural variation in humans and other animals (Gosling & John 1999). Here, personality is taken to refer to individual behavioural dispositions that exhibit substantial consistency across time and situations (Roberts & DelVecchio 2000; Mischel & Shoda 1995).

The widely used Five Factor Model (FFM) of personality (Digman 1990; Costa & McCrae 1992) identifies five broad dimensions or factors of personality (the so-called 'Big Five'): openness, conscientiousness, extraversion, agreeableness, and emotional stability (sometimes referred to by its opposite pole: neuroticism). The openness

dimension, sometimes referred to as intellect/imagination, measures intellectual curiosity, behavioural flexibility and openness to new experiences. Conscientiousness refers to a tendency to be organized and a preference for planning over spontaneity. Extraversion covers such traits as sociability, assertiveness, and a tendency to experience positive emotions. Agreeableness is a disposition to trustfulness, friendliness and cooperativeness, as opposed to hostility, suspiciousness and uncooperativeness toward others. Finally, emotionally more stable individuals have a lower tendency to experience psychological distress.

A 50-item questionnaire (see appendix to chapter 2) based on the International Personality Item Pool (IPIP; Goldberg 1999) was administered during a computer session at the Teen Focus 2 clinic, when participating adolescents were around 13.5 years old. The IPIP is based on the Five Factor Model (FFM) of personality (Digman 1990). Participants were presented with 50 statements of the form "I am the life of the party" (extraversion) and "I pay attention to details" (conscientiousness) and asked to indicate how well each statement described them on a five-point Likert scale (ranging from 1 = very inaccurate to 5 = very accurate). An overall score for each the Big Five was calculated, ranging between 10 and 50. The IPIP uses emotional stability rather than neuroticism (although the one is simply the inverse of the other).

2.3 Recurring methods

2.3.1 Multiple classification models for quantifying social clustering

2.3.1.1 Reasons for using multilevel models

Multilevel models provide three major benefits that make them appropriate for my purposes, viz., they allow the researcher to 1) account for dependencies in the data due to social structure, 2) quantify the amount of variation at different levels of the social world, and 3) find out how much of the variation can be explained by predictors of interest.

2.3.1.1.1 Dependencies in the data due to social structure

In chapters 3 and 4, I examine whether a set of predictors selected based on life history theoretical considerations can explain whether an adolescent has had sexual intercourse yet (chapter 3) or how cooperative they are (chapter 4). A single-level model assumes independence of the residuals of each unit, an assumption that might be violated because of structure in the data (Snijders & Bosker 2012). Since ALSPAC is geographically based, this assumption is likely to be violated as individuals are nested in particular social spheres, such as neighbourhoods, schools, and friendship networks. If residuals are not, in fact, independent, then a single-level model will underestimate the standard errors associated with regression coefficients, increasing the probability of false positive results (type I errors). Multilevel models give accurate standard errors, assuming the structure in the data has been incorporated adequately. Multilevel models actually quantify the amount of (residual) variance present at each level, a feature I make use of in chapter 3-5.

2.3.1.1.2 Quantifying social clustering

Even without predictors, multilevel models can be very informative with regard to the importance of a particular social contextual level for understanding between-individual differences (Snijders & Bosker 2012). A consideration of some hypothetical results will illustrate the point. Three scenarios are given in Table 7.

Table 7.Three hypothetical scenarios of clustering of some outcome of interest. Total variance is set at 1 so that the variance estimates can be read as proportions of total variance.

	Variance at different levels (sums to 1)			
Scenario	**Individual**	**Neighbourhood**	**School**	**Friends**
1: All variation occurs at the neighbourhood level	0	1	0	0
2: All variation occurs at the individual level	1	0	0	0
3: Variation is spread equally across levels	0.25	0.25	0.25	0.25

In scenario 1, all of the variation in the outcome of interest occurs at the neighbourhood level; within neighbourhoods, there is no variation. In this case, it is all but certain that some neighbourhood-related mechanism explains all differences between individuals. Perhaps the value of the outcome variable reflects the area crime rate – perfectly, in this extreme scenario; or perhaps there is complete residential segregation based on a (small) preference for similarity in the trait of interest (Schelling 1971). Faced with this kind of partitioning of variance, researchers can avoid a futile search for school- or friendship network-level differences in a bid to explain the distribution of trait values in the population.

By contrast, in scenario 2, all of the variation is found at the individual level. This strongly suggests that contextual effects are negligible, at least for the social spheres accounted for in the multilevel model. Finally, in the third scenario 3, variance is spread equally across the social structure, suggesting that mechanisms operating at several levels of the social structure play a part in bringing about the population distribution of the outcome of interest.

In sum, different clustering patterns have different implications for the plausibility of causal processes suggested to explain between-individual differences. Studies with data which allow them to incorporate key elements of the social structure in their statistical models and partition the variance across the social structure accordingly, can therefore be extremely valuable in guiding research efforts.

In linear multilevel models, if the outcome variable is normally distributed and standardized (i.e., transformed so that mean = 0 and SD = 1), total variance sums to 1 and the variance estimate for a level or classification is equivalent to an *intraclass correlation*. The intraclass correlation (ICC) is a measure of the similarity of members of

the same group (e.g., pupils in the same school). Specifically, it is the expected correlation in the outcome of interest between two randomly selected members of the same group.

In the following chapters, I also run logistic multiple classification models. For those, the model estimates of the classification variance parameters can be used to calculate (residual) intraclass correlation coefficients with a latent variable approach (Snijders & Bosker 2012). In the latent variable approach, the ICC is defined as the ratio of the variance at the level or classification of interest to the total (= residual + explained) variance. The residual variance at the individual level is fixed at $\pi^2/3$ (≈ 3.290) and residual variances at other levels are estimated by the model. The explained variance is the variance of the so-called linear predictor, a variable containing each individual's model-based predicted value (for the latent variable) (Snijders & Bosker 2012).

Intraclass correlations are not readily calculable for other kinds of regressions, such as Poisson or ordinal logistic regressions. In the analyses that follow, where possible, the dependent variable was standardized and modelled as a continuous variable. Where this was not possible, either because the variable was categorical or the distribution could not be transformed to approximate normality, the variables were dichotomized (if not already binary) in order to facilitate the calculation of ICCs.

As an example of this sort of quantification of clustering, consider a study of the smoking behaviour of over 8,000 adults in the North West Thames Region in England (Kleinschmidt et al. 1995). The outcome measure in this study was whether someone was currently a smoker or not and respondents were nested in 498 electoral wards, which have around 5,500 inhabitants on average. A two-level logistic regression with respondent sex and age and ward-level deprivation included as independent variables revealed that roughly 6% of the variation in smoking status occurred at the neighbourhood (= ward) level (leaving ~94% at the individual level).

This 6% is most easily interpreted as an intraclass correlation – it tells us that the correlation in smoking status between two randomly chosen inhabitants of the same ward is 0.06. If smoking status did *not* exhibit social clustering in wards, the intraclass correlation would have been zero. In the latter case, the predicted smoking status of a randomly selected individual from the population, about whom we know nothing else,

would simply be the population mean, regardless of the ward he or she lives in. Knowing the smoking status of a second randomly selected individual from the same ward would not alter our prediction for the first individual because ward membership is not informative with regard to smoking status when there is no ward-level clustering of smoking behaviour. By contrast, given an intra-ward correlation of 0.06, knowing the smoking status of another inhabitant of the same ward would lead one to slightly adjust one's prediction of the smoking status of the first individual to more closely match the smoking status of the second individual. (Since neighbourhood deprivation was a significant predictor, the intraclass correlation for wards would presumably have been higher before adding neighbourhood deprivation to the multilevel model. However, the authors did not report the unadjusted intra-ward correlation.)

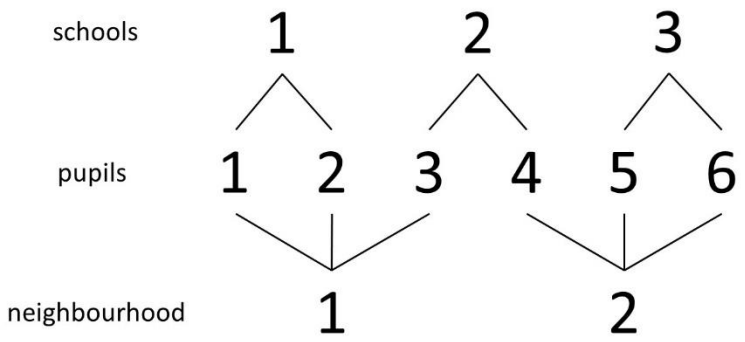
2.3.1.1.3 Explaining social clustering

Having quantified the variation at different social levels, one can then start adding predictors of interest to one's models and observe how their addition affects the residual variances associated with particular social spheres. If adding a certain predictor reduces the amount of variance at a particular level, then this suggests that the predictor, or something associated with it, explains some of the clustering at said level – and it allows one to quantify roughly *how much* of the variation it can account for. For example, in scenario 1, we might have reason to believe that the local crime rate is an important predictor of the outcome of interest and find that after adding neighbourhood crime rate, the residual variance at the level of neighbourhoods is reduced from 1 to 0.4, while explained variance goes from nothing to 0.6. This show that 60% of the outcome variance at the neighbourhood level is explained by neighbourhood crime rates.

2.3.1.2 Multiple classification models

Standard multilevel models assume a hierarchical data structure, with each lower level nested in a higher level (e.g., people in neighbourhoods). In many cases, however, more complex structures exist in the data. For example, Figure 6 illustrates a situation in which pupils are nested in schools and neighbourhoods, but schools are not strictly nested in neighbourhoods, nor are neighbourhoods nested in schools.

Figure 6. Unit diagram showing pupils nested in both schools and neighbourhoods; schools and neighbourhoods are cross-classified



If, say, schools were strictly nested in neighbourhoods, then all pupils of a particular school would live in the same neighbourhood. In Figure 6, this is not the case: pupil 3 attends the same school as pupil 4 but lives in a different neighbourhood. The fact that pupil 3 resides in the same neighbourhood as pupils 1 and 2 but goes to a different school similarly shows that neighbourhoods are not nested in schools. ALSPAC has this type of *cross-classified* data structure. Multiple classification (or cross-classified) models are able to account for clustering in data at different levels but do not assume hierarchical relationships among levels (which are, for that reason, usually referred to as *classifications*).

The multiple classification models discussed in the following chapters make use of Markov chain Monte Carlo (MCMC) estimation methods, as implemented in MLwiN (Browne 2005). Statistical modelling was performed in MLwiN 2.30 (Rasbash et al. 2014) run from within Stata 12 (StataCorp. 2011) using the command *runmlwin* (Leckie & Charlton 2012).

Models can be compared on the basis of the Deviance Information Criterion (DIC), a measure that combines model fit and complexity (Spiegelhalter et al. 2002). A lower DIC indicates a 'better' model. Some rules of thumb for the interpretation of information criteria are as follows (Burnham & Anderson 2004). When the difference in DIC between a particular model and the best model in the candidate set (i.e., the model with the lowest DIC) is less than or equal to two points, the model in question has "substantial support." A model whose DIC is between 4-7 points higher than the best

model has "considerably less support." A model with a DIC that is 10 or more points higher has "essentially no support."

2.3.1.3 Social structure in the ALSPAC data

Social network studies tend not to take into account school- or neighbourhood-level clustering, while, conversely, studies that take into account clustering in schools and neighbourhoods rarely look at social networks as sources of dependence in the data (Tranmer et al. 2014). I include all three in the multiple classification models in chapters 3-6. Here, I discuss the neighbourhood, school, and friendship network classifications as present in the ALSPAC data.

2.3.1.3.1 Neighbourhoods

I use two neighbourhood/residential area classifications. The main one is the aforementioned Lower Super Output Area (2.2.2.2). For privacy reasons, ALSPAC does not provide LSOA identifiers for individuals residing in LSOAs with few participants, resulting in some missing data. The LSOA identifiers I use indicate where respondents were living on the 1st of January 2008, when they were, on average, about 17 years old. ALSPAC has LSOA data for this time point for 14,303 study children, of which 1,862 (13.0%) were set to missing because of low cell counts.

For the 13,617 core sample children alive at 1 year and excluding twins, a valid neighbourhood identifier was available for 11,414 individuals (83.8%). These children lived in 580 different LSOAs. The mean number of study children in a participant's own LSOA (including self) in this sample was 22.47 (SD = 7.0), ranging between 5 and 42.

I assume that neighbourhoods as defined by the Office for National Statistics have socio-ecological validity as communities and living environments. While this need not always be the case, LSOAs are quite small, containing between 400 and 1200 households, and are therefore more likely to correspond to an individual's actual living environment than larger areas like wards. Moreover, they were specifically designed to cover a relatively small geographic area and exhibit some degree of social homogeneity (using criteria related to housing) (Office for National Statistics n.d.).

2.3.1.3.2 Schools

For the school classification, I use ALSPAC's anonymized secondary school identifiers at Key Stage 4, when pupils are ~15 years old. For the 13,617 core sample children alive at 1 year and excluding twins, a valid school identifier was available for 11,279 individuals (82.8%). The children in this sample attended 711 different secondary schools at the time of Key Stage 4, although 363 of these schools were attended by only 1 ALSPAC participant (probably reflecting relocation outside the ALSPAC catchment area). The mean number of ALSPAC participants in an ALSPAC participant's own school (including self) was 292.6 (SD = 203.0), with a range between 1 and 655.

2.3.1.3.3 Friendship networks

In 2008, when they were 15-17 years old, ALSPAC participants were sent a questionnaire called *You and Your Friends*, which asked them to list up to five friends. Nominated friends' names were used to link them to ALSPAC (Burgess et al. 2011). On request, ALSPAC supplied me with a directed edge list, that is, a list of nominators and nominees. This data set contained data for 3,098 participants who nominated 14,503 friends (11,327 unique individuals). Restricting the sample to ALSPAC participants only, I was left with 2,396 respondents who listed 6,961 friends (4,572 unique individuals). Of the 4,572 unique ALSPAC nominees, 1,335 (29%) were also nominators and these were nominated a total of 2,358 times. Out of the potential 2,358 reciprocal nominations, 1488 (63%) were actually reciprocal.

The procedure I used for creating the friendship networks classification was as follows. I first converted the directed edge list, which distinguishes between nominators and nominees, to an undirected edge list, which does not make said distinction. This amounts to assuming that if A considers B a friend, B would judge A to be a friend as well. I did this for two reasons. Firstly, because many nominees did not complete the *Friends* questionnaire even though they were in, fact, ALSPAC participants, making reciprocity of most ties impossible to ascertain. Secondly, this procedure maximized the number of ties that could be used in the analyses.

Next, individuals with a valid outcome – e.g., experience with sexual intercourse at Teen Focus 4 in chapter 3 – were assigned to friendship networks based on the undirected

edge list. Two kinds of links between individuals were used. Firstly, if respondents A and B were directly linked to each other (because A nominated B, vice versa, or both), they were considered part of the same friendship network. Secondly, if respondents A and B were both linked to a third individual C (who need not have a valid outcome), then A and B were assigned to a friendship network defined by C. In this case, A and B might have a mutual friend in C but not be friends themselves. Thus, we are dealing with a more general friendship network than would have been the case if I had relied solely on direct nominations, whether reciprocated or not. While this could certainly weaken the behavioural clustering one might find at the friendship network level – cf., "three degrees of influence" in (Christakis & Fowler 2009) – I opted to include the second type of link because of the resulting increase in the number of friendship networks that could be incorporated in the analyses. For example, for the analyses in chapter 3, by doing this we could assign 1,115 individuals to 411 friendship networks rather than 446 individuals to 223 friendship networks. While some individuals belong to multiple friendship networks, to avoid overcomplicating the statistical models, I used only one randomly chosen friendship network per respondent for each set of analyses. Because of the small size of the friendship networks, confidence intervals associated with this classification will be much larger than those for neighbourhoods and, especially, schools.

For the social clustering analyses in chapters 3-5, a large number of individuals could not be assigned to a friendship network or were the only ones in a friendship network with a valid outcome. Rather than exclude such individuals, those with no friendship network ID were assigned a unique one (to avoid missing cases being treated as all belonging to the same friendship network). The null clustering results in the following chapters were checked against clustering in subsamples with only friendship networks with at least two members. Generally, the social classification variances were found to be very similar so the larger sample was used in each case. For the models looking at mother-rated prosociality, mother-rated conduct problems, and teacher-rated prosociality, the addition of an indicator variable to the model (indicating whether the friendship network was single-member (= 0) or multiple-member (= 1) was found, empirically, to slightly improve the estimates (in the sense of edging them closer to the

estimates of the multiple-member networks-only clustering results), and therefore included in the models.

2.3.2 Multiple imputation of missing data

For various reasons, including attrition, inconsistent study participation, and incomplete questionnaires, many of the variables used in the analyses that follow have considerable levels of missing data. The simplest response to missing data, list-wise deletion or complete-case analysis, risks biasing parameter estimates and often comes at the cost of a substantial loss of statistical power because analyses are based on less information (Sterne et al. 2009).

To address these problems, missing data are handled by *multiple imputation*. Starting from an original data set with missing values, multiple imputation involves the creation of multiple data sets in which missing values are replaced by imputed values (Sterne et al. 2009). Parameter estimates, e.g., regression coefficients, are calculated for each imputed data set individually and then combined using Rubin's rules (Rubin 1987). Multiple rather than single imputation is used to allow for uncertainty associated with the imputation process itself.

Imputations are based on imputation models, which make use of observed data to predict unobserved data. They usually include the other variables to be included in one's statistical models, including the dependent variable, as well as other variables available to the analyst that are thought to be predictive of missingness (Spratt et al. 2010).

Multiple imputation will only produce unbiased parameter estimates if data are what is referred to as 'missing at random' (MAR) rather than 'not missing at random' (NMAR). Data are MAR if whether or not values are missing depends on observed but not unobserved data (Sterne et al. 2009). The missingness mechanism is not directly testable, but by including a fair number of potentially important covariates in the imputation models, I hope to have made the MAR assumption sufficiently plausible.

At present, there are no hard and fast rules on how to determine the number of imputations required in a particular data situation. However, older recommendations which, based on a concern with the stability of point estimates (efficiency), suggested

that around five imputations would usually suffice are no longer considered tenable (Spratt et al. 2010). In particular, more imputations are often needed in order to obtain accurate estimates of the standard errors associated with parameter estimates (and therefore p-values and confidence intervals). The number of imputations used in the multiple imputation procedures in chapter 3-6 (20-25 imputations) represent a compromise between increased accuracy associated with a greater number of imputations and additional computation time required for running models on more imputed data sets and combining the resulting estimates, but fit with existing recommendations (Spratt et al. 2010).

Chapter 3: Life history factors, personality and the social clustering of sexual experience in British adolescents

3.1 Introduction

During adolescence, individuals reach sexual maturity and start to pursue and compete for potential reproductive partners (Ellis et al. 2012). Life history factors and personality differences, which have been suggested to represent alternative life history strategies, may affect adolescent sexual behaviour and have the theoretical potential to explain its social clustering. In this chapter, I use data from ALSPAC – which allows me to observe social clustering at various levels and include a wide range of predictors considered relevant from a life history perspective – to examine the clustering of experience with sexual intercourse by ~17.5 years of age across the social world of adolescents, and to what extent life history predictors and the Big Five personality factors can account for variation in this outcome, in line with evolutionary predictions (as listed in 1.4), and its pattern of social clustering.

3.1.1 A life history perspective

Life history theory – discussed in more detail in chapter 1 – seeks to explain how individuals allocate the resources at their disposal over the life course in order to maximize inclusive fitness in a given environment (Stearns 1992; Roff 1992). Between-individual variation in life history trajectories may, from an evolutionary perspective, represent a functional response to individual circumstances. Environments characterized by high levels of extrinsic mortality (a.k.a. "harsh" environments) have been argued to favour faster life histories because such a strategy would be the best route to ensure at least some reproductive success in the face of a high mortality risk. In such environments, individuals would reach sexual maturity relatively early, reproduce at a younger age, have shorter interbirth intervals and higher fertility, and provide less parental investment. Faster life history trajectories would further be characterized by more unstable pair bonds and a larger number of lifetime sexual partners, reflecting a stronger emphasis on mating rather than parenting effort. By contrast, low mortality environments should favour slower life history strategies because investments in

individual longevity and offspring quality are more likely to pay off (Promislow & Harvey 1990; Chisholm 1993).

Father absence, low parental investment, a stressful and unpredictable home environment, and household socioeconomic and neighbourhood deprivation have all been implicated as accelerators of sexual behavioural development, supposedly serving as cues to a harsh environment in which a faster life history strategy is adaptive (Draper & Harpending 1982; Belsky et al. 1991; Nettle 2010; Nettle, Coall, et al. 2011); but see (Moya & Sear 2014) for an alternative explanation of father absence effects. One reason why individuals with higher levels of education tend to follow a slower life history trajectory (Schvaneveldt et al. 2001) are the correlations between socioeconomic status (SES), educational qualifications, and mortality and morbidity (Feinstein 1993). In addition, in societies with skill-based economies and competitive labour markets, investments in education (embodied capital) that make individuals more successful at resource acquisition are incompatible with early reproduction.

Given these causal hypotheses derived from life history, it is conceivable that much if not all of the social clustering of experience with sexual intercourse ascribed to social transmission is, in fact, due to social clustering on life history factors, determined, in part, by the local environment.

3.1.2 Personality

Personality, which has a strong genetic basis in humans (Bouchard & Loehlin 2001), is one differentiating factor that appears to be key to understanding behavioural variation in humans and other animals (Gosling & John 1999). Here, personality is taken to refer to individual behavioural dispositions that exhibit substantial consistency across time and situations (Roberts & DelVecchio 2000; Mischel & Shoda 1995). Personality differences are associated with differences in sexual behaviour (Hoyle et al. 2000; Miller et al. 2004; Zietsch et al. 2010) and reproductive behaviour, e.g., extravert males appear to have higher reproductive success (Alvergne et al. 2010; Nettle 2005). Thus, if individuals cluster on personality traits, clustering on sexual behaviour could arise as a by-product. This possibility is all the more pertinent since a tendency to become friends with others with similar personality traits has actually been demonstrated in the

friendship networks in the study population – in particular, similarity in extraversion seemed to play an important role in friendship formation (Burgess et al. 2011).

There is some evidence to suggest that adolescents are more likely to form friendships with others if they have a more similar level of intention to have sex (Baams, Overbeek, et al. 2015). A recent longitudinal study of emerging friendship networks showed that first-year university students were more likely to form friendships if they were more similar in (self-assessed) openness, extraversion and agreeableness (Selfhout et al. 2010) (but see Baams, Overbeek, et al. (2015), which only found an effect of *dissimilarity* in agreeableness among early adolescents).

Considering the Big Five personality traits as possible alternative life history strategies, as suggested by some theorists (1.3.4), I derived predictions about two of the Big Five and adolescent experience with sexual intercourse (1.4.1). If extraversion does indeed represent a life history strategy focused on mating effort, and exploratory and social, behaviour, then extraverts should be more likely to have had sex. Conscientious adolescents, by contrast, are predicted to be less likely to have had sex because of their more long-term orientation (which would suggest a life history strategy on the slow end of the spectrum).

3.1.3 Sex; educational achievements; pubertal development

Sex of the respondent may also influence whether he or she has had sex. As explained in Chapter 1 (1.2.3; 1.4.1), boys may be more likely to have had sex than girls of the same age because – for evolutionary reasons related to greater male reproductive variance – they are more inclined to take risks and violate societal norms of correct behaviour (to the limited extent that having sex by 17.5 can be seen as risky behaviour or a norm violation). Moreover, boys may be more opportunistic than girls when it comes to taking advantage of sexual opportunities because of their dramatically lower minimum level of parental investment (1.2.3; 1.4.1).

In addition to personality and sex, other individual factors may be important. Several studies have found an inverse relationship between adolescents' educational expectations and achievements and their likelihood of having had sex (Luster & Small 2010; Perkins et al. 1998; Lammers et al. 2000). Earlier puberty predicts an earlier

sexual debut (Baams, Dubas, et al. 2015). Therefore any ecological characteristics that influence these variables could potentially generate clustering.

3.1.4 Family characteristics

Children may inherit life history traits from their parents, whether culturally, genetically or both. On the cultural side, parents act as behavioural models for their children and often make efforts to instil values they deem important and transmit norms of appropriate behaviour to their offspring. Variation in sexual behaviour, and the timing of puberty, may have a genetic basis has as well (Mustanski et al. 2007). Thus, one might expect the offspring of parents on a faster life history trajectory to be more likely to be sexually experienced.

Life history models predict that the quantity and quality of parental investment received by an offspring will affect its reproductive strategy development: lower levels of parental investment should push offspring to adopt faster life history trajectories. Fathers may be particularly influential (Ellis 2004). Unlike female parental investment which is generally high in humans, male parental investment is extremely variable within and between societies (Geary 2000; Lawson & Mace 2009).

Numerous studies have reported a positive association between low household SES and sexual behaviour (Santelli et al. 2000). Household composition, in particular the presence or absence of a father figure, also appears to have an effect. Many studies have reported a positive association between father absence and an early sexual debut relative to age peers (Hogan & Kitagawa 1985; Newcomer & Udry 2013; Kiernan & Hobcraft 1997; Quinlan 2003; Ellis et al. 2003). Parent-child closeness fairly consistently predicts later first sexual intercourse, fewer sexual partners, and positive patterns of contraceptive use (reviewed in Miller 2002).

3.1.5 Friends

Numerous studies have confirmed that adolescents tend to be similar to their friends in terms of a range of attitudes, beliefs and behaviour (e.g., Kandel 1978; Eiser et al. 1991). While these similarities are often interpreted as evidence of peer effects (‘peer pressure’, ‘conformity’), causality is hard to demonstrate because of alternative pathways to behavioural similarity, such as shared ecology and similarity-based

assortment, that are often difficult to tell apart on the basis of observational data (Shalizi & Thomas 2010), especially if data are not longitudinal. Nonetheless, studies using a range of different methodologies designed to identify such a causal link, have suggested the existence of friend effects on adolescent sexual behaviour (Jaccard et al. 2005; Ali & Dwyer 2011; Card & Giuliano 2012; van de Bongardt et al. 2014).

Friend effects are largely thought to operate through conformity to peer norms. At least three types of peer norms can be distinguished: *descriptive norms* describe actual or perceived peer behaviour; *injunctive norms* reflect (perceived) peer (dis)approval of a behaviour; and *peer pressure* involves explicit social pressure to engage (or not engage) in a particular behaviour (Cialdini & Trost 1998). A recent meta-analysis of the literature on peer norms and sexual activity found that descriptive peer norms were most strongly associated with an adolescent's own behaviour (sexual activity) (Van de Bongardt et al. 2015). The current study uses actual (self-reported) sexual activity of friends, that is, descriptive norms.

3.1.6 Schools

Schools may affect sexual behaviour through a number of channels, including peer effects (Ali & Dwyer 2011). As children become adolescents, the role of the family as the child's dominant socializer shifts to the age peer group, which, in modern societies, tends to be heavily concentrated within a young person's school. Since friends tend to be at the same school, a study without information on friendships, could mistake clustering in friendship networks as clustering in schools. A consensus on the existence and importance of school-peer effects is yet to emerge, possibly due to the methodological difficulties associated with differentiating between reasons for behavioural clustering in schools (Manski 1993).

3.1.7 Neighbourhoods

Neighbourhoods could influence the behaviour of adolescents as arenas for social transmission of behaviours, attitudes, and beliefs. A recent study (Warner et al. 2011) suggests that the normative climate of a neighbourhood – operationalized as a neighbourhood-aggregated measure of sexual attitudes among adolescents – is associated with tendencies toward risky sexual behaviour (as indicated by early sex,

casual sex, number of sexual partners), net of the impact of neighbourhood deprivation and demographic characteristics.

Neighbourhoods are also resource environments marked by differing levels of (perceived) opportunity for social advancement and may present residents with varying morbidity and mortality cues. In line with life history predictions, young people from poorer, more crime-ridden and perceived-as-dangerous neighbourhoods have been reported to start having sex at earlier ages, be less likely to use contraception and, if female, more likely to become pregnant (Miller 2002). Lower neighbourhood-level life expectancy predicts earlier female reproduction (Wilson & Daly 1997; Nettle 2010; Uggla & Mace 2016).

3.1.8 A multisystem approach

The vast majority of papers investigating social-environmental influences on adolescent sexual behaviour focus on only one or two social spheres at the same time, typically the family and one additional sphere such as the neighbourhood or school. A multisystem approach, however, is required to gain a fuller understanding of contextual influences (DiClemente et al. 2005) and correct for dependencies in the data due to social structure. By comparing models, the approach allows us to estimate how the variance that is attributed to similarity at a certain level changes when relevant variables, that might predict both the behaviour in question and clustering in the behaviour in question, are added into the model.

The multisystem approach is in line with the influential ecological model (Bronfenbrenner & Morris 2006), which recognises that individuals occupy multiple micro- and macro-contexts – ranging from families to schools, peer groups to neighbourhoods, but including a range of other influences (e.g., television and film or the internet) – which may interact in significant ways with each other and with individual attributes in shaping people's attitudes, beliefs and behaviour.

Only a few studies have taken a multisystem approach to the study of the antecedents of adolescent sexual behaviour, incorporating influences from three or more social contexts simultaneously. Miller et al. 2000, Voisin et al. 2014, and Chen et al. 2010 all examined predictors of several measures of risky sexual behaviour in different

populations in the US while including a variety of family, peer, school and neighbourhood predictors. Across these studies, risky sexual behaviour was significantly associated with factors from all social contexts (although neighbourhood factors did not follow life history theory predictions with perceived neighbourhood quality showing a negative association with sexual risk-taking), demonstrating the potential importance of considering multiple social contexts.

3.1.9 The current study

I used data from the Avon Longitudinal Study of Parents and Children (Golding et al. 2001), (Boyd et al. 2013) to investigate how much of the variation observed in a life history trait – experience with sexual intercourse by 17.5 years of age – is found at different levels of the social world of adolescents: individual and family, neighbourhood, school, and friendship networks. The inclusion of friendship networks as an additional classification in a multiple classification multilevel model (cf., Tranmer et al. 2014), alongside schools and neighbourhoods, is a novel feature. Having revealed the pattern of clustering, I examined how much of this clustering can be explained by similarity in a set of individual and neighbourhood level predictors believed to be important from an evolutionary, life history perspective.

3.2 Methods

3.2.1 Data and Participants

The primary data source for this study was the Avon Longitudinal Study of Parents and Children (ALSPAC) (Boyd et al. 2013; Golding et al. 2001). ALSPAC is a large and ongoing birth cohort study centred on the city of Bristol (population in 2014: 437,500) in the South-West of England. The original sample contained 14,451 pregnancies, with expected delivery dates between the 1 April 1991 and 31 December 1992, which resulted in 14,062 live births (13,988 children alive at 1 year of age). The study sample is broadly representative of the British population in terms of socioeconomic and medical markers although there is some overrepresentation of White, affluent Britons. Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees. The ALSPAC website contains details of all the data that are available through a fully searchable data dictionary (http://www.bris.ac.uk/alspac/researchers/data-access/data-dictionary/).

Most of the data used in the current study were collected through postal questionnaires which were sent to the study children's mothers every few months. Information on adolescent sexual behaviour was obtained during the so-called Teen Focus 4 clinic (TF4; target age = 17.5), during which the study teenagers were asked to complete a computer session on sexual behaviour.

For this age group, sexual activity can be considered normative behaviour in the population under consideration (British teenagers). According to figures from the third National Surveys of Sexual Attitudes and Lifestyles (Natsal-3), the median age at first heterosexual intercourse in England, Scotland and Wales for the age group 16-24 years is 16 (IQR: 15-18) for both males and females, with about 30% reporting heterosexual intercourse before the age of 16 (Mercer et al. 2013). 64% of the teenagers in the ALSPAC sample used here had experienced sexual activity by 17.5 years of age.

The Office for National Statistics produced the local deprivation data. ALSPAC has been matched to the UK government's National Pupil Database, which provides the educational data used in the current study (viz., an anonymized school identifier and educational achievement at the end of Key Stage 4).

The initial study sample consisted of adolescents who were in the core ALSPAC sample and had a valid outcome value (had sexual intercourse by TF4: yes/no) (n = 4,058). I excluded twins to avoid issues of non-independence (new n = 3,973). Individuals without a valid school or area identifier were dropped from the sample (new n = 3,140). Finally, adolescents with missing values for more than of 14 out of the 20 predictors were also excluded (final n = 2,877).

A comparison of the resulting analysis sample with the attrition sample – i.e., all individuals (singleton births) in the core ALSPAC sample who were alive at 1 year but not included in the analysis sample – reveals that the analysis sample is skewed toward families of higher socioeconomic status (see Table 78 in the appendix to chapter 3 for full comparison). At baseline (study pregnancy), parents in the analysis sample were, on average, more educated and less likely to be renting their home (rather than mortgaging). Mothers in these families were older when they became pregnant for the first time. Families in the analysis sample also tended to reside in less deprived areas. Compared to national figures, only 2.8% of the study adolescents (n = 81) lived in the 10% most deprived areas in England. Finally, the study adolescents tend to perform better in secondary education.

3.2.2 Variables

3.2.2.1 Dependent variables

At Teen Focus 4, participants were asked a number of questions about their sexual history in the context of chlamydia screening, including whether they had ever had sexual intercourse with another young person. Unfortunately, they were not asked directly about their age at first sex.

3.2.2.2 Independent variables

3.2.2.2.1 Socioeconomic status

Socioeconomic status (SES) is known to be reliably associated with numerous outcomes. In addition, household SES has been conceptualized as a measure of environmental harshness in a life history framework (Ellis et al. 2009). Here, household

socioeconomic status was operationalized as maternal and paternal education at the study child's pregnancy, financial difficulties, and home ownership status.

Extended education and early parenthood are incompatible, and investment in education is generally associated with a slower life history strategy as discussed above. Maternal and paternal education were included as (ordinal) categorical variables with five categories based on the highest educational qualification obtained, as explained in chapter 2 (2.1.1). The categories are: 1) no degree/CSE; 2) vocational qualification; 3) O-levels; 4) A-levels; and 5) degree.

A trichotomous categorical variable indicated whether mothers reported experiencing no, some, or many financial difficulties when the study child was approximately 7 years old, based on reported difficulties in affording food, clothing, heating, rent or mortgage, "things you need for your children", "costs of educational courses", medical or dental care, and child care.

Home ownership status - renting, mortgaging, or owning – was assessed when the study child was around 10 years old.

3.2.2.2.2 Parental life history trajectories

The analysis models included several variables intended to capture parental life history pace. The two most direct measures were whether the mother reported having sex before the age of sixteen and maternal age at first pregnancy. I also included mother's retrospectively reported age at menarche, as timing of puberty is also considered a life history trait which also predicts the onset of sexual behaviour (Ellis 2004), and paternal age at index pregnancy. Male first pregnancy data were not available.

3.2.2.2.3 Parental investment and father absence before the age of 10

The parenting scores used to examine the importance of paternal and maternal care, first derived for (Lawson & Mace 2009), are standardized measures based on the frequency with which the mother reported engaging in a set of parenting activities involving her direct interaction with the study child (mother score) and the frequency with which the father was reported by the mother to perform the same set of activities (father score; see Box 1 for the full list of assessed childcare activities). The minimum score of 0 indicates that a parent did not engage in any of the parenting activities, while

the maximum score of 10 means that he or she engaged in all of them at maximum frequency, that is, 'nearly every day'.

Box 1. Activities assessed for ALSPAC parenting scores

Show pictures/reading / Cuddle with child / Play with toys / Physical play / Feed/prepare food / Take walking/to playground / Sing to child / Bathe child / Imitation games / Put to bed / Make things with / Swimming / Draw or paint / Take to classes / Shopping / Watch sports / Help with homework / Conversations / Prepare things for school

I also examined the association between father absence before the age of 10 and adolescent sexual behaviour. If the biological father was present in the household at 10 years, the adolescents were considered to have grown up in a father-present household; if the biological father was not present at 10 years, they were treated as having grown up in a father-absent household.

3.2.2.2.4 Neighbourhood deprivation

The measure of neighbourhood deprivation used here was the Index of Multiple Deprivation 2010. Individual records in ALSPAC can be linked (using post codes) to indices of local deprivation produced by the UK government's Office for National Statistics (ONS). The English Indices of Deprivation 2010 (see McLennan et al. (2011) for details on their construction) are measures of deprivation for so-called Lower layer Super Output Areas (LSOAs). LSOAs are geographical areas defined by the ONS for statistical purposes, with populations numbering between 1,000 and 3,000 (or 400 and 1,200 households).

The English Indices of Deprivation 2010 comprise indices of deprivation in seven domains plus a summary measure known as the Index of Multiple Deprivation 2010 (IMD 2010). The domain indices roughly correspond to the proportion of the population on a low income; involuntary unemployment; poor health outcomes; lack of educational achievement; access to essential services (primary school, Post Office, supermarket/convenience store and GP) and housing; crime levels; and the quality of housing and the living environment (see McLennan et al. (2011) for a full description). The IMD 2010 mainly uses data from 2008. Higher IMD scores indicate a higher level of

deprivation. More information about this measure of neighbourhood deprivation can be found in 2.2.2.2.

3.2.2.2.5 Personality

A 50-item questionnaire based on the International Personality Item Pool (IPIP) (Goldberg 1999) was administered during a computer session at the Teen Focus 2 clinic, when participating adolescents were around 13.5 years old. The IPIP is based on the Five Factor Model (FFM) of personality (Digman 1990). The IPIP uses emotional stability rather than neuroticism (although the one is simply the inverse of the other). For the sample, Cronbach's α ranged between 0.72 for agreeableness to 0.85 for extraversion, indicating acceptable to good internal consistency for all scales. See chapter 1 (1.3.4) for more on personality from an evolutionary perspective and chapter 2 (2.2.4) for more on the Big Five personality factors and the IPIP.

3.2.2.2.6 Adolescent's educational achievement

I considered the educational achievement of participating adolescents at the end of Key Stage 4, when participants were generally around 16 years old. At this stage of their school careers, pupils in England typically complete a number of General Certificates of Secondary Education (GCSEs). These are graded, from best to worse, A*, A, B, C, D, E, F, G, or U (which stands for ungraded or unclassified). The measure of educational achievement used in this study is the number of GCSEs graded A or A*.

3.2.2.2.7 Pubertal development

I included measures of pubertal development as they are predictive of the timing of the start of sexual behaviour. A binary measure of pubertal development was created based on information from a questionnaire administered when the study adolescents were about 13 years old. If a girl had started her menstrual periods or a boy's voice had changed, this was coded as 1 (not started menstrual periods/no change in voice = 0).

3.2.2.2.8 Age and sex

As there was non-negligible variation in the age of young people when they attended Teen Focus 4 (mean = 17.75, SD = 0.35), assessment age was a covariate in all models.

Finally, the sex of the respondent was included to account for possible sex differences in sexual behavioural development.

3.2.2.3 Social structure

3.2.2.3.1 Friendship networks

Details about the construction of the friendship network identifiers can be found in chapter 2 (2.3.1.3.3). They are based on a questionnaire called *You and Your Friends*, which ALSPAC participants were sent in 2008, when they were 15-17 years old, and which asked them to list up to five friends. The directed edge list was converted to an undirected edge list because. Individuals with a valid outcome were then assigned to friendship networks based on the undirected edge list, as described in chapter 2. This procedure left me with 1,115 individuals in 411 friendship networks with 2 or more members. While some individuals belong to multiple friendship networks, I use only one, randomly chosen friendship network per respondent in the analyses that follow.

3.2.2.3.2 Schools

I used ALSPAC's anonymized secondary school identifiers at Key Stage 4, when pupils are ~15 years old, as the school classification. These were missing for around 18% of the core sample. Respondents attended 79 schools with a mean of 36.4 respondents per school (range: 1-204).

3.2.2.3.3 Neighbourhoods

LSOAs functioned as the neighbourhood classification. For privacy reasons, ALSPAC does not provide LSOA identifiers for individuals residing in LSOAs with few participants, resulting in some missing data (~16% of the core ALSPAC sample of live-births). The LSOA data indicate where respondents were living on the 1st of January 2008, when they were, on average, about 17 years old. The respondents in the study sample resided in 563 areas (on the 1st of January 2008), with a mean of 5.1 respondents per neighbourhood (range: 1-18). Between 1/1/2001 and 1/1/2005, 457 of the 2,839 (16.1%) respondents for which I know the residential LSOA at both time points moved to a different LSOA (in the Bristol area). Between 1/1/2005 and

1/1/2008, 216 out of the 2,868 (7.5%) respondents moved to a different LSOA (in the Bristol area).

LSOAs are quite small, containing between 400 and 1200 households, and are therefore likely to correspond to an individual's actual living environment than larger areas like wards, and were designed to cover a relatively small geographic area and exhibit some degree social homogeneity (using criteria related to housing).

3.2.3 Analysis

3.2.3.1 Modelling approach

First, I ran a set of models without substantive predictors (apart from age and sex) in order to assess the amount of variance located at different levels of the social structure (individual/family, school, area, friendship network). This set consists of 8 models, each one using different combination of the three social structure classifications (neighbourhood, school, friendship network), from an individual-only model to a model with all classifications. While the full model is of most interest, running the full set of social structure models may nonetheless be instructive as it can suggest ways in which models with a simpler (social) structure lead to the misattribution of variation.

Next, I ran five models with different blocks of life history predictors. A *socioeconomic status* model included maternal education, paternal education, financial difficulties and home ownership status; a *parental life history* model used the following measures of parental life history pace: maternal age at menarche, maternal age at first birth, maternal age at first sexual intercourse (<16 or older) and paternal age at index pregnancy; a *parental investment* model included female and male parenting scores and father absence before the age of 10; a *neighbourhood deprivation* model with the Index of Multiple Deprivation 2010; a *personality* model with the Big Five personality factors; a *pubertal development* model with a measure of the timing of pubertal development; and a model with all of the foregoing predictors. Additionally, I ran two slightly modified versions of the last model. In the first, I added the participant's educational achievement in order to assess the impact of a young person's own educational prospects. I did not include this in earlier models because this is arguably itself a life history trait and, moreover, strongly related to parental SES. In the second variation on

the full model, I added an interaction between father absence and neighbourhood deprivation in order to examine whether the effect of father absence before the age of 10 depends on neighbourhood deprivation (cf., Smith & Elander 2006).

If adding a predictor leads to a reduction of the share of the total variance at a particular level of the social structure, it suggests that part of the similarity of members of the same group at that level is actually due to similarity at that level of the added predictor (Tranmer et al. 2014). For example, if adding personality traits leads members of the same friendship network to appear less similar in their level of sexual experience, as indicated by a lower share of the variance at the level of friendship networks after adding personality traits, then this suggests that part of the similarity of friends in sexual behaviour stems from their similarity in personality.

3.2.3.2 Modelling technique

I ran logistic multiple classification models (Fielding & Goldstein 2006) with individuals nested in schools, areas and friendship networks (Tranmer et al. 2014) to investigate the social clustering of the binary outcome "respondent had sex by Teen Focus 4" and its association with life history predictors. Four classifications were considered here: 1) the individual/household; 2) secondary school during Key Stage 4; 3) neighbourhood (Lower layer Super Output Area); and 4) friendship networks. The analyses used Markov chain Monte Carlo (MCMC) estimation methods, as implemented in MLwiN (Browne 2005). Statistical modelling was performed in MLwiN 2.30 (Rasbash et al. 2014) run from within Stata 12 (StataCorp. 2011) using the command *runmlwin* (Leckie & Charlton 2012).

3.2.3.3 Intraclass correlation and explained variance

The model estimates of the classification variance parameters from the logistic regressions were used to calculate residual intraclass correlation coefficients (ICCs) with a latent variable approach (Snijders & Bosker 1999), as explained in chapter 2 (2.3.1.1.2). Briefly, the intraclass correlation is a measure of the similarity of members of the same group (e.g., pupils in the same school), viz., the expected correlation in the outcome of interest between two randomly selected members of the same group. The explained variance is the variance of the so-called linear predictor, a variable containing

each individual's model-based predicted value (for the latent variable) (Snijders & Bosker 1999).

3.2.3.4 Missing data

The proportion of missing data varied between 19.4% for conscientiousness to 0% for sexual experience by ~17.5, sex, age, and neighbourhood deprivation. For participants, the mean number of missing values in the final sample was 2.05, with a maximum of 14, although more than 80% of participants in the final sample had fewer than 5 missing values. I used multiple imputation, conducted in Stata 12, to avoid well-known problems associated with complete-case analysis (i.e., biased parameter estimates and loss of power) (Sterne et al. 2009). Prior to imputation, I standardized all age variables, neighbourhood deprivation, parenting scores, and personality trait scores, and log-transformed neighbourhood deprivation, cubed the mother's parenting score, and squared the father's parenting score in order to approximate normal distributions. All analyses were performed on 20 imputed data sets. I used 'mi estimate' command in Stata 12 which calculates parameter estimates for each imputed data set individually and then combines them according to Rubin's rules (Rubin 1987).

Data were more likely to be missing if collected later during the study. Family socioeconomic status was negatively correlated with the proportion of missing data. For example, the mean number of missing values was 3.5 if mothers were in the lowest education category, which decreased with increasing educational level to 1.3 for the highest education category.

3.3 Results

3.3.1 Sample description

Descriptive statistics for all of the study variables are given in Table 8. Pairwise correlations between the study variables can be found in Table 79 in the appendix to chapter 3.

Table 8. Descriptive statistics for model variables

		All		Did not have sex	Had sex
Variables	**Units *or* categories**	**Mean (SD) or distribution across categories (%)**	**n (% of sample)**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**
Had sexual intercourse by Teen Focus 4	No	1,031 (35.8%)	2,877 (100%)	1,031 (100%)	0 (0%)
	Yes	1,846 (64.2%)		0 (100%)	1,846 (100%)
Age	Years	17.75 (0.35); range = 16.42 – 19.42	2,877 (100%)	17.69 (0.31)	17.78 (0.37)
Sex	Male	1,244 (43.2%)	2,877 (100%)	531 (51.5%)	713 (38.6%)
	Female	1,633 (56.8%)		500 (48.5%)	1133 (61.4%)
Maternal education	None/CSE	350 (12.4%)	2,826 (98.2%)	93 (9.2%)	257 (14.2%)
	Vocational	230 (8.1%)		68 (6.7%)	162 (8.9%)
	O-levels	1,050 (37.2%)		334 (33.0%)	716 (39.5%)
	A-levels	745 (26.4%)		293 (29.0%)	452 (24.9%)
	Degree	451 (16.0%)		223 (22.1%)	228 (12.6%)
Paternal education	None/CSE	509 (18.5%)	2,754 (95.7%)	138 (13.9%)	371 (21.1%)
	Vocational	235 (8.5%)		74 (7.4%)	161 (9.2%)
	O-levels	640 (23.2%)		222 (22.3%)	418 (23.8%)
	A-levels	786 (28.5%)		283 (28.4%)	503 (28.6%)
	Degree	584 (21.2%)		279 (28.0%)	305 (17.4%)
Financial difficulties	None	1,272 (50.4%)	2,522 (87.7%)	498 (53.6%)	774 (48.6%)
	Some	964 (38.2%)		336 (36.2%)	628 (39.4%)
	Many	286 (11.3%)		95 (10.2%)	191 (12.0%)
Home ownership status	Mortgaged	2110 (84.8%)	2,487 (86.4%)	793 (85.7%)	1,317 (84.1%)
	Owned	176 (7.1%)		82 (8.9%)	94 (6.0%)
	Rented	201 (8.1%)		50 (5.4%)	151 (9.7%)
Mother had sex with boyfriend when <16	No	2,154 (85.3%)	2,526 (87.8%)	827 (90.0%)	1,327 (82.6%)
	Yes	372 (14.7%)		92 (10.0%)	280 (17.4%)
Maternal age at first pregnancy	Years	25.72 (4.81); range = 14 – 42	2,845 (98.9%)	26.57 (4.71)	25.25 (4.80)
Maternal age at menarche	Years	12.83 (1.47); range = 8 – 22	2,515 (87.4%)	12.89 (1.49)	12.80 (1.46)
Paternal age at index pregnancy	Years	31.42 (5.44); range = 16 – 60	2,693 (93.6%)	31.95 (5.29)	31.12 (5.50)
Female parental care at 18 months	10-point scale	8.01 (0.86)	2,740 (95.2%)	8.01 (0.84)	8.02 (0.86)
Male parental care at 18 months	10-point scale	6.18 (1.55)	2,653 (92.2%)	6.23 (1.54)	6.16 (1.56)
Father absence at 10 years	Present	2,187 (83.8%)	2,610 (90.7%)	842 (88.5%)	1,345 (81.1%)
	Absent	423 (16.2%)		109 (11.5%)	314 (18.9%)
Index of Multiple Deprivation	Composite score	13.97 (11.45); range = 1.43 - 70.36	2,877 (100%)	12.97 (10.80); range = 1.43 - 70.36	14.52 (11.76); range = 1.43 - 70.36
Pubertal development: voice broken (m) or started menstrual periods (f)	No	884 (43.6%)	2,026 (70.4%)	396 (52.2%)	488 (38.5%)
				362 (47.8%)	780 (61.5%)
	Yes	1,142 (56.4%)			
Extraversion	IPIP score	35.15 (6.97)	2,420 (84.1%)	32.60 (7.04)	36.60 (6.50)
Agreeableness	IPIP score	38.38 (5.01)	2,365 (82.2%)	38.12 (5.07)	38.52 (4.97)
Conscientiousness	IPIP score	32.10 (5.65)	2,318 (80.6%)	32.96 (5.66)	31.61 (5.58)
Emotional stability	IPIP score	31.65 (6.49)	2,346 (81.5%)	32.31 (6.24)	31.27 (6.60)
Openness	IPIP score	36.26 (5.58)	2,366 (82.2%)	36.49 (5.62)	36.13 (5.55)
Adolescent education: GCSE results	No A or A* result	1,179 (40.1%)	2,877 (100%)	308 (29.9%)	871 (47.2%)
	1 A or A* result	382 (13.3%)		126 (12.2%)	256 (13.9%)
	2 A or A* results	228 (7.9%)		85 (8.2%)	143 (7.8%)
	3 A or A* results	170 (5.9%)		62 (6.0%)	108 (5.9%)
	4-6 A or A* results	393 (13.7%)		174 (16.9%)	219 (11.9%)
	7-13 A or A* results	525 (18.3%)		276 (26.8%)	249 (13.5%)

3.3.2 Clustering

The first set of logistic multiple classification models explored the clustering of "had sex by Teen Focus 4" across the social structure (while including sex and age as covariates). Table 9 lists the clustering models in order of goodness of fit, starting with the best-fitting model according to the deviance information criterion (DIC; see 2.3.1.2). The school-only model (DIC = 3643.90), neighbourhood-only model (DIC = 3664.82), and friendship-network-only model (DIC = 3610.51) all fitted the data better than the individual-only model (DIC = 3672.43). However, the neighbourhood classification did not improve the fit when included alongside either the school or the friendship network classification (or both), which suggests that neighbourhoods were 'borrowing' variance from schools and/or friendship networks in the neighbourhood-only model. Inclusion of the friendship network had the largest impact on model fit. Using the rules of thumb for DIC interpretation given in chapter 2, it is clear that models that did not contain both the friendship network and the school classification receive essentially no support ($\Delta DIC \geq 10$). The model without the neighbourhood classification, however, received substantial support ($\Delta DIC \leq 2$), suggesting that the neighbourhood classification could be left out of the model without much of an impact on model fit.

Table 9. Social clustering models ranked by model fit, in descending order based on Deviance Information Criterion

Classifications included	DIC	ΔDIC
Individual + school + neighbourhood + friendship network	3585.97	0
Individual + school + friendship network	3586.96	0.99
Individual + friendship network	3610.51	24.54
Individual + neighbourhood + friendship network	3610.81	24.84
Individual + school + neighbourhood	3643.32	57.35
Individual + school	3643.90	57.93
Individual + neighbourhood	3664.82	78.85
Individual	3672.43	86.46

Table 10 provides model estimates of the (residual) variance associated with the different classifications, for the single-classification models and the combined model, and expresses these as intraclass correlations (ICCs). Even in the single-classification models without substantive predictors (apart from respondent age and sex), the residual intraclass correlation at the level of schools (0.029) and neighbourhoods (0.033) was very modest. In the combined model, a residual ICC of 0.025 was found for

schools while only 0.010 remained for neighbourhoods. A far larger residual ICC was found for friendship networks: 0.25 in the combined model.

Table 10. The social clustering of adolescent sexual behaviour: residual variances and intraclass correlations (rICC's) at the school-, neighbourhood-, and friendship-network-level

		Individual	School	Neighbourhood	Friendship network	Combined
Classification						
School	Variance		0.098			0.107
	rICC		0.029			0.023
Neighbourhood	Variance			0.113		0.048
	rICC			0.033		0.010
Friendship network	Variance				1.248	1.146
	rICC				0.275	0.250
	DIC	3672.43	3643.90	3664.82	3610.51	3585.97

3.3.3 Life history predictors

3.3.3.1 Unadjusted models

The results for unadjusted socioeconomic status, parental life histories, and parental investment models are given in Table 11, while those for neighbourhood deprivation, personality, and pubertal development are given in Table 12. Household socioeconomic status was negatively associated with the probability of a young person having had sex. Young people were less likely to be sexually experienced if their parents were more educated (OR = 0.50, p = 0.003 for maternal degree vs. no educational qualification or CSE; OR = -0.59, p = 0.01 for paternal degree vs. no educational qualification or CSE) or if they were living in rented rather than owned accommodation (OR = 0.55, p = 0.04). Mother-reported financial difficulties did not independently predict whether adolescents had had sex. When considering the explained variance, note that control variables age and sex explained about 3.5% of the variance when considered in isolation.

Table 11. Model results for unadjusted socioeconomic status, parental life histories, and parental investment models predicting whether adolescents have had sexual intercourse

	Socioeconomic status			Parental life histories			Parental investment		
Parameter	OR	95% CI	p	OR	95% CI	p	OR	95% CI	p
Age at Teen Focus 4	1.35	1.21 – 1.50	<0.001	1.35	1.21 – 1.49	<0.001	1.36	1.23 – 1.51	<0.001
Sex	0.55	0.45 – 0.67	<0.001	0.54	0.44 – 0.66	<0.001	0.53	0.44 – 0.65	<0.001
Maternal education (ref.: none/CSE)									
Vocational	0.92	0.58 – 1.46	0.714						
O-level	0.87	0.60 – 1.24	0.436						
A-level	0.68	0.46 – 0.99	0.047						
Degree	0.50	0.32 – 0.79	0.003						
Paternal education (ref.: none/CSE)									
Vocational	0.85	0.55 – 1.31	0.466						
O-level	0.76	0.54 – 1.07	0.114						
A-level	0.76	0.55 – 1.05	0.099						
Degree	0.59	0.40 – 0.86	0.007						
Home ownership status (ref.: rented)									
Mortgaged	0.74	0.48 – 1.13	0.167						
Owned	0.55	0.31 – 0.97	0.041						
Financial difficulties (ref.: none)									
Some	1.12	0.89 – 1.41	0.328						
Many	1.02	0.72 – 1.44	0.925						
Maternal age at menarche				0.95	0.86 – 1.05	0.313			
Maternal age at first pregnancy				0.80	0.72 – 0.90	<0.001			
Mother had sex when <16				1.72	1.28 – 2.33	0.001			
Paternal age at index pregnancy				0.96	0.86 – 1.07	0.462			
Maternal parenting score							1.00	0.90 – 1.11	0.998
Paternal parenting score							1.02	0.91 – 1.13	0.786
Father absence before the age of 10 (ref.: present)							1.87	1.40 – 2.49	<0.001
	Variance	Proportion of total variance		Variance	Proportion of total variance		Variance	Proportion of total variance	
Explained variance	0.377	0.076		0.329	0.069		0.256	0.053	
Residual variance	4.557	0.924		4.457	0.931		4.802	0.947	
School residual variance	0.064	0.013		0.079	0.016		0.120	0.025	
Neighbourhood residual variance	0.052	0.011		0.054	0.011		0.074	0.015	
Friends residual variance	1.151	0.233		1.035	0.216		1.062	0.221	
Individual residual variance	3.290	0.667		3.290	0.687		3.290	0.685	
Total variance	4.934	1		4.786	1		4.802	1	

Table 12. Model results for unadjusted neighbourhood deprivation, personality models predicting whether adolescents have had sexual intercourse

	Neighbourhood deprivation			Personality			Puberty		
Parameter	OR	95% CI	p	OR	95% CI	P	OR	95% CI	p
Age at Teen Focus 4	1.36	1.23 – 1.51	<0.001	1.36	1.22 – 1.51	<0.001	1.35	1.22 – 1.50	<0.001
Sex	0.53	0.43 – 0.65	<0.001	0.68	0.54 – 0.85	0.001	0.57	0.47 – 0.70	<0.001
Index of Multiple Deprivation 2010	1.14	1.03 – 1.28	0.015						
Big Five personality dimensions									
Extraversion				2.19	1.92 – 2.50	<0.001			
Agreeableness				0.90	0.79 – 1.02	0.090			
Conscientiousness				0.83	0.73 – 0.94	0.004			
Emotional stability				0.80	0.71 – 0.91	0.001			
Openness				0.92	0.81 – 1.04	0.198			
Pubertal development							1.72	1.38 – 2.16	<0.001
	Variance	Proportion of total variance		Variance	Proportion of total variance		Variance	Proportion of total variance	
Explained variance	0.222	0.046		0.781	0.154		0.255	0.053	
Residual variance	4.576	0.954		4.286	0.846		4.557	0.947	
School residual variance	0.117	0.024		0.130	0.026		0.145	0.030	
Neighbourhood residual variance	0.075	0.016		0.110	0.022		0.069	0.014	
Friends residual variance	1.095	0.228		0.756	0.149		1.053	0.219	
Individual residual variance	3.290	0.686		3.290	0.649		3.290	0.684	
Total variance	4.798	1		5.066	1.000		4.812	1	

Two parental life history variables were significant in the unadjusted parental life histories model. Adolescents whose mother was older at first pregnancy were less likely to have had sex (OR = 0.80, p < 0.001). Those whose mother had an early sexual debut, defined as voluntary sexual intercourse with another young person before the age of 16, were more likely to have had sex (OR = 1.72, p = 0.001). Maternal age at menarche and paternal age at index pregnancy did not add predictive power to the model.

Parenting scores were not significantly associated with sexual experience in late adolescence. Adolescents who grew up in a father-absent household were more likely to have had sexual intercourse (OR = 1.87, p < 0.001). Finally, higher levels of neighbourhood deprivation were associated with an increased probability of my measure of sexual experience (OR = 1.14, p = 0.02).

Three of the Big Five personality factors were significant predictors of whether an adolescent had had sex by 17.5 years of age. Adolescents who score higher on extraversion (OR = 2.19, p < 0.001), lower on conscientiousness (OR = 0.83, p = 0.004), and lower on emotional stability (OR = 0.80, p = 0.001) were more likely to have had sex. The unadjusted personality model, with age and sex, explains 13.3% of the variance. Adding personality reduced the residual intraclass correlation at the level of friendship networks from 0.250 to 0.181, a reduction of about 28%, a finding that suggests that some of the similarity between friends in sexual activity may be due to similarity in personality traits.

Adolescents who experienced earlier puberty were more likely to have had sex (OR = 1.72, p < 0.001), consistent with the idea that they are on a faster developmental trajectory.

3.3.3.2 All predictors apart from educational achievement

In the full, adjusted model (Table 13; see Figure 7 for visual impression of effect sizes), parental education was still a significant predictor (OR = 0.50, p = 0.01 for maternal degree vs. no educational qualification or CSE), although paternal degree (OR = 68, p = 0.07) just lost significance at the 5% level, while the coefficients for home ownership status were substantially smaller and no longer significant (OR = 0.82, p = 0.52 for owned vs. rented). Maternal age at first pregnancy is no longer significant (OR = 0.93, p

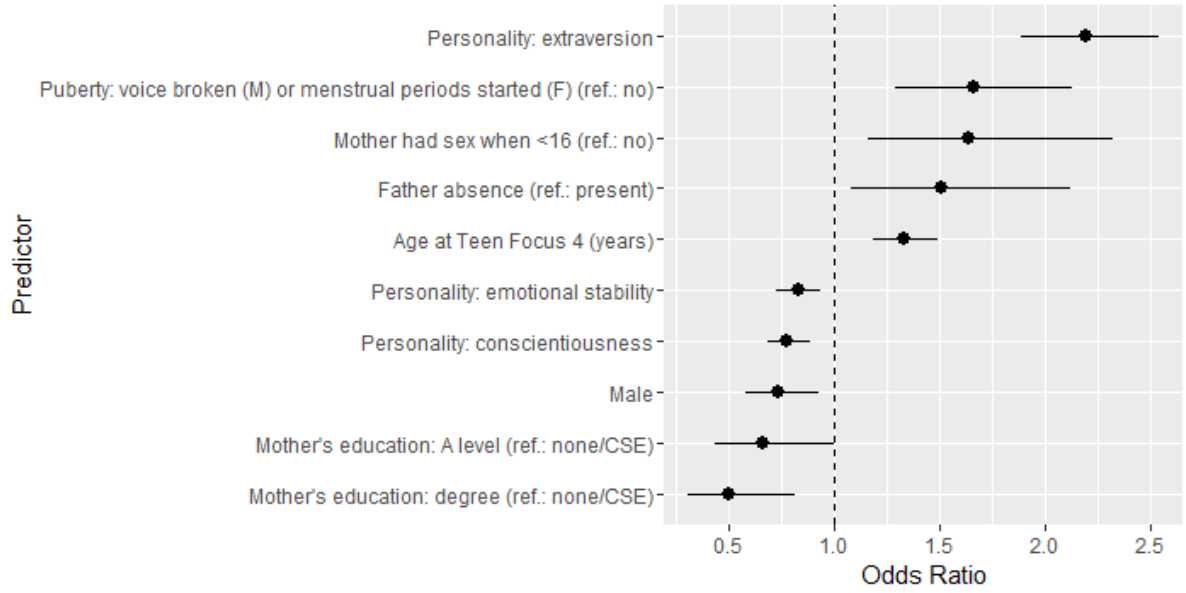
= 0.25). Another notable difference between the full and unadjusted models is that the estimate of the coefficient for IMD 2010 was strongly reduced and no longer significant (1.02, p = 0.73). Extraversion (OR = 2.19, p < 0.001), conscientiousness (B = 0.78, p < 0.001), and emotional stability (OR = 0.83, p = 0.005) remained significant predictors; agreeableness (OR = 0.92, p = 0.25) and openness (OR = 0.97, p = 0.67) did not predict sexual behaviour.

Table 13. Model results for a combined household socioeconomic status + parental life histories + parental investment + neighbourhood deprivation + personality model; the same model plus respondent's education

	All predictors except adolescent education			All predictors including adolescent education		
Parameter	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Age at Teen Focus 4	1.33	1.19 – 1.49	<0.001	1.34	1.19 – 1.50	<0.001
Sex	0.74	0.58 – 0.93	0.012	0.64	0.50 – 0.82	<0.001
Maternal education (ref.: none/CSE)						
Vocational	0.93	0.57 – 1.53	0.784	0.93	0.56 – 1.53	0.768
O-level	0.83	0.57 – 1.22	0.354	0.87	0.59 – 1.28	0.467
A-level	0.66	0.44 – 1.00	0.048	0.75	0.49 – 1.14	0.176
Degree	0.50	0.31 – 0.82	0.006	0.63	0.39 – 1.04	0.071
Paternal education (ref.: none/CSE)						
Vocational	0.85	0.54 – 1.34	0.481	0.83	0.53 – 1.31	0.431
O-level	0.88	0.61 – 1.26	0.478	0.93	0.64 – 1.34	0.690
A-level	0.82	0.58 – 1.16	0.257	0.90	0.63 – 1.27	0.535
Degree	0.68	0.45 – 1.02	0.066	0.83	0.55 – 1.26	0.387
Home ownership status (ref.: rented)						
Mortgaged	0.97	0.61 – 1.54	0.882	1.06	0.66 – 1.71	0.796
Owned	0.82	0.45 – 1.50	0.522	0.93	0.51 – 1.72	0.823
Financial difficulties (ref.: none)						
Some	1.05	0.83 – 1.32	0.704	1.02	0.80 – 1.29	0.894
Many	0.90	0.61 – 1.33	0.609	0.89	0.60 – 1.31	0.546
Maternal age at menarche	0.97	0.86 – 1.09	0.602	0.96	0.85 – 1.08	0.495
Maternal age at first pregnancy	0.93	0.82 – 1.05	0.254	0.94	0.83 – 1.07	0.330
Mother had sex when <16	1.64	1.16 – 2.32	0.005	1.63	1.15 – 2.31	0.006
Paternal age at index pregnancy	1.00	0.88 – 1.12	0.932	1.00	0.89 – 1.13	0.992
Maternal parenting score	1.00	0.90 – 1.12	0.959	1.02	0.91 – 1.14	0.769
Paternal parenting score	1.07	0.95 – 1.21	0.257	1.08	0.96 – 1.21	0.226
Father absence (ref.: present)	1.51	1.08 – 2.12	0.016	1.46	1.04 – 2.04	0.029
Index of Multiple Deprivation 2010	1.02	0.90 – 1.15	0.728	0.98	0.87 – 1.11	0.728
GCSE results (ref.: no A or A*)						
One				0.68	0.49 – 0.96	0.027
Two				0.49	0.32 – 0.74	0.001
Three				0.56	0.35 – 0.89	0.016
Four, five or six				0.44	0.31 – 0.63	<0.001
Seven or more				0.31	0.22 – 0.45	<0.001
Big Five personality dimensions						
Extraversion	2.19	1.89 – 2.54	<0.001	2.13	1.83 – 2.47	<0.001
Agreeableness	0.92	0.81 – 1.06	0.251	0.95	0.83 – 1.09	0.427
Conscientiousness	0.78	0.69 – 0.89	<0.001	0.80	0.70 – 0.91	0.001
Emotional stability	0.83	0.73 – 0.94	0.005	0.84	0.73 – 0.96	0.01
Openness	0.97	0.85 – 1.11	0.670	1.08	0.94 – 1.24	0.273
Pubertal development	1.66	1.29 – 2.13	<0.001	1.69	1.31 – 2.17	<0.001
	Variance	**95% CI**	**Proportion of total variance**	**Variance**	**95% CI**	**Proportion of total variance**
Explained variance	1.193		0.209	1.396		0.236
Residual variance	4.522		0.791	4.526		0.764
School residual variance	0.079	-0.02 – 0.19	0.014	0.051	-0.04 – 0.14	0.009
Neighbourhood residual variance	0.078	-0.08 – 0.24	0.014	0.075	-0.09 – 0.24	0.013
Friends residual variance	1.075	0.35 – 1.80	0.188	1.110	0.35 – 1.87	0.187
Individual residual variance	3.290		0.576	3.290		0.556
Total variance	5.715		1.000	5.922		1.000

Compared to the multiple classification model without substantive predictors (apart from age and sex), the residual ICC of schools decreased from 0.023 to 0.014, that of neighbourhoods from 0.010 to 0.014, and that of friendship networks by nearly roughly a quarter, from 0.250 to 0.188. The proportion of explained variance for the full model, without respondent's educational achievement, was 0.209.

Figure 7. Odds ratios with 95% confidence intervals for significant predictors of experience with sexual intercourse. For continuous predictors the OR corresponds to a 1 SD increase; for categorical variables, the OR compares membership of a category to a reference category



3.3.3.3 All predictors including educational achievement

Respondent's educational achievement was a highly significant predictor of onset of sexual behaviour (Table 13). Generally, the higher the number of A or A* results a respondent achieved, the lower was the probability of him or her having had sex by 17.5 years of age. Adding educational achievement increased the explained variance, as a proportion of total variance, from 0.209 (full model without respondent's educational achievement) to 0.236. Adding the respondent's educational achievement to the full model markedly reduced the estimates of the effects of maternal and paternal education, neither of which were then significant. The proportion of explained variance for an education-only model (with age and sex; Table 80 in the appendix to chapter 3) was 0.10.

3.3.3.4 Interaction between father absence and neighbourhood deprivation

The interaction between father absence and neighbourhood deprivation (Table 80 in the appendix to chapter 3) was not significant (OR = 0.76, p = 0.09), suggesting that the father absence effect was independent from neighbourhood deprivation.

3.4 Discussion

3.4.1 Main findings

In a sample of contemporary British adolescents, experience of sexual behaviour by 17.5 years clustered at the level of friendship networks but not in schools or neighbourhoods. This clustering among friends was not due, for the most part, to clustering of life history factors that predict sexual behaviour. Friendship formation based on similarities in personality traits did appear to explain about a quarter of the clustering of experience of sexual activity among friends. Life history predictors such as SES and father absence before the age of 10 did account for some of the variation found in adolescent experience of sexual behaviour but no evidence was found for effects of parental care or neighbourhood deprivation, counter to predictions of some life history models of adolescent development.

The almost complete lack of clustering of sexual activity at the school or neighbourhood level, even before adding control variables such as household SES, contrasts with previous studies showing the impact of neighbourhood characteristics on risky sexual behaviour (Chen et al. 2010) (Warner et al. 2011) and early reproduction (Nettle 2010), including studies on teenage pregnancy rates in Britain which show very strong associations with neighbourhood deprivation (Conrad 2012). The reason for these discrepancies may be that this study's outcome measure, having experience with sexual intercourse by 17.5 years, is normative. The fact that we found no school-level clustering to speak of, is possibly due to my definition of the school classification, which was simply based on a schoo**l** identifier. A school class classification might have revealed clustering consistent with school peer influences (cf., Fletcher 2007; Ali & Dwyer 2011; Van de Bongardt et al. 2015), but secondary school teaching in the UK mixes different classes for different subject lessons, so school class is not as meaningful as it is in primary schools.

Friends are far more similar than non-friend age peers going to the same school or living in the same neighbourhood. This suggests that differences between schools and neighbourhoods, in this sample, have little impact on adolescent experience of sexual activity by age 17.5. Nor do schools and neighbourhoods appear to possess differing normative climates resulting in different levels of sexual activity. My results are

consistent with the possibility of a multiplier effect for individual-level interventions as behaviours may cascade through friendship networks (Ali & Dwyer 2011). This does require that the similarity of friends is at least partly due to social influence, something I was unable to test directly.

In contrast to expectations based on life history theory (1.4.1), neighbourhood deprivation did not predict experience of sexual activity. This lack of neighbourhood-level clustering is consistent with the results of previous multisystem studies of risky adolescent sexual behaviour (Miller et al. 2000; Voisin et al. 2014; Chen et al. 2010), which did not find measures of perceived neighbourhood quality or exposure to violence to show the associations predicted by life history theory. On the other hand, other studies, for example Nettle (2010), Wilson and Daly (1997) and Uggla and Mace (2015), did find that ecological context (neighbourhood characteristics of socioeconomic deprivation and life expectancy) had effects on age at first birth. These differences might be explained by the fact that the studies mentioned used age at first birth as an outcome rather than experience with sexual intercourse. Moreover, the neighbourhoods in Wilson & Daly (1997) showed an extraordinary range in homicide levels and (homicide-adjusted) life expectancy, which might result in more pronounced life history effects. It should be noted, however, that Nettle (2010) did not control for household SES; and Wilson & Daly (1997) was performed entirely at the neighbourhood-level. The study from Northern Ireland (Uggla & Mace 2016) that did look at both individual and neighbourhood levels found individual SES was by far the largest predictor of age at first birth, but neighbourhood characteristics had small additional effects.

In line with evolutionary predictions (1.4.1), lower household SES and father absence were both associated with a greater probability of having had sex, possibly functioning as cues to a harsh environment in which a faster life history strategy is appropriate, although the current study design does not allow me to decide among competing explanations (which requires a focus on pathways).

Personality was the strongest predictor of experience of sexual intercourse, in line with existing studies on sexual behaviour (Hoyle et al. 2000; Nettle 2006; Miller et al. 2004; Nettle 2005) and reproductive success (Alvergne et al. 2010; Jokela et al. 2011). My

results also suggest that a sizeable part, around a quarter in the sample, of the similarity of sexual behaviour among friends is due to clustering of personality traits in friendship networks. Thus studies that do not take similarity in personality into account may be overestimating the effect of (descriptive) peer norms on adolescent sexual behaviour.

Our finding that extraverted individuals are more likely to have had sex is consistent with previous findings on extraversion and risky sexual behaviour (Hoyle et al. 2000; Nettle 2006; Miller et al. 2004; Nettle 2005), and fits with Nettle's suggestion that extraversion evolved as a life history strategy premised on high mating success (Nettle 2005; Nettle 2006), characterized by an early sexual debut, unstable pair-bonds, and a high number of sexual partners. The fact that lower conscientiousness predicted a higher probability of having had sex is also in line with previous studies (Hoyle et al. 2000; Schmitt 2004), and the general short-term orientation of low-conscientiousness individuals. Both of these findings had been predicted on evolutionary grounds (1.4.1), based on Nettle's theoretical model.

The negative relationship between emotional stability and sexual intercourse is also in line with the existing empirical literature (Hoyle et al. 2000). Unlike several previous studies (reviewed in Hoyle et al. 2000), which found a negative association between agreeableness and risky sexual behaviour, we did not find an effect of agreeableness on the probability of having had sex. This difference may be due to the nature of our outcome measure, which did not measure *risky* sexual behaviour. Moreover, agreeableness is a desirable attribute in a potential partner which, by increasing opportunities for entering romantic relationships, could counteract any negative effect agreeableness might have on the tendency to engage in sexual intercourse.

In contrast to our prediction of sex difference based on evolutionary theoretical considerations, with boys being predicted to be more likely to have had sex because of a greater tendency to norm violation and opportunistic mating behaviour (1.4.1), girls were found more likely to have had sex by ~17.5. This may partly reflect the fact that experience with sexual intercourse is not contra-normative in this age group in this society. Perhaps this sex difference reflects greater variance in mating success in boys than girls, which *would* be in line with evolutionary thinking about greater male variance in reproductive success, more boys being locked out of the mating market than

girls. Since I included a measure of pubertal development (and most girls *and* boys will be in an advanced stage by ~17.5), it is unlikely to reflect differences in physical maturation, although differences in psychological maturation may play a part.

Whilst I cannot test for it directly, my results indicate more scope for social transmission of sexual norms and attitudes between members of a friendship network, than between peers in school or neighbourhoods who are not friends. However, assortment on the outcome, or similarity in unmeasured predictors thereof, could also account for this clustering. From an evolutionary perspective, the association with educational achievement suggests this may in part reflect trade-offs made by adolescents in how they invest their efforts between education and social and sexual behaviour. Friends (or their parents) may be influential in making such decisions (Burgess & Umaña-Aponte 2011) or indeed help each other achieve their social or educational goals.

3.4.2 Strengths and limitations

This study has a number of strengths. Firstly, and most importantly, unlike other studies in this area, this one includes friendship networks, neighbourhoods and schools in the same multiple classification modelling framework, allowing for a simultaneous estimation of social clustering at each of these different levels while taking the others into account. I was also able to include a wide range of theoretically interesting predictors, such as neighbourhood deprivation and personality, because of ALSPAC's comprehensiveness. The use of ALSPAC also ensured the availability of a relatively large sample.

Several limitations should be kept in mind when interpreting the results reported here. Firstly, our outcome – whether an individual has had sex by the age of ~17.5 – is a fairly crude measure that hides a lot of theoretically and empirically important variation in adolescent sexual behaviour (for instance, age at and relationship context of first sex, number of different sexual partners and contraceptive use). From an evolutionary perspective, mere experience with sexual intercourse might not be the most critical measure. The fact that sex by this age is not contra-normative in the sample could be problematic if life history theory is particularly useful in explaining more extreme life

history trajectories (e.g., very early sexual debut relative to a population). It would be interesting in future work to apply the statistical framework used here to an outcome like teenage pregnancy, which appears to show much stronger associations with what we have called life history predictors (e.g., neighbourhood deprivation: Conrad 2012).

Sample selection is another issue. The effects of life history predictors, such as environmental harshness, as indexed by neighbourhood deprivation, may largely or exclusively manifest themselves at (one or both) extremes of their distribution. As noted above, individuals in the most deprived neighbourhoods made up a relatively small part of our sample: only 2.8% of the study adolescents lived in the 10% most deprived areas in England. More generally, our analysis sample is skewed toward families of higher socioeconomic status (as discussed in Data and Participants).

I would expect most friendship nominations to be reciprocal but a sizeable proportion not to be (Vaquera & Kao 2008). If peer influence is present and moderated by the closeness of the relationship between adolescents, such that closer friends, who are more likely to reciprocate friendship nominations, are more influential (e.g., Mercken et al. 2007), then the inclusion of non-reciprocated friendship nominations would bias (downwards) our estimate of friend similarity. When a study based on data from the National Longitudinal Study of Adolescent to Adult Health (Add Health) explicitly addressed this question in an investigation of the influence on a target individual's sexual activity of that person's closest friend, it found no evidence for an interaction between the sexual activity of the closest friend and whether or not the relevant friend nomination had been reciprocated (Jaccard et al. 2005). If generalizable, this result would indicate that inclusion of non-reciprocated friendship nominations may have had little effect on our results. I also included individuals in the same friendship network if they share a friend, which likewise has the potential to dilute social clustering.

3.4.3 Conclusion

In a sample of British adolescents, experience with sexual intercourse clustered in adolescent friendship networks, but not in neighbourhoods or schools. Thus, the clustering I found in friendship networks was not due to friends experiencing similar socioecological circumstances at the level of neighbourhoods or schools, which would

have been consistent with adaptive flexibility in response to environmental variation. While life history predictors did explain some of the variation in sexual activity, they did not explain much social clustering, strongly suggesting that similarity of life history predictors among friends is not responsible for clustering of sexual experience in friendship networks. Instead, the social clustering of sexual behaviour among friends could be due a tendency to associate with similar others, perhaps because of potential coordination benefits from similarity, or due to social transmission of norms of behaviour among friends, possibly reflecting conformism or prestige bias.

Chapter 4: Social clustering of cooperativeness and its relation to life history predictors

4.1 Introduction

4.1.1 The problem of cooperation

One of the central theoretical questions in evolutionary biology concerns the evolution of cooperation among ultimately self-interested biological units, be they individual cells or multicellular organisms. Humans, in particular, cooperate with unrelated individuals on a remarkable scale, from food-sharing hunter-gatherers to Wikipedia's online community of amateur encyclopaedists. The nub of the problem, from an evolutionary perspective, is that in the struggle for survival and reproduction, co-operators appear destined to being outcompeted by selfish individuals who, while reaping the benefits of the cooperators' behaviour, do not incur its costs.

The problem is often presented in a game-theoretical setting, using the Prisoner's Dilemma (PD) (Axelrod & Hamilton 1981). The situation can be summarized as follows: starting with a well-mixed population, and given a Standard Prisoner's Dilemma (PD) pay-off matrix and a world in which everyone plays one-shot games of PD with randomly selected others, defection is the dominant strategy. This means that, whatever the initial (non-zero) frequencies of strategies C (cooperate) and D (defect), the entire population of strategies will, given enough time, come to consist of D (Nowak 2006; Axelrod & Hamilton 1981). Thus, "natural selection in well-mixed populations needs help for establishing cooperation" (Nowak 2006, p.1560).

4.1.2 Cooperation can evolve through 'correlated interaction'

Theorists have suggested and formally developed a number of evolutionary mechanisms capable of explaining the emergence of cooperation without violating the principle of inclusive fitness maximization. This literature provides clear grounds for predicting that cooperativeness will cluster in social networks, the subject of the present empirical effort.

The five most prominent mechanisms theoretically capable of supporting the evolution of cooperation are: 1) kin selection, 2) direct reciprocity, 3) indirect reciprocity, 4)

network reciprocity, and 5) group selection (Nowak 2006). All of these mechanisms, except kin selection (which alters the PD pay-off matrix), work through "correlated interaction" (Okasha 2005), whereby cooperators are more likely to cooperate with other cooperators than expected based on random interactions. When the assumption of random interactions is relaxed and individuals are, for some reason – for example, because they tend to live with kin, dispersal is limited, or have the ability to actively choose their interaction partners – more likely to meet others using the same strategy than would be the case if encounters were random, then cooperativeness can be favoured by natural selection (Eshel & Cavalli-Sforza 1982).

Perhaps the most relevant mechanism, for our purposes, is network reciprocity (for a theoretical treatment, see Ohtsuki et al. 2006). The key theoretical result here is that cooperation can pay fitness dividends if co-operators form clusters of cooperation. This leads directly to a prediction of clustering of cooperation in social networks (assuming variation in cooperativeness is present in the population).

4.1.3 Partner choice models and friendship

The theoretical insight that cooperativeness can co-evolve with selectivity in interactions (Eshel & Cavalli-Sforza 1982) has given rise to a literature focused on *partner choice models* (e.g., Ashlock et al. 1996; Hruschka & Henrich 2006; McNamara et al. 2008; Debove et al. 2015). The defining feature of partner-choice models is that individuals are not forced to interact repeatedly with randomly selected others but rather have some level of choice in whom to interact (or stop interacting) with. This makes it possible for long-term cooperative relationships between the same pairs of individuals to develop.

Evolutionary simulations have demonstrated that when individuals are choosy with regard to whom they are willing to cooperate with, based on how cooperative the other individual is, this will lead to increased levels of cooperativeness by locking insufficiently cooperative individuals out of the market for cooperation partners (McNamara et al. 2008). Higher levels of cooperativeness in a population select for higher levels of choosiness, which select for increased cooperativeness, and so on. When cooperativeness and choosiness coevolve in this way, the two traits become correlated

in individuals: more cooperative individuals will require more cooperation from an interaction partner (McNamara et al. 2008). And this leads directly to social clustering of cooperativeness (assuming inter-individual differences in cooperativeness and partner choice).

Partner choice thus sets up conditions for a biological market in relation to cooperation (Noe & Hammerstein 2010; Barclay 2013). Where cooperativeness is a valued commodity provided by social partners, the most generous individuals, relative to others in a population, will have the highest market value (all other things equal). Assortativity on cooperativeness is now likely to emerge. The most cooperative individuals will naturally tend to form ties with each other, comparable to the assortment on physical attractiveness found in the mating market place (Feingold 1988). Somewhat less cooperative individuals can do no better than form ties with others with a similar tendency to cooperate since the most cooperative individuals are already off the market – and so on down the spectrum of cooperativeness. Indeed, less cooperative individuals may actually prefer forming ties with less cooperative others since this allows them to avoid wasting resources in pursuit of potential partners with a high market value who are likely to reject them. Competition for cooperative partners may work through a general reputation for a tendency to be generous or helpful as much as through direct benefits bestowed on one's social partners (Barclay 2013). Thus, it becomes important to signal one's ability and willingness to provide benefits to others, which can take many forms (for example, publicly giving to charity or volunteering).

As discussed in chapter 1 (1.2.4.1), the (expectation of) mutual aid that characterises friendships is perhaps a defining feature of this type of social relationship (Hruschka 2010). Friendships as are long-term cooperative partnerships. Importantly, they are not based on simple direct reciprocity or balanced accounting. In fact, a better description, in most cases, of a response to a friend's request for help is "knee-jerk altruism" (Hruschka 2010). At the proximate level, we help our friends *because* they are our friends. According to Hruschka's evolutionary model (1.2.4.1.3), we form enduring cooperative relationships with trusted others as a way of dealing with the uncertain environments that we occupy. Within such social relationships, we help someone

because they are friends who would help us when we are in need of assistance ourselves in the future (although none of this has to be consciously perceived).

Given the cooperative nature of friendships and assuming some freedom of partner choice, one would predict cooperativeness to cluster in friendship networks, in line with the biological market argument outlined above (4.1.3).

4.1.4 Social selection and social influence and clustering of cooperativeness

An evolutionary view on clustering of cooperation would typically be that such clustering arises, primarily, from fixed types – co-operators and defectors in the simplest models – assorting or being caused to assort (through limited dispersal or some other mechanism) on cooperativeness, i.e., a social selection process. This makes sense given the evolutionist's interest in uncovering the conditions under which a cooperation gene can spread in a population, which often requires that co-operators interact with other co-operators. It is possible, however, that some of the social clustering of cooperation, where it is found empirically, is due to a social influence process. This could also makes adaptive sense, a fact taken into account by conditional cooperative strategies that adjust their own cooperativeness to the cooperative climate around them. In general, where similarity is adaptive – whether because of coordination benefits, in order to not be exploited, or for some other reason – it may be achieved through either social selection or social influence processes.

The empirical evidence on social influence effects on prosociality is rather limited. Such effects have been reported, based on observational studies, for American high school students (Barry & Wentzel 2006) and pre-schoolers (Fabes et al. 2012). Further evidence for peer effects on cooperation comes from experimental data from economic games. When people play public goods games[2] (PGGs) in *random* networks (i.e., networks whose members change randomly after each round), cooperative and selfish behaviour cascades through such networks via behavioural mimicry (Fowler & Christakis 2010). Further evidence for the contagious spread of cooperation and selfish

[2] In a public goods game, players are given a number of tokens which they then (privately) choose to contribute to a communal pot or not. After each player has contributed, the number of tokens in the pot Is multiplied by a certain factor and shared equally among all participants.

comes from PGG-based experiments using *fixed* networks (i.e., networks that do not change from round to round) (Jordan et al. 2013) and spatial Prisoner's Dilemmas[3] (Grujic et al. 2010; Gracia-Lazaro et al. 2012; Grujić et al. 2012).

4.1.5 Social clustering of cooperativeness

While studies that find social influence on cooperativeness or prosociality imply some level of social clustering, surprisingly few empirical studies have explicitly addressed the clustering of cooperation in real-world human social networks (outside of an experimental context), the literature on this topic consisting largely of theoretical modelling exercises and experiments using economic games designed to test the predictions of evolutionary and social contagion models.

One relevant study, while still relying on online economic games, did make use of real-world social networks (Leider et al. 2009). While not the main focus of the study, the authors reported statistically significant correlations among friends of levels of "baseline altruism", measured by giving behaviour in dictator and helping games with nameless strangers. Similarly, high school students in the US with a higher prosociality score, based on a self-completed survey, also reported receiving higher levels of social support from family, school, and other sources (Wilson et al. 2009).

A recent study among the Hadza, a population of hunter-gatherers in northern Tanzania, tested for clustering of cooperation (Apicella et al. 2012). The researchers first identified two kinds of social network, a 'campmate network' (comprising the individuals one wants to live with in the next camp) and a 'gift network' (based on actual gifts of honey sticks provided by the researchers). Cooperation was measured as contributions in a public goods game. Hadza social networks were found to display clustering of a number of traits, including cooperation. From an evolutionary perspective, this study is of particular relevance since modern hunter-gatherers may provide some insights into the lifestyles of ancestral humans – although with several important caveats, including the fact that foraging groups display great variation along many important dimensions (Kelly 1995).

[3] In a spatial Prisoner's Dilemma, players are assigned a fixed location, e.g., on a lattice, and interactions between players are confined to their local neighbourhoods.

4.1.6 Life history theory and cooperation

So far I have dealt with explanations of the evolution of cooperation as such and how they relate to the distribution of cooperativeness across a population. A different evolutionary perspective on cooperation is provided by life history theory, which focuses on explaining for between-individual variation in recourse-allocation across the life course (1.3). In section 1.4.1, listed several predictions derived from life history theoretical models, viz., that: 1) Adolescents from socioeconomically more deprived households are less likely to be cooperative; 2) Adolescents who experienced father absence during childhood are less likely to be cooperative; and 3) Adolescents living in more deprived areas are less likely to be cooperative. These three predictions are all based on the idea that harsh environments favour a more opportunistic and sometimes exploitative interpersonal style. Here I will elaborate on these ideas, which are tested against empirical data later in the chapter.

Theorists have argued that cooperativeness or prosociality is, at least to some extent, a life history trait, responsive to the same kinds of features of a person's ecological context as more typical life history traits like age at first birth. On this view, environments that channel development towards a fast life history strategy should lead people to act in a less cooperative, more exploitative way, and vice versa (Belsky et al. 1991; Wilson & Daly 1997; McCullough et al. 2012). In harsh and unpredictable environments, people's time horizons are shorter, or, which is the same thing, they discount the future more (Hill et al. 2008; Ramos et al. 2013; Pepper & Nettle 2013). This has important consequences for the expected pay-offs associated with cooperative and exploitative behaviours. Prosocial acts whose costs are offset by benefits in the future – as in direct and indirect reciprocity and possibly friendships – become less attractive, whereas immediate benefits associated with exploitative acts carry more weight because costs incurred in the future carry less. In this context, it might be useful to think about two associated "interpersonal orientations" – to be understood as prototypical illustrations of a continuum, – viz., an *opportunistic* one, "geared toward opportunistic advantage taking" (Belsky et al. 1991, p.649), and a *reciprocally-rewarding* one, "[geared] toward mutual commitment and reciprocal benefit" (ibid.).

On the other hand, one could argue that uncertain environments should lead to *higher* levels of cooperation since cooperation can be used as a risk management strategy. Consistent with this idea, it has been found that people are more willing to lie for a friend, to help them avoid serious trouble with the authorities (after witnessing their friend hit a pedestrian with a car), in societies characterised by higher levels of uncertainty (political, legal, economic, as rated by the World Bank) (Hruschka 2010). It is not clear, however, whether this increased cooperativeness is specific to friendships, scenario-specific, or more generalized. Some authors similarly argue that people living in hostile environments, as indicated low social class, may be more attuned to social context and exhibit more prosocial behaviour because they are more dependent on others to achieve desirable outcomes (Piff et al. 2010).

Important suggested indicators of harsh, stressful or uncertain environments include socioeconomic deprivation and father absence.

While empirical results are not entirely consistent, the balance of evidence suggests that socioeconomic deprivation affects people's cooperativeness *negatively*. This relationship has been found in studies conducted at the level of individuals and households as well as neighbourhoods (although it is not clear to what extent neighbourhood characteristics matter over and above individual and household SES). For instance, it has repeatedly been observed that people living in deprived areas tend to behave less cooperatively in a variety of economic games (Nettle, Colleony, et al. 2011; McCullough et al. 2012; Falk & Zehnder 2013) or when assessed by naturalistic measures such as the likelihood of posting a lost letter (Nettle, Colleony, et al. 2011; Holland et al. 2012; Silva & Mace 2014).

When a sample of American college students were asked to play an iterated prisoner's dilemma game, male (but not female) participants exposed to a harsh social environment during childhood – as gauged by exposure to neighbourhood crime and violence and within-family neglect, conflict and violence – were found to exhibit an increased tendency to defect, both unprovoked and in retaliation (McCullough et al. 2012). Similarly, lower individual SES predicts a lower probability of making a donation, rather than keeping a researcher-distributed endowment, in a donation experiment (Silva & Mace 2014). And self-assessed prosociality in Italian adolescents is lower in

those from neighbourhoods with fewer perceived 'social resources' (social cohesion, friends in the neighbourhood, and attachment to neighbourhood) (Lenzi et al. 2012).

While most studies suggest that socioeconomic deprivation, in general, reduces cooperativeness and prosocial behaviour, markedly contrasting, and much-cited, results have been reported based on a set of studies from the US which found that individuals from lower social classes, measured both subjectively and objectively, were *more* prosocial than those from a more privileged socioeconomic background: lower social class individuals were more generous in a dictator game, believed people should donate proportionally more of their income to charity, displayed greater trust in a trust game, and were more helpful in a helping experiment (Piff et al. 2010). The same research group also reported on a set of studies showing that higher social class individuals were more likely to engage in various forms of unethical behaviour, for instance, lie in the context of a negotiation or cheat in order to win a prize (Piff et al. 2012).

However, a recent "large scale test" of the relationship between social class and prosocial behaviour – a set of studies similar to the ones used in Piff et al. (2010) but using much larger (international[4]) samples – did not find a statistically significant negative association between social class and prosocial behaviour in *any* of its sub-studies (Korndörfer et al. 2015). Indeed, several of its sub-studies did reveal significant associations between social class and prosocial behaviour, but always in the opposite direction (i.e., a positive relationship between SES and prosocial behaviour). It should further be noted that the aforementioned paper on social class and unethical behaviour (Piff et al. 2012) has been argued to show signs of (presumably unintentional) publication bias (Francis 2012). At present, it is not clear what the source of these disparities is, whether they are due to cultural differences between study populations, methodological differences between studies, publication bias, or some other factor(s) (Korndörfer et al. 2015).

[4] Four studies in Korndörfer et al. 2015 used data from Germany and three from the United States. Study 6, which looked at social class and charitable giving, used data from the International Social Survey Program for 30 countries, viz., Australia, Austria, Bulgaria, Canada, Chile, Cyprus, the Czech Republic, Denmark, France, Germany, Hungary, Ireland, Israel, Italy, Japan, Latvia, the Netherlands, New Zealand, Norway, the Philippines, Poland, Portugal, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America.

Most evolutionary studies of the effects of father absence have focussed on age at menarche and sexual and reproductive behaviour. There appears to be a dearth of studies that explicitly address the empirical relationship between father absence and cooperativeness or prosocial behaviour motivated by evolutionary theoretical concerns. To my knowledge, no study has looked at father absence and cooperative behaviour in economic games. The wider literature does contain some relevant work, which suggests that growing up in a father-absent household is associated with a reduction in prosocial behaviour, e.g., volunteering in young adulthood (Lichter et al. 2002), and an increase in conduct problems in children, such as aggressive behaviour and delinquency (Amato & Keith 1991), and an increased risk of incarceration as late adolescents or young adults (Harper & McLanahan 2004).

I have also included the Big Five personality factors as potential predictors of cooperation in the analyses that follow. It has been suggested that these represent alternative life history strategies (1.3.4), which may have different associations with cooperativeness. In Chapter 1 (1.4.2), I made the following predictions. Since agreeableness has been suggested to be a part of a life history strategy that reaps the benefits of cultivating cooperative relationships, more agreeable individuals are predicted to be more cooperative. More conscientious individuals, who are argued to follow a strategy more sensitive to future benefits, are predicted to be more willing to invest in (potential) long-term cooperative relationships, which manifests as a more cooperative attitude in the present.

On evolutionary grounds, one might also anticipate a sex difference in people's tendency to cooperate. Male intrasexual competition is more physical in nature and, theoretically, more intense since (potential) reproductive variance is greater in males than females and females are the choosier sex as a result of their dramatically higher level of minimum investment. As a consequence, women have not evolved the same kinds of physical tools and possibly psychological inclination to using (threat of) physical force, to achieve their goals in social situations. They may therefore be more inclined to opt for cooperative solutions to problems (Weisfeld 1999). I therefore predicted that girls are, on average, more likely to show cooperative behaviour than boys (1.4.2).

4.1.7 Study aims

The first aim of the present study is to test for the presence of clustering of cooperation in adolescent friendship networks, neighbourhoods and schools in a modern setting, using data from the Avon Longitudinal Study of Parents and Children (ALSPAC). Social clustering of cooperation is predicted based on evolutionary models of cooperation, which, essentially, propose different ways of achieving the correlated interaction necessary for cooperation to gain evolutionary traction and spread. Based on partner choice models, biological markets thinking, and the view of friendship as long-term cooperative relationships, it will be particularly interesting to see if cooperativeness clusters in friendship networks.

A second aim is to examine whether life history factors predict cooperativeness in line with theoretical expectations (outlined above and in section 1.4.2). Following on from this, a third aim is to assess to what extent they can explain any social clustering that may exist.

This study thus contributes to the literature on several fronts. Firstly, it expands the small empirical literature looking at the clustering of cooperation in real-world human populations rather than *in silico* or the somewhat artificial context of economic games experiments. Secondly, it should help us better understand the role of life history predictors in calibrating cooperativeness to a locally appropriate level by examining multiple life history predictors simultaneously for a range of cooperation-related outcomes. Finally, it should give insight into the relationship between life history factors and the social clustering of cooperativeness.

4.2 Methods

4.2.1 Data and participants

The main data source for this chapter is once again ALSPAC. The bulk of the data used in this chapter was collected through (or derived from) postal questionnaires completed at several time points by the mothers of the study children/adolescents (socioeconomic information, parental life history traits, father absence, maternal study participation, and teenager prosociality and conduct problems) and by the adolescents themselves (personality and friendship networks). Additional sources of information are the Office for National Statistics for neighbourhood deprivation and the study children's teachers in year 3 of the National Curriculum (ages 7-8) for child prosociality.

The analysis sample differs by outcome. For each of the five outcomes, I started with all of the adolescents in the core ALSPAC sample who had a valid outcome for the outcome in question. I then dropped those without a valid school or area identifier.

The resulting analysis sample sizes were as follows: attended Teen Focus 4 = 5,012; returned Friends questionnaire = 5,588; teacher-rated prosocial score = 4,837; mother-rated prosociality = 3,878; and mother-rated conduct problems = 3,879. As a general rule, because of attrition, the later measurements have fewer observations.

4.2.2 Variables

4.2.2.1 Dependent variables

Five measures of cooperation were used in the analyses in this chapter. Two of these are measures of study participation (4.2.2.1.1), three are behavioural assessments performed by a teacher (prosociality) and the study child's mother (prosociality and conduct problems) (4.2.2.1.2).

4.2.2.1.1 Study participation as cooperation

The first two outcomes are based on responses, or the lack thereof, to participation requests sent by ALSPAC. In April and May 2008, a questionnaire entitled 'You and Your Friends' was sent to 7,558 of the young people (those born after 1st September 1991, to ensure all respondents would still be in school). At this time, respondents were between

15 and 17 years old. In this case, returning the questionnaire is the cooperative act while not returning the questionnaire *despite being invited* is considered non-cooperation (defection). Note that the study teenagers were directly asked for their help, not via their parents.

People are more likely to respond to surveys if the topic is, for some reason, of particular interest to them (Groves et al. 2004). Because of this *survey salience* effect, it might be the case that those young people who returned the Friends questionnaire had, on average, stronger friendship ties and, perhaps, more friends. If so, those who returned the friendship questionnaire, identifying them as co-operators, might have been be more likely to be nominated as friends, identifying them as linked to other co-operators, simply as a result of the survey topic. To circumvent this potential pitfall, I also investigated a participation measure unrelated to the friendship questionnaire, viz., attendance at Teen Focus 4.

When the study adolescents were approximately 17.5 years old, about two-thirds (10,101) of them were invited to attend the Teen Focus 4 clinic. Individuals who were invited to participate in Teen Focus 4 and did in fact attend the clinic I designated 'co-operators' while those who were invited but did not attend were classified as 'non-co-operators'. Note that attending the clinic required considerable time and effort (for instance, travel) on the part of the participants.

4.2.2.1.2 Prosociality and conduct problems

The other three measures are taken from the Strengths and Difficulties Questionnaire (SDQ) a widely used behavioural screening questionnaire aimed at children and young people aged 4 to 16 years (Goodman 1997). One of its five dimensions is prosocial behaviour, which is assessed through 5 items that together make up the SDQ prosocial scale. Respondents, typically parents or teachers, are asked whether the focal child or young person is "Considerate of other people's feelings", "Shares readily with other children (treats, toys, pencils etc.)", "Helpful if someone is hurt, upset, or feeling ill", "Kind to younger children", and whether he or she "Often volunteers to help others (parents, teachers, other children)" – to which they can respond "not true" (scored 0), "somewhat true" (scored 1) or "certainly true" (scored 2) (Goodman 1997: 582).

Summing the five item scores yields a prosocial score between 0 and 10, from low to high prosociality.

Here, I use SDQ prosocial scores based on teacher's reports on the study children when they were in year 3 (ages 7-8) and mother's reports when the adolescents were about 16.5 years old. Because the scores are strongly skewed to the left (and could not be transformed to normality), I dichotomized them. Scores of 8, 9 or 10 were recoded as 1 (high prosociality), while scores of 7 or lower were recoded as 0 (low prosociality).

Finally, I made use of the conduct problems scale of the SDQ. The conduct problems score is calculated in the same way as the prosocial score, based on the following items: "Often has temper tantrums or hot tempers", "Generally obedient, usually does what adults request", "Often fights with other children or bullies them"; "Often lies or cheats", and "Steals from home, school or elsewhere" (Goodman 1997: 582). The score used in this study is based on the mother's reports at ~16.5. Again, because of a heavily skewed distribution, I dichotomized the conduct problems score. Scores of 2 or higher were recoded as 1 (some or many conduct problems); 0 and 1 were recoded as 0 (no conduct problems). Here I treat the conduct problems score as a measure of uncooperativeness or unattractiveness as a potential cooperative partner.

4.2.2.2 Independent variables

Many of the predictors included in the models presented in this chapter were discussed in chapter 2 (2.2), to which I refer for further information about the following variables (all assessed at pregnancy unless otherwise specified): maternal education, paternal education, financial difficulties (T = 7 years), home ownership status (T = 7 years), mother's age at first pregnancy, whether the mother had sex with a boyfriend before turning 16, mother's age at menarche, paternal age at index pregnancy, father absence from the household by the age of 10, neighbourhood deprivation (Index of Multiple Deprivation 2000 for teacher-rated prosociality, IMD 2010 for other outcomes), and the Big Five personality factors (extraversion, agreeableness, conscientiousness, emotional stability, and openness).

When modelling Teen Focus 4 attendance and friendship questionnaire return, I included a predictor counting the number of times the respondent was nominated as a

friend by another ALSPAC participant. The idea behind this is that if, as I have argued, returning the friendship questionnaire can be considered a form of cooperation, then being nominated as a friend suggests that one's friends are more cooperative. If having more cooperative friends predicts being more cooperative oneself, then this implies that cooperation clusters in friendship networks. To these two models I also added binary maternal study participation variables at five time points (1 year and 9 months, 6 years and 1 month, 12 years and 1 month, 13 years and 1 month, and 16 years and 6 months). This was done in order to control for the fact that adolescent study participation may be largely a function of parental participation.

4.2.2.3 Social structure

With the goal of laying bare the social clustering of cooperation I included several social classifications in the models, viz., schools, neighbourhoods, and friendship networks. More details about these classifications are found in chapter 2 (2.3.1.3). For all models, I used the Lower Super Output Area as of the 1st of January 2008 as the neighbourhood classification and the Key Stage 4 secondary school as the school classification.

Because the friendship networks are based on information provided on the 'You and Your Friends' questionnaire, the inclusion of friendship networks as a level in the models looking at return of the friendship questionnaire was considered statistically dubious and they were consequently omitted from the relevant multiple classification models. Instead, I included as a predictor the number of times someone was nominated as a friend, as discussed above. The same approach was used for modelling attendance at Teen Focus 4, in order to make that model, which should not suffer from salience bias, comparable to the Friends questionnaire model.

4.2.3 Analysis

4.2.3.1 Statistical approach

As a first step, null clustering models were run for all outcomes. These multiple classification logistic regression models contained no substantive predictors apart from sex. They provide estimates of the intra-class correlations for each of the groupings –

school, neighbourhood, and friendship network if applicable – before adding life history predictors or personality factors.

Next, the life history predictors, Big Five personality factors, friend cooperation variable (for attended TF4 clinic and returned Friends questionnaire), and maternal study participation variables (idem) were added as a single block. The resulting output shows which of these variables predict cooperation, allowing for comparison with predictions derived from life history theory, and also whether they (partly) explain the intra-class correlations found in the previous modelling step. Odds ratios for continuous predictors are reported as standardized odds ratios (which is derived calculated based on the standardized logistic regression coefficient = [unstandardized coefficient]*[standard deviation of predictor variable]).

4.2.3.2 Missing data

There was a substantial amount of missing data. For example, the proportion of missing data for the friendship questionnaire return sample varied between 0% for sex, maternal questionnaire return, friend cooperation (= number of times the respondent was nominated as a friend), and neighbourhood deprivation, and 44% for conscientiousness. More information about data availability for each of the cooperation samples can be found in the descriptive statistics tables in the appendix to chapter 4. The models with substantive predictors were performed on 25 imputed data sets, which provided parameter estimates which were then combined according to Rubin's rules (Rubin 1987) in Stata 12 (StataCorp. 2011). The Index Multiple of Deprivation scores were log-transformed to approximate normality prior to imputation.

Due to sample attrition, data were more likely to be missing at later time points. Study dropout was not random. In particular, low SES is a risk factor for dropping out of the study (see Table 81 for a comparison of the analysis and attrition samples for the mother-rated prosocial score, which illustrates this point).

4.3 Results

4.3.1 Sample description

The appendix to chapter 4 contains descriptive statistics and pairwise correlations for each of the five samples associated with one of the outcomes.

4.3.2 Unadjusted clustering models

The residual intra-class correlations for the different social groupings (schools, neighbourhoods, friendship networks) for the null clustering models unadjusted for sex are reported in Table 14, and those adjusted for sex are found in Table 15. Adjusting for sex had little effect on the patterns of clustering. Both ALSPAC participation measures – returning the Friends questionnaire and attending Teen Focus 4 – showed an increased similarity in schools and neighbourhoods, as indicated by models comparisons based on the DIC (see 2.3.1.2), but the extent of this clustering was very small, the residual intra-class correlations ranging between 0.027 and 0.055. Teacher-rated prosociality showed a similar level of clustering at the neighbourhood level (residual ICC = 0.038 when adjusted for sex), but did not cluster at the level of schools. Neither of the mother-rated SDQ measures (prosociality and conduct problems) showed any clustering at the school or neighbourhood level.

Friendship networks were only included as levels for the three SDQ scores. Two of these measures – teacher-rated prosociality and mother-rated conduct problems – showed modest clustering in friendship networks. The (residual) intra-class correlations for teacher-rated prosociality were 0.13 for the null clustering model unadjusted for sex and 0.10 for the clustering model adjusted for sex. The same figures for mother-rated conduct problems were 0.14 and 0.15 respectively.

Table 14. Null clustering: intraclass correlations of measures of cooperation for schools, neighbourhoods and friendship networks (logistic multiple classification models)

	Residual Intraclass Correlation		
Outcome	**School**	**Neighbourhood**	**Friendship networks**
Returned friendship questionnaire	0.053*	0.027*	NA
Attended Teen Focus 4	0.055*	0.036*	NA
Teacher-rated prosocial score	0.007	0.028*	0.128*
Mother-rated prosocial score	0.002	0.003	0.037
Mother-rated conduct problems	0.002	0.007	0.136*

* Dropping the classification reduces the DIC by > 2 points

Table 15. Clustering after adjusting for sex: intraclass correlations of measures of cooperation for schools, neighbourhoods and friendship networks (logistic multiple classification models)

	Residual Intraclass Correlation		
Outcome	**School**	**Neighbourhood**	**Friendship networks**
Returned friendship questionnaire	0.043*	0.032*	NA
Attended Teen Focus 4	0.053*	0.037*	NA
Teacher-rated prosocial score	0.003	0.038*	0.100*
Mother-rated prosocial score	0.002	0.004	0.028
Mother-rated conduct problems	0.002	0.008	0.147*

* Dropping the classification reduces the DIC by > 2 points

4.3.3 Study participation as cooperation

4.3.3.1 Returned the friendship questionnaire

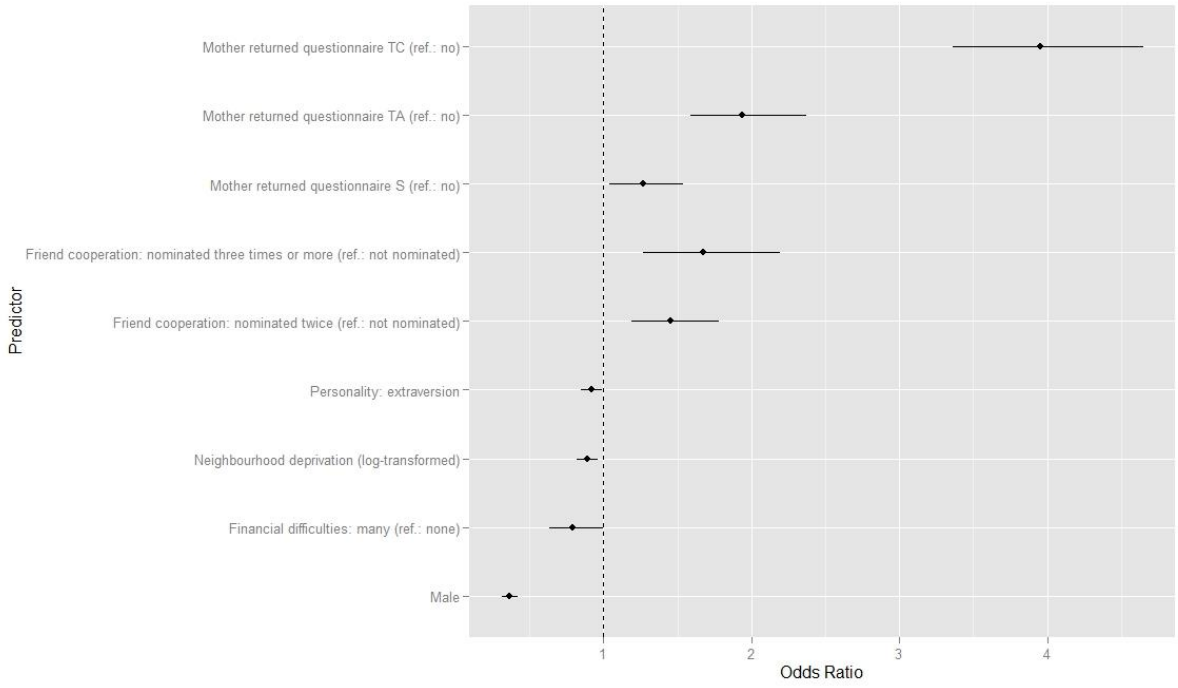
The results for returning the friendship network questionnaire as a measure of cooperation are given in Table 16.

Table 16. Logistic multiple classification model results for returning the friendship network questionnaire (no vs. yes)

Predictor		**OR**	**95% CI**	**p**
Sex (ref.: female)		0.36	0.31 – 0.42	<0.001
Mother's education (ref.: none/CSE)				
	Vocational	0.87	0.66 – 1.14	0.311
	O-level	1.14	0.93 – 1.42	0.212
	A-level	1.04	0.82 – 1.32	0.717
	Degree	1.29	0.95 – 1.76	0.108
Father's education (ref.: none/CSE)				
	Vocational	0.95	0.73 – 1.23	0.677
	O-level	0.86	0.70 – 1.06	0.157
	A-level	0.95	0.77 – 1.17	0.627
	Degree	1.06	0.81 – 1.40	0.660
Financial difficulties (ref.: none)				
	Some	0.97	0.83 – 1.13	0.701
	Many	0.79	0.63 – 1.00	0.046
Home ownership status (ref.: rented)				
	Mortgaged	0.94	0.72 – 1.23	0.666
	Owned	0.83	0.55 – 1.24	0.364
Neighbourhood deprivation (IMD 2010)		0.89	0.82 – 0.96	0.003
Mother's age at first pregnancy		1.08	1.00 – 1.17	0.058
Mother's age at menarche		1.01	0.94 – 1.08	0.845
Mother had sex when <16 years old		1.09	0.89 – 1.33	0.402
Father's age at index pregnancy		1.05	0.98 – 1.14	0.177
Biological father absent at 10 years (ref.: present)		0.87	0.72 – 1.05	0.142
Extraversion		0.92	0.85 – 0.99	0.035
Agreeableness		1.04	0.95 – 1.14	0.397
Conscientiousness		1.08	0.99 – 1.18	0.083
Emotional stability		1.05	0.97 – 1.15	0.191
Openness		1.01	0.92 – 1.11	0.868
Mother returned questionnaire G (ref.: no)		0.97	0.77 – 1.22	0.791
Mother returned questionnaire L (ref.: no)		1.20	0.99 – 1.47	0.070
Mother returned questionnaire S (ref.: no)		1.27	1.04 – 1.54	0.016
Mother returned questionnaire TA (ref.: no)		1.94	1.59 – 2.37	<0.001
Mother returned questionnaire TC (ref.: no)		3.95	3.36 – 4.65	<0.001
Friend cooperation (ref.: not nominated as a friend)				
	Nominated once	1.12	0.97 – 1.30	0.133
	Nominated twice	1.45	1.19 – 1.78	<0.001
	Nominated three or more times	1.67	1.27 – 2.19	<0.001
		Variance	**Proportion of total variance**	**p**
Explained variance		1.677	0.332	
Residual variance		3.368	0.668	
School (Key Stage 4)		0.009	0.002	0.360
Neighbourhood (LSOA)		0.069	0.014	0.118
Individual		3.290	0.652	
Total		5.045	1	

Statistically significant effects are illustrated in Figure 8.

Figure 8. Odds ratios with 95% confidence intervals for significant predictors of returning the You and Your Friends questionnaire. For continuous predictors the (standardized) OR corresponds to a 1 SD increase; for categorical variables, the OR compares membership of a category to a reference category



Boys were less likely than girls to have returned the questionnaire (OR = 0.36, p < 0.001). Individuals whose mothers had reported experiencing many financial difficulties (assessed when the study child was around 7 years), were less likely to cooperate (OR = 0.79, p = 0.046), as were those from more deprived areas (OR = 0.89, p = 0.003). More extraverted adolescents were also less inclined to return the friendship questionnaire (OR = 0.92, p = 0.035).

The strongest predictor of adolescent cooperation was whether the study adolescent's mother cooperated with ALSPAC by returning their questionnaires (Figure 8), with stronger associations for more recent participation (mother returned questionnaire TC: OR = 3.95, p < 0.001). To a large extent, adolescent participation appeared to be a function of maternal participation.

The more times someone was nominated as a friend by another study participant, the more likely they were to return the friendship network questionnaire (nominated once: OR = 1.12, p = 0.13 (ref.: not nominated); nominated twice: OR = 1.45, p < 0.001; nominated three times or more: OR = 1.67, p < 0.001).

No significant residual clustering was found at the level of schools (rICC = 0.002, p = 0.36) or level of neighbourhoods (rICC = 0.014, p = 0.118).

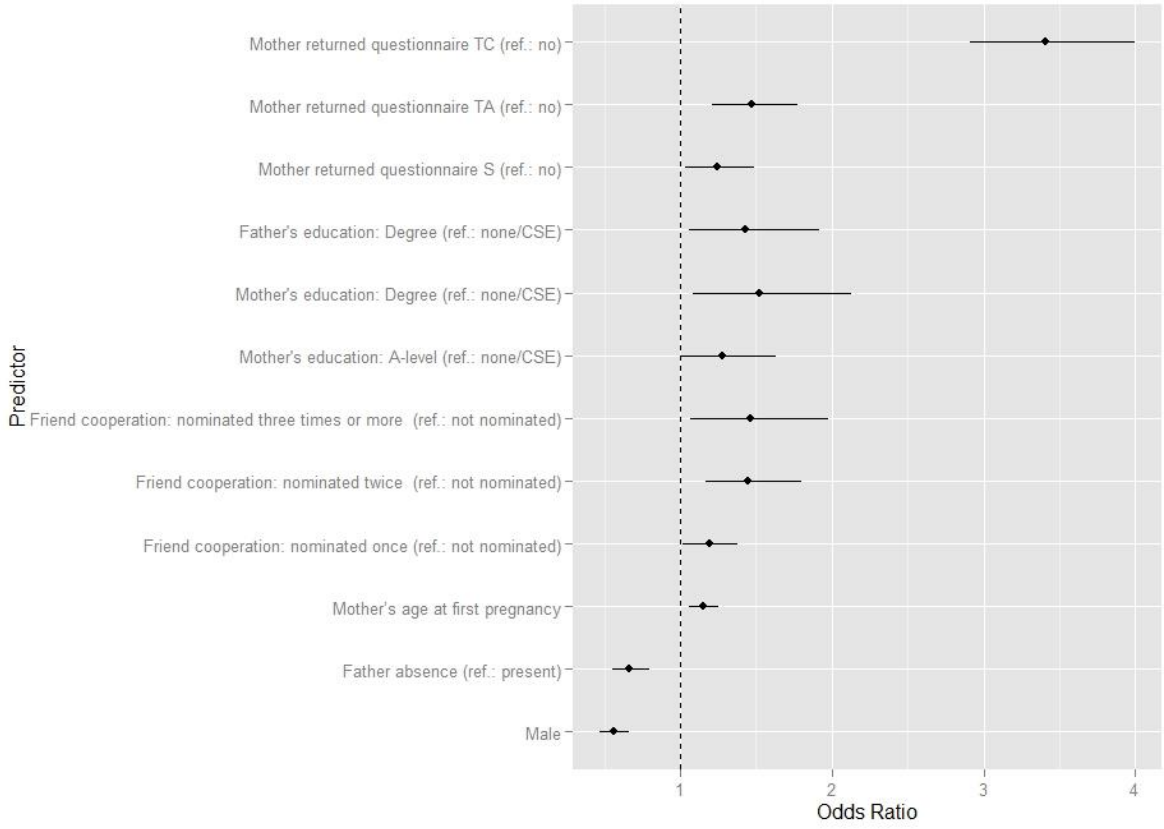
4.3.3.2 Attended Teen Focus 4

The same model was run for attending the ALSPAC clinic session Teen Focus 4 (Table 17).

Table 17. Logistic multiple classification model results for attending Teen Focus 4 (no vs. yes)

Predictor		**OR**	**95% CI**	**p**
Sex (ref.: female)		0.56	0.47 – 0.66	<0.001
Mother's education (ref.: none/CSE)				
	Vocational	0.93	0.71 – 1.22	0.609
	O-level	1.18	0.95 – 1.46	0.130
	A-level	1.28	1.01 – 1.63	0.043
	Degree	1.52	1.08 – 2.13	0.016
Father's education (ref.: none/CSE)				
	Vocational	1.20	0.92 – 1.57	0.180
	O-level	0.99	0.80 – 1.23	0.949
	A-level	1.08	0.88 – 1.32	0.485
	Degree	1.43	1.06 – 1.92	0.018
Financial difficulties (ref.: none)				
	Some	1.01	0.85 – 1.19	0.916
	Many	0.99	0.78 – 1.26	0.930
Home ownership status (ref.: rented)				
	Mortgaged	0.86	0.65 – 1.13	0.273
	Owned	0.83	0.54 – 1.26	0.374
Neighbourhood deprivation (IMD 2010)		0.97	0.89 – 1.05	0.401
Mother's age at first pregnancy		1.15	1.06 – 12.5	0.001
Mother's age at menarche		0.98	0.92 – 1.06	0.641
Mother had sex when <16 years old		1.06	0.86 – 1.29	0.594
Father's age at index pregnancy		1.04	0.96 – 1.12	0.351
Biological father absent at 10 years (ref.: present)		0.66	0.55 – 0.80	<0.001
Extraversion		0.92	0.84 – 1.02	0.112
Agreeableness		1.10	0.99 – 1.22	0.074
Conscientiousness		0.96	0.86 – 1.06	0.359
Emotional stability		1.05	0.96 – 1.16	0.267
Openness		1.12	0.99 – 1.26	0.059
Mother returned questionnaire G (ref.: no)		0.99	0.80 – 1.23	0.957
Mother returned questionnaire L (ref.: no)		1.09	0.90 – 1.31	0.399
Mother returned questionnaire S (ref.: no)		1.24	1.03 – 1.49	0.023
Mother returned questionnaire TA (ref.: no)		1.47	1.21 – 1.77	0.000
Mother returned questionnaire TC (ref.: no)		3.41	2.91 – 4.00	0.000
Friend cooperation (ref.: not nominated as a friend)				
	Nominated once	1.19	1.02 – 1.38	0.031
	Nominated twice	1.45	1.17 – 1.80	0.001
	Nominated three or more times	1.46	1.07 – 1.98	0.015
Classification		**Variance**	**Proportion of total variance**	**p**
Explained variance		1.256	0.270	
Residual variance		3.389	0.730	
School (Key Stage 4)		0.070	0.015	0.130
Neighbourhood (LSOA)		0.029	0.006	0.164
Individual		3.290	0.708	
Total		4.646	1.000	

Figure 9. Odds ratios with 95% confidence intervals for significant predictors of attending Teen Focus 4 clinic. For continuous predictors the (standardized) OR corresponds to a 1 SD increase; for categorical variables, the OR compares membership of a category to a reference category



Again, boys were less likely to participate (OR = 0.56, p < 0.001). Maternal and, to a lesser extent, paternal education were positively associated with attendance. Adolescents whose mothers were older during their first pregnancy were more likely to attend (OR = 1.15, p = 0.001), while father absence was associated with a lower probability of attending (OR = 0.66, p < 0.001). Mirroring the result for returning the friendship questionnaire, the strongest predictor of attendance of Teen Focus 4 was active study participation by mothers (OR = 3.41, p < 0.001; as measured by return of questionnaires; Figure 9).

Adolescents who were nominated as a friend more often, which means they are linked to more co-operators (as defined by study participation), were more likely to attend Teen Focus 4 (nominated once: OR = 1.19, p = 0.031; nominated twice: OR = 1.45, p = 0.001; nominated three times or more: OR = 1.46, p = 0.015).

Attendance of Teen Focus 4 did not exhibit significant clustering at the level of schools (rICC = 0.015, p = 0.13) or neighbourhoods (rICC = 0.006, p = 0.16).

4.3.4 Prosociality and conduct problems

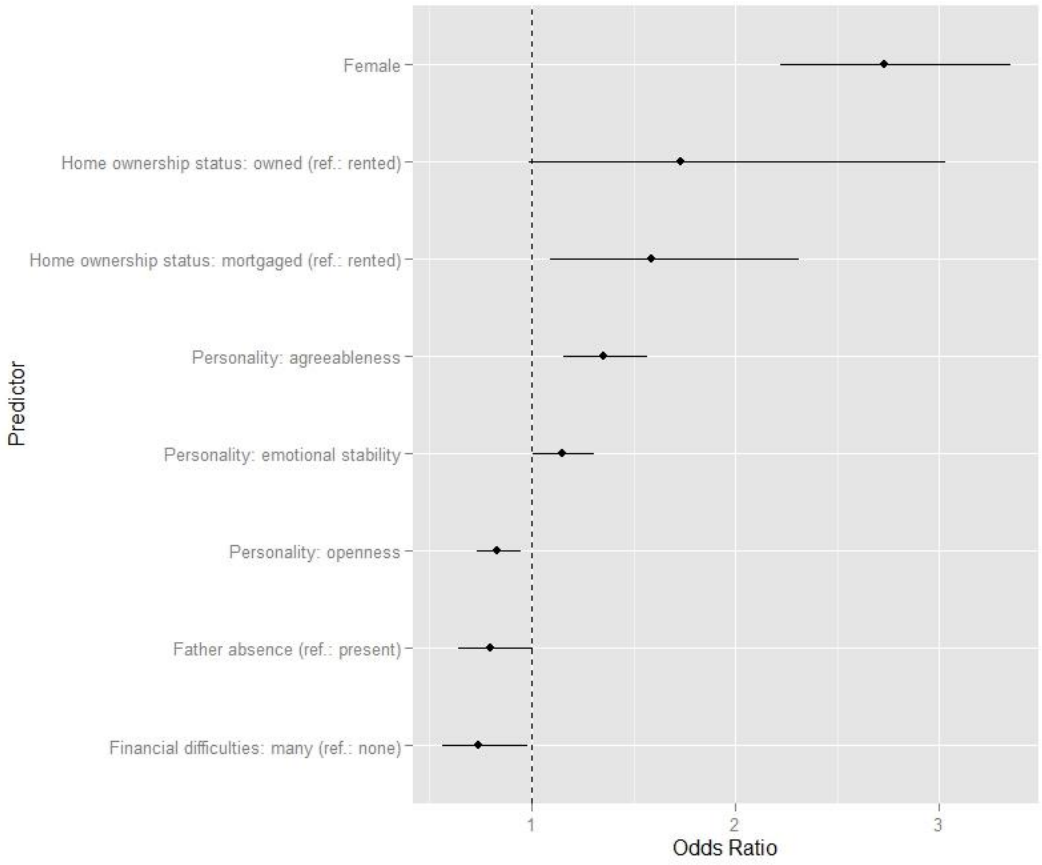
4.3.4.1 Teacher-rated prosocial score

The results for the teacher-rated SDQ prosocial score, assessed when study children were aged ~7, are presented in Table 18.

Table 18. Logistic multiple classification model results for teacher-rated prosocial score (low vs. high)

Predictor		**OR**	**95% CI**	**p**
Sex (ref.: male)		2.73	2.22 – 3.35	<0.001
Mother's education (ref.: none/CSE)				
	Vocational	1.04	0.77 – 1.39	0.799
	O-level	1.13	0.90 – 1.43	0.293
	A-level	1.12	0.85 – 1.47	0.433
	Degree	0.91	0.62 – 1.33	0.618
Father's education (ref.: none/CSE)				
	Vocational	1.11	0.82 – 1.50	0.494
	O-level	1.12	0.88 – 1.43	0.358
	A-level	0.99	0.78 – 1.26	0.952
	Degree	0.95	0.68 – 1.33	0.777
Financial difficulties (ref.: none)				
	Some	0.88	0.71 – 1.08	0.221
	Many	0.74	0.56 – 0.98	0.034
Home ownership status (ref.: rented)				
	Mortgaged	1.59	1.09 – 2.31	0.016
	Owned	1.73	0.99 – 3.03	0.056
Neighbourhood deprivation (IMD 2000 in 1998)		1.06	0.95 – 1.17	0.292
Mother's age at first pregnancy		1.08	0.99 – 1.18	0.085
Mother's age at menarche		1.00	0.93 – 1.09	0.940
Mother had sex when <16 years old		0.99	0.79 – 1.24	0.949
Father's age at index pregnancy		0.92	0.83 – 1.01	0.073
Biological father absent at 10 years (ref.: present)		0.80	0.64 – 1.01	0.059
Extraversion		0.93	0.84 – 1.04	0.219
Agreeableness		1.35	1.16 – 1.57	<0.001
Conscientiousness		1.02	0.89 – 1.17	0.735
Emotional stability		1.15	1.01 – 1.31	0.031
Openness		0.83	0.73 – 0.95	0.007
Indicator variable		1.70	1.43 – 2.03	<0.001
		Variance	**Proportion of total variance**	**p**
Explained variance		0.561	0.121	
Residual variance		4.072	0.789	
School (Key Stage 4)		0.016	0.003	0.373
Neighbourhood (LSOA)		0.157	0.034	0.008
Friendship network		0.609	0.132	0.033
Individual		3.290	0.710	
Total		4.633	1	

Figure 10. Odds ratios with 95% confidence intervals for significant predictors of teacher-rated prosocial score. For continuous predictors the (standardized) OR corresponds to a 1 SD increase; for categorical variables, the OR compares membership of a category to a reference category



Girls received higher prosocial scores based on the answers of their teachers to the SDQ questions pertaining to prosocial behaviour provided by their teachers (OR = 2.73, $p < 0.001$). Children were judged to be less prosocial when their mothers reported many financial difficulties (around the same time as the teachers were asked to fill out the SDQ yielding the prosocial score; OR = 0.74, $p = 0.034$) and more prosocial if they lived in a mortgaged (OR = 1.59, $p = 0.016$) or owned home (OR = 1.73, $p = 0.056$ but low power for this category due to fewer cases). Children from father-absent households tended to have lower scores (OR = 0.80, $p = 0.059$). Self-assessed agreeableness around 13.5 years was positively associated with teacher-rated prosociality at age 7 (OR = 1.35, $p < 0.001$) as was emotional stability (OR = 1.15, $p = 0.031$), while openness exhibited a negative association (OR = 0.83, $p = 0.007$).

Teacher-rated prosociality showed minor but statistically significant clustering at the neighbourhood level (rICC = 0.034, p = 0.008) and more substantial, although still modest, clustering at the level of friendship networks (rICC = 0.132, p = 0.033).

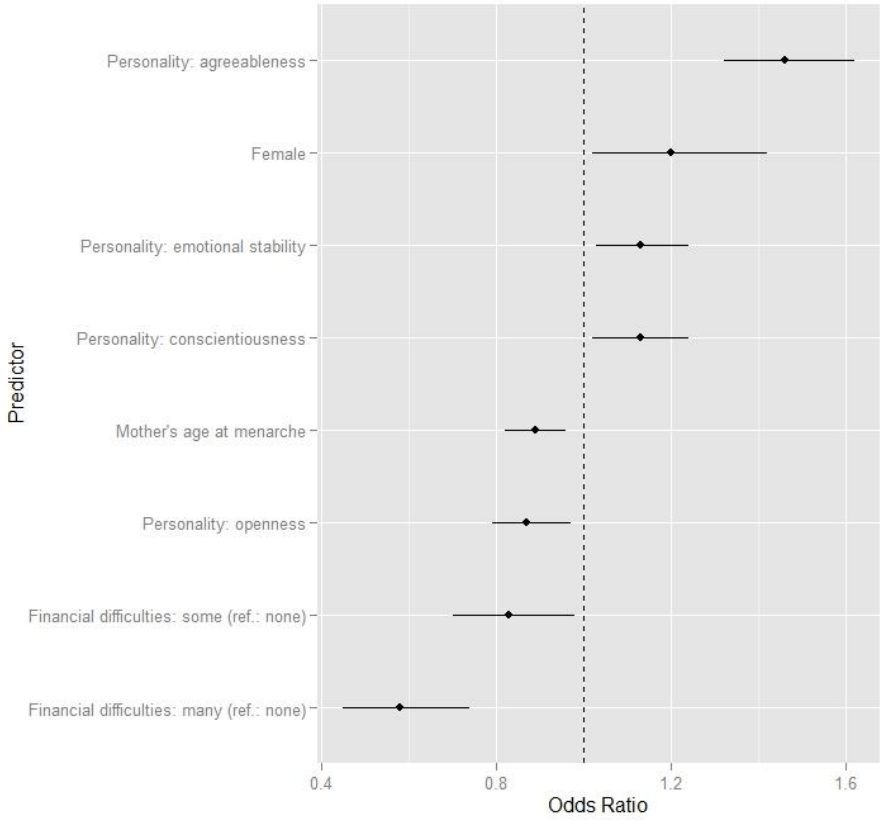
4.3.4.2 Mother-rated prosocial score

The results for the mother-rated prosocial score, assessed at ~16.5 years, are presented in Table 19.

Table 19. Logistic multiple classification model results for mother-rated prosocial score (low vs. high)

Predictor		**OR**	**95% CI**	**p**
Sex (ref.: male)		1.18	1.00 – 1.40	0.048
Mother's education (ref.: none/CSE)				
	Vocational	1.06	0.76 – 1.46	0.745
	O-level	1.14	0.89 – 1.47	0.297
	A-level	1.23	0.93 – 1.62	0.151
	Degree	1.13	0.81 – 1.60	0.471
Father's education (ref.: none/CSE)				
	Vocational	1.03	0.76 – 1.39	0.851
	O-level	0.90	0.72 – 1.14	0.402
	A-level	1.12	0.89 – 1.40	0.353
	Degree	0.96	0.72 – 1.28	0.773
Financial difficulties (ref.: none)				
	Some	0.83	0.70 – 0.98	0.025
	Many	0.58	0.45 – 0.75	<0.001
Home ownership status (ref.: rented)				
	Mortgaged	1.06	0.78 – 1.44	0.694
	Owned	0.85	0.56 – 1.28	0.437
Neighbourhood deprivation (IMD 2000 in 1998)		1.05	0.97 – 1.15	0.178
Mother's age at first pregnancy		0.95	0.87 – 1.03	0.151
Mother's age at menarche		0.89	0.82 – 0.96	0.003
Mother had sex when <16 years old		0.81	0.65 – 1.00	0.052
Father's age at index pregnancy		1.02	0.94 – 1.11	0.550
Biological father absent at 10 years (ref.: present)		0.91	0.74 – 1.12	0.385
Extraversion		1.01	0.92 – 1.11	0.904
Agreeableness		1.46	1.32 – 1.62	<0.001
Conscientiousness		1.13	1.02 – 1.24	0.016
Emotional stability		1.13	1.03 – 1.24	0.014
Openness		0.87	0.79 – 0.97	0.008
Indicator variable				0.051
		Variance	**Proportion of total variance**	**p**
Explained variance		0.243	0.066	
Residual variance		3.451	0.934	
School (Key Stage 4)		0.008	0.002	0.402
Neighbourhood (LSOA)		0.015	0.004	0.419
Friendship network		0.138	0.037	0.384
Individual		3.290	0.891	
Total		3.694	1	

Figure 11. Odds ratios with 95% confidence intervals for significant predictors of mother-rated prosocial score. For continuous predictors the (standardized) OR corresponds to a 1 SD increase; for categorical variables, the OR compares membership of a category to a reference category



Girls were considered somewhat more prosocial (OR = 1.18, p = 0.048). Out of the SES variables, only financial difficulties had a significant effect, predicting a lower prosocial score (OR = 0.83, p = 0.025 for some difficulties; OR = 0.58, p < 0.001 for many difficulties). A *later* maternal age at menarche was associated with a lower prosocial score (OR = 0.89, p = 0.003), while early maternal experience with sexual intercourse (when aged < 16) predicted a lower prosocial score (OR = 0.81, p = 0.052). Four out of the Big Five personality factors were found to predict the prosocial score. Those with a higher score for self-rated agreeableness, in particular, were judged to be more prosocial by their mother (OR = 1.46, p < 0.001). Further, prosocial scores were positively associated with conscientiousness (OR = 1.13, p = 0.016) and emotional stability (OR = 1.13, p = 0.014) but negatively associated with openness (OR = 0.87, p = 0.009).

None of the social classifications exhibited statistically significant clustering.

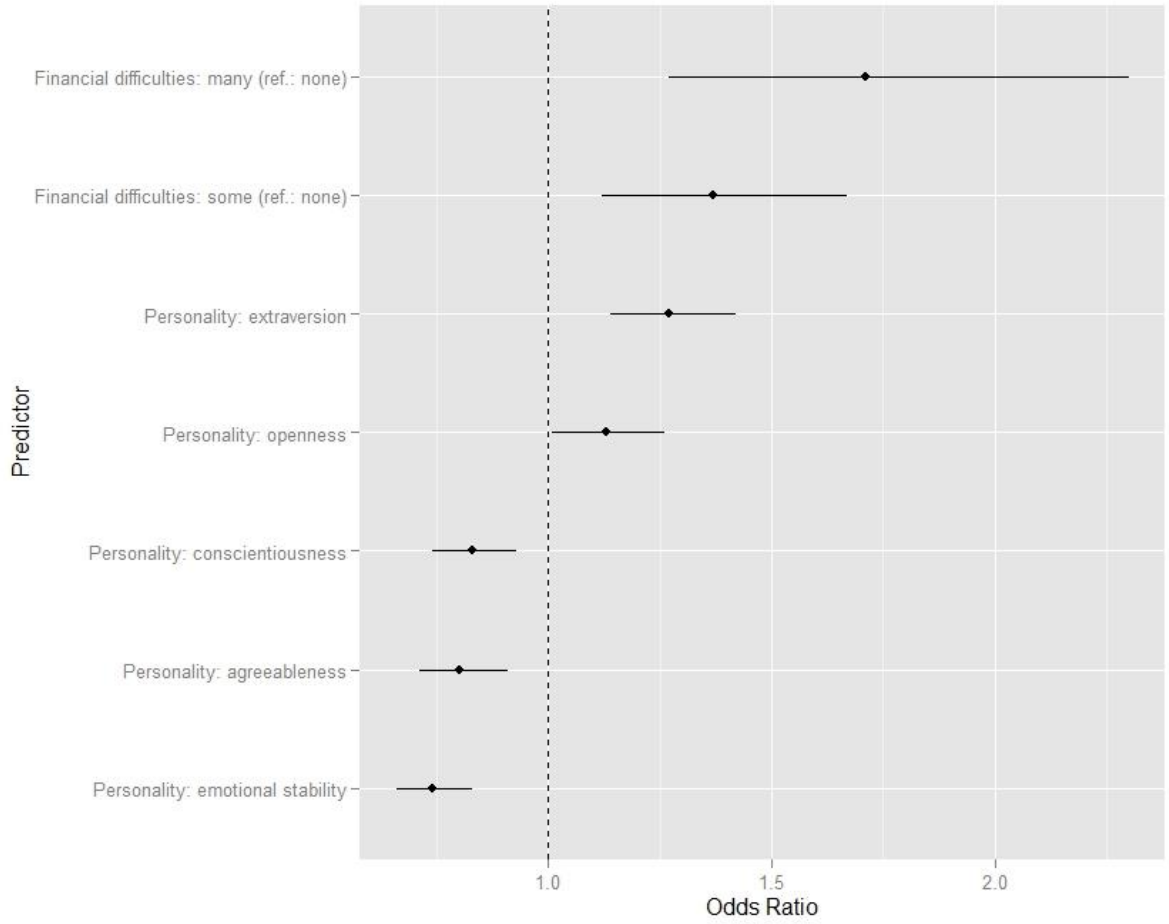
4.3.4.3 Mother-rated conduct problems

Table 20 displays the results for the mother-rated SDQ conduct problems score (assessed at ~16.5 years).

Table 20. Logistic multiple classification model results for mother-rated conduct problems (low vs. high)

Predictor		**OR**	**95% CI**	**p**
Sex (ref.: male)		1.16	0.95 – 1.41	0.150
Mother's education (ref.: none/CSE)				
	Vocational	1.04	0.72 – 1.50	0.831
	O-level	0.81	0.61 – 1.08	0.152
	A-level	0.81	0.59 – 1.11	0.190
	Degree	0.77	0.52 – 1.15	0.207
Father's education (ref.: none/CSE)				
	Vocational	1.10	0.78 – 1.55	0.573
	O-level	1.03	0.78 – 1.36	0.853
	A-level	0.96	0.73 – 1.25	0.760
	Degree	0.93	0.65 – 1.32	0.673
Financial difficulties (ref.: none)				
	Some	1.37	1.12 – 1.67	0.002
	Many	1.71	1.27 – 2.30	<0.001
Home ownership status (ref.: rented)				
	Mortgaged	0.73	0.52 – 1.03	0.076
	Owned	0.75	0.47 – 1.22	0.245
Neighbourhood deprivation (IMD 2000 in 1998)		0.98	0.89 – 1.08	0.663
Mother's age at first pregnancy		1.04	0.94 – 1.15	0.417
Mother's age at menarche		1.09	0.99 – 1.20	0.071
Mother had sex when <16 years old		1.02	0.79 – 1.32	0.859
Father's age at index pregnancy		0.98	0.89 – 1.08	0.666
Biological father absent at 10 years (ref.: present)		0.89	0.70 – 1.14	0.355
Extraversion		1.27	1.14 – 1.42	<0.001
Agreeableness		0.80	0.71 – 0.91	0.001
Conscientiousness		0.83	0.74 – 0.93	0.001
Emotional stability		0.74	0.66 – 0.83	0.000
Openness		1.13	1.01 – 1.26	0.034
Indicator variable		0.83	0.69 – 0.99	0.040
		Variance	**Proportion of total variance**	**p**
Explained variance		0.275	0.064	
Residual variance		4.023	0.936	
School (Key Stage 4)		0.007	0.002	0.418
Neighbourhood (LSOA)		0.035	0.008	0.393
Friendship network		0.690	0.161	0.026
Individual		3.290	0.765	
Total		4.298	1	

Figure 12. Odds ratios with 95% confidence intervals for significant predictors of mother-rated conduct problems. For continuous predictors the (standardized) OR corresponds to a 1 SD increase; for categorical variables, the OR compares membership of a category to a reference category



Financial difficulties predicted conduct problems (OR = 1.37, p = 0.002 for some difficulties; OR = 1.71, p < 0.001 for many difficulties). All of the personality factors showed statistically significant associations with conduct problems. Conduct problems were reported more frequently for adolescents with higher scores on the extraversion (OR = 1.27, p < 0.001) and openness (OR = 1.13, p = 0.034) dimensions, but less frequently for those who scored higher on agreeableness (OR = 0.80, p = 0.001), conscientiousness (OR = 0.83, p = 0.001) and emotional stability (OR = 0.74, p < 0.001).

Clustering at the level of schools and neighbourhoods was effectively zero ($rICC_{school}$ = 0.002, p = 0.42; $rICC_{neighbourhood}$ = 0.008, p = 0.39). By contrast, substantial and statistically significant clustering was found for friendship networks (rICC = 0.161, p = 0.026).

4.4 Discussion

In this study I, firstly, tried to determine whether cooperation exhibits the kind of social clustering predicted by models of the evolution of cooperation, in a population of adolescents in an industrial society. Secondly, I examined whether life history predictors are associated with the tendency to cooperate or behave in a prosocial manner – in line with predictions from life history models about calibration of cooperativeness to one's environment – and whether some of the clustering I find could be attributed to such predictors.

4.4.1 Main findings

4.4.1.1 Cooperation clusters in adolescent friendship networks

I found clear evidence for clustering of cooperativeness in friendship networks, in line with recent work among hunter-gatherers (Apicella et al. 2012). Four of the five measures of cooperativeness showed evidence of clustering in friendship networks. Individuals who had been nominated more often as a friend – who, on average, would be expected to have friends who are more cooperative (based on the assumption that the act of participating and nominating is cooperative) – were more likely to have completed and returned the friendship questionnaire or attended Teen Focus 4. Quite strikingly, prosociality as assessed by a child's primary school teacher around age 8 showed statistically significant clustering in friendship networks when the adolescents were around 16-17 years old. Conduct problems, reported by the mother when the adolescents were ~16.5 years old, showed a similar level of clustering in friendship networks.

Only with respect to mother-rated prosociality did adolescents not appear to be more similar to their friends than random peers in the population. This is somewhat surprising considering that mother-rated prosociality was assessed almost contemporaneously with the friendship networks, while the teacher-rated version of the same outcome, which *did* cluster, was actually measured about 9 years earlier. A possible explanation of this apparent anomaly could be related to the fact that the SDQ questions intended to assess prosociality are about social interactions that occur, partly at least, in the sphere of interactions with age peers (e.g., 'readily shares with other

children/children and teenagers'), which primary school teachers will often be in a better position to witness on a regular basis compared to parents of teenagers. If it is true that the teacher-rated prosocial score provides a better measure of a child's interpersonal style in a peer context than the mother-rated prosocial score, then this, assuming some behavioural consistency over time, could explain why the former shows more clustering among friends than the latter. It is perhaps significant in this regard that of the four SDQ measures (hyperactivity, emotional symptoms, conduct problems, and prosociality), prosociality has by far the lowest parent-teacher correlation, reported as 0.37 by Goodman (Goodman 1997), raising questions about the extent to which they measure the same thing.

While life history predictors and personality did explain some of the variation in our measures of cooperativeness, our results did not suggest that (clustering of) life history predictors or personality traits was behind the social clustering of cooperation in friendship networks.

The data and methods used here do not allow me to identify the mechanism responsible for the clustering of cooperativeness among friends. I cannot say whether this is due to social selection, social influence, or a combination of the two. Based on the model results, it *is* possible to conclude that friends' similarity in cooperativeness was probably not due to similarity of life history predictors. If that were the case, the intraclass correlation for friendship networks would have been substantially reduced after adding the life history predictors, which is not what I found. The fact that teacher-rated prosociality clusters in adolescent friendship networks assessed roughly 8 years later, seems more consistent with a social selection process in which prosocial individuals are more likely to form friendships with other prosocial individuals, since many of the friendships are likely to postdate the prosociality assessment.

The null clustering models indicated some minor but statistically significant clustering of the study participation measures in schools and neighbourhoods. This clustering largely disappeared, however, after adding life history predictors. This suggests that what little variation in cooperativeness there was between schools and between neighbourhoods was due to similarity in life history factors at those levels. (Because

personality does not cluster at the neighbourhood or school level (see chapter 5), it cannot account for clustering of cooperativeness in neighbourhoods or schools.)

4.4.1.2 Life history predictors explain some of the variation in cooperativeness

All of the measures of cooperation exhibited statistically significant associations with at least one or several of the life history predictors, always in the predicted direction. There was, however, some inconsistency as to which specific predictor(s) showed a significant association with each of the different measures of cooperativeness.

The most consistent results pertained to the effect of financial difficulties. Children whose mother reported experiencing financial difficulties (at 7 years) were less likely to return the Friends questionnaire, less prosocial according to their teachers' answers to the SDQ, and less prosocial but displaying more conduct problems according to their mothers' SDQ answers. Only attendance of Teen Focus 4 was unrelated to financial difficulties. A possible interpretation is that the experience of economic hardship during childhood, through some unknown mechanism, serves as a cue that one is living in a resource-poor or unpredictable environment in which the future benefits of long-term investments, including those in cooperative social relationships, are less likely to materialize; an environment in which a focus on short-term gains is appropriate. It is perhaps telling that, of all the socioeconomic variables included in this study, financial difficulties is the most directly experiential, the most subjective, relating to actual experiences of economic hardship (as reported by the mother).

I found additional evidence for a negative link between socioeconomic deprivation and cooperativeness or prosociality: children living in rented versus mortgaged or owned accommodation were less likely to display prosocial behaviour according to teachers' reports on their behaviour; adolescents living in more deprived neighbourhoods were less likely to complete and return the Friends questionnaire, consistent with existing reports of the effects of neighbourhood deprivation on cooperation (Nettle, Colleony, et al. 2011; Holland et al. 2012; Silva & Mace 2014); and those with more educated parents were more likely to cooperate with ALSPAC by attending Teen Focus 4.

Overall, then, our analyses provide considerable support for an eroding effect of socioeconomic deprivation on cooperativeness, in line with most of the published

literature (4.1.6), but in contrast to some recent work in social psychology (Piff et al. 2010; Piff et al. 2012).

Father absence predicted a lower tendency to cooperate for two outcomes, attending Teen Focus 4 and, less pronouncedly, teacher-rated prosociality. These findings are consistent with the suggestion that father absence guides individuals onto a slower life history trajectory characterized by a decreased tendency to cooperate.

As predicted, girls were more likely to cooperate, exhibiting more cooperative behaviour, on average, for all of the measures of cooperation apart from conduct problems (for which no sex difference was detected). As argued in Chapter 1 (1.2.3.3.2 and 1.4.2), this sex difference may reflect a greater tendency in human females to solve social problems in a cooperative manner, reflecting differences in the nature of intrasexual competition between males and females.

The inconsistency with regard to which life history predictors matter for particular outcomes is in need of explanation. While some of it may be ascribable to the random noise inherent in any observational study, it is possible that 'cooperativeness' is not as unitary a trait as I have assumed here. It may be a worthwhile theoretical project to attempt to develop a taxonomy of cooperative acts.

4.4.1.3 Personality differences account for some of the observed variation in cooperativeness

The expectation of a positive association between agreeableness and cooperativeness was largely borne out by the data. A higher score on the agreeableness dimension significantly predicted higher teacher-rated and mother-rated prosociality scores and fewer conduct problems (and just failed to reach significance for Teen Focus 4 attendance). These results are consistent with Nettle's (2007) proposal that high agreeableness represents a strategy to increase fitness through the fostering of cooperative social relationships[5].

[5] Of course, the finding of an association between agreeableness and measures of cooperativeness or prosociality could be argued to be something of a tautology. The correlations between agreeableness and the measures of cooperation (appendix to chapter 4) are not of such a magnitude as to make the inclusion of agreeableness as an independent variable worrying from a statistical perspective.

Conscientiousness was associated with more cooperativeness in the form of a higher mother-rated prosocial score and a lower conduct problems score. Higher cooperativeness in more conscientious individuals chimes with the notion that conscientious individuals are focussed on long-term fitness benefits (Nettle 2007).

More emotionally stable (= less neurotic) individuals scored, on average, higher on teacher-rated and mother-rated prosociality and had fewer conduct problems. From an evolutionary perspective, neuroticism has been interpreted as a state of increased vigilance to threats (Nettle 2007). Translated to the social sphere, this may manifest itself as a lower disposition to trust others (Evans & Revelle 2008) and a consequently reduced tendency to cooperate.

More extraverted adolescents were less likely to return the Friends questionnaire and more likely to display conduct problems. It is tempting to interpret the latter finding in terms of extraversion as a life history strategy geared towards mating success. It is not clear why extraverts were less likely to cooperate by attending Teen Focus 4.

Finally, I did not make any specific predictions about openness to experience and cooperativeness. Our empirical findings are that while individuals more open to new experiences seemed somewhat more likely to return the Friends questionnaire (although this just failed to reach significance), they were judged to be less prosocial by both teachers and mother and more likely to have conduct problems.

4.4.2 Strengths and limitations

One of this study's main strengths is its reliance on five different measures of cooperativeness. This allows us to compare results across outcomes and to separate, at least to some extent, more general from more outcome-specific findings. For example, the clustering of cooperation in friendship networks and the corrosive effect of financial hardship on cooperativeness were found to be quite general (both in evidence for 4 out of 5 outcomes), while, for instance, parental education only had predictive power with regard to whether invited adolescents took part in the Teen Focus 4 clinic.

The use of multiple measures also goes some way towards dealing with the possibility that certain kinds of cooperative tasks will appeal more to certain kinds of people, regardless of any differences in their baseline tendency to help. I have already

mentioned this possibility in relation to survey salience. Because it is doubtful that a truly neutral measure of cooperation even exists, and it is not clear whether it would be recognized as such if it did, using multiple measures would seem advisable. The fact that teacher-rated prosociality and mother-rated conduct problems also appear to cluster in friendship networks suggests that cooperativeness genuinely does display social clustering in adolescent friendship networks.

The use of a multilevel modelling allowed us to pinpoint more precisely where exactly in the social structure clustering of cooperation is located than would have been possible had I made use of only one level above the individual (in which case there is a much greater risk of clustering at one level masquerading as clustering at another). Because of the way the social network data were collected for ALSPAC, they are too limited to allow for some of the social network analytical techniques that one might wish to use when studying the social clustering of a trait like cooperation, for example, to gain insights into the extent of clustering beyond simple dyads.

Three of the measures, namely, those derived from the Strengths and Difficulties questionnaire, are based on observations by teachers and mothers, who will by necessity only witness a small part of the young people's social lives, raising questions about the context-specificity (or not) of reported behaviour. Furthermore, the Strengths and Difficulties Questionnaire is a screening instrument; each score is based on only five simple items. It is not clear how sensitive this instrument is across the spectrum of cooperativeness that we are interested in.

While the study participation measures are, arguably, naturalistic, they are still somewhat contrived and may not reflect day-to-day cooperativeness all that well. More clearly naturalistic measures of cooperation would have been preferable but were unavailable in our data set.

4.4.3 Conclusions

The occurrence of social clustering with respect to cooperativeness is a critical but rarely empirically tested prediction of evolutionary models of cooperation between non-relatives. The absence of such clustering in a real-world population would raise doubts about the viability of the most prominent theoretical explanations of large-scale

cooperation in humans. However, this study confirmed the existence of social clustering of cooperativeness, specifically in friendship networks, in a population of adolescents in an industrial society – in line with partner choice models of human cooperation and biological markets thinking (McNamara et al. 2008; Barclay 2013).

The results also suggest that adverse childhood conditions, such as economic hardship, have a negative effect on cooperativeness. This is consistent with the idea that childhood adversity signals an environment in which an opportunistic, less cooperative interpersonal style is more appropriate (e.g., Belsky et al. 1991; McCullough et al. 2012), but argues against the proposed positive effect of socioeconomic deprivation on prosociality, supposedly reflecting a higher dependence on others (Piff et al. 2010).

Chapter 5: Comparing the social clustering of multiple behavioural and non-behavioural traits

5.1 Introduction

Behaviours and non-behavioural traits show varying levels of clustering in the social structures adolescents are embedded in, as discussed in chapter 1 and demonstrated empirically in chapters 2 and 3. Different academic disciplines bring different ideas to the table when it comes to explaining social clustering. In this chapter, I consider explanatory models from the human evolutionary behavioural sciences and how these might translate into particular patterns of social clustering. I then look at the actual patterns of social clustering – at the level of neighbourhoods, schools and friendship networks – of a range of behavioural and non-behavioural measures in samples of British adolescents (from ALSPAC) to assess which explanatory models are more or less consistent with the empirical data in this particular population. The explanatory models in question are adaptive flexibility in response to socioecological variation, coordination benefits from similarity, and conformist bias.

The focus in this chapter is very much on establishing broad patterns, if any exist, and determining the scope for different kinds of (evolutionary) explanations in accounting for behavioural variation that manifests itself as social clustering.

In addition, because all models in this chapter are run with and without sex – to account for possible sex differences and possible confounding effects of social clustering of sex on social clustering of other measures – I also evaluate a number of predictions, based on evolutionary considerations, of sex differences in the outcomes studied (outlined in 1.4.3). Specifically, boys are predicted to be more likely to have engaged in substance use of various kinds, viz., cigarette smoking, trying cannabis, drinking alcoholic beverages, because of a greater propensity for risk-taking related to intrasexual competition (1.2.3.3.1); boys are predicted to be more extravert because they are more tolerant of the risks associated with extravert behaviour; and girls are predicted to be more agreeable than boys because of sex differences in the nature of intrasexual competition, which leaves girls less well-equipped to solve social problems through (threat of) physical force, but more inclined to use a cooperative approach.

5.1.1 Evolutionary perspectives on social clustering of behaviour in humans

In this section, I discuss several explanatory models from the human evolutionary behavioural sciences and how they might be able to throw light on the social clustering patterns of different kinds of behaviour. Each of these explanatory models has its own way of approaching the problem of explaining behavioural variation. From this follows a particular way of categorizing behaviours, which in turn may imply different social clustering patterns. The explanatory models, their categorizations of behaviour, and implications for clustering are summarized in Table 21.

Table 21. Overview of explanatory models, their categorizations of behaviour and implications for social clustering

Explanatory model	Categorization of behaviour	Social clustering implications
Adaptive flexibility in response to environmental variation (5.1.1.1)	Fitness-related behaviour – different variants provide a better fit in different environments	Clustering at level of variation of adaptively relevant environmental features
	Fitness-related behaviour – one variant best in entire range of environments	Universal
	Behaviour not directly related to fitness	No specific clustering predictions
Coordination benefits from similarity (5.1.1.2)	Behaviour itself subject to coordination benefits from similarity	Clustering at level of variation at which coordination benefits are provided (i.e., among collaborative partners)
	No coordination benefits from similarity in behavioural trait itself	No clustering OR clustering among collaborative partners due to similarity acting as a cue to the possibility of successful behavioural coordination
Social transmission biases (5.1.1.3)	Individual learning is effective and not too costly	Clustering dependent on who face problem
	Clear link between skill and result, so success-based learning appropriate	Clustering in group whose members have access to the same cultural models (to extent that group members all face same problem)
	Link between skill and result not very apparent or behaviour not obviously linked to fitness at all	Prestige bias and conformist bias may lead to clustering of behaviour in a reference group, e.g., among friends or school peers

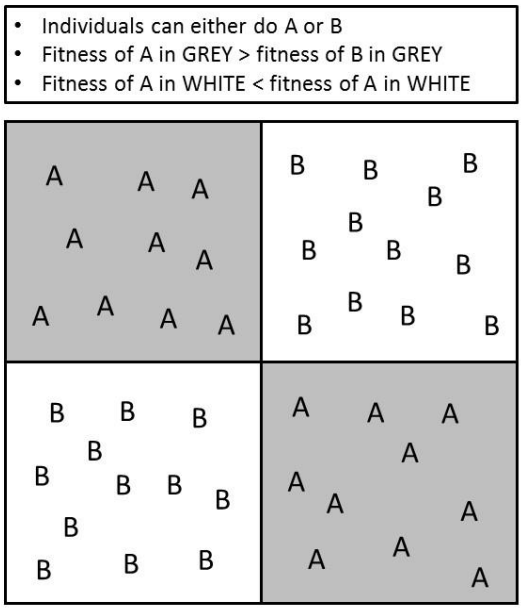
5.1.1.1 Adaptive flexibility in response to socioecological variation

When confronted with unexplained behavioural variation, human behavioural ecology asks, in the first instance, whether it represents adaptive flexibility in response to socioecological variation (Smith et al. 2001). Humans, on this view, have evolved the ability to tailor their behavioural strategies so as to create a better fit between

behavioural phenotype and environment. For example, in high-mortality environments, reproduction cannot be postponed too long – in favour of, say, investing in resource acquisition skills – without running the risk of incurring significant fitness costs, such as those suffered when not reproducing at all. A negative association between age at first birth and (extrinsic) mortality (Low et al. 2008) may thus represent adaptive flexibility in response to environmental variation.

In terms of categorizing a particular behaviour, the most critical question, from the adaptive flexibility perspective, is to what degree it is fitness-related. This perspective has little to say about how varying traits not directly related to fitness should cluster. When a behavioural trait is fitness-related and exhibits adaptive flexibility, this explanatory model implies that the social level at which a behaviour varies is the level at which adaptively relevant environmental features vary (Figure 13). In terms of the clustering mechanisms mentioned in chapter 1, this explanatory model falls under the banner of 'similar responses to a shared ecology' (1.2.2.2.2).

Figure 13. Adaptive flexibility in response to environmental variation leads to social clustering. For behaviour X, individuals can adopt either A or B. If they live in a grey environment, they do A, because this A has a higher fitness than B in a grey square. In white environments, the opposite situation occurs. Because the adaptively relevant feature (grey- or whiteness) varies at the level of squares, behaviour (A or B) clusters in squares.



With its environmental emphasis, human behavioural ecology would predict social clustering of *adaptively relevant* behaviours to occur largely at the level of

neighbourhoods and schools (as geographical units), because this is the kind of scale at which at which important features of the environment are likely to vary – for example, morbidity and mortality levels, which vary with socioeconomic deprivation (Eachus et al. 1996; Mackenbach et al. 1997). On this account, clustering at the level of friendship networks would be a by-product of the fact that friends are typically drawn from those who live nearby and are therefore likely to share many environmental features. Social clustering might actually be strongest at a level higher than the ones I look at here. Going back to the example of mortality rates and reproductive timing (Low et al. 2008), mortality rates often vary much more between societies than within different parts of the same society.

5.1.1.2 Coordination benefits from similarity

Sometimes it is advantageous to individuals to be similar or behave similarly to those around them because of coordination benefits, which may ultimately translate to fitness benefits (1.2.4.2.2). If this is the case, a preference for similarity leading to similarity-based assortment, or a tendency to conform to a local norm might confer fitness benefits on those who are so predisposed and be selected for in their own right (Cole & Bruno Teboul 2004; Fu et al. 2012; Koski & Burkart 2015). Conforming to the law of the land when it comes to which side of the road to drive on is an obvious example of a coordination benefit of similarity: following the local norm makes traffic coordination easier and comes with tangible fitness benefits.

As discussed in chapter 1 (1.2.4.2.2), coordination in collaborative task performance might be easier achieved between similar individuals, who are more predictable to each other and more likely to agree on means and ends (Cole & Bruno Teboul 2004). When individuals need to do the same thing to reap the greatest reward, then doing so with similar others increases the chance that people do indeed make the same choices (Chierchia & Coricelli 2015).

At first glance, the most important information needed to categorize a behaviour, from this perspective, would be whether coordination benefits are to be gained from similarity in the behaviour in question. If so, clustering of the behaviour among collaborative partners would be expected, based on some kind of clustering mechanism, such as a preference for similarity. This would, arguably, be especially the case if the

behaviour is strongly tied to some component of fitness. However, if numerous behaviours are subject to coordination benefits from similarity, a general preference for similarity of frequent collaborative partners, such as friends, may have evolved (Fu et al. 2012). This would manifest itself as behavioural clustering among groups of collaborators, such as friends, along all sorts of dimensions, many of which might have nothing to do with biological fitness nor be subject to coordination benefits. Thus, behaviours not subject to clear coordination benefits from similarity may nonetheless cluster in networks of close associates. Alternatively, a similar pattern of social clustering might result if a wide variety of indicators of similarity can be used to infer the similarity of thought required to be able to coordinate actions effectively (Chierchia & Coricelli 2015).

Coordination benefits resulting from similarity of collaboration partners are a widely accepted explanation of why friends and other close social associates are often similar in many respects. However, few empirical tests of this idea have been conducted in humans or other animals. One study, already discussed in chapter 1 (1.2.4.2.2), manipulated the perceived similarity of pairs of players playing coordination games and found that pairs manipulated into thinking they were similar in some personality trait, were more likely to achieve coordination in a 'stag hunt' game and more willing to take a risk by choosing a higher but uncertain payoff, which required matching choices, over a safe payoff, which did not require such coordination (Chierchia & Coricelli 2015). One interpretation of this result is that players have more confidence in their ability to predict the other player's behaviour and are more likely to want the same thing, namely go for the higher payoff, if they are more similar to them, revealing a psychological predisposition geared towards coordination benefits from similarity.

5.1.1.3 Social transmission biases

As discussed in chapter 1 (1.2.3), cultural evolutionary studies suggest at least three mechanisms that can lead to social clustering, viz., transmission biases that evolved by natural selection because, on balance, they increase the adoption of socially transmitted behaviours beneficial to an individual's inclusive fitness (Henrich & McElreath 2003; Richerson & Boyd 2005). The patterns of social clustering one would expect to find based on these mechanisms depend on many factors, such as the reference groups of

conforming individuals, ideas about who the prestigious individuals in a society or other reference group are, and the differential susceptibility of behaviours and individuals to success, conformist and prestige bias.

The dynamics of cultural evolution have been invoked to explain differences between-group differences at the level of small-scale societies (Henrich et al. 2001). But perhaps they can also be used to explain patterns of social clustering within larger societies. If transmission biases are at work but only within the boundaries of specific reference groups, such as particular adolescent peer networks, then clustering may result because different behaviours are favoured in different reference groups, because of differences in the most frequent behaviour (conformist bias) or in the behaviour of the most prestigious individuals (prestige bias). Cognitive biases originally selected in ancestral small-scale societies because they increased the efficiency of social transmission of adaptive behaviour may, in modern societies, give rise to patterns of social clustering of adolescent behaviour that are largely neutral or, occasionally, maladaptive (Richerson & Boyd 2005).

In sum, it is not entirely clear which patterns of social clustering to expect based on the existence of conformist and prestige bias, although they are certainly consistent with adopting the norms of one's peer group or the most popular individuals in or admired by one's peer group, and therefore with behavioural clustering in friendship networks, perhaps above all, and possibly schools and neighbourhoods as wider arenas of peer influence as well (e.g., Ali & Dwyer 2010; Warner et al. 2011). These transmission biases might be especially powerful where behaviours are not related in obvious ways to fitness components, that is, where individual learning or success-based copying are less appropriate strategies.

5.1.2 Study aims

In this chapter, I compare the clustering in schools, neighbourhoods and friendship networks of a wide selection of traits in a sample of British adolescents. The traits in question are: sex, BMI, maternal education, paternal education, home ownership status, educational achievement, the Big Five personality factors, smoking, drinking, cannabis use, experience with sexual intercourse, prosociality and conduct problems. In earlier

chapters, I already quantified the clustering of experience with sexual intercourse and cooperative behaviour.

The aim of this exercise is to use the overall clustering patterns to assess the plausibility and scope of different ideas about the origins of social clustering in behaviour, specifically those derived from explanatory models in the human evolutionary behavioural sciences. The point here is not to test very specific hypotheses – for example, about conformism and smoking or environmental harshness and risky behaviour – but to get a handle on the plausibility of different evolutionary approaches to explaining social clustering in adolescent behaviour.

If, for instance, behaviours cluster mainly at the neighbourhood level but not at the level of friendship networks (once neighbourhood clustering is taken into account), this suggests that explanations based on adaptive flexibility in response to environmental variation are more plausible explanations of said clustering than those that rely on conformist or prestige bias or coordination benefits of similarity. By contrast, if neighbourhood and school clustering pale in comparison to clustering in friendship networks, this suggests at best a minor role for adaptive flexibility in response to environmental variation, in explaining behavioural variation in this sample of adolescents, but a much bigger potential role for mechanisms like conformist and prestige bias, or a similarity preference for coordination purposes. If different behaviours show very different clustering patterns, then this suggests explanations tailored to specific behaviours are in order; if behaviours tend to cluster in similar ways, then a more general explanation might be appropriate.

Several of the traits for which social clustering is examined here are not behavioural traits as such. So why do I look at them here? The social clustering of household socioeconomic status is mainly included to determine to what extent behavioural clustering across the social world of adolescents could plausibly reflect the social clustering of SES, which is sometimes treated as an index of environmental harshness in life history theory-based studies. In addition, since adolescents do not influence each other's household SES, the extent of clustering of SES at the level of friendship networks may provide a useful comparison point for behavioural clustering at the level of friendship networks, in terms of judging the probability that such clustering is due to

assortment or social influence – although this is simply a plausibility argument that should not be given too much weight.

Similarly, the plausibility of a scenario in which personality similarities among friends drive behavioural similarity is assessed. The clustering of personality factors at the level of friendship networks, which are behavioural measures, may also serve a benchmark purpose with regard to social influence, since personality factors are thought to largely reflect stable behavioural predispositions with a strong genetic basis. Thus, if behavioural measures show clustering among friends similar to that of personality factors, this would increase the plausibility of the suggestion that such behavioural similarities are due to a preference for forming or maintaining associations with similar others (in line with a coordination benefits from similarity), rather than due to social influence (in line with social transmission biases).

5.2 Methods

5.2.1 Data and participants

In this chapter, I look at the clustering of 21 traits across the social world of adolescents (schools, neighbourhoods and friendship networks), using data from ALSPAC (2.1). They are based on information gathered through ALSPAC's postal questionnaires sent to the mothers of the study child, the study child's teacher and the adolescent him- or herself, ALSPAC clinic visits (Teen Focus 2, 3 and 4), and academic performance data extracted by ALSPAC from the UK's Department of Education's National Pupil Database (NPD).

For each trait, I started with the ALSAC core sample, dropping cases without a valid school or neighbourhood identifier and those missing the outcome in question. The resulting sample sizes differ by outcome, ranging from 2,944 for experience with sexual intercourse by Teen Focus 4 to 9,986 for sex and academic achievement.

5.2.2 Variables

5.2.2.1 Behavioural variables: substance use, sexual experience, prosociality

5.2.2.1.1 Substance use

Four measures of substance use were investigated. Adolescents attending the ASPAC clinic Teen Focus 2 were asked whether they had ever smoked a cigarette. Their responses provided me with a binary cigarette ever-use variable. Similarly, at Teen Focus 3 (target age = 13 years and 6 months), they were asked whether they had ever tried cannabis, giving a cannabis ever-use variable. The final two substance use measures, also from TF3, are binary variables relating to alcohol consumption, one of which indicates whether the respondent has ever had a whole alcoholic drink and the other whether he or she has ever consumed four alcoholic drinks (or more) in a 24-hour period. Based on the existing literature, the clearest expectation with regard to social clustering is a clustering of substance use behaviours among friends (1.2.1).

5.2.2.1.2 Experience with sexual intercourse

Social clustering of sexual behavioural development was assessed using two binary sexual experience variables, one at Teen Focus 3 (0 = respondent has not had sexual intercourse, 1 = respondent has had sex) and the other at Teen Focus 4 (same coding; target age = 17 years and 6 months). Experience with sexual intercourse by Teen Focus 4 was the outcome variable in chapter 3.

5.2.2.1.3 Prosociality

I looked at the social clustering of three measures of cooperation: mother-rated prosociality and conduct problems (when adolescent were around 16.5 years old) and teacher-rated prosociality (when the study children were approximately 7 or 8 years old). More details about these measures can be found in Chapter 4. They were treated as binary because their heavily skewed distributions did not allow for transformation to normality to allow for linear regression.

5.2.2.2 Personality factors

In order to investigate the social clustering of adolescents' personalities, I used (continuous) scores for the Big Five personality factors (2.2.4), derived from the International Personality Item Pool (IPIP), which was administered during the Teen Focus 2 clinic when respondents were about 13.5 years old on average. I investigated the social clustering of each of the Big Five, i.e., extraversion, agreeableness, conscientiousness, emotional stability (the opposite of neuroticism), and openness. Extraversion was squared in order to better approximate a normal distribution. All were standardized so that variance estimates for each social classification were equivalent to intra-class correlations.

5.2.2.3 Sex, household SES, father absence, educational achievement, and body mass index

5.2.2.3.1 Sex

Most friendship ties among adolescents are between members of the same sex (McPherson et al. 2001; Shrum et al. 1988). If any of the other traits vary by sex, this

could masquerade as clustering at the level of friendship networks. For this reason, I ran all clustering models twice, without and with sex.

5.2.2.3.2 Socioeconomic status

Three measures of SES were considered: maternal degree (0 = mother does not have degree, 1 = mother has degree), paternal degree (0 = mother does not have degree, 1 = mother has degree), and home ownership status at index pregnancy (0 = accommodation is rented, 1 = mortgaged or owned). For more details on SES in ALSPAC, see section 2.1 in chapter 2. While the original variables have more than two categories – five categories for parental education and three for home ownership status – I converted these to binary variables to facilitate the calculation of intraclass correlations (2.3.1.1.2).

5.2.2.3.3 Father absence

Father absence has been linked to a range of adolescent behaviours, including early sexual debut (e.g., Newcomer & Udry 2013; Kiernan & Hobcraft 1997; Hogan & Kitagawa 1985) and various kinds of substance use (McLanahan et al. 2013). Thus, if father absence clusters at particular levels of the social world of adolescents, this may lead to clustering of its consequences as well. The variable used to investigate social clustering of father absence indicates whether (biological) fathers were present in the household at 10 years. If divorce shows socioeconomic patterning, father absence may cluster in schools and neighbourhoods insofar as SES differs geographically. The results should also indicate whether adolescents are more likely to befriend those from households of a similar composition (father present vs. absent) after taking into account school and neighbourhood differences.

5.2.2.3.4 Individual educational achievement

Individual educational achievement was measured with a binary variable indicating whether the study adolescent had received at least one A or A* grade as part of their GCSE assessments (see 3.2.2.2.6 for a brief explanation). The distribution of the original variable was not normal, nor could it be transformed to approximate normality. One might expect school performance to cluster in schools and neighbourhoods for a number of reasons. Social clustering of socioeconomic status might give rise to social

clustering of academic achievement since parents of higher SES are often more educated and may therefore be more likely confer an academic orientation and aptitude on their children. In addition, some schools may offer a higher quality education or attract more academically able pupils. They may also put pupils together based on (demonstrated) academic ability, thereby manipulating the selection of peers adolescents are likely to make friends with. Finally, adolescents may actually prefer to be friends with age peers similar to them in terms of academic orientation or ability.

5.2.2.3.5 Body mass index

Adolescents' body mass index was calculated based on height and weight measurements taken when the adolescents attended the Teen Focus 3 clinic. BMI may cluster for a number of reasons. For the ALSPAC cohort, it has been shown that adolescents from lower socioeconomic backgrounds are more likely to be overweight (Matijasevich et al. 2009). Thus, if SES exhibits social clustering, BMI might follow passively. Adolescents may also be more likely to make friends with similar physical characteristics such as BMI (e.g., Simpkins et al. 2013). Finally, it has been claimed on the basis of longitudinal social network analysis that obesity spreads through social networks (Christakis & Fowler 2007), which could further induce social clustering of BMI, particularly among friends.

5.2.3 Social structure

Three social groupings were included as classifications in the following multiple classification models, namely, schools, neighbourhoods and friendship networks.

For the school classification, I used ALSPAC's anonymized secondary school identifiers at Key Stage 4, when the adolescents were around 15 year old. To give an indication of the kinds of numbers involved, the mean number of participants per school for the smallest sample (n = 2,944 for experience with sexual intercourse by Teen Focus 4) was 104.1 (SD = 60.9), while for the largest sample (n = for 9,986 for sex and educational achievement) it was 318.7 (SD = 185.8).

The neighbourhood classification was the Lower Super Output Area where adolescents were residing on the 1st of January 2008, when they were approximately 17 years old.

For the smallest sample, the mean number of participants in a neighbourhood was 7.1 (SD = 3.4); for the largest sample, the corresponding mean was 20.2 (SD = 6.7).

Friendship networks were incorporated as described in 2.3.1.3.3.

5.2.4 Analysis

I ran multiple classification models (Fielding & Goldstein 2006; Tranmer et al. 2014; 2.3.1) for each of the 21 outcomes.

Because sex is known to cluster quite strongly in adolescent friendship networks – that is, adolescent friendship ties are predominantly between members of the same sex (Mercken et al. 2009; McPherson et al. 2001) – and some of the traits under examination here may exhibit sex differences, I ran two models for each outcome, one empty, null clustering version and one adjusted for sex. In this way, I could be certain that any clustering found in friendship networks was not simply a by-product of assortment on sex.

As mentioned, all outcomes were modelled using either linear or logistic regression in order to facilitate the calculation of intra-class correlations, making it easy to compare social clustering across outcomes (for mathematical details, see 2.3.1.1.2). The Big Five personality factors and BMI at Teen Focus 3 were modelled as continuous variables; all other outcomes as binary variables.

5.3 Results

5.3.1 Descriptive statistics

Table 22 presents descriptive statistics for the samples used to look at clustering in this chapter.

Table 22. Descriptive statistics for clustering analyses

Variable	N	Units *or* categories	Mean (SD) or distribution across categories (%)
Sex	9,986	Male	5,094 (51.0%)
		Female	4,892 (49.0%)
BMI TF3	3,967	kg/m^2	21.49 (3.62); range = 14.09 – 41.63
Extraversion	4,263	IPIP score	35.36 (6.80); range = 10 – 50
Agreeableness	4,183	IPIP score	37.76 (5.17); range = 15 – 50
Conscientiousness	4,068	IPIP score	31.88 (5.71); range = 10 – 50
Emotional stability	4,122	IPIP score	31.53 (6.52); range = 10 – 50
Openness	4,159	IPIP score	35.69 (5.64); range = 14 – 50
Maternal degree	8,855	No	8,041 (90.8%)
		Yes	814 (9.2%)
Paternal degree	8,492	No	7,380 (86.9%)
		Yes	1,112 (13.1%)
Home ownership status	9,055	Renting	2,138 (23.6%)
		Mortgaged or owned	6,917 (76.4%)
Individual academic achievement	9,986	No A or A* grade	6,276 (62.9%)
		At least 1 A or A*	3,710 (37.2%)
Father absence	6,729	Present	5,102 (75.8%)
		Absent	1,627 (24.2%)
Ever smoked a cigarette	4,466	No	3,581 (80.2%)
		Yes	885 (19.8%)
Ever tried cannabis	3,901	No	2,898 (74.3%)
		Yes	1,003 (25.7%)
Ever had a whole alcoholic drink	3,927	No	521 (13.3%)
		Yes	3,406 (86.7%)
Ever had 4 alcoholic drinks in 24 hours	3,884	No	1,531 (39.4%)
		Yes	2,353 (60.6%)
Had sexual intercourse by TF3	3,828	No	3,073 (80.3%)
		Yes	755 (19.7%)
Had sexual intercourse by TF4	2,944	No	1,043 (35.4%)
		Yes	1,901 (64.6%)
Mother-rated prosocial score	3,878	Low	1,335 (34.4%)
		High	2,543 (65.6%)
Mother-rated conduct problems	3,879	Low	2,844 (73.3%)
		High	1,035 (26.7%)
Teacher-rated prosocial score	4,837	Low	1,927 (39.8%)
		High	2,910 (60.2%)

5.3.2 Clustering results

5.3.2.1 Behavioural variables: substance use, sexual experience, and prosociality

5.3.2.1.1 Substance use

5.3.2.1.1.1 Cigarette use

Whether someone had ever smoked a cigarette, at Teen Focus 2, clustered in friendship networks (ICC = 0.309) but not in schools (ICC = 0.006) or neighbourhoods (ICC = 0.008) (Table 23).

Table 23. Clustering results: Ever smoked a cigarette – Teen Focus 2 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.028	0.001	0.100	0.006
Neighbourhood	0.037	0.001	0.129	0.008
Friends	1.497	0.763	2.440	0.309
Individual	3.290			0.678

Girls were more likely to have at least tried a cigarette (OR = 1.62, $p < 0.001$) but I found no indications that this accounted for the similarity of friends in cigarette smoking behaviour (Table 24).

Table 24. Clustering results: Ever smoked a cigarette – Teen Focus 2 (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.027	0.001	0.099	0.005
Neighbourhood	0.040	0.001	0.187	0.008
Friends	1.519	0.806	2.469	0.308
Individual	3.290			0.667
Explained				0.012
Predictor	**OR**			**p**
Sex	1.62	1.33	1.96	<0.001

5.3.2.1.1.2 Cannabis use

The results for cannabis ever-use by Teen Focus 3 (Table 25) were similar to those for cigarette use. Clustering of cannabis use in schools (ICC = 0.014) and neighbourhoods (ICC = 0.014) was negligible while friends displayed marked similarity (ICC = 0.408).

Table 25. Clustering results: Ever tried cannabis – Teen Focus 3 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.084	0.010	0.209	0.014
Neighbourhood	0.079	0.000	0.277	0.014
Friends	2.376	1.434	3.543	0.408
Individual	3.290			0.564

Cannabis ever-use was not predicted by sex (Table 26).

Table 26. Clustering results: Ever tried cannabis – Teen Focus 3 (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.087	0.013	0.216	0.015
Neighbourhood	0.053	0.001	0.263	0.009
Friends	2.397	1.526	3.562	0.411
Individual	3.290			0.565
Explained	0.000			0.000
Predictor	**OR**			**p**
Sex	1.03	0.83	1.26	0.405

5.3.2.1.1.3 Alcohol use: ever had whole drink

A similar pattern was also found for whether, by Teen Focus 3, the respondent had ever had consumed a whole alcoholic drink (Table 27). Again, 'membership' of particular schools and neighbourhoods had almost no predictive value while friends were clearly more similar to each other (ICC = 0.262) than randomly selected adolescents in the sample.

Table 27. Clustering results: Ever had whole alcoholic drink – Teen Focus 3 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.063	0.002	0.192	0.014
Neighbourhood	0.065	0.002	0.261	0.014
Friends	1.211	0.582	2.021	0.262
Individual				0.711

Similar to what I found for cigarette use, girls were more likely to have consumed at least one whole alcoholic drink by Teen Focus 3 (OR = 1.33, p = 0.006). This difference between boys and girls did not, however, underpin the clustering of this measure of alcohol use among friends.

Table 28. Clustering results: Ever had whole alcoholic drink – Teen Focus 3 (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.066	0.002	0.193	0.014
Neighbourhood	0.066	0.002	0.271	0.014
Friends	1.184	0.568	1.946	0.256
Individual	3.290			0.711
Explained	0.020			0.004
Predictor	**OR**			**p**
Sex	1.33	1.07	1.65	0.006

5.3.2.1.1.4 Alcohol use: ever consumed 4 drinks in 24 hours

The second measure of alcohol use – whether the respondent had ever consumed 4 (or more) alcoholic beverages in a 24-hour period (by Teen Focus 3) – showed essentially the same pattern of non-clustering in schools and neighbourhoods and substantial clustering in friendship network (ICC = 0.307; Table 29).

Table 29. Clustering results: Ever had 4 alcoholic drinks in 24 hours – Teen Focus 3 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.022	0.001	0.077	0.005
Neighbourhood	0.036	0.001	0.171	0.007
Friends	1.480	0.932	2.190	0.307
Individual	3.290			0.681

Girls were somewhat more likely to have, at least once, consumed four alcoholic drinks (or more) in a 24-hour period (OR = 1.20, p = 0.021), but this sex difference was not responsible for the pattern of social clustering I found (i.e., friend similarity).

Table 30. Clustering results: Ever had 4 alcoholic drinks in 24 hours – Teen Focus 3 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.024	0.001	0.081	0.005
Neighbourhood	0.040	0.001	0.152	0.008
Friends	1.491	0.930	2.194	0.307
Individual	3.290			0.678
Explained	0.008			0.002
Predictor	**OR**			**p**
Sex	1.20	1.01	1.43	0.021

5.3.2.1.2 Experience with sexual intercourse

5.3.2.1.2.1 Had sex by Teen Focus 3

Experience with sexual intercourse by Teen Focus 3 did not cluster in schools (ICC = 0.005) or neighbourhoods (ICC = 0.009), but adolescents in the same friendship

network tended to be more similar to each other (ICC = 0.333) than randomly selected adolescents in the sample (Table 31).

Table 31. Clustering results: Has had sex – Teen Focus 3 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.025	0.001	0.110	0.005
Neighbourhood	0.045	0.001	0.187	0.009
Friends	1.675	0.884	2.783	0.333
Individual	3.290			0.653

Girls were more likely to have had sex (OR = 1.44, p = 0.001) but this was not the basis for the similarity of members of the same friendship network (Table 32).

Table 32. Clustering results: Has had sex – Teen Focus 3 (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.027	0.001	0.118	0.005
Neighbourhood	0.035	0.000	0.173	0.007
Friends	1.703	0.916	2.691	0.335
Individual	3.290			0.647
Explained	0.033			0.006
Predictor	**OR**			**p**
Sex	1.44	1.17	1.77	0.001

5.3.2.1.2.2 Had sex by Teen Focus 4

Similar results were found for experience with sexual intercourse by Teen Focus 4 (Table 33). The size of the variance estimate for friendship networks (ICC = 0.219) was around a third smaller than the one found for sexual experience by Teen Focus 3. A plausible substantive interpretation of this change is that as experience with sexual intercourse goes from being relatively uncommon (TF3) to normative (TF4), differences between friendship networks diminish.

Table 33. Clustering results: Has had sex – Teen Focus 4 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.149	0.049	0.310	0.033
Neighbourhood	0.061	0.001	0.224	0.014
Friends	0.981	0.445	1.647	0.219
Individual	3.290			0.734

As found for the Teen Focus 3 measure, girls were more likely to have had sex (OR = 1.86, p < 0.001) but this did not explain the similarity of friends in terms of sexual experience to any great extent (Table 34).

Table 34. Clustering results: Has had sex – Teen Focus 4 (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.139	0.046	0.295	0.031
Neighbourhood	0.064	0.001	0.226	0.014
Friends	0.897	0.297	1.601	0.200
Individual	3.290			0.734
Explained	0.094			0.021
Predictor	**OR**			**p**
Sex	1.86	1.53	2.25	<0.001

5.3.2.1.3 Prosociality

5.3.2.1.3.1 Mother-rated prosocial score

Mother-rated prosocial score did not exhibit any social clustering (Table 35).

Table 35. Clustering results: Mother-rated prosocial score (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.008	0.001	0.033	0.002
Neighbourhood	0.012	0.001	0.055	0.004
Friends	0.046	0.004	0.257	0.014
Individual				0.980

Based on mothers' reports on their behaviour, girls were more prosocial than boys (OR = 1.41, $p < 0.001$; Table 36).

Table 36. Clustering results: Mother-rated prosocial score (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.007	0.000	0.029	0.002
Neighbourhood	0.015	0.001	0.063	0.005
Friends	0.045	0.001	0.190	0.013
Individual	3.290			0.972
Explained	0.029			0.009
Predictor	**OR**			**p**
Sex	1.41	1.23	1.61	<0.001

5.3.2.1.3.2 Mother-rated conduct problems

Mother-rated conduct problems clustered at the level of friendship networks (ICC = 0.142; Table 37).

Table 37. Clustering results: Mother-rated conduct problems (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.008	0.001	0.032	0.002
Neighbourhood	0.032	0.001	0.127	0.008
Friends	0.551	0.052	1.168	0.142
Individual	3.290			0.848

Conduct problems were slightly more likely to be reported for girls (OR = 1.22, p = 0.010) but this did not influence their social clustering (Table 38).

Table 38. Clustering results: Mother-rated conduct problems (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.010	0.001	0.043	0.002
Neighbourhood	0.035	0.002	0.133	0.009
Friends	0.661	0.231	1.187	0.165
Individual	3.290			0.821
Explained	0.010			0.002
Predictor	**OR**			**p**
Sex	1.22	1.03	1.43	0.010

5.3.2.1.3.3 Teacher-rated prosocial score

A prosocial score based on prosocial behaviour reported by the study child's teacher, when the study child was 7 or 8, showed clear clustering in teenage friendship networks (ICC = 0.198; Table 39).

Table 39. Clustering results: Teacher-rated prosocial score (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.032	0.001	0.138	0.007
Neighbourhood	0.144	0.047	0.262	0.033
Friends	0.856	0.365	1.516	0.198
Individual	3.290			0.761

Girls were more frequently reported to engage in prosocial behaviour by teachers (OR = 3.15, p < 0.001). Adding sex to the model led to a modest reduction of the ICC for friendship networks (rICC = 0.152) which means that some of the similarity in teacher-rated prosocial scores of members of the same friendship group might be due to the high number of same-sex friendship ties.

Table 40. Clustering results: Teacher-rated prosocial score (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.014	0.001	0.064	0.003
Neighbourhood	0.187	0.080	0.312	0.041
Friends	0.685	0.222	1.210	0.152
Individual	3.290			0.730
Explained				0.073
Predictor	**OR**			**p**
Sex	3.15	2.66	3.73	<0.001

5.3.2.2 Personality factors

5.3.2.2.1 Extraversion

Extraversion clusters at the level of friendship networks (ICC = 0.15) but not at the level of schools or neighbourhoods (Table 41). Friends appear to be more similar to each other in terms of their position on the extraversion scale than randomly selected adolescents in the population.

Table 41. Clustering results: Clustering of extraversion (no predictors)

Classification	Variance	SD	95% Credible interval		Prop.
School	0.004	0.003	0.001	0.013	0.004
Neighbourhood	0.007	0.006	0.001	0.022	0.007
Friends	0.145	0.030	0.086	0.204	0.145
Individual	0.846	0.033	0.782	0.913	0.844

Sex is a significant predictor of extraversion in this sample (OR = 1.26, $p < 0.001$), such that female adolescents tend, on average, to be more extraverted than their male counterparts. Still, adding sex to the clustering model only marginally reduces the ICC for friends, from 0.15 to 0.13, which means that the higher similarity of extraversion among friends is not simply due to the high prevalence of same-sex friendship ties.

Table 42. Clustering results: Extraversion (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.003	0.000	0.010	0.003
Neighbourhood	0.007	0.001	0.022	0.007
Friends	0.127	0.070	0.184	0.126
Individual	0.851	0.788	0.917	0.850
Explained	0.013			0.013
Predictor	**OR**			**p**
Sex	1.26	1.19	1.34	<0.001

5.3.2.2.2 Agreeableness

Agreeableness shows some modest clustering at the level of friendship networks (ICC = 0.0092) as well as minor clustering at the level of schools (ICC = 0.035) (Table 43).

Table 43. Clustering results: Agreeableness (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.035	0.014	0.070	0.034
Neighbourhood	0.007	0.001	0.020	0.007
Friends	0.092	0.025	0.159	0.091
Individual	0.882	0.810	0.957	0.868

The clustering model adjusted for sex (Table 44) shows that girls, on average, score higher on agreeableness (OR = 1.88, p < 0.001). Adjusting for sex reduces clustering at both the school level (ICC from 0.035 to 0.021), consistent with a sex effect on agreeableness and clustering of sex at the level of schools, and at the level of friendship networks (ICC from 0.092 to 0.30), suggesting that clustering of agreeableness in friendship networks is largely a by-product, the preponderance of same-sex friendships in the sample.

Table 44. Clustering results: Agreeableness (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.021	0.007	0.043	0.020
Neighbourhood	0.012	0.001	0.029	0.012
Friends	0.030	0.001	0.089	0.030
Individual	0.844	0.778	0.900	0.839
Explained	0.100			0.099
Predictor	**OR**			**p**
Sex	1.88	1.77	2.00	<0.001

5.3.2.2.3 Conscientiousness

Conscientiousness showed little clustering at any level of the social world included in the models (Table 45). Possibly, friends are slightly more similar in terms of conscientiousness (ICC = 0.040).

Table 45. Clustering results: Conscientiousness (no predictors)

Classification	Variance	SD	95% Credible interval		Prop.
School	0.002	0.002	0.000	0.007	0.002
Neighbourhood	0.004	0.003	0.000	0.013	0.004
Friends	0.040	0.027	0.002	0.099	0.040
Individual	0.956	0.034	0.894	1.019	0.954

While sex was a significant predictor of conscientiousness (OR = 0.86, p < 0.001), boys having somewhat higher conscientiousness scores on average, adding it did not substantially affect the pattern of clustering.

Table 46. Clustering results: Conscientiousness (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.002	0.000	0.007	0.002
Neighbourhood	0.004	0.000	0.013	0.004
Friends	0.039	0.002	0.090	0.039
Individual	0.952	0.889	1.012	0.949
Explained	0.006			0.006
Predictor	**OR**			**p**
Sex	0.86	0.81	0.92	<0.001

5.3.2.2.4 Emotional stability

Emotional stability did not exhibit any social clustering to speak of (Table 47).

Table 47. Clustering results: Emotional stability (no predictors)

Classification	Variance	95% Credible interval	
School	0.003	0.000	0.008
Neighbourhood	0.006	0.001	0.018
Friends	0.023	0.001	0.080
Individual	0.970	0.903	1.027

Emotional stability was clearly associated with sex. On average, girls' emotional stability scores were lower than boys' (OR = 0.60, $p < 0.001$).

Table 48. Clustering results: Emotional stability (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.005	0.001	0.0141	0.005
Neighbourhood	0.006	0.001	0.018	0.006
Friends	0.010	0.001	0.041	0.010
Individual	0.918	0.870	0.963	0.914
Explained				0.065
Predictor	**OR**			**p**
Sex	0.60	0.57	0.64	<0.001

5.3.2.2.5 Openness

Openness (or 'intellect and imagination') was found to cluster at the level of friendship networks (ICC = 0.136) but not schools or neighbourhoods.

Table 49. Clustering results: Openness (no predictors)

Classification	Variance	SD	95% Credible interval	
School	0.009	0.006	0.001	0.024
Neighbourhood	0.015	0.008	0.002	0.033
Friends	0.136	0.031	0.076	0.197
Individual	0.844	0.034	0.778	0.913

While sex was a statistically significant predictor of openness, girls having slightly lower scores on average (OR = 0.90), clustering of sex did not explain friends' similarity in openness (Table 50).

Table 50. Clustering results: Openness (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.008	0.001	0.022	0.008
Neighbourhood	0.014	0.001	0.033	0.014
Friends	0.132	0.065	0.195	0.132
Individual	0.846	0.779	0.925	0.843
Explained				0.003
Predictor	**OR**			**p**
Sex	0.90	0.85	0.96	0.001

5.3.2.3 Sex, household SES, father absence, educational achievement, and body mass index

5.3.2.3.1 Sex

The results in Table 51 indicate that sex clusters strongly at the level of friendship networks (ICC = 0.56), indicating that most friendship links in the sample are between members of the same sex, and also shows a fair amount of clustering at the level of school (ICC = 0.232), presumably due to some adolescents attending single-sex schools, which are quite common in the UK.

Table 51. Clustering results: Sex (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	3.638	2.071	5.978	0.232
Neighbourhood	0.030	0.001	0.119	0.002
Friends	8.727	6.902	10.957	0.556
Individual	3.290			0.210

5.3.2.3.2 Household SES

5.3.2.3.2.1 Maternal degree

Whether an adolescent's mother had a university degree was clustered in schools (ICC = 0.191), neighbourhoods (ICC = 0.171) and friendship networks (ICC = 0.123). The school and neighbourhood results are evidence for geographic clustering of SES and differing socioeconomic profiles of secondary schools. Interestingly, even after adjusting for SES similarities ascribable to attending a particular school and living in a particular neighbourhood, friends were more similar in this measure of SES than expected based on random friendship formation. I suspect this may partly reflect clustering of adolescents on academic ability within schools (see clustering of educational achievement below).

Table 52. Clustering results: Maternal degree (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	1.224	0.705	1.993	0.191
Neighbourhood	1.091	0.766	1.487	0.171
Friends	0.788	0.323	1.408	0.123
Individual				0.515

Whether or not one's mother had a degree or not did not differ by sex (OR = 1.10, p = 0.166; Table 53).

Table 53. Clustering results: Maternal degree (with sex)

Classification	Variance	95% Credible interval		Prop.
School	1.226	0.698	2.025	0.193
Neighbourhood	1.087	0.761	1.485	0.171
Friends	0.750	0.128	1.403	0.118
Individual	3.290			0.518
Explained	0.002			0.000
Predictor	**OR**			**p**
Sex	1.10	0.91	1.32	0.166

5.3.2.3.2.2 Paternal degree

Whether an adolescent's father had a university degree showed similar clustering to maternal degree at the level schools (ICC = 0.189) and neighbourhoods (ICC = 0.235), although clustering at the friendship network was less pronounced (ICC = 0.041).

Table 54. Clustering results: Paternal degree (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	1.162	0.668	1.914	0.189
Neighbourhood	1.447	1.077	1.899	0.235
Friends	0.251	0.003	0.730	0.041
Individual				0.535

Sex did not predict whether someone's father had a degree (OR = 0.91, p = 0.124).

Table 55. Clustering results: Paternal degree (with sex)

Classification	Variance	95% Credible interval		Prop.
School	1.147	0.655	1.875	0.190
Neighbourhood	1.419	1.062	1.845	0.235
Friends	0.176	0.002	0.612	0.029
Individual	3.290			0.545
Explained	0.002			0.000
Predictor	**OR**			**p**
Sex	0.91	0.78	1.06	0.124

5.3.2.3.2.3 Home ownership status (pregnancy)

The next SES measure indicated whether an adolescent's parents were living in rented versus mortgaged or owned accommodation when the mother was pregnant with the study child. This measure clustered most strongly in neighbourhoods (ICC = 0.225) but also showed some clustering at the level of schools (ICC = 0.121) and friendship networks (ICC = 0.107).

Table 56. Clustering results: Home ownership status (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.726	0.378	1.277	0.121
Neighbourhood	1.353	1.021	1.762	0.225
Friends	0.645	0.086	1.318	0.107
Individual	3.290			0.547

Home ownership status did not differ by sex (OR = 1.09, p = 0.117; Table 57).

Table 57. Clustering results: Home ownership status (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.757	0.400	1.298	0.123
Neighbourhood	1.374	1.047	1.781	0.224
Friends	0.725	0.172	1.374	0.118
Individual	3.290			0.535
Explained	0.002			0.000
Predictor	**OR**			**p**
Sex	1.09	0.94	1.26	0.117

5.3.2.3.3 Father absence

Father absence at 10 years showed some modest clustering in schools (ICC = 0.074) and neighbourhoods (ICC = 0.074), which is very likely due to a positive association between SES and father absence.

Table 58. Clustering results: Father absence (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.299	0.128	0.589	0.074
Neighbourhood	0.300	0.191	0.433	0.074
Friends	0.149	0.002	0.675	0.037
Individual	3.290			0.815

Sex was not associated with father absence (OR = 1.11, p = 0.057; Table 59). The estimated ICC for friendship networks was slightly increased but this since the 95% confidence intervals for the variance associated with the friendship networks in the

models with and without sex are largely overlapping, I have not attempted to give a substantive interpretation of this minor shift.

Table 59. Clustering results: Father absence (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.325	0.142	0.633	0.076
Neighbourhood	0.315	0.198	0.462	0.074
Friends	0.331	0.033	0.853	0.078
Individual	3.290			0.772
Explained	0.003			0.001
Predictor	**OR**			**p**
Sex	1.11	0.97	1.26	0.057

5.3.2.3.4 Educational achievement

I also asked if adolescents' educational achievement varied across schools, neighbourhoods or friendship networks. The measure used for this was whether someone had received at least one A or A* grade at GCSE (Key Stage 4). Educational achievement clustered relatively strongly in schools (ICC = 0.411) but barely at all in neighbourhoods (ICC = 0.029), while there was also clear similarity of friends in educational achievement (ICC = 0.231). The school result presumably reflects some combination of selection of pupils into different schools according to academic ability and school effects on pupil performance. Schools in the United Kingdom typically group pupils according to (demonstrated) academic ability, thereby changing the pool of age peers from which adolescents are likely to draw their friends, which could explain the clustering of academic performance at the level of friendship networks. Alternatively, friends may actively select each other on the basis of a similar academic orientation or affect each other's academic careers through some form of peer influence.

Table 60. Clustering results: Educational achievement (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	4.115	2.606	6.239	0.411
Neighbourhood	0.288	0.180	0.415	0.029
Friends	2.307	1.752	2.909	0.231
Individual	3.290			0.329

Girls were more likely than boys to have received an A or A* grade (OR = 1.96, $p < 0.001$) but this did not account for (much of) the clustering in schools or friendship networks (Table 61).

Table 61. Clustering results: Educational achievement (sex)

Classification	Variance	95% Credible interval		Prop.
School	3.829	2.418	5.840	0.393
Neighbourhood	0.307	0.196	0.436	0.032
Friends	2.192	1.665	2.777	0.225
Individual	3.290			0.338
Explained	0.113			0.012
Predictor	**OR**			**p**
Sex	1.96	1.72	2.24	<0.001

5.3.2.3.5 Body mass index

BMI at Teen Focus 3 did not cluster in schools or neighbourhoods but possibly showed a slight clustering at the level of friendship networks (ICC = 0.074).

Table 62. Clustering results: Body Mass Index – Teen Focus 3 (no predictors)

Classification	Variance	95% Credible interval		Prop.
School	0.010	0.002	0.024	0.010
Neighbourhood	0.007	0.001	0.022	0.007
Friends	0.074	0.005	0.151	0.074
Individual	0.912	0.831	0.993	0.909

Girls tended to have a higher BMI than boys (OR = 1.29, $p < 0.001$) but this had little relation to the social clustering pattern of BMI (Table 63).

Table 63. Clustering results: Body Mass Index – Teen Focus 3 (with sex)

Classification	Variance	95% Credible interval		Prop.
School	0.010	0.002	0.023	0.010
Neighbourhood	0.008	0.001	0.024	0.008
Friends	0.061	0.007	0.132	0.061
Individual	0.908			0.905
Explained	0.016			0.016
Predictor	**OR**			**p**
Sex	1.29	1.21	1.37	<0.001

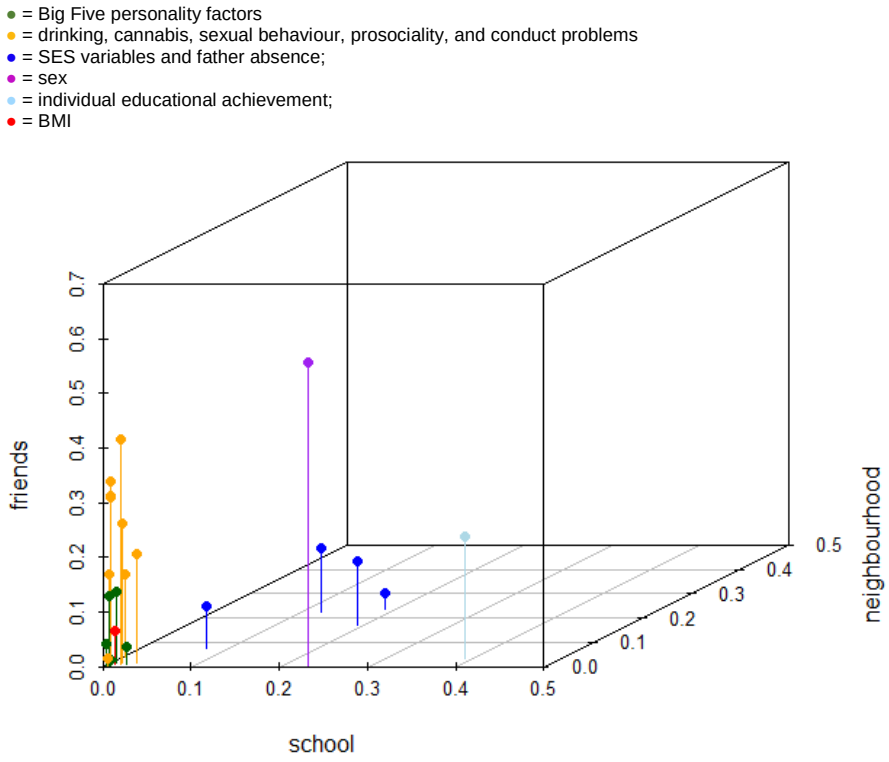
5.3.2.3 Overview of clustering results

Table 64 gives an overview of the clustering results just discussed, listing the intraclass correlations for schools, neighbourhoods and friendship networks for all the outcomes. Figure 14 is a visual presentation of the same results.

Table 64. Overview of clustering results (unadjusted and adjusted for sex). Intraclass correlations are given for friendship networks, schools and neighbourhoods

	NO PREDICTORS			ADJUSTED FOR SEX		
	Intraclass correlation			Intraclass correlation		
Outcome	**Friends**	**School**	**Neighbourhood**	**Friends**	**School**	**Neighbourhood**
Sex	0.56	0.23	0.00			
Extraversion	0.15	0.00	0.01	0.13	0.00	0.01
Agreeableness	0.09	0.04	0.01	0.03	0.02	0.01
Conscientiousness	0.04	0.00	0.00	0.04	0.00	0.00
Emotional stability	0.02	0.00	0.01	0.01	0.01	0.01
Openness	0.14	0.01	0.02	0.13	0.01	0.01
Mother has degree	0.12	0.19	0.17	0.12	0.19	0.17
Father has degree	0.04	0.19	0.24	0.03	0.19	0.24
Home ownership status	0.11	0.12	0.23	0.12	0.12	0.22
Father absence	0.04	0.07	0.07	0.08	0.08	0.07
At least on A or A*	0.23	0.41	0.03	0.23	0.39	0.03
Ever smoked cigarette (TF2)	0.31	0.01	0.01	0.31	0.01	0.01
Ever tried cannabis (TF3)	0.41	0.01	0.01	0.41	0.02	0.01
Ever had whole drink (TF3)	0.26	0.01	0.01	0.26	0.01	0.01
4 drinks in 24 hours (TF3)	0.31	0.01	0.01	0.31	0.01	0.01
Has had sex (TF3)	0.33	0.01	0.01	0.34	0.01	0.01
Has had sex (TF4)	0.22	0.03	0.01	0.20	0.03	0.01
BMI (TF3)	0.07	0.01	0.01	0.06	0.01	0.01
Conduct problems (TC)	0.14	0.00	0.01	0.17	0.00	0.01
Teacher-rated prosociality	0.20	0.01	0.03	0.15	0.00	0.04
Mother-rated prosociality	0.01	0.00	0.00	0.01	0.00	0.01

Figure 14. Social clustering patterns for multiple outcomes (controlled for sex)



Some patterns can be discerned in Figure 14. The behavioural variables – substance use, sexual experience, prosociality and conduct problems (the orange circles) – tend not to cluster at all in schools or neighbourhoods but do often show clear clustering in friendship networks. A similar pattern is found for personality traits, which indicate particular kinds of stable behavioural dispositions, although the similarity of friends' personalities tended to be less pronounced than that found for actual behaviour. The adolescents' individual educational achievement, which is at least partly a behavioural measure (e.g., those who perform better in school will tend to be more diligent towards school work), behaved similar to behavioural measures in that it clustered in friendship networks but not in neighbourhoods, but, additionally, exhibited clustering in schools. SES and, to a lesser extent, father absence do cluster in neighbourhoods and schools, as well as showing some minor clustering in friendship networks (but less than the behavioural variables).

5.4 Discussion

In this chapter, I quantified the social clustering of a wide variety behavioural (and some non-behavioural) traits in an adolescent sample, in order to assess the scope of different ideas about the origins of social clustering in behaviour, derived from explanatory models in the evolutionary behavioural sciences, in explaining the observed clustering patterns.

5.4.1 Main findings

5.4.1.1 Social clustering of behaviour

5.4.1.1.1 Behavioural variables only show clear clustering in friendship networks

When I examined the social clustering of behavioural variables – that is, cigarette, alcohol and cannabis use, experience with sexual intercourse, prosociality and conduct problems, and personality – I found them to exhibit fairly similar clustering patterns. They did not cluster much, if at all, in schools and neighbourhoods. By contrast, nearly all of them clustered, to varying degrees, in friendship networks. This similarity of friends across several measures echoed a study on an earlier generation of Bristolian adolescents (Eiser et al. 1991).

This pattern of results suggests that the ability of the explanatory model 'adaptive flexibility in response to environmental variation' to account for the social clustering of behaviour in adolescents, in this population, is limited. Shared ecology as captured by neighbourhood or school membership – for instance, differences in socioeconomic deprivation experienced by adolescents as adolescents or during childhood – does not explain much if anything of the friend similarity evident in the data. In other words, the results clearly refute the suggestion that clustering among friends is simply a by-product of the fact that friends tend to be drawn from a pool of individuals who go the same school and live in the same or a similar and nearby neighbourhood. Additional explanations to adaptive flexibility in response to socioecological variation are certainly required.

It is also clear that friend similarities in experiences with substance use and sexual intercourse are not simple derivatives of friends' personality similarities (although

those may contribute), since those behaviours show *stronger* clustering than personality factors. If we take clustering on personality in friendship networks as a benchmark for the tendency to form social ties with similar others – which is, perhaps, ultimately related to coordination benefits from similarity – then the additional clustering among friends of behaviours like substance use might reflect some form of social influence, in line with ideas about transmission biases.

5.4.1.1.2 Low school and neighbourhood clustering: interpretation and implications

The general lack of behavioural clustering in schools and neighbourhoods point to the conclusion that schools and neighbourhoods are not the social spheres to look for critical factors explaining the social clustering of many behaviours in adolescents. While school- or neighbourhood-level factors may be present, they will only be able to account for a small part of behavioural variation in this population – although rare but powerful causal factors at these levels cannot be ruled out. Adaptive flexibility in response to socioecological variation, to the extent that it posits variation in adaptively relevant environmental features at the level of neighbourhoods and schools (as geographical units), cannot contribute much to explaining social clustering of adolescent behaviour.

While the analyses of cooperation (chapter 4) and sexual behaviour (chapter 3) already suggested this was the case for those specific outcomes, I was able to show that this pattern appears to obtain quite generally by comparing many behavioural outcomes in the same population of adolescents. It should be noted that these results do not undermine targeting interventions at these levels (e.g., school programs aimed at reducing harmful substance use). The fact that outcomes do not show much variation beyond randomness at a particular level does not mean that interventions cannot be effectively administered at that level.

Social transmission processes also do not lead adolescents in one school to adopt one norm leading to a low prevalence of a particular behaviour, while pupils in another school adopt another norm leading to a high prevalence of the same behaviour; nor do they produce such an effect at the level of neighbourhoods.

5.4.1.1.3 Friendship network clustering: interpretation and implications

The fact that friends do show fairly substantial similarities, which are not due to similar individuals sorting into the same schools or neighbourhoods, is consistent with both a tendency to form social ties with similar others, possibly to, ultimately, gain coordination benefits from similarity, and cultural transmission biases acting to make friends more similar than random age peers. Because of the scope for social influence here, friend effects are a legitimate potential target of behavioural interventions and interventions aimed at the individual level could have a social multiplier effect.

5.4.1.2 Additional remarks about individual variables

5.4.1.2.1 Educational achievement

Educational achievement – at least 1 A or A* at GCSE examinations – clustered most strongly in schools (ICC = 0.39, adjusted for sex), consistent with a sorting of pupils across schools according to academic ability and school effects on academic achievement. There was also some clustering of educational achievement in friendship networks (ICC = 0.23, adjusted for sex). This suggests that, within schools, pupils are more likely to be friends with other pupils of similar academic aptitude or orientation, which could be due to social influence or social selection processes. There is thus scope for both transmission biases and assortment based on similarity to gain coordination benefits from similarity.

5.4.1.2.2 Personality factors

The sex-adjusted null clustering models for personality, indicate social clustering of personality, specifically extraversion (ICC = 0.13) and openness (ICC = 0.13). These results are consistent with earlier studies (Burgess et al. 2011; Selfhout et al. 2010). Because personality is a fairly stable attribute of a person, with a strong genetic basis, this result is likely to reflect some form of social selection, possibly the exercise of a preference for others with a similar personality (as regards extraversion and openness). This could ultimately be related to coordination benefits from similarity, although it is not clear why extraversion and openness would cluster for this reason, while

agreeableness – which should involve a tendency to be trusting and cooperate and would therefore be predicted to cluster (see chapter 4) – would not.

5.4.1.2.3 Sex

Sex clustered quite strongly in friendship networks: most friendships are between members of the same sex. The sex-adjusted models showed that this did not explain much of the clustering in friendship networks in other behaviours, except for some clustering of agreeableness and teacher-rated prosociality. The only evolutionary explanatory model, of the ones discussed above, that is potentially relevant here is coordination benefits from similarity.

5.4.1.2.4 Body mass index

There was possibly some minor clustering of BMI at the level of friendship networks. This could be due to the social transmission of ideas or behaviours[6] (cf., Christakis & Fowler 2007) related to nutrition and exercise or a tendency to form social ties with others based on similarity in body composition or factors related to body composition (e.g., participation in a particular sport) (de la Haye et al. 2010).

5.4.1.2.5 Sex differences in substance use and personality traits

Based on evolutionary arguments about differing risk-taking propensities in males and females, argued to result from sex differences in (potential) reproductive variance (1.2.3.3.1), I predicted that boys would be more likely to have engaged in various kinds of substance use. The results did not support this prediction. In fact, girls were more likely, by Teen Focus 3, to have ever had a whole alcoholic drink, had 4 or more alcoholic drinks in 24 hours, or to have smoked a cigarette, while no sex difference was found for ever having used cannabis. One possible explanation of these unexpected results is that girls are more developmentally advanced at this time point, something I did not control for in the reported analyses. At the same time, the substance use behaviours in question might not be very risky or norm-violating or not the right *kind* of risk to find the predicted sex difference. The lack of a male bias during adolescence in

[6] An intriguing but at present highly speculative possibility is that social network ties influence the composition of an individual's microbiome, as occurs, for example, in wild baboons (Tung et al. 2015), which in turn might influence body composition (Turnbaugh et al. 2006).

'mild' forms of substance use, like the behavioural measures used here, has been reported elsewhere (e.g., Lynch et al. 2002).

I further predicted that boys would be more extravert and girls more agreeable (1.4.3). While the latter prediction was confirmed, the results showed girls to be more extraverted as well, a result in need of explanation. An international comparison showed extraversion to be higher in 30 of 37 countries, though notably not in the United Kingdom, raising questions about the possible influence of culture on this gender difference (Lynn & Martin 1997).

5.4.2 Strengths and limitations

A major strength of this study is that the social clustering of multiple traits at multiple social levels was examined in samples from the same population of adolescents. The comparison of clustering across traits made it possible to find for more general patterns than the trait-specific studies which make up the bulk of the published literature related to social clustering. By including multiple social classifications simultaneously, I could assess clustering at each level while parcelling out clustering at other levels. It is still uncommon for studies to simultaneously incorporate more than two social levels at the same time, even though a misspecification of the social structure can have serious consequences for the reliability of one's results (Fielding & Goldstein 2006; see Teitler & Weiss 2000 on effect of omitting school level when evaluating neighbourhood clustering of sexual experience, mentioned in 1.2.1.2.2).

While the current study does well relative to most published work in terms of the number of important social classifications incorporated in its statistical models, it has its own limitations in this regard. Potentially key social groupings, such as the country or household, were not included. In order to find scope for strong effects of adaptive flexibility in response to socioecological variation, it might be required to look at higher levels, such as the country or societal level (cf., Low et al. 2008), since that is the level at which some important socioecological variables are likely to vary most strongly (e.g., extrinsic mortality). The inclusion of a household level would have strengthened the study considerably by allowing the separation of individual from household-level variation. In the statistical models in this thesis, both were treated as individual

variation. While I have emphasised higher levels when talking about adaptive flexibility, family-level factors might also be important environmental factors to adjust to, even if they do not function as a cue to the wider socio-ecology.

A significant limitation is the lack of more direct evidence pertaining to the mechanisms giving rise to the observed clustering patterns. For some traits, such mechanisms are obvious (e.g., sex and SES) or an educated guess is possible (e.g., about school clustering of educational achievement). The most problematic traits are those for which both social transmission and a preference for similarity are viable explanations of higher similarity within social groups. Ultimately, other research designs are more suited to this, although some headway can be made by assessing the impact on residual clustering of adding substantive predictors to multiple classification models (see chapters 3 and 4).

In order to maximize sample representativeness and statistical power, I chose to use the largest sample available for each outcome, based on the availability of the outcome and school and neighbourhood identifiers. As a result, the samples differ by outcome, which means that when we make comparisons of clustering across outcomes, we are not strictly comparing clustering in the same samples. The samples will not be entirely representative of the wider population as individuals from lower SES households are more likely to drop out of the study over time (see comparisons between analysis and attrition samples in appendices to chapters 3 and 4).

5.4.3 Conclusions and future directions

This empirical investigation into the social clustering of multiple behaviours in British adolescents found that the behaviours under investigation exhibited little clustering in schools and neighbourhoods but did cluster in friendship networks. Most of the variation in behaviour in this population occurs at the level of individuals and may reflect random variation, the contingencies of life (e.g., meeting a potential sexual partner or not), or unmeasured inter-individual (or between-household) differences. With regard to explanatory models from the evolutionary behavioural sciences, adaptive flexibility in response to environmental variation is unlikely to be of much help in explaining the social clustering of adolescent behaviour – at least in this population

and at the examined social levels – since it would predict clustering to occur at the level of neighbourhoods and schools-as-geographical-units, as this is where the most relevant socioecological variation would be expected to occur. The modest but definite behavioural clustering at the level of adolescent friendship networks indicates a greater scope for social transmission processes or a preference for similarity, possibly related to coordination benefits, in explaining social clustering of adolescent behaviour in this population.

Future studies might try to compare evolutionary explanations of social clustering of behaviour with study designs that can get a firmer grasp on causal mechanisms, although such a study would be extremely challenging from a methodological perspective. As mentioned in chapter 1, there is a clear gap in the literature when it comes to experimentally testing for coordination benefits from similarity, both in humans and non-human animals (Chierchia & Coricelli 2015), which is required for the evolution of a behavioural tendency to form ties with similar individuals (Fu et al. 2012), so this could prove a fruitful avenue of research as well. It is possible that most of the 'signal' part of behavioural variation is at a higher level of the social structure, e.g., the societal level, and most of the variation that is left is just noise. Future work might therefore look at behavioural clustering at even more levels, including especially higher levels such as society or country, while also including the levels of neighbourhoods and friendship networks, and perhaps households, although the data requirements for such a study would obviously be formidable.

Chapter 6: Quality of the childhood environment and pubertal development

6.1 Introduction

The physical changes associated with puberty are significant developmental milestones, the timing of which has been linked to important outcomes later in life. Earlier puberty, in particular, has been shown to be predictive of a wide range of health problems (Day et al. 2015) and an increased risk of death (Charalampopoulos et al. 2014). A recent report based on the very large UK Biobank study (N ≈ 500,000) identified numerous positive associations between early (and late) pubertal timing and adverse health outcomes (Day et al. 2015). Early pubertal onset is further associated with an early age at first sex (Baams, Dubas, et al. 2015), early age at first birth (Udry & Cliquet 1982), and psychological problems in adolescence (Mendle et al. 2007; Mendle & Ferrero 2012). Given these and other sequelae of pubertal timing, a lot of research effort has been devoted to uncovering causes of variation in pubertal timing. From an evolutionary perspective, the timing of pubertal onset is interesting as a possible life history trait and, more broadly, as a marker of an individual's reproductive strategy.

6.1.1 Life history theory and pubertal timing

From a life history theoretical perspective, early puberty is one of a suite of traits that together make up a fast life history strategy (1.3.1.3). The key proposal, for the current study, is that pubertal timing may exhibit adaptive calibration to local socio-ecological conditions (Draper & Harpending 1982; Belsky et al. 1991; Chisholm 1993).

Aside from the possibility that 'childhood adversity' effectively signals the state of one's wider socioecological context, growing up in an unfavourable developmental environment may have direct negative effects on an individual's health and therefore life expectancy, which would also favour early reproduction (Nettle et al. 2013). Alternatively, 'child development theory' (Ellis 2004) holds that pubertal timing is phenotypically plastic and calibrated to the quality of the family environment during childhood, such that a high-quality rearing environment causes an extension of the pre-reproductive phase so as to maximize the benefits gained from growing up in such a nurturing environment, while a low-quality environment induces an early transition to

the reproductive phase because little is to be gained, and time is lost, by extending childhood when investments are not forthcoming. Child development theory does not, however, assume that family-level factors serve as cues to a broader socio-ecological context.

A mutual prediction from such models, then, is that experiencing childhood adversity, as indicated, for instance, by low parental socioeconomic position and growing up in a fatherless household, leads to earlier puberty, either as part of a switch to a fast life history strategy or as a way of cutting short the pre-reproductive developmental phase in an unfavourable environment.

Alternatively, as discussed in chapter 1 (1.3.3.4) intergenerational conflict about reproductive opportunities may explain the association between father absence and reproductive development (Moya & Sear 2014). When a child's father leaves, any subsequent offspring of his or her mother with a new partner will be less related than full siblings, which alters the expected fitness costs and benefits of supporting parental reproduction rather than reproducing oneself. For this reason, father absence may lead to earlier sexual maturity.

6.1.2 Socioeconomic deprivation, father absence and pubertal timing

In this study, I look at three kinds of childhood adversity: family socioeconomic deprivation, neighbourhood deprivation, and father absence. Here, I review the literature about the relationship between these factors and pubertal timing.

6.1.2.1 Socioeconomic status and pubertal timing

The relationship between socioeconomic status and pubertal timing is not entirely straightforward. A major empirical challenge to the notion that an unfavourable childhood environment leads to faster physical maturation comes from widely observed secular trends in the age at menarche. Looking at broad historical patterns, the steady increase in socioeconomic conditions in many places around the world during the last 150 years or so has been accompanied by a substantial *decrease* in the mean age at menarche (Parent et al. 2003, the source for this section except where otherwise specified). In Europe and Northern America, the mean age at menarche declined from

about 17 years to less than 14 years between the mid-19th century and mid-20th century. Within developing countries, a socioeconomic gradient in age at menarche has repeatedly been observed, such that that girls from higher SES households tend to have their first period at a younger age (reviewed in Parent et al. 2003; also Ellis 2004). Although there are fewer relevant historical data, a parallel trend towards an earlier pubertal onset is assumed to have occurred in boys.

Rather than supporting a link between childhood adversity and accelerated pubertal development, these results are in line with energetics theory, which states that humans adaptively calibrate physical maturational processes to a situation characterized by chronically low energy availability by *slowing down* development (Ellison 2001). An individual in such an environment should invest more of her scarce resources into maintenance but less in growth and reproduction, as a consequence of which she will grow more slowly and reach puberty later. The well-established finding that higher BMI values are associated with earlier puberty (e.g., Davison et al. 2003; Sørensen et al. 2010) can be interpreted in terms of energetics theory.

As Ellis (2004) points out, however, in studies from developed countries in which "lower SES groups do not suffer from systemic malnutrition and disease", SES is generally unrelated to age at menarche (reviewed in Ellis 2004; Matchock & Susman 2006; Papadimitriou et al. 2008). Indeed, in the UK, girls from the lowest socioeconomic stratum appear to have actually had the lowest mean age at menarche since the levelling off of the mean age at menarche in the mid-20th century (Morris et al. 2011).

In places like the United Kingdom, then, socioeconomic progress over the past century and a half may have, first, produced a general downward trend in pubertal timing, with improved childhood nutrition a likely mechanism, and, subsequently, largely removed the nutritional brake on pubertal development. In the process, the association between SES and pubertal timing may have disappeared or even reversed. In a society with little nutritional stress, SES may be a proxy for morbidity and mortality rather than a correlate of childhood nutritional status, in which case lower SES would be expected to predict earlier puberty. While most studies in high-income populations find no association between SES and pubertal timing, several recent studies have found growing up in a low SES household to be predictive of earlier puberty in well-fed

populations (Romans et al. 2003; Quinlan 2003; Braithwaite et al. 2009 for white American girls, although the opposite relationship was found in black girls; Arım et al. 2011; Culpin et al. 2014; Sheppard et al. 2015).

There is a dearth of studies looking at the relationship between socioeconomic status and pubertal development in boys. James and colleagues (2012) did not find any association in boys between SES, a score based on parental occupation and education, and a measure of pubertal timing derived from multiple items (growth spurt, skin changes, body hair growth, facial hair growth, and voice changes). Similarly, Bogaert (2005) did not find male respondents' current SES – which may function as a proxy for childhood SES if social mobility is sufficiently limited – to be predictive of the time when puberty started (reported retrospectively). Nor did Sheppard and Sear (2011) find a link between parental social class at birth and the timing of voice breaking in a cohort of British boys (born in 1958). A recent Canadian cohort study did find that boys whose father was less educated were more likely to have started puberty early (i.e., they were in the youngest 25% at pubertal onset), as judged by facial and body hair growth and voice changes, although no effects were found for family income or parental unemployment (Arım et al. 2011). The only ALSPAC-based study on boys' pubertal development, as far as I am aware of, focused exclusively on pubic hair growth and did not find evidence for a link between SES, as gauged by maternal occupation-based social class, and pubertal progression (Monteilh et al. 2011). Taken together, there is little evidence for a socioeconomic gradient within high-income societies in pubertal timing in boys.

I am not aware of any studies looking specifically at neighbourhood deprivation and its association with pubertal timing.

6.1.2.2 Father absence and pubertal timing

6.1.2.2.1 Girls

The bulk of work looking at father absence and pubertal timing is concerned with girls' age at menarche, the least ambiguous marker of the onset of puberty. The majority of these studies have found a statistically significant, if modest, association between father absence and age at menarche, with girls growing up in a fatherless household tending to

have their first period at a slightly younger age (Quinlan 2003; Hoier 2003; S.E. Romans et al. 2003; Mustanski et al. 2004; Maestripieri et al. 2004; Bogaert 2005; Matchock & Susman 2006; Tither & Ellis 2008; Neberich et al. 2010; Jean et al. 2011; James et al. 2012; Culpin, Heron, Araya, Melotti, et al. 2014b).

Far fewer studies have looked at other measures of pubertal timing in girls. In a Finnish sample, 14 year old twin girls' breast and body hair development was judged to be more advanced in father-absent families (Mustanski et al. 2004). Some studies have reported relationship between father absence and girls' pubertal development based on scores derived from multiple items of the Puberty Development Scale (Petersen et al. 1988), but it is not possible to say which specific items were responsible for the association in these studies (Ellis et al. 1999; Ellis & Garber 2000).

6.1.2.2.2 Boys

Relatively little work has explored boys' pubertal development in relation to parental absence, and the available literature does not reveal a consistent pattern.

In a sample of Canadian students, father absence was shown to predict, retrospectively, earlier spermarche (i.e., first seminal emission) (Kim & Smith 1998). In a study based on a national probability sample from the United States, father absence at age 14 predicted earlier onset of puberty in boys, as indicated by an earlier recalled age when puberty started (Bogaert 2005). In the latter study, voice change and pubic hair growth were given as examples of indicators of pubertal onset but participants were not asked explicitly to indicate when a specific event associated with pubertal development occurred, so it is not possible in this case to establish a clear link between father absence and any particular measure of puberty other than its timing. In a longitudinal study of twin pairs from Finland, father absence at age 14 was associated with more advanced pubertal development as indexed by self-reported stage of body hair growth, skin changes, voice-breaking, and beard growth (Mustanski et al. 2004).

In contrast, a study using longitudinal data from the UK National Child Development Study, found that late father absence, defined as the natural father leaving when the child is between 11 and 16 years old, predicted a lower probability of voice-breaking by

age 13, while early father absence was not associated with this measure of pubertal timing (Sheppard & Sear 2012).

Finally, a longitudinal study into the effects of aspects of parenting – closeness, harshness, and emotionality – on pubertal timing did not find any effects on male pubertal onset as measured by Tanner stages for pubic hair and genital development (Belsky et al. 2007).

6.1.3 ALSPAC-based studies of predictors of pubertal timing

There have been a number of published studies using ALSPAC data to look at predictors of pubertal timing in both girls (Rubin et al. 2009; Christensen et al. 2010; Culpin, Heron, Araya, Melotti, et al. 2014b; Culpin, Heron, Araya & Joinson 2014) and boys (Monteilh et al. 2011). Here I briefly discuss these investigations, insofar as they are relevant to the current study.

Having a less educated mother (no qualifications vs. ≥ secondary school), financial problems, and living in rented rather than owned (or mortgaged) accommodation were found to be associated with earlier menarche (Culpin, Heron, Araya, Melotti, et al. 2014b; Culpin, Heron, Araya & Joinson 2014), but partner's social class, based on the occupation of the mother's partner as reported during pregnancy, was not associated with the timing of girls' first period (Rubin et al. 2009). For progression through breast development and pubic hair stages, no SES effects were found using maternal education and maternal social class as indices of SES (Christensen et al. 2010). I have already mentioned the negative association found between early father absence and age at menarche (Culpin, Heron, Araya, Melotti, et al. 2014b; Culpin, Heron, Araya & Joinson 2014). Finally, concurrent BMI was associated with more earlier progression through Tanner stages of breast development and pubic hair growth (Christensen et al. 2010), while BMI at 8 was associated with a higher likelihood of having experienced menarche by age 11 (Rubin et al. 2009).

The analyses reported in this chapter add to this small body of ALSPAC-based work on predictors of pubertal development of girls in several ways. I examine the association between father absence and outcomes other than menarche, look at the effect of neighbourhood deprivation, and also consider an additional outcome in armpit hair

growth. Another distinguishing feature of the current investigations are the age at peak velocity and peak velocity models (6.2.2.1.2).

To my knowledge, only one ALSPAC-based study has investigated predictors of pubertal timing in boys, specifically, Tanner stage transitions (stage >1, >2, and >3) for pubic hair growth (Monteilh et al. 2011). With regard to independent variables similar to the ones I am including here, it did not find an association between pubertal timing and maternal social class (based on occupation), but did find that BMI at 8 was negatively associated with age at transition to Tanner stage >2 and Tanner stage >3.

The analyses for boys reported in this chapter examine several additional measures of pubertal development – development of the genitalia, voice breaking, and armpit hair growth, – and include a number of additional predictors of particular interest from a life history perspective, such as father absence and neighbourhood deprivation. Again, I look at age at peak velocity and peak velocity models.

6.1.4 Study aims

The main aim of the current study is to test predictions derived from life history theory about the accelerating effects of supposed cues of a harsh or resource-poor environment on pubertal development. In particular, I test whether measures of the quality of the childhood environment – household SES, father absence, and neighbourhood deprivation – are associated with multiple measures of pubertal development: pubic and armpit hair growth for both sexes; menarche and breast development for girls; and voice breaking and penis and scrotum development for boys. A secondary aim was to expand the empirical literature on life history predictors and male pubertal development as this is a relatively understudied area. In addition to standard statistical approaches to studying predictors of pubertal timing, I also examine whether life history predictors are associated with parameters summarizing developmental trajectories of specific measures of pubertal development, following a recently proposed methodology.

6.2 Methods

6.2.1 Data and participants

The main data source for this study is ALSPAC (2.1). Household socioeconomic data, household composition (father presence/absence) and maternal age at menarche were collected through several of ALSPAC's frequent postal questionnaires. ALSPAC's repeated puberty questionnaires (*Growing and Changing*) provide the pubertal development variables that served as outcomes. These were largely filled out by mothers, mothers and children together, or just the children, shifting from mostly the parent for younger children to mostly the child for middle and late adolescents. The study child's body mass index was calculated based on height and weight as measured at the Focus@7 ALSPAC clinic visit, when the children were approximately 7.5 years old. Neighbourhood deprivation data were prepared by the Office for National Statistics of the United Kingdom (2.2.2).

The sample sizes in this chapter vary across models. One set of analyses investigated age at menarche and measures of pubertal development at a single time point (e.g., breast development at 11 years and 8 months, voice changes at 13 years and 1 month). In order to be included, a respondent needed to have a valid value for at least 1 of the 6 outcome measures, which left samples of 4,321 girls and 3,330 boys. A second set of analyses modelled parameters that summarized developmental trajectories based on multiple measurements for each measure. Again, at least on valid outcome had to be available for someone to be included, leaving sample sizes of 2,350 for girls and 1,429 for boys.

The appendix to chapter 6 contains comparisons of selected baseline variables between analysis and attrition samples for the first set of analyses. They reveal that the analysis samples for both girls and boys adolescents are biased towards adolescents from more privileged socioeconomic backgrounds, as indicated by levels of parental education, home ownership status and neighbourhood deprivation. Maternal age at menarche does not differ between the analysis and attrition samples.

6.2.2 Analysis

6.2.2.1 Statistical approach

6.2.2.1.1 Pubertal progression measures

As mentioned, I conducted two types of analyses. The first investigated age at menarche and a range of measures of pubertal development at a single time point. For girls, I modelled age at menarche (linear regression), breast development and pubic hair growth (ordinal logistic regressions), and armpit hair growth (logistic regression). For boys, the outcomes were voice changes (logistic regression), genital development and pubic hair growth (ordinal logistic regressions), and armpit hair growth (logistic regression).

6.2.2.1.2 Summarizing developmental trajectories

In addition to these relatively straightforward models, I also applied a recently developed mixed effects logistic modelling approach to studying developmental trajectories (Cole et al. 2014). The idea behind this technique is to use longitudinal developmental data, such as those provided by the ALSPAC puberty questionnaires, to derive a small number of parameters that summarize developmental trajectories, which can then be used as dependent or independent variables in further analyses. The main motivation for this approach is to allow researchers to make use of all available measurements rather than looking at a single developmental stage at a single time point (e.g., Tanner stage X reached by time point Y). In addition, where trajectories are summarized by more than one parameter, these might have different interpretations and show different empirical associations.

Here I illustrate the approach for Tanner stage models; for binary outcomes (e.g., menarche has happened/not happened), the methods are similar but simpler (Cole et al. 2014).

The developmental trajectory for Tanner stage progression can be modelled with the following equation:

$$E(y_{it}) = 1 + \frac{4}{1 + e^{-(t-\beta_i)/e^{-\gamma_i}}}$$

Here $E(y_{it})$ is the expected value of the outcome, for instance, Tanner stage for pubic hair growth, for individual i at age t; and β_i and γ_i are relative timing and rate parameters, respectively, for individual i. When t is zero or small, $E(y_{it}) = 1 + 0 = 1$; but when t is very large, $E(y_{it}) = 1 + 4 = 5$. In this way, with time, individuals modelled by this equation progress from Tanner stage I to Tanner stage V. The timing parameter, β_i, represents the individual's mean age in Tanner stage III, halfway through the developmental process (when $t = \beta_i, y_{it} = 3$). Because this is when the rate of change is highest, β_i is the *age at peak velocity* (APV). It can be seen from the equation that individuals with a higher β_i have a lower expected value of y_{it} at the same age. Similarly, the relative rate parameter, γ_i, adjusts for differences in *peak velocity* (PV), i.e., the rate of change when change is most intense.

Implementation requires one to define a sample-average developmental trajectory and then summarize individual deviations from the average curve in a few parameters. In practice, β_i and γ_i are separated into a fixed component, which represents the average individual in the sample, and a random component, which captures individual deviation from the sample mean. The random components are used as dependent variables in the APV and PV models in this chapter. The APV and PV parameters were derived from longitudinal data in R 3.2.0 (R Core Team 2015).

For all measures, this method produces an age at peak velocity parameter. (Strictly speaking, the estimated parameter tells us how the individual's APV deviates from the sample-average APV.) The APV estimate can be interpreted as an indicator of the timing of puberty, although it is not strictly an indicator of the timing of pubertal onset but rather tells us when development proceeds at its highest rate. In addition to the APV, for breast and genital development, pubic hair growth, and voice changes, an estimate of peak velocity (PV) was also generated. (Again, strictly speaking, this parameter gives the deviation from the sample-average PV.) Differences in peak velocity suggest differences in developmental rate. By separating developmental trajectories into two components (timing and velocity), it might be possible to determine more precisely how particular predictors are associated with development. The APV and PV parameters are normally distributed continuous variables and were therefore modelled with linear regressions.

6.2.2.1.3 Backward selection

For all outcome measures, I started with a model containing all of the following predictors: maternal education, paternal education, financial difficulties, home ownership status, neighbourhood deprivation, maternal age at menarche, and BMI at 7. I then dropped the variable with the highest p-value above 0.10 and re-ran the regression, repeating this process until all remaining predictors had a p-value of less than 0.10. All analyses were performed in Stata 12 (StataCorp. 2011).

6.2.2.2 Missing data

Multiple imputation using chained equations (MICE), as implemented in Stata 12 (StataCorp. 2011), was used to impute missing data in the samples defined above. Twenty-five imputed data sets were created for each of the four samples, based on imputation models containing all predictor and pubertal development variables used in the analyses.

6.2.3 Variables

6.2.3.1 Puberty questionnaires

Questionnaires about the physical changes of puberty were sent at nine set time points between 8 years and 1 month ('Growing and Changing 1') and 17 years ('Growing and Changing 9'). For girls, they addressed menstruation, breast development, pubic hair growth, armpit hair growth, and changes in height and weight. For boys, the questions covered the development of male genitalia (testes, scrotum and penis), voice changes, and again pubic hair growth, armpit hair growth, and height and weight changes. The early questionnaires were completed largely by a parent or, less frequently, by the parent and study child together. Over time, questionnaires became more likely to be answered by the parent and study child together or by the child alone. From 'Growing and Changing 6' (sent at 14 years and 7 months) onwards, the puberty questionnaires were addressed directly to the study teenagers who, in the great majority of cases (~90%), filled out the questionnaire without help from a parent or someone else.

6.2.3.2 Dependent variables: measures of pubertal timing

ALSPAC puberty questionnaires (Growing and Changing) at 8 time points provided the pubertal timing data used in this chapter. The time points were: 8 years and 1 month, 9 years and 7 months, 10 years and 8 months, 11 years and 8 months, 13 years and 1 month, 14 years and 7 months, 15 years and 6 months, and 16 years.

6.2.3.2.1 Girls

For girls, I used menarche, armpit hair growth, and Tanner stages of breast development and pubic hair growth (1.2.1.2.1) as indicators of pubertal timing.

Age at menarche was modelled as a continuous outcome in a linear regression. The earliest reported age at menarche was used since reports closest to the event will be most reliable. I also ran an APV model based on reports on whether menarche has occurred at 6, 7 or 8 time points.

Breast development was assessed using Tanner stages. Breast development was modelled in three ways. Firstly, I performed an ordinal logistic regression of breast development Tanner stage at 11 years and 8 months (*Growing and Changing 4*) on the predictor variables. Secondly, I ran a logistic regression of Tanner stage III reached (0 = no, 1 = yes) at the same age. And thirdly, I ran APV and PV models using breast development Tanner stages at 7 or 8 time points, depending on how many measurements were available for an individual.

Pubic hair growth was also assessed using the relevant Tanner stages, measured at 11 years and 8 months. I performed an ordinal logistic regression of Tanner stage reached (1-5), a logistic regression of stage III reached (0 = no, 1= yes), and APV and PV models based pubic hair growth reports at 7 or 8 time points.

Armpit hair growth in girls was treated as a binary outcome (0 = armpit hair has not started growing, 1 = armpit hair has started growing) and modelled at 10 years and 8 months in a logistic regression and in an APV model based on 5 or 6 time points.

6.2.3.2.2 Boys

For boys, I used voice breaking, armpit hair growth, and Tanner stages of genital development and pubic hair growth (1.2.1.2.2) as indicators of pubertal timing.

Voice breaking at 13 years and 1 month was modelled as a binary variable (0 = voice has not changed, 1 = voice is occasionally a lot lower or has totally changed) in a logistic regression. I also ran APV and PV models based on voice breaking stage at 6 or 7 time points with three outcome categories (no change, changed somewhat, changed completely).

Genital development was modelled based on Tanner stages, in a similar fashion to breast development and pubic hair growth. I ran an ordinal logistic regression of Tanner stage at 11 years and 8 months and APV and PV models based on data from 7 or 8 time points.

Pubic hair growth was treated in the same way for boys as it was for girls except that in the case of boys pubic hair growth at 13 years and 1 month was used for the ordinal logistic and logistic regressions. Armpit hair growth in boys was handled in the same way as in girls except that armpit hair growth at 13 years and 1 months used for the logistic regression. Later time points were used for boys than for girls in order to get somewhat similar distributions across Tanner stages (boys, on average, mature later than girls).

6.2.3.3 Independent variables

In order to control for the heritability of pubertal timing (e.g., van den Berg et al. 2006), I included the mother's age at menarche (in years), as recalled during the index pregnancy, in each of the starting models. The study child's body mass index (BMI) at approximately 7.5 years, calculated based on height and weight measured at the Focus@7 ALSPAC clinic, was added to the starting models in order to control for the effects of weight and body composition (e.g., Davison et al. 2003; Sørensen et al. 2010).

Mothers' and fathers' highest educational qualification were included as SES variables (1 = no educational qualifications or CSE, 2 = vocational, 3 = O-level, 4 = A-level, 5 = degree; see section 2.1.1 in chapter 2 for more information on educational qualifications in the UK). In addition to parental education, I included financial difficulties at 33 months (0 = no financial difficulties, 1 = some difficulties, 2 = many difficulties) and home ownership at 21 months (0 = rented, 1 = mortgaged, 2 = owned) as measures of socioeconomic status/deprivation experienced during childhood. The measure of

neighbourhood deprivation was the Index of Multiple Deprivation 2000 (2.2.2), matched to the study children's ward of residence at birth. This measure was log-transformed in preparation of imputation of missing data.

Finally, a binary father absence variable was included, indicating whether the biological father was co-residing with the mother and the study child (0) or absent from the household (1) by the time the study child reached his or her fifth birthday. The cut-off was put at 5 years because of earlier work using ALSPAC showing that only early father absence was associated with earlier menarche (Culpin, Heron, Araya, Melotti, et al. 2014b), in line with suggestions of a critical period (Draper & Harpending 1982; Belsky et al. 1991).

6.3 Results

6.3.1 Descriptive statistics

Table 65 gives descriptive statistics for the sample of girls used for age at menarche (linear regression), breast development (ordinal logistic regression), pubic hair growth (ordinal logistic regression), and armpit hair growth (logistic regression). Descriptive statistics for the samples use for the APV and PV analyses can be found in the appendix to chapter 6. Again, the odds ratios for continuous predictors are reported as standardized odds ratios.

Table 65. Descriptive statistics for the sample of girls used for age at menarche (years), breast development (Tanner stages), pubic hair growth (Tanner stages), and armpit hair growth (not started vs. started)

Variables	n (% of sample)	Units or categories	Mean (SD) or distribution across categories (%)
Age at menarche	3,798 (87.9%)	Years	12.59 (1.17); range = 7.58 – 16.33
Breast development	3,059 (70.8%)	Tanner stage 1	388 (12.7%)
		Tanner stage 2	1,025 (33.5%)
		Tanner stage III	1,116 (36.5%)
		Tanner stage 4	465 (15.2%)
		Tanner stage 5	65 (2.1%)
Pubic hair growth	2,990 (69.2%)	Tanner stage 1	813 (27.2%)
		Tanner stage 2	912 (30.5%)
		Tanner stage III	699 (23.4%)
		Tanner stage 4	416 (13.9%)
		Tanner stage 5	150 (5.0%)
Armpit hair growth	2,866 (66.3%)	Has not started	2,231 (77.8%)
		Has started	635 (21.2%)
Maternal age at menarche	3,725 (86.2%)	Years	12.85 (1.51); range = 8 – 24
BMI at Focus@7	3,306 (76.5%)	kg/m^2	16.33 (2.16); range = 10.85 – 34.88
Maternal education	4,139 (95.8%)	None/CSE	636 (15.4%)
		Vocational	371 (9.0%)
		O-levels	1,452 (35.1%)
		A-levels	1,040 (25.1%)
		Degree	640 (15.5%)
Paternal education	4,029 (93.2%)	None/CSE	906 (22.5%)
		Vocational	331 (8.2%)
		O-levels	842 (20.9%)
		A-levels	1,123 (27.9%)
		Degree	827 (20.5%)
Financial difficulties	3,736 (86.5%)	None	1,393 (37.3%)
		Some	1,591 (42.6%)
		Many	752 (20.1%)
Home ownership status	3,755 (86.9%)	Rented	593 (15.8%)
		Mortgaged	3,083 (82.1%)
		Owned	79 (2.1%)
Father absence by 5 years	4,004 (92.7%)	Present	3,329 (83.1%)
		Absent	675 (16.9%)
Index of Multiple Deprivation	4,100 (94.9%)	Composite score	20.00 (14.81); range = 3.87 – 66.80
		Log-transformed	2.73 (0.73); range = 1.35 – 4.20

Descriptive statistics for the sample of boys used to examine voice breaking (logistic regression), genital development (ordinal logistic regression), pubic hair growth (ordinal logistic regression), and armpit hair growth (logistic regression) are provided

in Table 66. Descriptions of the samples used in the developmental trajectory (APV and PV) analyses of male pubertal development can be found in the appendix to chapter 6.

Table 66. Descriptive statistics for the sample of boys used for voice breaking (has not occurred vs. voice has changed), genital development (Tanner stages), pubic hair growth (Tanner stages), and armpit hair growth (not started vs. started)

Variables	n (% of sample)	Units or categories	Mean (SD) or distribution across categories (%)
Voice breaking	2,494 (74.9%)	Voice has not changed	1,341 (53.8%)
		Voice has changed	1,153 (46.2%)
Genital development	2,441 (73.3%)	Tanner stage 1	256 (10.5%)
		Tanner stage 2	734 (30.1%)
		Tanner stage III	954 (39.1%)
		Tanner stage 4	454 (18.6%)
		Tanner stage 5	43 (1.8%)
Pubic hair growth	2,271 (68.2%)	Tanner stage 1	293 (12.9%)
		Tanner stage 2	529 (23.3%)
		Tanner stage III	597 (26.3%)
		Tanner stage 4	709 (31.2%)
		Tanner stage 5	143 (6.3%)
Armpit hair growth	2,451 (73.6%)	Has not started	1,507 (61.5%)
		Has started	944 (38.5%)
Maternal age at menarche	2,919 (87.7%)	Years	12.86 (1.50); range = 9 – 19
BMI at Focus@7	2,705 (81.2%)	kg/m^2	16.08 (1.93); range = 11.78 – 28.34
Maternal education	3,242 (97.4%)	None/CSE	400 (12.3%)
		Vocational	275 (8.5%)
		O-levels	1,180 (36.4%)
		A-levels	858 (26.5%)
		Degree	529 (16.3%)
Paternal education	3,147 (94.5%)	None/CSE	570 (18.1%)
		Vocational	243 (7.7%)
		O-levels	690 (21.9%)
		A-levels	887 (28.2%)
		Degree	757 (24.1%)
Financial difficulties	3,024 (90.8%)	None	1,142 (37.8%)
		Some	1,295 (42.8%)
		Many	587 (19.4%)
Home ownership status	3,004 (90.2%)	Rented	417 (13.9%)
		Mortgaged	2,522 (84.0%)
		Owned	65 (2.0%)
Father absence by 5 years	3,231 (97.0%)	Present	2,742 (84.9%)
		Absent	489 (15.1%)
Index of Multiple Deprivation	3,133 (94.1%)	Composite score	19.19 (14.04); 3.87 – 66.80
		Log-transformed	2.70 (0.72); 1.35 – 4.20

Table 67 gives the pairwise correlations among the variables used in the linear regression analysis of age at menarche. Correlations between the independent variables and breast development (Tanner stages), pubic hair growth (Tanner stages), and armpit hair growth (not started vs. started), respectively, can be found in Table 68, which also gives the correlations between these four pubertal outcome measures. Similarly for boys, Table 69 presents the pairwise correlations among the variables used in the logistic regression analysis of voice breaking, while Table 70 completes the picture of correlations for male genitalia (Tanner stages), pubic hair growth (Tanner stages), and armpit hair growth (not started vs. started).

Table 67. Pairwise correlations between variables in the age at menarche (linear regression) sample

	1	2	3	4	5	6	7	8	9
1: Maternal age at menarche	1								
2: BMI at Focus@7	-0.12***	1							
3: Maternal education	-0.01	-0.07***	1						
4: Paternal education	0.02	-0.07***	0.55***	1					
5: Financial difficulties	-0.01	0.02	-0.21***	-0.26***	1				
6: Home ownership status	0.03	-0.04*	0.24***	0.23***	-0.28***	1			
7: Father absence by 5 years	-0.00	0.02	-0.16***	-0.20***	0.24***	-0.29***	1		
8: Index of Multiple Deprivation	0.01	0.08***	-0.26***	-0.28***	0.20***	-0.27***	0.18***	1	
9: Age at menarche	0.27***	-0.28***	0.08***	-0.05**	0.05**	0.05**	-0.08***	-0.05**	1

*** p < 0.001, ** p < 0.01, * p < 0.05

Table 68. Pairwise correlations between predictors and breast development, pubic hair growth, and armpit hair growth; and among the outcomes

	Breast development	Pubic hair growth	Armpit hair growth
Maternal age at menarche	-0.23***	-0.23***	-0.07***
BMI at Focus@7	0.29***	0.20***	0.23***
Maternal education	-0.04*	-0.04	-0.03
Paternal education	-0.05**	0.00	-0.00
Financial difficulties	0.06**	0.03	0.03
Home ownership status	-0.03	0.00	-0.02
Father absence by 5 years	0.00	0.01	0.02
Index of Multiple Deprivation	0.04*	0.01	0.04*
Age at menarche	-0.62***	-0.58***	-0.29***
Breast development	1		
Pubic hair growth	0.63***	1	
Armpit hair growth	0.30***	0.45***	1

*** p < 0.001, ** p < 0.01, * p < 0.05

Table 69. Pairwise correlations between variables in the voice breaking (logistic regression) sample

	1	2	3	4	5	6	7	8	9
1: Maternal age at menarche	1								
2: BMI at Focus@7	-0.11***	1							
3: Maternal education	-0.05**	-0.03	1						
4: Paternal education	0.00	-0.02	0.56***	1					
5: Financial difficulties	-0.04*	0.02	-0.19***	-0.25***	1				
6: Home ownership status	0.00	-0.06**	0.20***	0.21***	-0.22***	1			
7: Father absence by 5 years	0.00	0.03	-0.13***	-0.18***	0.23***	-0.26***	1		
8: Index of Multiple Deprivation	-0.02	0.06**	-0.24***	-0.27***	0.17***	-0.19***	0.12***	1	
9: Voice breaking	-0.12***	0.13***	0.04	0.04	0.06**	-0.01	-0.00	0.03	1

*** p < 0.001, ** p < 0.01, * p < 0.05

Table 70. Pairwise correlations between predictors and genital development, pubic hair growth, and armpit hair growth; and among the outcomes

	Male genitalia	Pubic hair growth	Armpit hair growth
Maternal age at menarche	-0.07**	0.15***	-0.13***
BMI at Focus@7	-0.04	-0.13***	0.18***
Maternal education	-0.07***	0.01	0.01
Paternal education	-0.05*	0.00	0.02
Financial difficulties	0.05*	0.06**	0.02
Home ownership status	-0.05*	-0.03	-0.04*
Father absence by 5 years	0.09***	0.02	0.02
Index of Multiple Deprivation	0.07***	0.03	-0.03
Voice breaking	0.27**	0.50***	0.38***
Male genitalia	1		
Pubic hair growth	0.38***	1	
Armpit hair growth	0.21***	0.50***	1

*** p < 0.001, ** p < 0.01, * p < 0.05

All remaining correlations among the study variables can be found in the appendix to chapter 6.

6.3.2 Model output

A summary of the final model results is provided in Table 71.

Table 71. Summary of final model results. Measures of pubertal development – the dependent variables are listed in the leftmost column. Associations with the predictors in the rows are indicated by their direction and significance level

	Mother's age at menarche	BMI	Maternal education	Paternal education	Home ownership status	Financial difficulties	Father absence	Index of multiple deprivation
GIRLS								
Age at menarche	↑***	↓***	↑~ * ***				↓***	
Menarche: APV	↑***	↓***						
Breasts: Tanner stages	↓***	↑***				↑x**		
Breasts: Tanner stage 3	↓***	↑***				↑x *		
Breasts: APV	↑***	↓***						
Breasts: PV		↓***	↓x * ~				↑*	
Pubic hair: Tanner stages	↓***	↑***				↑~		
Pubic hair: Tanner stage 3	↓***	↑***						
Pubic hair: APV	↑***	↓***						
Pubic hair: PV						↑~ *		
Armpit hair: F	↓***	↑***						
Armpit hair: APV	↑***	↓***	↑~a					
BOYS								
Voice breaking: no, yes	↓***	↑***		↑x * *		↑* **		
Voice breaking: APV	↑**	↓~	↑x * * ~					
Voice breaking: PV								
Genitalia: Tanner stages	↓***	↓*	↓x * * ~				↑**	↑*
Genitalia: Tanner stage 3	↓**	↓*	↓x * *				↑**	
Genitalia: APV	↑***	↑~					↓**	↓**
Genitalia: PV	↓***							
Pubic hair: Tanner stages	↓***	↑***				↑x *		
Pubic hair: Tanner stage 3	↓***	↑***			↓x ~	↑x ~		
Pubic hair: APV	↑***	↓***				↓x *		
Pubic hair: PV		↑*			↓* ~			
Armpit hair: no, yes	↓***	↑***			↓*			↓*
Armpit hair: APV	↑***	↓***						

[a] Maternal education (highest educational qualification) was dichotomized: 0 = none/CSE, 1 = vocational or O-level or A-level or degree; the exact value of p was 0.056

6.3.2.1 Girls

Tables 72 and 73 show the output for the final models for age at menarche, breast development (Tanner stages and Tanner stage III), pubic hair growth (Tanner stages and Tanner stage III), and armpit hair growth. Results for the related APV and PV models are found in Table 74.

6.3.2.1.1 Menarche

In both the standard age at menarche model and the APV model, mothers' age at menarche predicted when daughters had their first period ($p < 0.001$ in both) and a higher BMI was associated with menarche ($p < 0.001$ in both). Based on the former model, a 1-year increase in a mother's age at menarche translates to a 2.2 months increase in the daughter's predicted age at menarche. An increase of 5 BMI units (kg/m^2) translates to a decrease in the predicted age at menarche of 8.3 months.

Two additional variables were significant predictors of age at menarche in the linear regression of age at menarche. Daughters whose mother had no educational qualifications or whose highest qualification was a CSE tended to experience an earlier menarche, by about 2 months, compared to those with mothers with a higher level of education. Girls who experienced early father absence (by 5 years) are predicted to experience menarche about 2.2 months earlier ($B = -0.18$, $p < 0.001$), in line with a previous ALSPAC-base study (Culpin, Heron, Araya, Melotti, et al. 2014b).

6.3.2.1.2 Breast development

The results for mother's age at menarche and BMI in the ordinal logistic regression of breast development Tanner stage by 11 years and 8 months mirror those found for age at menarche. Later maternal pubertal development, as measured by their age at menarche, predicted less advanced breast development in daughters ($OR = 0.76$, $p < 0.001$), while a higher BMI predicts more advanced breast development ($OR = 1.64$, $p < 0.001$). In addition, if the mother reported experiencing many financial difficulties during the study child's childhood (around 2 years and 9 months), breast development was more advanced as well ($OR = 1.26$, $p = 0.001$). The results for the logistic regression for reaching Tanner stage III by 11 years and 8 months tell the same story as the ordinal logistic regression.

Mother's age at menarche and BMI at 7 again show the expected associations with pubertal timing as measured by age at peak velocity. Age at peak velocity was negatively associated with peak velocity, indicating that later breast development was associated with slower progression through the Tanner stages.

Peak velocity was, somewhat surprisingly, lower when BMI was higher ($B = -0.31$, $p < 0.001$), that is, a higher BMI was associated with a slower progression through the Tanner stages, although, as mentioned, breast development did start earlier in girls with a higher BMI. Some small but statistically significant associations were also found between peak velocity of breast development and both mother's education and early father absence. Those whose mother had no educational qualification or only a CSE appeared to be developing somewhat faster than those whose mother was more educated. Girls who experienced early father absence likewise progressed through the Tanner stages of breast development at a quicker rate.

6.3.2.1.3 Pubic hair growth

For pubic hair growth at 11 years and 8 months again, I found a positive association between the pubertal timing of mothers (maternal age at menarche) and that of their daughters (Tanner stage of pubic hair growth) in the ordinal logistic regression. There was a suggestion of a positive association between experiencing many financial difficulties and Tanner stage of pubic hair growth, although this failed to reach significance at an alpha of 5% ($OR = 1.16$, $p = 0.09$).

The binary measure of pubic hair growth, which indicated whether the girl had reached Tanner stage III by 11 years and 8 months, only showed the familiar associations with mother's age at menarche and childhood BMI. Similarly, age at peak velocity for progression through the Tanner stages of pubic hair growth only showed the expected associations with mother's age at menarche and BMI, in addition to a negative association with peak velocity.

Finally, peak velocity appeared to be higher in girls whose mother had reported experiencing financial difficulties (some difficulties: $B = 0.04$, $p = 0.064$; many difficulties: $B = 0.05$, $p = 0.045$).

6.3.2.1.4 Armpit hair growth

Armpit hair growth in girls was less advanced in girls whose mother had a later age at menarche (logistic regression: OR = 0.90, p = 0.003; linear regression of age at peak velocity: B = 0.12, p < 0.001) and girls with a lower BMI at 7 years old (logistic regression: OR = 1.61, p < 0.001; linear regression of age at peak velocity: B = -1.46, p < 0.001). In addition, those girls with the least educated mothers appeared to be developing at a higher rate (OR = 1.26, p = 0.053 for a combined category of vocational, O-levels, A-levels or degree versus the reference category of no educational qualification or only a CSE).

Table 72. Final model results for age at menarche (linear regression), breast development (Tanner stages; ordinal logistic regression), and breast development (Tanner stage III; logistic regression)

		Age at menarche			Breast development (Tanner stage)			Breast development (Tanner stage 3 reached)		
		B	95% CI	p	OR	95% CI	p	OR	95% CI	p
Intercept		14.90	14.17 – 15.63	<0.001***						
Mother's age at menarche		0.18	0.16 – 0.20	<0.001***	0.76	0.73 – 0.79	<0.001***	0.76	0.71 – 0.82	<0.001***
BMI at 7 (square-root transformed)		-1.15	-1.29 – -1.01	<0.001***	1.64	1.52 – 1.76	<0.001***	1.66	1.51 – 1.81	<0.001***
Mother's education (ref.: none/CSE)										
	Vocational	0.15	-0.01 – 0.31	0.058$^{\sim}$						
	O-level	0.14	0.02 – 0.26	0.017*						
	A-level	0.20	0.08 – 0.32	0.001**						
	Degree	0.16	0.02 – 0.30	0.018*						
Financial difficulties (ref.: none)										
	Some	0.10	-0.04 – 0.24	0.157				1.09	0.94 – 1.28	0.221
	Many	0.31	0.13 – 0.49	0.001**				1.26	1.03 – 1.53	0.018*
Father absence by 5 years		-0.18	-0.28 – -0.08	<0.001***						
					B	95% CI	p	B	95% CI	p
Intercept								-5.30	-7.04 – -3.56	<0.001***
/cut1					3.01	1.56 – 4.46	<0.001***			
/cut2					4.92	3.47 – 6.37	<0.001***			
/cut3					6.76	5.29 – 8.23	<0.001***			
/cut4					9.03	7.56 – 10.50	<0.001***			

Table 73. Final models results for girls' pubic hair growth (Tanner stages; ordinal logistic regression), pubic hair growth (Tanner stage III; logistic regression), armpit hair growth (logistic regression)

		Pubic hair growth (Tanner stage)			Pubic hair growth (Tanner stage 3 reached)			Armpit hair growth		
		OR	95% CI	p	OR	95% CI	p	OR	95% CI	p
Mother's age at menarche		0.76	0.73 – 0.79	<0.001***	0.74	0.69 – 0.79	<0.001***	0.90	0.84 – 0.96	0.003**
BMI at 7 (square-root transformed)		1.37	1.28 – 1.45	<0.001***	1.38	1.28 – 1.49	<0.001***	1.61	1.47 – 1.76	<0.001***
Financial difficulties (ref.: none)										
	Some	0.98	0.85 – 1.12	0.816						
	Many	1.16	0.97 – 1.39	0.088~						
		B	95% CI	p	B	95% CI	p	B	95% CI	p
Intercept					-2.36	-3.97 – 0.75	0.005**	-7.97	-9.81 – -6.13	<0.001***
/cut1		1.01	-0.34 – 2.97	0.150						
/cut2		2.37	1.00 – 4.33	0.001**						
/cut3		3.55	2.20 – 5.51	<0.001***						
/cut4		5.07	3.70 – 7.03	<0.001***						

Table 74. Final model results for age at peak velocity and peak velocity parameters for girls: menarche (APV), breast development (APV and PV), pubic hair growth (APV and PV), and armpit hair growth (APV)

AGE AT PEAK VELOCITY[1]	Menarche			Breast development			Pubic hair growth			Armpit hair growth		
	B	95% CI	p	B	95% CI	p	B	95% CI	p	B	95% CI	p
Intercept	1.68	0.92 – 2.44	<0.001***	5.36	4.30 – 6.42	<0.001***	1.96	0.92 – 3.00	<0.001***	4.10	2.65 – 5.55	<0.001***
Maternal age at menarche	0.16	0.14 – 0.18	<0.001***	0.15	0.11 - 0.19	<0.001***	0.16	0.12 – 0.20	<0.001***	0.12	0.08 – 0.16	<0.001***
BMI (square-root transformed)	-0.92	-1.08 – -0.76	<0.001***	-1.82	-2.04 – -1.60	<0.001***	-0.98	-1.20 – -0.76	<0.001***	-1.46	-1.75 – -1.17	<0.001***
Maternal education[2]										0.23	-0.01 – 0.47	0.053~
Peak velocity				-0.98	-1.16 – -0.80	<0.001***	-0.83	-0.99 – -0.67	<0.001***			

[1] No significant associations were found for father's education, financial difficulties, home ownership status, father absence or neighbourhood deprivation
[2] No educational qualification or CSE versus vocational, O-level, A-level or degree

PEAK VELOCITY[1]		Breast development			Pubic hair growth		
		B	95% CI	p	B	95% CI	p
Intercept		1.30	1.06 – 1.54	<0.001***	-0.02	-0.04 – 0.00	0.112
BMI (square-root transformed)		-0.31	-0.37 – -0.25	<0.001***			
Maternal education[1] (ref.: none/CSE)							
	Vocational	-0.04	-0.12 – 0.04	0.269			
	O-level	-0.05	-0.09 – -0.01	0.038*			
	A-level	-0.06	-0.10 – -0.02	0.019*			
	Degree	-0.05	-0.11 – 0.01	0.065~			
Financial difficulties (ref.: None)							
	Some				0.04	0.00 – 0.08	0.064~
	Many				0.05	-0.01 – 0.11	0.045*
Father absence		0.05	0.01 – 0.09	0.041*			
Age at peak velocity		-0.06	-0.08 – -0.04	<0.001***	-0.08	-0.10 – -0.06	<0.001***

[1] No significant associations were found for maternal age at menarche, father's education, home ownership status, or neighbourhood deprivation

6.3.2.2 Boys

Tables 75 and 76 show the output for the final models for voice breaking, development of genitalia (Tanner stages and Tanner stage III), pubic hair growth (Tanner stages and Tanner stage III), and armpit hair growth. Results for the related APV and PV models are found in Table 77. For all of the measures of boys' pubertal timing, I found that a lower mother's age at menarche and a higher BMI predicted earlier puberty, except for male genital development as measured by Tanner Stages which showed an unexpected negative association with BMI (although the same association did not hold for age at peak velocity).

6.3.2.2.1 Voice breaking

In line with predictions based on life history theory and the results for girls' pubertal development, the logistic regression of voice changes indicated that financial difficulties were associated with earlier voice breaking (some difficulties: OR = 1.21, p = 0.040; many difficulties: OR = 1.45, p = 0.002).

Unexpectedly, a boy's voice was less likely to have changed by 13 years and 1 month if his father had no educational qualification or only a CSE (A-level: OR = 1.38, p = 0.023; degree: OR = 1.43, p = 0.010). The linear regression of age at peak velocity revealed a possible association with maternal education (degree: B = -0.29, p = 0.066). Similar to the unexpected paternal education result just mentioned, boys whose mother was in the least educated category tended to be *older* when their voice broke (degree: B = -0.29, p = 0.07).

6.3.2.2.2 Development of genitalia

The ordinal logistic regression results for development of genitalia, at ~11 years and 8 months, indicated that early father absence is associated with more advanced pubertal development (OR = 1.48, p = 0.002). Neighbourhood deprivation also showed an accelerating effect (OR = 1.11, p = 0.015). Finally, those boys whose mothers have a university degree, the most educated category, appear to be less advanced in terms of genital development at this time point (OR = 0.37, p = 0.056).

The results of the logistic regressions – modelling whether Tanner stage III had been reached by 11 years and 8 months – echoed the results of the ordinal logistic regression

(maternal degree: OR = 0.66, p = 0.020; father absence: OR = 1.46, p = 0.005), apart from the neighbourhood deprivation effect.

The age at peak velocity model indicated that neighbourhood deprivation (B = -0.18, p = 0.004) and father absence (B = 0.38, p = 0.005) were both associated with an earlier puberty (lower age at peak velocity). For this outcome, age at peak velocity was positively associated with peak velocity (B = 1.77, p < 0.001), suggesting that later developers progressed more quickly through the Tanner stages.

A higher maternal age at menarche predicted a lower peak velocity (B = -0.03, p < 0.001), controlling for age at peak velocity. Thus, there is the somewhat puzzling result that while later developers appeared to develop more quickly, those whose *mother* was a later developer exhibit slower progression through the Tanner stages.

6.3.2.2.3 Pubic hair growth

The results for the ordinal logistic regression of pubic hair growth stage at ~13 years and 1 month showed that pubic hair growth was more advanced in boys if their mother reported experiencing many financial difficulties (Or = 1.23, p = 0.045).

When considering whether a boy had reached Tanner stage III by 13 years and 1 month, none of the predictors apart from age at menarche and BMI at 7 were associated with the outcome at a statistically significant level. However, living in owned rather than rented accommodation did appear to be associated with a lower probability of having reached stage III (OR = 0.53, p = 0.054). The 'owned' category is rather small, leading to limited power to detect statistically significant differences with the reference category. The effect of many versus no financial difficulties was similar to that found in the ordinal logistic regression, though not significant (OR = 1.25, p = 0.094).

The APV model found, again, that when the study adolescent's mother reported many versus no financial difficulties, boys' pubic hair growth tended to take place at a younger age (B = -0.19, p = 0.033). Home ownership appeared to be associated pubic with peak velocity. Pubertal development, as measured by pubic hair growth, appeared to be progressing at a slower rate in boys living in mortgaged (B = -0.08, p = 0.023) or owned (B = -0.14, p = 0.071) rather than rented accommodation.

6.3.2.2.4 Armpit hair growth

In the logistic regressions, boys were less likely to have started growing armpit hair if they lived in owned accommodation rather than renting (OR = 0.47, p = 0.040). By contrast, neighbourhood deprivation was negatively associated with armpit hair growth (OR = 0.91, p = 0.035), against expectations. The age at peak velocity models did not reveal any further associations apart from those with maternal age at menarche and BMI.

Table 75. Final model results for voice breaking (logistic regression), genital development (Tanner stages; ordinal logistic regression), genital development (Tanner stage III; logistic regression)

		Voice has changed			Genitalia (Tanner stages)			Genitalia (Tanner stage 3)		
		OR	95% CI	p	OR	95% CI	p	OR	95% CI	p
Mother's age at menarche		0.78	0.72 – 0.85	<0.001***	0.87	0.80 – 0.96	0.001***	0.87	0.80 – 0.96	0.005**
BMI at 7 (square root-transformed)		1.29	1.19 – 1.41	<0.001***	0.90	0.83 – 0.98	0.013*	0.89	0.81 – 0.98	0.018*
Mother's education (ref.: none/CSE)										
	Vocational				1.14	0.75 – 1.72	0.549	1.08	0.68 – 1.73	0.730
	O-level				0.95	0.72 – 1.25	0.696	0.92	0.69 – 1.24	0.597
	A-level				0.88	0.65 – 1.18	0.366	0.87	0.62 – 1.21	0.403
	Degree				0.73	0.52 – 1.01	0.056$^{\sim}$	0.66	0.46 – 0.94	0.020*
Father's education (ref.: none/CSE)										
	Vocational	1.34	0.94 – 1.90	0.105						
	O-level	1.19	0.90 – 1.56	0.222						
	A-level	1.38	1.05 – 1.81	0.023*						
	Degree	1.43	1.09 –1.89	0.010*						
Financial difficulties (ref.: none)										
	Some difficulties	1.21	1.01 – 1.44	0.040*						
	Many difficulties	1.45	1.14 – 1.83	0.002**						
Father absence by 5 years					1.48	1.17 – 1.87	0.002**	1.46	1.13 – 1.89	0.005**
Index of Multiple Deprivation (log-transformed)					1.11	1.01 – 1.20	0.015*			
		B	**95% CI**	**p**	**B**	**95% CI**	**p**	**B**	**95% CI**	**p**
Intercept		-3.01	-4.75 – -1.27	0.001**				3.63	1.55 – 5.71	0.001**
/cut1					-4.86	-6.66 – -3.06	<0.001***			
/cut2					-3.09	-4.87 – -1.31	0.001**			
/cut3					-1.32	-3.08 – 0.44	0.146			
/cut4					1.37	-0.43 – 3.17	0.140			

Table 76. Final model results for boys' pubic hair growth (Tanner stages; ordinal logistic regression), pubic hair growth (Tanner stage III; logistic regression), armpit hair growth (logistic regression)

		Pubic hair growth (Tanner stage)			Pubic hair growth (Tanner stage 3 reached)			Armpit hair growth		
		OR	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**
Mother's age at menarche		0.77	0.72 – 0.84	<0.001***	0.80	0.73 – 0.87	<0.001***	0.77	0.70 – 0.84	<0.001***
BMI at 7 (square root-transformed)		1.27	1.17 – 1.37	<0.001***	1.26	1.14 – 1.39	<0.001***	1.47	1.32 – 1.64	<0.001***
Home ownership status										
	Mortgaged				1.09	0.85 – 1.41	0.518	0.81	0.62 – 1.07	0.115
	Owned				0.53	0.28 – 1.01	0.054~	0.47	0.23 – 0.97	0.040*
Financial difficulties (ref.: none)										
	Some difficulties	1.06	0.91 – 1.24	0.480	1.09	0.92 – 1.31	0.327			
	Many difficulties	1.23	1.01 – 1.50	0.045*	1.25	0.97 – 1.61	0.094~			
Father absence by 5 years										
Index of Multiple Deprivation (log-transformed)								0.91	0.84 – 0.99	0.035*
		B	**95% CI**	**p**	**B**	**95% CI**	**p**	**B**	**95% CI**	**p**
Intercept					-1.61	-3.61 - 0.39	0.115	-4.34	-6.40 – -2.28	<0.001***
/cut1		-0.02	-1.63 – 1.59	0.978						
/cut2		1.35	-0.24 – 2.94	0.099~						
/cut3		2.45	0.86 – 4.04	0.003**						
/cut4		4.69	3.08 – 6.30	<0.001***						

Table 77. Final model results for age at peak velocity and peak velocity parameters for boys: voice breaking (APV and PV), genital development (APV and PV), pubic hair growth (APV and PV), and armpit hair growth (APV)

AGE AT PEAK VELOCITY[1]	Voice breaking			Male genitalia			Pubic hair growth			Armpit hair growth		
	B	95% CI	p	B	95% CI	p	B	95% CI	p	B	95% CI	p
Intercept	-0.41	-2.06 – 1.24	0.629	-2.81	-4.63 – -0.99	0.003**	1.11	-0.12 – 2.34	0.079~	2.92	1.47 – 4.37	<0.001***
Maternal age at menarche	0.13	0.07 – 0.19	<0.001***	0.14	0.08 – 0.20	<0.001***	0.14	0.10 – 0.18	<0.001***	0.08	0.04 – 0.12	0.001**
BMI (square-root transformed)	-0.29	-0.62 – 0.04	0.085~	0.37	-0.04 – 0.78	0.083~	-0.70	-0.97 – -0.43	<0.001***	-1.00	-1.31 – -0.69	<0.001***
Maternal education[1]												
Vocational	-0.19	-0.60 – 0.22	0.372									
O-level	-0.20	-0.51 – 0.11	0.212									
A-level	-0.21	-0.50 – 0.08	0.151									
Degree	-0.29	-0.60 – 0.02	0.066~									
Financial difficulties ref.: None)												
Some							-0.09	-0.21 – 0.03	0.132			
Many							-0.19	-0.37 – -0.01	0.033*			
Father absence				-0.45	-0.72 – -0.18	0.001**						
Neighbourhood deprivation				-0.18	-0.30 – -0.06	0.004**						
Peak velocity	-0.12	-0.24 – 0.00	0.052~	1.77	1.53 – 2.01	<0.001***						

[1] No significant associations were found for father's education or home ownership status

PEAK VELOCITY[1]	Voice breaking			Male genitalia			Pubic hair growth		
	B	95% CI	p	B	95% CI	p	B	95% CI	p
Intercept	-0.01	-0.07 – 0.05	0.730	0.34	0.16 – 0.52	<0.001***	-0.29	-0.66 – 0.08	0.121
Maternal age at menarche				-0.03	-0.05 – -0.01	<0.001***			
BMI (square-root transformed)							0.09	0.01 – 0.17	0.040*
Home ownership status (ref.: rented)									
Mortgaged							-0.08	-0.16 – 0.00	0.023*
Owned							-0.14	-0.30 – 0.02	0.071~
Age at peak velocity	-0.05	-0.11 – 0.01	0.069~	0.10	0.08 – 0.12	<0.001***			

[1] No significant associations were found for mother's education, father's education, financial difficulties, home ownership status, father absence or neighbourhood deprivation

6.4 Discussion

In this chapter, I set out to test whether indicators of the quality of an adolescent's childhood environment – viz., household SES, father absence and neighbourhood deprivation – are associated with a suite of measures of female and male pubertal development, as predicted by evolutionary models of adolescent development. I also wanted to add substantially to the empirical literature on the effects of life history predictors on pubertal timing in boys, which comparatively few studies have addressed empirically. Finally, I wanted to model associations, not just between life history predictors and measures of pubertal progression at particular time points, but also between life history predictors and parameters, derived from multiple observations over time, that summarize developmental trajectories.

6.4.1 Main findings

6.4.1.1 Socioeconomic deprivation predicts pubertal timing in girls *and* boys

None of the measures of socioeconomic status was consistently associated with all of the measures of pubertal development. Overall, however, the results provided fairly clear, if not overwhelming, support for the notion that children growing up in a socioeconomically deprived household environment tend to experience earlier puberty, in line with a number of recent studies (S.E. Romans et al. 2003; Quinlan 2003; Braithwaite et al. 2009; Arım et al. 2011; Culpin, Heron, Araya, Melotti, et al. 2014b; Sheppard et al. 2015). Note that this pattern of results is unlikely to be a result of confounding effects of body mass index, since all starting models included the respondents' BMI at age 7. Given the number of outcomes and independent variables tested, some false positive results may have occurred. It is hard to put an exact number to this for a number of reasons, including the fact that many of the outcomes are correlated and the use of categorical predictor variables involving more than two categories. However, the overall pattern of results provides reasonable support for the hypothesised link between socioeconomic deprivation and pubertal development. In the absence of the proposed association, the distribution of the direction of the statistically significant results would be expected to be random with regard to the hypothesis. Instead, all but two of them went in the predicted direction.

Of the socioeconomic variables, experience of financial difficulties was the most consistent predictor of pubertal timing. Girls whose mothers had reported many difficulties in affording items such as food, clothing, heating or the rent, tended to be more advanced in terms of breast development when they were almost 12 years old and, possibly, pubic hair growth as well. Financial difficulties were also associated with earlier puberty in boys as measured by voice breaking and, again, pubic hair growth. These findings are consistent with the hypothesis that economic hardship during childhood can result in earlier puberty (S E Romans et al. 2003; Quinlan 2003; Arım et al. 2011; Culpin, Heron, Araya, Melotti, et al. 2014b; Sheppard et al. 2015), for girls as well as, notably, boys. Possibly, the experience of financial difficulties was most consistently associated with pubertal timing, of all the life history predictors, because it is the most directly related to the lived experience of the respondents, whereas measures such as parental education are less direct indicators of day-to-day experiences and any associated psychosocial stress.

Daughters of the least educated mothers were, on average, slightly younger when they had their first period, appeared to have somewhat faster breast development, and possibly experienced armpit hair growth at a later age. Similarly, sons of mothers with a university degree, had a relatively delayed pubertal onset as gauged by voice breaking and stage of genital development. Further evidence for an accelerating effect of socioeconomic deprivation on boys' pubertal development comes from the findings that boys who lived in owned rather than rented accommodation were less likely to have started growing armpit hair or to have reached Tanner stage III of pubic hair growth by age 13, and also appeared to be passing less quickly through the Tanner stages of pubic hair growth. In addition, boys living in more deprived neighbourhoods tended to have reached a more advanced stage of genital development. Contrary to expectation and the general pattern of results, however, boys from more deprived neighbourhoods also appeared somewhat less likely to have started growing armpit hair and voice breaking tended to occur somewhat earlier in boys with more highly educated fathers.

The apparent accelerating effect of socioeconomic deprivation on pubertal development, in both girls and boys, is consistent with both external and internal predictive adaptive response hypotheses (Nettle et al. 2013), as well as child

development theory (Ellis 2004), but my results do not allow me to distinguish empirically between these explanations. What is clear, however, is that, since all starting models included father absence, socioeconomic status variables are not simply acting as proxies for father absence, whose accelerating effect on specifically menarche has been well-established. The intergenerational conflict hypothesis may thus be a viable hypothesis when it comes to explaining father absence effects on pubertal timing, but cannot account for the effects of socioeconomic deprivation.

6.4.1.2 Father absence predicts earlier puberty in girls *and* boys

Father absence was not just associated with earlier puberty in girls, a finding that has been reported many times before (in relation to age at menarche), but also in boys.

In girls, early father absence (by 5 years) showed the expected negative association with age at menarche, as shown in an earlier ALSPAC-based study (Culpin, Heron, Araya, Melotti, et al. 2014b). Father absence also predicted a higher peak velocity for breast development, a new finding, to my knowledge, which should be interpreted with caution until confirmed in independent samples.

Interestingly, father absence was also associated with more advanced genital development in boys. The only study we are aware of that looked at the relationship between father absence and male genital development, which found no link, specifically investigated the timing of pubertal onset as indicated by *any* evidence of pubic hair growth *or* genital development beyond Tanner stage 1 (Belsky et al. 2007). By contrast, the present study looked at father absence as a predictor of Tanner stage of male genitalia and whether Tanner stage III had been reached (when boys were almost 12 years old), and age at peak velocity based on Tanner stage at multiple time points. The difference in outcomes may explain why the two studies did not find a similar result. This result further contrasts with an earlier study using data from the UK National Child Development Study (NCDS) which found no association between early father absence (before 7 years) and voice breaking and actually found voice breaking to be *delayed* in boys experiencing late father absence (when aged 11-16) (Sheppard & Sear 2012). However, it echoes, the association between recalled age at puberty and father absence in males in a US national probability sample (Bogaert 2005).

My results suggest that this apparent father absence effect is neither a by-product of socioeconomic status nor a result of confounding effects of BMI. They fit with both external and internal PAR hypotheses and also child development theory, but, in this case, the intergenerational conflict hypothesis provides a viable alternative explanation. While it is obviously more parsimonious not to propose a separate explanation for father absence effects on pubertal timing, what is ultimately required is some kind of empirical test able to distinguish between intergenerational conflict explanation and childhood adversity explanations – although it is difficult to imagine what such a test would look like.

6.4.1.3 Summarizing developmental trajectories

In general, I found fewer statistically significant associations between life history predictors and individuals' APV and PV parameters than I did for the standard measures, although where they were found they were in the predicted direction. Sample sizes were substantially smaller for the APV and PV models (2,350 versus 4,321 for girls, 1,429 versus 3,330 for boys), which may explain the relative lack of significant findings. It is also possible that improved results could be obtained with the use of more frequent measurements. While I believe the approach of summarizing developmental trajectories and looking at predictors of the parameters that describe individual trajectories is potentially fruitful, studies with larger sample sizes and more frequent measurements of the developmental outcomes of interest are needed to properly to assess whether different factors influence separable elements of developmental trajectories, such as age at peak velocity and peak velocity, in different ways.

6.4.1.4 Statistical associations between life history predictors and measures of pubertal development are inconsistent

While the overall pattern of results seems to support the hypothesised links between socioeconomic deprivation and father absence, on the one hand, and pubertal timing, on the other, there is, in this study and across studies, a notable lack of consistency of associations between specific predictors and pubertal timing across alternative measures of pubertal development.

For instance, I found that, in the study sample, father absence predicted earlier menarche and a higher peak velocity for breast development in girls and more advanced genital development in boys, but no evidence at all for a link between father absence and pubertal timing as judged by pubic hair growth, armpit hair growth, or voice breaking. More generally, there is, across published studies in this area, a lack of consistency of associations between similarly defined predictors and similarly defined outcomes. Consider, for example, the effects, or lack thereof, of SES on pubertal development in well-fed, high-income populations.

While some of these apparent inconsistencies may reflect genuine differences between mechanisms and sample features (e.g., ethnic composition), the small effect sizes typical of this area combined with often modest sample sizes raises concerns about the statistical power of many studies. Studies with low power suffer from a number of problems: they are more likely to produce false negative results; their positive findings are less likely to be true positives; and they are liable to overestimate true effect sizes (Button et al. 2013). High-power studies with rich information on both the predictors of interest and measures of pubertal development, preferably in multiple populations, may be required to throw more light on the nature of the inconsistencies. Are they an artefact of small effect sizes? Are different measures of pubertal development really differentially related to supposed life history predictors? Or is the underlying picture actually more straightforward? Note that none of the evolutionary models of pubertal development anticipates any of these inconsistencies.

6.4.2 Strengths and limitations

This study has a number of strengths that make it a valuable contribution to the literature. Unlike many studies in this area, the puberty data used in this study were longitudinal and therefore not susceptible to recall bias which could produce misleading results. I included multiple measures of male pubertal development and thus are able to contribute substantially to the small body of work looking at associations between life history predictors and male pubertal development. Several of the relationships, for example, between father absence and development of the male genitalia, have never been examined before (to my knowledge). Including multiple outcomes for both girls and boys also allowed us to compare results across outcomes for consistencies and

inconsistencies. And unlike most studies in this area, I controlled for adolescents' pre-pubertal BMI, thus making it highly unlikely that associations between life history predictors and pubertal developmental measures are simply by-products of associations between SES and BMI. Finally, sample sizes are larger than most in this area.

Several limitations deserve mentioning. Firstly, while the puberty measures were collected longitudinally, they did rely on subjective reports from parents and the adolescents themselves rather than the gold standard of physical examination by an experienced medical professional. Age at menarche, which is a distinct event, is likely to be recalled with a high level of precision, especially given the frequency with which the puberty questionnaires were administered. With regard to the other measures, agreement between self-reports and physical examination by a clinician varies quite widely across the handful of studies that have examined the matter, but seems to range from fair to high (Dorn & Biro 2011). A second limitation relates to attrition. There was clear evidence of a bias towards individuals from lower SES households dropping out of the study as time went by, leading to possible concerns about representativeness. Thirdly, the age at peak velocity and peak velocity models, in particular, may have suffered from too few data points per individual. Previous work demonstrating the validity of these techniques was based on far more frequent measurements than available to us (Cole et al. 2014). Whether and how this may have affected results is unclear. Finally, the study design is not genetically informative (although maternal age at menarche was included in the models). Thus, some associations, such as that between father absence and timing of menarche or genital development in boys, may reflect shared genes rather than a causal relationship between father absence and pubertal development.

6.4.3 Conclusions and future directions

This study adds to the body of evidence showing that an unfavourable childhood environment, characterized by socioeconomic deprivation or father absence, is associated with earlier puberty, in line with several evolutionary models of pubertal development. It further suggests that this is not just the case for girls but also boys, who, to date, have been understudied. A particularly striking finding, in need of replication, is

relationship between father absence and earlier progression through the Tanner stages of genital development in boys.

The results clearly suggest that the link between socioeconomic deprivation and adolescent physical development suggested by energetics theory – low SES being associated with later puberty because of energetic constraints – is not applicable to this well-fed, high-income population, although it is likely to have held in the fairly recent past (Parent et al. 2003).

I have already mentioned the need for high-power studies to shed light on the nature of the inconsistent associations between implicated predictors and measures of pubertal development in this and other studies.

The current study was not designed to distinguish between specific evolutionary models. External PAR hypotheses, such as psychosocial acceleration theory, internal PAR hypotheses, and child development theory all propose that unfavourable childhood circumstances should accelerate or bring forward pubertal development. Future studies might focus more on testing predictions that actually differentiate between evolutionary models. For example, objective health measures could be used to test the idea that adverse childhood environments matter because they reduce health and therefore put a premium on early sexual maturity and reproduction, as suggested by internal PAR hypotheses (Nettle et al. 2013).

Chapter 7: Conclusions

7.1 Introduction

In the Introduction to this thesis (1.1), I proposed to use social clustering as an entry point for the study of behavioural variation. Different theories about behavioural variation imply different clustering patterns, so that establishing those patterns can provide useful information about the explanatory potential of different theories, even without or before testing them directly. In subsequent chapters, I put these ideas into practice by uncovering the social clustering patterns of a range of behavioural traits in a population of British adolescent, including experience with sexual intercourse, cooperativeness, substance use, and the Big Five personality factors. The inclusion of friendship networks alongside school and neighbourhoods in these investigations is a key feature which sets the empirical investigations in this thesis apart from the existing literature (Tranmer et al. 2014).

A second major goal of this thesis was to test evolutionary theories of behavioural and physical-developmental variation in adolescents, in particular those derived from life history theory (1.3), and additionally bringing the two major strands together to ask whether predictors implicated by evolutionary models can account for social clustering of the outcomes of interest. At various points I paid attention to and tested predictions about possible sex differences based on evolutionary theoretical considerations (as discussed in 1.2.3).

For two of the behaviours, viz., sexual experience and cooperativeness, I investigated, after laying bare and quantifying their social clustering, the relationships between life history predictors and the behaviours in question, as well as the predictors' ability to account for the uncovered patterns of social clustering (chapters 3 and 4). In chapter 5, I established the social clustering patterns of a range of behavioural as well as some non-behavioural traits and used these to draw conclusions about the potential explanatory scope of important explanatory models in the human evolutionary behavioural sciences, namely, adaptive flexibility to socioecological variation, coordination benefits from similarity, and cultural transmission biases. In a final chapter, I focused on life history predictors of pubertal development, which allows me to compare the impact of life history predictors on both pubertal development and adolescent behaviour.

In these conclusions, I summarize the main findings of this thesis, draw connections across investigations and discuss their implications, and suggest some possible future directions of research. The core research agenda had two major strands – 1) social clustering and 2) and life history theoretical approaches to adolescent behaviour and physical development – which, for clarity's sake, I keep largely separated in the following.

7.2 Social clustering

Because this thesis investigated social clustering for a wide range of behaviours, it is possible to compare clustering patterns for specific behaviours and ask whether this points to a more general one. One of the most striking findings in this regard is the fairly consistent clustering of adolescent behaviours in friendship networks and the equally consistent lack of clustering in neighbourhoods and schools. This fits with the literature on friend similarities (Kandel 1978; McPherson et al. 2001; Eiser et al. 1991) and the small number of studies that have examined the social clustering of adolescent behaviour in schools and neighbourhoods simultaneously (Teitler & Weiss 2000; Dunn et al. 2015). This clustering pattern appears to hold whether one is talking about experience with sexual intercourse (chapters 3 and 5), alcohol, cigarette and cannabis use (chapter 5), cooperativeness (chapter 4 and 5), or personality factors (chapter 5). Friends are also similar in terms of educational achievement, which is to some extent a behavioural measure, although this also clusters in schools (which presumably reflects school effects and/or differential selection into schools based on academic ability or orientation).

The next three sections discuss some of the implications of this apparently quite general pattern of social clustering of adolescent behaviour.

7.2.1 Similarity of friends is not a by-product of a shared social context or ecology

Adolescent friends often attend the same school and tend to live in the same or a similar nearby neighbourhood. These shared social contexts might induce similarity in friends, through social contextual effects or differential selection into different social contexts (e.g., SES-based selection into neighbourhoods), and may therefore explain why friends often share behavioural traits. Conceivably, friend similarity is just a by-product of

shared social contexts. The results reported in chapter 3-5 convincingly show that this is not, in general, the case in a population of British adolescents. Across a range of behavioural measures, clustering in friendship networks not only remains after accounting for clustering in neighbourhoods and schools, but it far outstrips them; this in marked contrast to socioeconomic status which clusters more strongly in schools and neighbourhoods (chapter 5). For this population at least, this result severely limits the *a priori* scope for explanatory theories that centre on contextual or ecological influences in explaining behavioural variation, such as adaptive flexibility to environmental variation (5.1.1.1) or school or neighbourhood normative climates (Warner et al. 2011).

As a related practical implication, neighbourhoods and schools are not contexts where policy makers should expect to find major sources of influence on adolescent behaviour. The null clustering results reported here suggest that neighbourhood and school effects are very limited in this population (chapters 3-5), with the possible exception of school effects on academic achievement (chapter 5). This does not mean, however, that interventions cannot be effectively administered at these levels.

7.2.2 Scope for cultural transmission processes and preferential assortment on similarity

In addition to adaptive flexibility in response to socioecological variation, which appears to play little role in bringing about behavioural similarities in adolescent friends, I discussed two other evolutionary explanatory models that could potentially account for the similarity of friends: cultural transmission processes, in particular involving conformist or prestige bias (1.2.3), and preferential assortment based on similarity, which, theorists suggest, evolved to generate coordination benefits from similarity (1.2.4.2.2). While the results reported in these pages do not shed much further light on the question of social influence versus preferential assortment (although the personality results for sexual behaviour suggest a role for the latter), they do suggest that there is ample room for these processes to have occurred and produced the observed behavioural similarity of friends. Note that the 'preferential assortment based on coordination benefits hypothesis' operates at the ultimate level and is fully compatible with proximate ideas about similarity attraction (Byrne 1997). It is also

provides one possible evolutionary rationale for conformism (as pointed out by Koski & Burkart, 2015).

7.2.3 Similarity of friends likely reflects a non-specific clustering mechanism

The relative uniformity of social clustering patterns across behaviours suggests that a fairly non-specific clustering mechanism (or set of mechanisms) is at work, whether friends are influencing each other or forming ties based on similarity or possibly both. Based on parsimony considerations, very behaviour-specific explanations of friend-similarity should therefore be treated with suspicion (cf., Eiser, Morgan, Gammage, Brooks, & Kirby, 1991).

7.2.4 Future directions with regard to social clustering patterns

7.2.4.1 Clustering of cooperation

The empirical literature on clustering of cooperation is surprisingly sparse given its importance in evolutionary models of cooperation. With Chapter 4 I contribute to this literature, showing a modest degree of clustering of cooperativeness in adolescent friendship networks. In order to gain a better understanding of the mechanism(s) behind such clustering, it would be extremely useful to have detailed longitudinal social network data combined with longitudinal measures of cooperation dynamic changes in the network can be followed and linked to changes in measures of cooperation, which could include economic game behaviour, of the individuals in the networks. Are tie formation or dissolution predicted by individuals' cooperative behaviour? Does the cooperative behaviour of network ties predict individuals subsequent cooperative behaviour (adjusting for pre-existing behaviour). Advanced statistical techniques exist for this kind of work (Snijders et al. 2010) – the bottleneck is getting the right kind of data, which require significant effort to gather.

The adolescent school setting might be a very good place to perform such a study. From the start until the end of secondary school (= 'high school'), regular social network assessments (e.g., friendship networks) could be performed as well as longitudinal measures of cooperation collected (e.g., economic game behaviour, teacher assessments

of prosocial behaviour). Crucially, adolescents tend to form many, often most, of their friendships with school peers.

7.2.4.2 Empirical testing of coordination benefits of similarity

While it is not clear how one would test the coordination benefits hypothesis of friend similarities with the kind of data used in this thesis, this hypothesis does seem ripe for further testing in both humans and non-humans. Non-human friendship-forming species, such as chimpanzees or baboons, might provide better opportunities for linking the similarity of friendship dyads to fitness-relevant outcomes. In humans, coordination games experiments provide one possible approach to testing for coordination benefits of similarity (Chierchia & Coricelli 2015).

7.2.4.3 Taking the social clustering approach further

The approach taken in this thesis is still fairly unconventional, although the use of multiple classification models is increasing. Social clustering is seldom taken as a starting point for investigations into the sources of behavioural variation. However, as I have tried to illustrate in this thesis, it has much to recommend it.

With the use of statistical techniques for taking into account and quantifying social clustering at multiple (potentially) important social levels, one not only can avoid misattributing behavioural variation to sources at the wrong level, but can also get a picture of which social contexts might be important in understanding variation in a particular behavioural outcome, even before testing for associations between predictors and outcome. This immediately delimits the scope of different theories of behaviour, since different theories imply different patterns of social clustering; and can help one to avoid fruitless avenues of research (e.g., looking for neighbourhood effects for a behaviour that does not cluster in neighbourhoods). A particular pattern of social clustering can also suggest the need for new theory, if none of the existing ones is consistent with it. Once one has quantified social clustering, one can attempt to explain it and also quantify how well particular theories actually explain it.

Future research should therefore push this line or research further, by including more social classifications, such as country, school class and household, and more extensive

friendship networks, in multiple classification models. It should also include more predictors at all the various levels of the social structure.

7.3 Life history predictors and adolescence

7.3.1 Life history predicts are associated with sexual behaviour, cooperativeness and physical development but do not explain behavioural clustering

In chapter 3, I examined whether life history predictors could account for variation in experience with sexual intercourse by age 17.5 and for social clustering in this measure; in chapter 4, I did the same for a number of measures of cooperativeness. In both cases, it was found that life history predictors explained some of the behavioural variation, but did not explain the social clustering of these behaviours.

It would appear that, in this population, putative life history predictors, such as father absence or household socioeconomic deprivation, do not function as cues to a wider socioecological context, since friends would be expected to share such a context. This fits with the general lack of evidence for contextual effects mentioned above. This does not mean that evolutionary theories that posit such links (e.g., Draper & Harpending 1982; Belsky et al. 1991) are necessarily incorrect, since such links may have largely been broken in modern environments.

In chapter 6, I investigated the association between life history predictors and pubertal development in both girls and boys. The overall pattern of results supports the proposed link between childhood adversity and pubertal timing (1.3.3; 6.1.1), in both girls and boys. This thesis contributes to literature here by adding to the empirical literature on life history predictors and pubertal timing in boys, a relatively understudied topic.

7.3.2 Life history predictors show inconsistent associations with indicators of life history strategy

While, in general, putative life history predictors were associated with a faster life history pace, as judged by a higher probability of having had sex by ~17.5, a lower level of cooperativeness, and more advanced pubertal development at particular time points, the overall pattern of associations was quite messy. That is, the associations were fairly

inconsistent in terms of which indicators of life history strategy were associated with particular life history predictors. This was already highlighted for different measures of pubertal development (chapter 6), but is true for different measures of cooperativeness (chapter 4) and across chapters 3-6 as well. For instance, financial difficulties appears to be the most consistent life history predictor of pubertal development and cooperativeness, but did not predict sexual experience. The nature of these inconsistencies requires elucidation as they raise doubts about the existence of a unitary underlying process, as supposed by some life history models of adolescent development (e.g., childhood adversity -> fast life history strategy), or actually multiple processes.

7.3.2 Father absence predicts a faster life history pace according to multiple measures

The hypothesis that experiencing father absence during childhood switches individuals onto a generally faster life history trajectory (1.3.3; Figure 1) has received considerable empirical attention, particularly in the context of pubertal timing (6.1.2.2), and especially age at menarche (6.1.2.2.1). If this hypothesis is correct, then other elements of a fast life history strategy should also be more common in adolescents who grew up in father-absent households, and pubertal development of boys experiencing father absence would be expected to be accelerated as well. The results of the current thesis provide qualified support for the suggested general association between father absence and a fast life history strategy. Adolescents who experienced father absence during childhood were found to be more likely to have had sexual intercourse when they were ~17.5 years old (chapter 3), less cooperative (albeit only for 2 of 5 measures of cooperativeness; chapter 4), and to be experience earlier puberty, as judged by menarche and, possibly, breast development in girls and genital development in boys (chapter 6), all putative elements of a fast life history strategy. An important limitation to mention here is that I did not distinguish between different kinds of household structure, beyond father-present or father-absent (mothers were always present). I am therefore unable to distinguish between effects associated with parental versus father absence or the role of stepfathers (Sheppard et al. 2014).

7.3.3 Future directions with regard to life history predictors and adolescence

I will now discuss some of possible future directions that I think can advance the study of life history theoretical models as applied to adolescents in contemporary societies.

7.3.3.1 Dimensions of neighbourhood deprivation

In the empirical chapters, I repeatedly considered the question of whether neighbourhood deprivation, as a supposed measure of environmental harshness, predicted some aspect of a fast life history, reasoning that adolescents growing up in a harsher environment should, at a particular age, be more likely to have started having sex (Chapter 3), be less likely to cooperate (Chapter 4), and physically mature sooner (Chapter 6). Overall, little evidence was found for a clear, general deprivation effect on adolescent behaviour or physical development in line with predictions derived from life history theory. In each case, however, I used the Index of Multiple Deprivation devised by the Office for National Statistics of the UK government, which is made up for several subdomains (2.2.2), some of which might serve as better measures of or proxies for harshness than others. Theoretically, the health deprivation domain should arguably be the most powerful cue to local morbidity and mortality rates, the key factor according to many life history theorists. In future work, researcher should explore the impact of subdomains of the IMD, as well the combined measure itself, on indicators of life history pace.

7.3.3.2 Kinds of cooperation

In the chapter focused on cooperation, I effectively treated cooperativeness as a simple dispositional trait. However, from an evolutionary theoretical perspective, certain distinctions can be made that may affect one's predictions. For instance, cooperation with strangers may follow different rules than cooperation with familiar locals, since opportunities for reciprocation are far more likely for the latter. Thus, one should distinguish between cooperativeness as a behavioural disposition and cooperative relationships between specific individuals. Similarly, different kinds of cooperation exist in terms of the costs and benefits to the actor, viz., mutual benefit and altruism (West et al. 2007).

In Chapter 4, for example, I looked at cooperation with ALSPAC by attending the Teen Focus 4 clinic. Arguably, this does not benefit the adolescent respondent directly (no reward is involved) and concerns helping a stranger. By contrast, the prosociality scores will often be based on interactions with other children or adolescents who are well-known to the focus individual.

Future work might benefit from an explicit taxonomy of cooperative acts based on these and other evolutionary theoretical distinctions. A key goal would be to test whether different life history predictors associate differently with different kinds of cooperative acts. Does environmental harshness affect behaviour towards strangers and familiar others similarly? Or do have those inhabiting harsher environments have small and highly local but strong cooperation networks to buffer environmental risk, while being far warier of strangers? This work could be partly theory-driven, partly exploratory (possibly leading to new theory formation).

The type of secondary school-based study suggested above to look at the social network dynamics of cooperation (7.2.4.1) could be one way of approaching kind of study by including a range of different measures of cooperation that map onto the theoretical distinctions suggested by evolutionary theory as well as information on a range of life history predictors. This study, while very demanding from a design and data collection point of view, would be particularly strong because it also incorporates information about the cooperative behaviour of individuals in one's social network, which evolutionary theory suggests should be a key determinant of one's own cooperative behaviour.

7.3.3.3 Kinds of risk

A similar kind of suggestion can be made with regard to thinking about risk. In the evolutionary literature on adolescent behaviour, risk tends to be used in a fairly loose sense. The term is often used to signify something like societal norm-violating behaviour (what is sometimes referred to as deviant behaviour in the non-evolutionary literature). In many cases, the behaviour in question poses little risk in terms of physical harm or health (or ultimately evolutionary fitness). For example, cannabis use as such might be risky in the former sense but not, for many people, in the latter.

Making such distinctions and trying to incorporate them when designing studies of adolescent risk-taking may help advance our understanding of life history predictors of risk-taking behaviour. The study of such life history influences on risk *perceptions* is also a potentially fruitful avenue.

7.3.3.4 Life history predictors and male pubertal development

As emphasised in Chapter 6, when it comes to investigating predictions derived from life history as they apply to pubertal investment (1.4.4), boys are seriously understudied. Here I simply reiterate this point and suggest that researchers design longitudinal studies specifically aimed at this topic.

7.3.3.5 Differentiating between evolutionary models

As mentioned in the Discussion to Chapter 6 (on pubertal development), a range of evolutionary models exist that make similar predictions – e.g., that unfavourable childhood circumstances accelerate pubertal development – but for different reasons. Future studies could make explicit attempts to differentiate between these models by spelling out precise predictions of each and focusing not just on those predictions they share but especially on those they do not. For example, child development theory (Ellis 2004) does not predict other features of a fast life history, such as a less restricted socio-sexual orientation, to be independently associated with an earlier transition to physical adulthood (1.3.3.3), whereas most other evolutionary models do. In the same vein, it would be very interesting to *simultaneously* study the predictive power of environmental cues implicated by life history theorists versus actual measures of physical health, related to life expectancy, on individuals' sexual and reproductive behaviour and physical development. If the former predominate, this would provide support for external predictive adaptive response models; if, by contrast, health measures are clearly more predictive, this would strengthen the case for internal predictive response models (1.3.3.5).

7.3.3.6 Investigating inconsistent associations

The inconsistent associations between putative life history predictors and indicators of life history pace, highlighted above, need to be understood in order to be able to

properly assess the hypothesis that an unfavourable childhood environment in general leads to a fast life history strategy or that more specific processes are involved for different measures like sexual experience, cooperativeness, and pubertal timing. One approach would be to use sets of high-powered studies, conducted in as uniform a way as possible, to look at multiple putative life history traits and predictors in several independent samples from comparable populations (e.g., adolescents from industrial societies). If they reveal similar 'inconsistencies' – e.g., economic hardship reduces cooperativeness in all (or at least most) populations but is not associated with sexual experience – then this would add weight to the suggestion that we are not, in fact, dealing with a unitary underlying process.

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Appendix to chapter 2

A2.1 Summaries of deprivation indicators (IMD 2000)

The boxes below – reproduced from DETR publication 00HC0012/23: *Indices of deprivation 2000* – summarize the deprivation indicators used to create the Index of Multiple Deprivation 2000.

Geographical Access to Services: Summary of Indicators

- Access to a post office (General Post Office Counters) for April 1998
- Access to food shops (Data Consultancy) 1998
- Access to a GP (NHS, BMA, Scottish Health Service) for October 1997
- Access to a primary school (DfEE) for 1999

Employment Deprivation: Summary of Indicators

- Unemployment claimant counts (JUVOS, ONS) average of May 1998, August 1998, November 1998 and February 1999
- People out of work but in TEC delivered government supported training (DfEE)
- People aged 18-24 on New Deal options (ES)
- Incapacity Benefit recipients aged 16-59 (DSS) for 1998
- Severe Disablement Allowance claimants aged 16-59 (DSS) for 1999

Income Deprivation: Summary of Indicators

- Adults in Income Support households (DSS) for 1998
- Children in Income Support households (DSS) for 1998
- Adults in Income Based Job Seekers Allowance households (DSS) for 1998
- Children in Income Based Job Seekers Allowance households (DSS) for 1998
- Adults in Family Credit households (DSS) for 1999
- Children in Family Credit households (DSS) for 1999
- Adults in Disability Working Allowance households (DSS) for 1999
- Children in Disability Working Allowance households (DSS) for 1999
- Non-earning, non-IS pensioner and disabled Council Tax Benefit recipients (DSS) for 1998 apportioned to wards

Education, Skills and Training Deprivation: Summary of Indicators

- Working age adults with no qualifications (3 years aggregated LFS data at district level, modelled to ward level) for 1995-1998
- Children aged 16 and over who are not in full-time education (Child Benefit data – DSS) for 1999
- Proportions of 17-19 year old population who have not successfully applied for HE (UCAS data) for 1997 and 1998
- KS2 primary school performance data (DfEE, converted to ward level estimates) for 1998
- Primary school children with English as an additional language (DfEE) for 1998
- Absenteeism at primary level (all absences, not just unauthorised) (DfEE) for 1998

Health Deprivation and Disability: Summary of Indicators

- Comparative Mortality Ratios for men and women at ages under 65. District level figures for 1997 and 1998 applied to constituent wards (ONS)
- People receiving Attendance Allowance or Disability Living Allowance (DSS) in 1998 as a proportion of all people
- Proportion of people of working age (16-59) receiving Incapacity Benefit or Severe Disablement Allowance (DSS) for 1998 and 1999 respectively
- Age and sex standardized ratio of limiting long-term illness (1991 Census)
- Proportion of births of low birth weight (<2,500g) for 1993-97 (ONS)

Housing Deprivation: Summary of Indicators

- Homeless households in temporary accommodation (Local Authority HIP Returns) for 1997-98
- Household overcrowding (1991 Census)
- Poor private sector housing (modelled from 1996 English House Condition Survey and RESIDATA)

A2.2 International Personality Item Pool 50

The following version of the IPIP-50 was reproduced from http://ipip.ori.org/New_IPIP-50-item-scale.htm:

Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Indicate for each statement whether it is 1. Very Inaccurate, 2. Moderately Inaccurate, 3. Neither Accurate nor Inaccurate, 4. Moderately Accurate, or 5. Very Accurate as a description of you.

		Very Inaccurate	Moderately Inaccurate	Neither Accurate Nor Inaccurate	Moderately Accurate	Very Accurate	
1.	Am the life of the party.	O	O	O	O	O	(1+)
2.	Feel little concern for others.	O	O	O	O	O	(2-)
3.	Am always prepared.	O	O	O	O	O	(3+)
4.	Get stressed out easily.	O	O	O	O	O	(4-)
5.	Have a rich vocabulary.	O	O	O	O	O	(5+)
6.	Don't talk a lot.	O	O	O	O	O	(1-)
7.	Am interested in people.	O	O	O	O	O	(2+)
8.	Leave my belongings around.	O	O	O	O	O	(3-)
9.	Am relaxed most of the time.	O	O	O	O	O	(4+)
10.	Have difficulty understanding abstract ideas.	O	O	O	O	O	(5-)
11.	Feel comfortable around people.	O	O	O	O	O	(1+)
12.	Insult people.	O	O	O	O	O	(2-)
13.	Pay attention to details.	O	O	O	O	O	(3+)
14.	Worry about things.	O	O	O	O	O	(4-)
15.	Have a vivid imagination.	O	O	O	O	O	(5+)
16.	Keep in the background.	O	O	O	O	O	(1-)
17.	Sympathize with others' feelings.	O	O	O	O	O	(2+)
18.	Make a mess of things.	O	O	O	O	O	(3-)
19.	Seldom feel blue.	O	O	O	O	O	(4+)
20.	Am not interested in abstract ideas.	O	O	O	O	O	(5-)
21.	Start conversations.	O	O	O	O	O	(1+)
22.	Am not interested in other people's problems.	O	O	O	O	O	(2-)
23.	Get chores done right away.	O	O	O	O	O	(3+)
24.	Am easily disturbed.	O	O	O	O	O	(4-)
25.	Have excellent ideas.	O	O	O	O	O	(5+)
26.	Have little to say.	O	O	O	O	O	(1-)
27.	Have a soft heart.	O	O	O	O	O	(2+)
28.	Often forget to put things back in their proper place.	O	O	O	O	O	(3-)
29.	Get upset easily.	O	O	O	O	O	(4-)
30.	Do not have a good imagination.	O	O	O	O	O	(5-)
31.	Talk to a lot of different people at parties.	O	O	O	O	O	(1+)
32.	Am not really interested in others.	O	O	O	O	O	(2-)
33.	Like order.	O	O	O	O	O	(3+)
34.	Change my mood a lot.	O	O	O	O	O	(4-)
35.	Am quick to understand things.	O	O	O	O	O	(5+)
36.	Don't like to draw attention to myself.	O	O	O	O	O	(1-)
37.	Take time out for others.	O	O	O	O	O	(2+)
38.	Shirk my duties.	O	O	O	O	O	(3-)
39.	Have frequent mood swings.	O	O	O	O	O	(4-)
40.	Use difficult words.	O	O	O	O	O	(5+)
41.	Don't mind being the center of attention.	O	O	O	O	O	(1+)
42.	Feel others' emotions.	O	O	O	O	O	(2+)

43.	Follow a schedule.	O	O	O	O	O	(3+)
44.	Get irritated easily.	O	O	O	O	O	(4-)
45.	Spend time reflecting on things.	O	O	O	O	O	(5+)
46.	Am quiet around strangers.	O	O	O	O	O	(1-)
47.	Make people feel at ease.	O	O	O	O	O	(2+)
48.	Am exacting in my work.	O	O	O	O	O	(3+)
49.	Often feel blue.	O	O	O	O	O	(4-)
50.	Am full of ideas.	O	O	O	O	O	(5+)

The numbers in parentheses after each item indicate the scale on which that item is scored (i.e., of the five factors: (1) Extraversion, (2) Agreeableness, (3) Conscientiousness, (4) Emotional Stability, or (5) Intellect/Imagination) and its direction of scoring (+ or -).

Appendix to chapter 3

A3.1 Baseline characteristics of analysis vs. attrition sample

Table 78. Comparison of baseline characteristics for analysis and attrition sample

Variables	Units *or* categories	Analysis sample	Attrition sample	Test for difference
Maternal education	None/CSE	350 (12.4%)	2,089 (22.5%)	$X^2 = 180.6$, $p < 0.001$
	Vocational	230 (8.1%)	966 (10.4%)	
	O-levels	1,050 (37.2%)	3,135 (33.8%)	
	A-levels	745 (26.4%)	1,983 (21.4%)	
	Degree	451 (16.0%)	1,103 (11.9%)	
	Total	2,826	9,276	
Paternal education	None/CSE	509 (18.5%)	2,529 (28.5%)	$X^2 = 115.0$, $p < 0.001$
	Vocational	235 (8.5%)	750 (8.5%)	
	O-levels	640 (23.0%)	1,822 (20.5%)	
	A-levels	786 (28.5%)	2,247 (25.3%)	
	Degree	584 (21.0%)	1,526 (17.2%)	
	Total	2,754	8,874	
Home ownership (at pregnancy)	Mortgaged	2,357 (85.6%)	6,674 (70.3%)	$X^2 = 273.8$, $p < 0.001$
	Owned	61 (2.2%)	217 (2.3%)	
	Rented	337 (12.2%)	2,608 (27.5%)	
	Total	2,755	9,499	
Index of Multiple Deprivation (ward at birth)	Composite score	Median = 14.2; range = 3.9 – 66.8	18.3; range = 3.9 – 66.8	Median test: $X^2 = 273.8$, $p < 0.001$
	Total	2,696	10,048	
Maternal age at first pregnancy	Years	25.7 (4.8)	24.0 (5.0)	$t = 16.9$, $p < 0.001$
	Total	2,845	9,970	
Education (GCSE results): number of A or A* results	0	1,179 (41.0%)	5,764 (67.2%)	$X^2 = 682.7$, $p < 0.001$
	1	382 (13.3%)	830 (9.7%)	
	2	228 (8.0%)	421 (4.9%)	
	3	170 (5.9%)	290 (3.4%)	
	4-6	393 (14.0%)	634 (7.4%)	
	7-14	525 (18.0%)	637 (7.4%)	
	Total	2,877	8,576	

NB: The attrition sample consists of all individuals (singleton births) in the core ALSAC sample who were alive at 1 year but not included in the analysis sample.

A3.2 Pairwise correlations between study variables

Table 79. Pairwise correlations between study variables

Variable	1	2	3	4	5	6	7	8	9	10	11
1: Age	1.00										
2: Sex	0.02	1.00									
3: Maternal education	-0.05*	-0.04**	1.00								
4: Paternal education	-0.05**	-0.07***	0.52***	1.00							
5: Financial difficulties	0.04*	0.00	-0.17***	-0.22***	1.00						
6: Home ownership status	-0.05*	-0.02	0.20***	0.19***	-0.18***	1.00					
7: Mother had sex when aged <16	0.05*	0.02	-0.14***	-0.11***	0.11***	-0.12***	1.00				
8: Maternal age at first pregnancy	-0.07***	-0.04*	0.35***	0.31***	-0.15***	0.26***	-0.24***	1.00			
9: Maternal age at menarche	0.03	0.01	-0.03	-0.01	-0.02	0.04	-0.13*	0.04***	1.00		
10: Paternal age at index pregnancy	-0.06**	-0.05*	0.21***	0.20***	-0.04	0.18***	-0.10***	0.39***	0.02	1.00	
11: Female parental care	-0.01	0.04*	0.11***	0.09***	-0.04	0.02	-0.04	0.10***	-0.02	0.01	1.00
12: Male parental care	-0.02	-0.02	0.19***	0.19****	-0.11***	0.05**	-0.06**	0.17***	-0.02	0.00	0.33***
13: Father absence	0.03	0.03	-0.13***	-0.18***	0.26***	-0.24***	0.08***	-0.17***	0.00	-0.12***	0.00
14: IMD 2010	0.04*	0.03	-0.25***	-0.26****	0.20****	-0.30****	0.11***	-0.24***	-0.02	-0.12***	-0.08***
15: Extraversion	0.02	0.14***	-0.02	-0.03	0.00	-0.05*	0.02	-0.07***	0.02	-0.02	0.07***
16: Agreeableness	0.02	0.30***	0.13***	0.08***	-0.02	0.05*	-0.01	0.06**	0.02	0.07**	0.11***
17: Conscientiousness	-0.04	-0.08***	-0.05*	-0.02	-0.03	0.00	0.00	-0.01	0.01	-0.03	0.00
18: Emotional stability	-0.03	-0.25***	0.06**	0.06**	-0.07***	0.03	-0.06**	0.05*	0.02	0.02	0.04
19: Openness	-0.04	-0.06**	0.17***	0.17***	-0.02	0.05*	-0.02	0.13***	-0.01	0.12***	0.11***
20: Adolescent's education	-0.05**	0.07***	0.40***	0.38***	-0.15***	0.19***	-0.11***	0.28***	-0.01	0.18***	0.11***
21: Pubertal development	0.05*	-0.16***	-0.01	-0.02	0.01	-0.03	0.04	-0.02	-0.20***	-0.03	0.03
22: Adolescent had sex by TF4	0.12***	0.12***	-0.14***	-0.13***	0.05*	-0.09***	0.10***	-0.13***	-0.03	-0.07***	0.00
Variable	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
12: Male parental care	1.00										
13: Father absence	-0.14***	1.00									
14: IMD 2010	-0.11***	0.16***	1.00								
15: Extraversion	0.05*	0.02	0.01	1.00							
16: Agreeableness	0.05*	-0.05*	-0.06**	0.28***	1.00						
17: Conscientiousness	0.02	-0.05*	0.03	-0.02	0.18***	1.00					
18: Emotional stability	0.08***	-0.11***	-0.03	0.15***	0.01	0.29***	1.00				
19: Openness	0.10***	0.00	-0.05**	0.19***	0.40***	0.29***	0.07***	1.00			
20: Adolescent's education	0.15***	-0.15***	-0.24***	-0.03	0.22***	0.11***	0.05*	0.32***	1.00		
21: Pubertal development	-0.00	0.01	0.00	0.05*	0.06*	-0.05*	-0.09***	0.02	0.01	1.00	
22: Adolescent had sex by TF4	-0.02	0.10***	0.07***	0.28***	0.04	-0.12***	-0.08***	-0.03	-0.21***	0.13***	1.00

A3.3 Additional model output

Table 80. Full model (without adolescent's education) with an interaction between father absence and neighbourhood deprivation; unadjusted model for adolescent's education

	All predictors (apart from adolescent's education) + interaction between father absence and neighbourhood deprivation			Adolescent's education		
Parameter	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Age at Teen Focus 4	1.34	1.20 – 1.50	<0.001	1.35	1.21 – 1.49	<0.001
Sex	0.68	0.54 – 0.87	0.002	0.47	0.38 – 0.58	<0.001
Maternal education (ref.: none/CSE)						
Vocational	0.94	0.57 – 1.54	0.805			
O-level	0.83	0.57 – 1.23	0.355			
A-level	0.66	0.44 – 1.00	0.053			
Degree	0.50	0.31 – 0.81	0.005			
Paternal education (ref.: none/CSE)						
Vocational	0.81	0.51 – 1.27	0.353			
O-level	0.84	0.58 – 1.20	0.327			
A-level	0.78	0.55 – 1.11	0.166			
Degree	0.65	0.43 – 0.99	0.043			
Home ownership status (ref.: rented)						
Mortgaged	0.90	0.55 – 1.46	0.662			
Owned	0.77	0.40 – 1.48	0.438			
Financial difficulties (ref.: none)						
Some	1.03	0.81 – 1.31	0.811			
Many	0.92	0.64 – 1.34	0.680			
Maternal age at menarche	0.92	0.82 – 1.03	0.139			
Maternal age at first pregnancy	0.93	0.82 – 1.05	0.255			
Mother had sex when <16	1.63	1.17 – 2.28	0.005			
Paternal age at index pregnancy	0.99	0.88 – 1.12	0.902			
Maternal parenting score	0.99	0.89 – 1.11	0.925			
Paternal parenting score	1.07	0.95 – 1.21	0.266			
Father absence (ref.: present)	1.57	1.12 – 2.19	0.008			
Index of Multiple Deprivation 2010	1.06	0.93 – 1.21	0.360			
Father absence * IMD 2010	0.76	0.56 – 1.04	0.086			
Big Five personality dimensions						
Extraversion	2.18	1.90 – 2.50	<0.001			
Agreeableness	0.93	0.82 – 1.07	0.315			
Conscientiousness	0.77	0.67 – 0.89	<0.001			
Emotional stability	0.83	0.73 – 0.95	0.008			
Intellect and imagination	0.99	0.86 – 1.13	0.826			
GCSE results (ref.: no A or A*)						
One				0.65	0.48 – 0.88	0.002
Two				0.51	0.36 – 0.74	<0.001
Three				0.52	0.34 – 0.79	0.001
Four, five or six				0.40	0.30 – 0.54	<0.001
Seven or more				0.24	0.18 – 0.32	<0.001
	Variance	**Proportion of total variance**		**Variance**	**Proportion of total variance**	
Explained variance	1.135	0.201		0.499	0.104	
Residual variance	4.502	0.799		4.300	0.896	
School residual variance	0.069	0.012		0.040	0.008	
Neighbourhood residual variance	0.082	0.015		0.037	0.008	
Friends residual variance	1.061	0.188		0.933	0.194	
Individual residual variance	3.290	0.584		3.290	0.686	
Total variance	5.637	1		4.799	1.000	

Appendix to chapter 4

A4.1 Baseline characteristics of analysis vs. attrition sample

Table 81. Comparison of baseline characteristics for mother-rated prosocial score analysis and attrition sample

Variables	Units or categories	Analysis sample	Attrition sample	Test for difference
Maternal education	None/CSE	449 (11.8%)	1,990 (24.0%)	$X^2 = 273.9$, $p < 0.001$
	Vocational	332 (8.8%)	864 (10.4%)	
	O-levels	1,440 (37.9%)	2,745 (33.1%)	
	A-levels	1,009 (26.6%)	1,719 (20.7%)	
	Degree	566 (14.9%)	988 (11.9%)	
	Total	3,796	8,306	
Paternal education	None/CSE	711 (19.2%)	2,327 (29.4%)	$X^2 = 138.4$, $p < 0.001$
	Vocational	323 (8.7%)	662 (8.4%)	
	O-levels	857 (23.1%)	1,605 (20.3%)	
	A-levels	1,086 (29.3%)	1,947 (24.6%)	
	Degree	726 (19.6%)	1,384 (17.5%)	
	Total	3,703	7,925	
Home ownership (at pregnancy)	Mortgaged	3,195 (86.1%)	5,836 (68.3%)	$X^2 = 436.6$, $p < 0.001$
	Owned	71 (1.9%)	207 (2.4%)	
	Rented	444 (12.0%)	2,501 (29.3%)	
	Total	3,710	8,544	
Index of Multiple Deprivation (ward at birth)	Composite score	Median = 13.8; range = 3.9 – 66.8	18.3; range = 3.9 – 66.8	Median test: $X^2 = 230.2$, $p < 0.001$
	Total	3,614	7,868	
Maternal age at first pregnancy	Years	25.7 (SD = 4.7)	23.8 (SD = 5.0)	$t = -20.1$, $p < 0.001$
	Total	3,837	8,978	

NB: The attrition sample consists of all individuals (singleton births) in the core ALSAC sample who were alive at 1 year but not included in the analysis sample.

A4.2 Descriptive statistics and pairwise correlations

A4.2.1 Returned 'You and Your Friends' questionnaire

Table 82. Descriptive statistics for variables used in returning friendship network questionnaire model

			All	Cooperated	Did not cooperate
Variables	**n (% of sample)**	**Units *or* categories**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**
Returned questionnaire	5,588 (100%)	No	3,408 (61.0%)	0 (0.0%)	3,408 (100%)
		Yes	2,180 (39.0%)	2,180 (100%)	0 (0.0%)
Sex	5,588 (100%)	Male	2,739 (49.0%)	799 (29.2%)	1,940 (70.8%)
		Female	2,849 (51.0%)	1,381 (48.5%)	1,468 (51.5%)
Maternal education	5,259 (94.1%)	None/CSE	967 (18.4%)	275 (12.9%)	692 (22.1%)
		Vocational	532 (10.1%)	166 (7.8%)	366 (11.7%)
		O-levels	1,973 (37.5%)	804 (37.8%)	1,169 (37.4%)
		A-levels	1,219 (23.2%)	553 (26.0%)	666 (21.3%)
		Degree	568 (10.8%)	331 (15.6%)	237 (7.6%)
Paternal education	5,067 (90.7%)	None/CSE	1,285 (25.4%)	415 (20.1%)	870 (29.0%)
		Vocational	467 (9.2%)	176 (8.5%)	291 (9.7%)
		O-levels	1,159 (22.9%)	444 (21.5%)	715 (23.8%)
		A-levels	1,382 (27.3%)	602 (29.1%)	780 (26.0%)
		Degree	774 (15.3%)	431 (20.8%)	343 (11.4%)
Financial difficulties	4,217 (75.5%)	None	2,008 (47.6%)	990 (51.6%)	1,018 (44.3%)
		Some	1,662 (39.4%)	735 (38.3%)	927 (40.3%)
		Many	547 (13.0%)	192 (10.0%)	355 (15.4%)
Home ownership status	4,101 (73.4%)	Rented	495 (12.1%)	164 (8.6%)	331 (15.1%)
		Mortgaged	3,361 (82.0%)	1,618 (85.1%)	1,743 (79.3%)
		Owned	245 (6.0%)	120 (6.3%)	125 (5.7%)
Mother had sex with boyfriend when <16	4,645 (83.1%)	No	3,838 (82.6%)	1,637 (84.6%)	2,201 (81.2%)
		Yes	807 (17.4%)	298 (15.4%)	509 (18.8%)
Maternal age at first pregnancy	5,419 (97.0%)	Years	24.7 (4.8); range = 13 – 44	25.8 (4.8)	24.1 (4.7)
Maternal age at menarche	4,712 (84.3%)	Years	12.9 (1.5); range = 8 – 19	12.9 (1.5)	12.9 (1.5)
Paternal age at index pregnancy	4,969 (88.9%)	Years	30.9 (5.6); range = 15 – 60	31.6 (5.6)	30.4 (5.6)
Father absence at 10 years	4,595 (82.2%)	Present	3,567 (77.6%)	1,643 (82.9%)	1,924 (73.6%)
		Absent	1,028 (22.4%)	339 (17.1%)	689 (26.4%)
Index of Multiple Deprivation	5,588 (100%)	Composite score	16.1 (13.3); range = 1.4 – 70.4	13.6 (11.5)	17.7 (14.1)
Extraversion	3,277 (58.6%)	IPIP score	35.5 (6.7)	35.2 (6.8)	35.7 (6.6)
Agreeableness	3,213 (57.5%)	IPIP score	37.8 (5.1)	38.4 (5.0)	37.1 (5.1)
Conscientiousness	3,119 (55.8%)	IPIP score	31.9 (5.7)	32.3 (5.7)	31.5 (5.7)
Emotional stability	3,163 (56.6%)	IPIP score	31.5 (6.5)	31.6 (6.5)	31.4 (6.5)
Openness	3,197 (57.2%)	IPIP score	35.8 (5.6)	36.1 (5.7)	35.5 (5.5)
Mother returned G	5,588 (100%)	No	815 (14.6%)	175 (8.0%)	640 (18.8%)
		Yes	4,773 (85.4%)	2,005 (92.0%)	2,768 (81.2%)
Mother returned L	5,588 (100%)	No	1,282 (22.9%)	263 (12.1%)	1,019 (29.9%)
		Yes	4,306 (77.1%)	1,917 (87.9%)	2,389 (70.1%)
Mother returned S	5,588 (100%)	No	1,858 (33.3%)	347 (15.9%)	1,511 (44.3%)
		Yes	3,730 (66.8%)	1,833 (84.1%)	1,897 (55.7%)
Mother returned TA	5,588 (100%)	No	1,741 (31.2%)	275 (12.6%)	1,466 (43.0%)
		Yes	3,847 (68.8%)	1,905 (87.4%)	1,942 (57.0%)
Mother returned TC	5,588 (100%)	No	2,553 (45.7%)	429 (19.7%)	2,124 (62.3%)
		Yes	3,035 (54.3%)	1,751 (80.3%)	1,284 (37.7%)
Friend cooperation: times nominated as friend	5,588 (100%)	Not nominated	3,165 (56.6%)	1,024 (47.0%)	2,141 (62.8%)
		Once	1,447 (25.9%)	612 (28.1%)	835 (24.5%)
		Twice	646 (11.6%)	341 (15.6%)	305 (9.0%)
		Three or more	330 (5.9%)	203 (9.3%)	127 (3.7%)

Table 83. Pairwise correlations between variables used in returning friends questionnaire model

	return~e	sex	matedu	patedu	FDiff85	HomeQ_~d	mumse~16
returned_F~e	1.0000						
sex	-0.1978	1.0000					
	0.0000						
matedu	0.1720	0.0084	1.0000				
	0.0000	0.5423					
patedu	0.1428	0.0210	0.5276	1.0000			
	0.0000	0.1355	0.0000				
FDiff85	-0.0914	0.0093	-0.1696	-0.1980	1.0000		
	0.0000	0.5461	0.0000	0.0000			
HomeQ_ref_~d	0.0837	0.0174	0.2119	0.2150	-0.2022	1.0000	
	0.0000	0.2646	0.0000	0.0000	0.0000		
mumsexU16	-0.0440	-0.0166	-0.1205	-0.1033	0.1066	-0.1119	1.0000
	0.0027	0.2567	0.0000	0.0000	0.0000	0.0000	
matfirstpreg	0.1735	0.0114	0.3555	0.3251	-0.1970	0.2825	-0.2868
	0.0000	0.4031	0.0000	0.0000	0.0000	0.0000	0.0000
matmenarche	-0.0011	0.0067	-0.0548	-0.0297	-0.0115	0.0284	-0.1429
	0.9388	0.6457	0.0002	0.0488	0.4845	0.0909	0.0000
patagepreg	0.1016	0.0314	0.1888	0.2028	-0.0633	0.2109	-0.1429
	0.0000	0.0268	0.0000	0.0000	0.0001	0.0000	0.0000
biodaddi~10y	-0.1101	-0.0207	-0.1180	-0.1640	0.2770	-0.2904	0.1047
	0.0000	0.1605	0.0000	0.0000	0.0000	0.0000	0.0000
logimd201~08	-0.1495	-0.0222	-0.2747	-0.2963	0.1919	-0.2744	0.1074
	0.0000	0.0977	0.0000	0.0000	0.0000	0.0000	0.0000
Extraversi~G	-0.0324	-0.1117	-0.0155	-0.0150	-0.0130	-0.0338	0.0393
	0.0635	0.0000	0.3840	0.4040	0.4903	0.0715	0.0365
Agreeablen~G	0.1246	-0.3090	0.1392	0.1286	-0.0234	0.0588	-0.0249
	0.0000	0.0000	0.0000	0.0000	0.2173	0.0019	0.1908
Conscienti~G	0.0708	0.0811	-0.0182	0.0238	-0.0280	0.0135	-0.0229
	0.0001	0.0000	0.3185	0.1967	0.1455	0.4845	0.2350
EmotionalS~G	0.0188	0.2593	0.0642	0.0726	-0.0809	0.0530	-0.0749
	0.2904	0.0000	0.0004	0.0001	0.0000	0.0056	0.0001
IntellectI~G	0.0507	0.0499	0.1754	0.1972	-0.0306	0.0571	-0.0211
	0.0041	0.0048	0.0000	0.0000	0.1072	0.0027	0.2665
mumG	0.1486	0.0167	0.1426	0.1027	-0.0440	0.0930	-0.0230
	0.0000	0.2116	0.0000	0.0000	0.0043	0.0000	0.1170
mumL	0.2069	0.0199	0.1762	0.1366	-0.0135	0.1407	-0.0582
	0.0000	0.1368	0.0000	0.0000	0.3806	0.0000	0.0001
mumS	0.2942	0.0028	0.1923	0.1602	-0.0622	0.0808	-0.0658
	0.0000	0.8330	0.0000	0.0000	0.0001	0.0000	0.0000
mumTA	0.3202	-0.0098	0.1917	0.1521	-0.0403	0.0613	-0.0432
	0.0000	0.4654	0.0000	0.0000	0.0088	0.0001	0.0032
mumTC	0.4176	-0.0371	0.2547	0.2148	-0.0820	0.1619	-0.0845
	0.0000	0.0055	0.0000	0.0000	0.0000	0.0000	0.0000
howoftenno~t	0.1830	-0.1684	0.1662	0.1579	-0.0745	0.1116	-0.0438
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029

	matfi~eg	matmen~e	patag~eg	biod~10y	logim~08	Extrav~G	Agreea~G
matfirstpreg	1.0000						
matmenarche	0.0644	1.0000					
	0.0000						
patagepreg	0.3624	0.0207	1.0000				
	0.0000	0.1678					
biodaddi~10y	-0.2148	-0.0002	-0.1338	1.0000			
	0.0000	0.9889	0.0000				
logimd201~08	-0.2840	-0.0077	-0.1376	0.1729	1.0000		
	0.0000	0.5992	0.0000	0.0000			
Extraversi~G	-0.0420	0.0109	-0.0174	0.0326	-0.0132	1.0000	
	0.0172	0.5617	0.3391	0.0753	0.4487		
Agreeablen~G	0.0919	-0.0144	0.0989	-0.0381	-0.0734	0.2401	1.0000
	0.0000	0.4494	0.0000	0.0397	0.0000	0.0000	
Conscienti~G	0.0345	0.0026	-0.0037	-0.0409	0.0203	-0.0137	0.1962
	0.0560	0.8939	0.8420	0.0297	0.2567	0.4478	0.0000
EmotionalS~G	0.0708	0.0090	0.0233	-0.0842	-0.0604	0.1721	-0.0050
	0.0001	0.6392	0.2086	0.0000	0.0007	0.0000	0.7801
IntellectI~G	0.1237	-0.0177	0.1090	0.0024	-0.0515	0.1426	0.4302
	0.0000	0.3513	0.0000	0.8959	0.0036	0.0000	0.0000
mumG	0.1463	-0.0091	0.0950	-0.0705	-0.1269	-0.0258	0.0081
	0.0000	0.5342	0.0000	0.0000	0.0000	0.1395	0.6463
mumL	0.1774	-0.0012	0.0935	-0.1223	-0.1461	-0.0108	0.0391
	0.0000	0.9358	0.0000	0.0000	0.0000	0.5359	0.0268
mumS	0.2114	0.0368	0.1144	-0.1121	-0.1553	-0.0172	0.0496
	0.0000	0.0115	0.0000	0.0000	0.0000	0.3262	0.0049
mumTA	0.1967	0.0046	0.1009	-0.1009	-0.1486	-0.0282	0.0363
	0.0000	0.7514	0.0000	0.0000	0.0000	0.1059	0.0394
mumTC	0.2377	-0.0109	0.1387	-0.1413	-0.1984	-0.0494	0.0728
	0.0000	0.4560	0.0000	0.0000	0.0000	0.0047	0.0000
howoftenno~t	0.1397	-0.0398	0.0638	-0.1015	-0.1483	0.0343	0.1667
	0.0000	0.0063	0.0000	0.0000	0.0000	0.0494	0.0000

	Consci~G	Emotio~G	Intell~G	mumG	mumL	mumS	mumTA
Conscienti~G	1.0000						
EmotionalS~G	0.2811	1.0000					
	0.0000						
IntellectI~G	0.3291	0.0471	1.0000				
	0.0000	0.0089					
mumG	-0.0018	-0.0072	0.0137	1.0000			
	0.9180	0.6843	0.4392				
mumL	-0.0215	0.0071	0.0527	0.4245	1.0000		
	0.2293	0.6909	0.0029	0.0000			
mumS	0.0361	0.0613	0.0276	0.3283	0.4415	1.0000	
	0.0439	0.0006	0.1181	0.0000	0.0000		
mumTA	0.0303	0.0569	0.0493	0.3033	0.4168	0.6284	1.0000
	0.0904	0.0014	0.0053	0.0000	0.0000	0.0000	
mumTC	0.0468	0.0547	0.0726	0.2806	0.3745	0.5385	0.5504
	0.0090	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000
howoftenno~t	0.0507	0.0071	0.0817	0.0908	0.1021	0.1280	0.1233
	0.0046	0.6893	0.0000	0.0000	0.0000	0.0000	0.0000

	mumTC	howoft~t
mumTC	1.0000	
howoftenno~t	0.1642	1.0000
	0.0000	

A4.2.2 Attended Teen Focus 4

Table 84. Descriptive statistics for variables used in attending Teen Focus 4 model

			All	Cooperated	Did not cooperate
Variables	**n (% of sample)**	**Units *or* categories**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**
Attended Teen Focus 4	5,012 (100%)	No	2,190 (43.7%)	0 (0%)	2,190 (100%)
		Yes	2,822 (56.3%)	2,822 (100%)	0 (0%)
Sex	5,012 (100%)	Male	2,443 (48.7%)	1,214 (43.0%)	1,229 (56.1%)
		Female	2,569 (51.3%)	1,608 (57.0%)	961 (43.9%)
Maternal education	4,731 (94.4%)	None/CSE	799 (16.9%)	340 (12.4%)	459 (23.0%)
		Vocational	479 (10.1%)	222 (8.1%)	257 (12.9%)
		O-levels	1,773 (37.5%)	1,008 (36.8%)	765 (38.4%)
		A-levels	1,137 (24.0%)	741 (27.1%)	396 (19.9%)
		Degree	543 (11.5%)	425 (15.5%)	118 (5.9%)
Paternal education	4,560 (91.0%)	None/CSE	1,110 (24.3%)	510 (19.2%)	600 (31.6%)
		Vocational	426 (9.3%)	241 (9.1%)	185 (9.7%)
		O-levels	1,035 (22.7%)	578 (21.7%)	457 (24.1%)
		A-levels	1,251 (27.4%)	769 (28.9%)	482 (25.4%)
		Degree	738 (16.2%)	563 (21.2%)	175 (9.2%)
Financial difficulties	3,869 (77.2%)	None	1,851 (47.8%)	1,233 (50.3%)	628 (43.7%)
		Some	1,518 (39.2%)	933 (38.4%)	585 (40.7%)
		Many	500 (12.9%)	275 (11.3%)	225 (15.6%)
Home ownership status	3,793 (75.7%)	Rented	444 (11.7%)	222 (16.0%)	222 (9.2%)
		Mortgaged	3,123 (82.3%)	1,095 (79.0%)	2,028 (84.3%)
		Owned	226 (6.0%)	70 (5.1%)	156 (6.5%)
Mother had sex with boyfriend when <16	4,192	No	3,475 (82.9%)	2,069 (84.9%)	1,406 (80.2%)
		Yes	717 (17.1%)	369 (15.1%)	348 (19.8%)
Maternal age at first pregnancy	4,866 (97.1%)	Years	24.9 (4.8); range = 13 – 44	25.7 (4.8)	23.7 (4.6)
Maternal age at menarche	4,250 (84.8%)	Years	12.9 (1.5) ; range = 8 – 19	12.8 (1.5)	12.9 (1.6)
Paternal age at index pregnancy	4,468 (89.1%)	Years	30.9 (5.6) ; range = 15 – 60	31.5 (5.5)	30.1 (5.6)
Father absence at 10 years	4,189 (83.6%)	Present	3,262 (77.9%)	2,099 (82.6%)	1,163 (70.6%)
		Absent	927 (22.1%)	442 (17.4%)	485 (29.4%)
Index of Multiple Deprivation	5,012 (100%)	Composite score	16.0 (13.2); range = 1.4 – 70.4	14.3 (11.8)	18.1 (14.5)
Extraversion	3,240 (64.6%)	IPIP score	35.4 (6.7); range = 10 – 50	35.4 (6.9)	35.7 (6.4)
Agreeableness	3,174 (63.3%)	IPIP score	37.8 (5.1); range = 15 – 50	38.2 (5.0)	36.8 (5.3)
Conscientiousness	3,082 (61.5%)	IPIP score	31.9 (5.7) ; range = 10 – 50	32.0 (5.7)	31.8 (5.7)
Emotional stability	3,125 (62.4%)	IPIP score	31.5 (6.5) ; range = 10 – 49	31.6 (6.5)	31.4 (6.5)
Openness	3,160 (63.0%)	IPIP score	35.8 (5.6) ; range = 15 – 50	36.1 (5.6)	35.0 (5.6)
Mother returned G	5,012 (100%)	No	698 (13.9%)	263 (9.3%)	435 (19.9%)
		Yes	4,314 (86.1%)	2,559 (90.67%)	1,755 (80.1%)
Mother returned L	5,012 (100%)	No	1,096 (21.9%)	404 (14.3%)	692 (31.6%)
		Yes	3,916 (78.1%)	2,418 (85.7%)	1,498 (68.4%)
Mother returned S	5,012 (100%)	No	1,523 (30.4%)	537 (19.0%)	986 (45.0%)
		Yes	3,489 (69.6%)	2,285 (81.0%)	1,204 (55.0%)
Mother returned TA	5,012 (100%)	No	1,411 (28.2%)	465 (16.5%)	946 (43.2%)
		Yes	3,601 (71.9%)	2,357 (83.5%)	1,244 (56.8%)
Mother returned TC	5,012 (100%)	No	2,098 (41.9%)	691 (24.5%)	1,407 (64.3%)
		Yes	2,914 (58.1%)	2,131 (75.5%)	783 (35.8%)
Friend cooperation: times nominated as friend	5,012 (100%)	Not nominated	2,787 (55.6%)	1,386 (49.1%)	1,401 (640%)
		Once	1,310 (26.1%)	788 (27.9%)	522 (23.8%)
		Twice	605 (12.1%)	415 (14.7%)	190 (8.7%)
		Three or more	310 (6.2%)	233 (8.3%)	77 (3.5%)

Table 85. Pairwise correlations between variables used in attending Teen Focus 4 model

	attend~4	sex	matedu	patedu	FDiff85	HomeQ_~d	mumse~16
attendedtf4	1.0000						
sex	-0.1300	1.0000					
	0.0000						
matedu	0.2130	0.0049	1.0000				
	0.0000	0.7337					
patedu	0.1851	0.0245	0.5267	1.0000			
	0.0000	0.0977	0.0000				
FDiff85	-0.0761	0.0043	-0.1651	-0.1984	1.0000		
	0.0000	0.7873	0.0000	0.0000			
HomeQ_ref_~d	0.0950	0.0186	0.2203	0.2203	-0.1975	1.0000	
	0.0000	0.2525	0.0000	0.0000	0.0000		
mumsexU16	-0.0616	-0.0142	-0.1227	-0.1010	0.1011	-0.1067	1.0000
	0.0001	0.3576	0.0000	0.0000	0.0000	0.0000	
matfirstpreg	0.2089	0.0116	0.3576	0.3313	-0.1865	0.2830	-0.2788
	0.0000	0.4204	0.0000	0.0000	0.0000	0.0000	0.0000
matmenarche	-0.0130	0.0029	-0.0525	-0.0204	-0.0071	0.0283	-0.1383
	0.3980	0.8478	0.0007	0.1967	0.6808	0.1036	0.0000
patagepreg	0.1219	0.0338	0.1978	0.2075	-0.0647	0.2096	-0.1366
	0.0000	0.0237	0.0000	0.0000	0.0001	0.0000	0.0000
biodaddi~10y	-0.1416	-0.0172	-0.1185	-0.1664	0.2719	-0.2892	0.0977
	0.0000	0.2645	0.0000	0.0000	0.0000	0.0000	0.0000
logimd201~08	-0.1366	-0.0291	-0.2663	-0.2926	0.1814	-0.2698	0.1049
	0.0000	0.0391	0.0000	0.0000	0.0000	0.0000	0.0000
Extraversi~G	-0.0208	-0.1123	-0.0132	-0.0119	-0.0158	-0.0329	0.0405
	0.2357	0.0000	0.4601	0.5105	0.4023	0.0812	0.0320
Agreeablen~G	0.1231	-0.3083	0.1385	0.1295	-0.0243	0.0593	-0.0260
	0.0000	0.0000	0.0000	0.0000	0.2021	0.0019	0.1732
Conscienti~G	0.0168	0.0796	-0.0208	0.0233	-0.0271	0.0108	-0.0234
	0.3517	0.0000	0.2569	0.2098	0.1614	0.5770	0.2263
EmotionalS~G	0.0083	0.2573	0.0641	0.0734	-0.0811	0.0499	-0.0731
	0.6412	0.0000	0.0004	0.0001	0.0000	0.0094	0.0001
IntellectI~G	0.0904	0.0516	0.1720	0.1944	-0.0299	0.0567	-0.0214
	0.0000	0.0037	0.0000	0.0000	0.1178	0.0030	0.2626
mumG	0.1510	0.0245	0.1371	0.1030	-0.0496	0.0905	-0.0289
	0.0000	0.0832	0.0000	0.0000	0.0020	0.0000	0.0610
mumL	0.2074	0.0195	0.1702	0.1321	-0.0075	0.1334	-0.0640
	0.0000	0.1668	0.0000	0.0000	0.6406	0.0000	0.0000
mumS	0.2803	0.0046	0.1788	0.1570	-0.0633	0.0724	-0.0663
	0.0000	0.7421	0.0000	0.0000	0.0001	0.0000	0.0000
mumTA	0.2947	-0.0091	0.1769	0.1396	-0.0386	0.0661	-0.0378
	0.0000	0.5202	0.0000	0.0000	0.0164	0.0000	0.0143
mumTC	0.3998	-0.0343	0.2441	0.2107	-0.0808	0.1563	-0.0878
	0.0000	0.0152	0.0000	0.0000	0.0000	0.0000	0.0000
howoftenno~t	0.1656	-0.1675	0.1634	0.1508	-0.0770	0.1092	-0.0405
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0087

	matfi~eg	matmen~e	patag~eg	biod~10y	logim~08	Extrav~G	Agreea~G
matfirstpreg	1.0000						
matmenarche	0.0630 0.0000	1.0000					
patagepreg	0.3700 0.0000	0.0314 0.0476	1.0000				
biodaddi~10y	-0.2131 0.0000	-0.0044 0.7886	-0.1306 0.0000	1.0000			
logimd201~08	-0.2812 0.0000	-0.0033 0.8316	-0.1335 0.0000	0.1725 0.0000	1.0000		
Extraversi~G	-0.0416 0.0188	0.0135 0.4754	-0.0179 0.3274	0.0315 0.0875	-0.0167 0.3425	1.0000	
Agreeablen~G	0.0911 0.0000	-0.0123 0.5211	0.0993 0.0000	-0.0412 0.0268	-0.0749 0.0000	0.2401 0.0000	1.0000
Conscienti~G	0.0348 0.0556	0.0070 0.7163	-0.0054 0.7723	-0.0404 0.0326	0.0213 0.2377	-0.0138 0.4462	0.1966 0.0000
EmotionalS~G	0.0703 0.0001	0.0085 0.6584	0.0229 0.2189	-0.0865 0.0000	-0.0602 0.0008	0.1692 0.0000	-0.0064 0.7251
IntellectI~G	0.1228 0.0000	-0.0152 0.4275	0.1086 0.0000	0.0013 0.9440	-0.0489 0.0059	0.1424 0.0000	0.4308 0.0000
mumG	0.1503 0.0000	-0.0149 0.3319	0.0965 0.0000	-0.0758 0.0000	-0.1277 0.0000	-0.0267 0.1285	0.0115 0.5174
mumL	0.1852 0.0000	-0.0051 0.7413	0.0884 0.0000	-0.1150 0.0000	-0.1414 0.0000	-0.0088 0.6177	0.0390 0.0281
mumS	0.2088 0.0000	0.0368 0.0165	0.1066 0.0000	-0.1130 0.0000	-0.1540 0.0000	-0.0178 0.3104	0.0513 0.0038
mumTA	0.1952 0.0000	0.0003 0.9819	0.0949 0.0000	-0.1095 0.0000	-0.1446 0.0000	-0.0279 0.1127	0.0389 0.0285
mumTC	0.2394 0.0000	-0.0145 0.3460	0.1412 0.0000	-0.1387 0.0000	-0.1996 0.0000	-0.0456 0.0094	0.0734 0.0000
howoftenno~t	0.1364 0.0000	-0.0315 0.0398	0.0637 0.0000	-0.1024 0.0000	-0.1446 0.0000	0.0368 0.0363	0.1675 0.0000

	Consci~G	Emotio~G	Intell~G	mumG	mumL	mumS	mumTA
Conscienti~G	1.0000						
EmotionalS~G	0.2817	1.0000					
	0.0000						
IntellectI~G	0.3295	0.0455	1.0000				
	0.0000	0.0120					
mumG	-0.0018	-0.0074	0.0132	1.0000			
	0.9198	0.6790	0.4599				
mumL	-0.0231	0.0090	0.0550	0.4257	1.0000		
	0.2003	0.6166	0.0020	0.0000			
mumS	0.0379	0.0637	0.0318	0.3307	0.4460	1.0000	
	0.0353	0.0004	0.0742	0.0000	0.0000		
mumTA	0.0313	0.0574	0.0512	0.3043	0.4244	0.6118	1.0000
	0.0819	0.0013	0.0040	0.0000	0.0000	0.0000	
mumTC	0.0452	0.0542	0.0732	0.2848	0.3857	0.5245	0.5345
	0.0121	0.0025	0.0000	0.0000	0.0000	0.0000	0.0000
howoftenno~t	0.0491	0.0068	0.0818	0.0884	0.1005	0.1261	0.1167
	0.0064	0.7034	0.0000	0.0000	0.0000	0.0000	0.0000

	mumTC	howoft~t
mumTC	1.0000	
howoftenno~t	0.1531	1.0000
	0.0000	

A4.2.3 Teacher-rated prosociality

Table 86. Descriptive statistics for variables used in teacher-rated prosocial score model

			All	Cooperated	Did not cooperate
Variables	**n (% of sample)**	**Units *or* categories**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**
Teacher-rated prosocial score	4,837 (100%)	Low	1,927 (39.8%)	0 (0%)	1,927 (100%)
		High	2,910 (60.2%)	2,910 (100%)	0 (0%)
Sex	4,837 (100%)	Male	2,445 (50.6%)	1,196 (41.1%)	1,249 (64.8%)
		Female	2,392 (49.5%)	1,714 (58.9%)	678 (35.2%)
Maternal education	4,325 (89.4%)	None/CSE	925 (21.4%)	519 (19.6%)	406 (24.2%)
		Vocational	459 (10.6%)	266 (10.0%)	193 (11.5%)
		O-levels	1,603 (37.1%)	1,018 (38.4%)	585 (34.9%)
		A-levels	940 (21.7%)	601 (22.7%)	339 (20.2%)
		Degree	398 (9.2%)	245 (9.3%)	153 (9.1%)
Paternal education	4,156 (85.9%)	None/CSE	1,154 (27.8%)	662 (25.8%)	492 (30.9%)
		Vocational	395 (9.5%)	252 (9.8%)	143 (9.0%)
		O-levels	921 (22.2%)	595 (23.2%)	326 (20.5%)
		A-levels	1,094 (26.3%)	689 (26.9%)	405 (25.4%)
		Degree	592 (14.2%)	365 (14.2%)	227 (14.3%)
Financial difficulties	2,989 (61.8%)	None	1,462 (48.9%)	961 (50.9%)	501 (45.6%)
		Some	1,144 (38.3%)	713 (37.7%)	431 (39.2%)
		Many	383 (12.8%)	216 (11.4%)	167 (15.2%)
Home ownership status	2,782 (57.5%)	Rented	288 (10.4%)	148 (8.5%)	140 (13.5%)
		Mortgaged	2,331 (83.8%)	1,493 (85.7%)	838 (80.7%)
		Owned	163 (5.9%)	102 (5.9%)	61 (5.9%)
Mother had sex with boyfriend when <16	3,709 (76.7%)	No	3,053 (82.3%)	1,889 (82.9%)	1,164 (81.3%)
		Yes	656 (17.7%)	389 (17.1%)	267 (18.7%)
Maternal age at first pregnancy	4,578 (94.6%)	Years	24.4 (4.8); range = 13 – 42	24.7 (4.6)	24.0 (5.0)
Maternal age at menarche	3,828 (79.1%)	Years	12.8 (1.5); range = 8 – 22	12.9 (1.5)	12.8 (1.6)
Paternal age at index pregnancy	4,074 (84.2%)	Years	30.5 (5.5); range = 16 – 60	30.5 (5.3)	30.5 (5.9)
Father absence at 10 years	3,341 (69.1%)	Present	2,595 (77.7%)	1,681 (80.5%)	914 (73.0%)
		Absent	746 (22.3%)	408 (19.5%)	338 (27.0%)
Index of Multiple Deprivation	4,837 (100%)	Composite score	16.2 (14.0); range = 1.4 – 70.4	15.5 (13.2)	17.4 (14.9)
Extraversion	2,082 (43.0%)	IPIP score	35.2 (6.8); range = 11 – 50	35.4 (6.9)	34.9 (6.7)
Agreeableness	2,039 (42.2%)	IPIP score	37.7 (5.2); range = 19 – 50	38.3 (5.1)	36.6 (5.2)
Conscientiousness	1,991 (41.2%)	IPIP score	32.0 (5.7); range = 13 – 50	32.0 (5.8)	31.9 (5.5)
Emotional stability	2,019 (41.7%)	IPIP score	31.7 (6.4); range = 12 – 48	31.7 (6.4)	31.6 (6.3)
Openness	2,038 (42.1%)	IPIP score	35.8 (5.7); range = 15 – 50	35.6 (5.8)	36.0 (5.4)

Table 87. Pairwise correlations between variables used in teacher-rated prosocial score model

	trp_7o~r	sex	matedu	patedu	FDiff85	HomeQ_~d	mumse~16
trp_7orlower	1.0000						
sex	0.2322	1.0000					
	0.0000						
matedu	0.0529	0.0024	1.0000				
	0.0005	0.8757					
patedu	0.0365	-0.0213	0.5283	1.0000			
	0.0185	0.1702	0.0000				
FDiff85	-0.0624	0.0096	-0.1505	-0.1924	1.0000		
	0.0006	0.6004	0.0000	0.0000			
HomeQ_ref_~d	0.0600	-0.0532	0.1783	0.1957	-0.1956	1.0000	
	0.0015	0.0050	0.0000	0.0000	0.0000		
mumsexU16	-0.0202	0.0078	-0.1034	-0.0982	0.0987	-0.0895	1.0000
	0.2191	0.6363	0.0000	0.0000	0.0000	0.0000	
matfirstpreg	0.0725	-0.0126	0.3610	0.3264	-0.1739	0.2407	-0.2678
	0.0000	0.3958	0.0000	0.0000	0.0000	0.0000	0.0000
matmenarche	0.0073	-0.0048	-0.0295	0.0031	0.0024	0.0297	-0.1573
	0.6515	0.7684	0.0740	0.8534	0.9035	0.1472	0.0000
patagepreg	-0.0048	-0.0289	0.1965	0.2145	-0.0719	0.2247	-0.1232
	0.7609	0.0649	0.0000	0.0000	0.0002	0.0000	0.0000
biodadab~10y	-0.0868	0.0066	-0.1347	-0.1716	0.2664	-0.2242	0.0845
	0.0000	0.7026	0.0000	0.0000	0.0000	0.0000	0.0000
logimd200~98	-0.0186	0.0337	-0.2618	-0.2742	0.1383	-0.2111	0.0589
	0.2116	0.0234	0.0000	0.0000	0.0000	0.0000	0.0005
Extraversi~G	0.0316	0.1495	-0.0188	-0.0156	0.0166	-0.0528	0.0475
	0.1491	0.0000	0.3976	0.4883	0.4808	0.0248	0.0439
Agreeablen~G	0.1522	0.3358	0.1186	0.0966	-0.0264	0.0701	-0.0138
	0.0000	0.0000	0.0000	0.0000	0.2674	0.0032	0.5641
Conscienti~G	0.0118	-0.0683	0.0027	0.0661	-0.0460	0.0171	-0.0111
	0.5999	0.0023	0.9055	0.0041	0.0570	0.4783	0.6456
EmotionalS~G	0.0077	-0.2212	0.0718	0.1056	-0.0931	0.0693	-0.0640
	0.7301	0.0000	0.0015	0.0000	0.0001	0.0037	0.0076
IntellectI~G	-0.0301	-0.0489	0.1772	0.1976	-0.0482	0.0819	-0.0075
	0.1742	0.0271	0.0000	0.0000	0.0430	0.0006	0.7516

	matfir~g	matmen~e	patage~g	biod~10y	logim~98	Extrav~G	Agreea~G
matfirstpreg	1.0000						
matmenarche	0.0726 0.0000	1.0000					
patagepreg	0.3804 0.0000	0.0225 0.1776	1.0000				
biodadab~10y	-0.2306 0.0000	0.0203 0.2789	-0.1711 0.0000	1.0000			
logimd200~98	-0.2523 0.0000	-0.0218 0.1923	-0.1620 0.0000	0.1410 0.0000	1.0000		
Extraversi~G	-0.0590 0.0076	-0.0180 0.4495	-0.0176 0.4401	0.0104 0.6494	-0.0264 0.2460	1.0000	
Agreeablen~G	0.0651 0.0036	0.0037 0.8769	0.0873 0.0002	-0.0621 0.0074	-0.0867 0.0002	0.2579 0.0000	1.0000
Conscienti~G	0.0553 0.0144	0.0185 0.4455	-0.0035 0.8825	-0.0159 0.4984	-0.0151 0.5165	-0.0498 0.0276	0.1929 0.0000
EmotionalS~G	0.0621 0.0057	0.0019 0.9358	0.0346 0.1367	-0.0836 0.0003	-0.0260 0.2603	0.1476 0.0000	-0.0013 0.9551
IntellectI~G	0.1131 0.0000	-0.0186 0.4394	0.1353 0.0000	-0.0075 0.7468	-0.0786 0.0006	0.1617 0.0000	0.4141 0.0000

	Consci~G	Emotio~G	Intell~G
Conscienti~G	1.0000		
EmotionalS~G	0.2869 0.0000	1.0000	
IntellectI~G	0.3190 0.0000	0.0441 0.0506	1.0000

A4.2.4 Mother-rated prosociality

Table 88. Descriptive statistics for variables used in mother-rated prosocial score model

			All	High prosociality	Low prosociality
Variables	**n (% of sample)**	**Units *or* categories**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**
Mother-rated prosocial score	3,878 (100%)	Low	1,335 (34.4%)	0 (0%)	1,335 (100%)
		High	2,543 (65.6%)	2,543 (100%)	0 (0%)
Sex	3,878 (100%)	Male	1,857 (47.9%)	1,144 (45.0%)	713 (53.4%)
		Female	2,021 (52.1%)	1,399 (55.0%)	622 (46.6%)
Maternal education	3,796 (97.9%)	None/CSE	449 (11.8%)	272 (10.9%)	177 (13.6%)
		Vocational	332 (8.8%)	208 (8.4%)	124 (9.5%)
		O-levels	1,440 (37.9%)	945 (38.0%)	495 (37.9%)
		A-levels	1,009 (26.6%	690 (27.7%)	319 (24.4%)
		Degree	566 (14.9%)	375 (15.1%)	191 (14.6%)
Paternal education	3,703 (95.5%)	None/CSE	711 (19.2%)	447 (18.4%	264 (20.8%)
		Vocational	323 (8.7%)	213 (8.8%)	110 (8.7%)
		O-levels	857 (23.1%)	544 (22.4%)	313 (24.6%)
		A-levels	1,086 (29.3%)	747 (30.7%)	339 (26.7%)
		Degree	726 (19.6%)	481 (19.8%)	245 (19.3%)
Financial difficulties	3,542 (91.3%)	None	1,759 (49.7%)	1,217 (52.4%)	542 (44.5%)
		Some	1,363 (38.4%)	874 (37.6%)	489 (40.2%)
		Many	420 (11.9%)	233 (10.0%)	187 (15.4%)
Home ownership status		Rented	285 (8.1%)	168 (7.2%)	117 (9.7%)
		Mortgaged	3,003 (85.0%)	2,008 (86.3%)	995 (82.4%)
		Owned	245 (6.9%)	150 (6.5%)	95 (7.9%)
Mother had sex with boyfriend when <16	3,436 (88.6%)	No	2,926 (85.2%)	1,937 (86.2%)	989 (83.2%)
		Yes	510 (14.8%)	310 (13.8%)	200 (16.8%)
Maternal age at first pregnancy	3,837 (98.9%)	Years	25.7 (4.7); range = 13 – 44	25.7 (4.6)	25.6 (4.9)
Maternal age at menarche	3,396 (87.6%)	Years	12.8 (1.5); range = 8 – 22	12.8 (1.5)	12.9 (1.5)
Paternal age at index pregnancy	3,632 (93.7%)	Years	31.5 (5.4); range = 17 – 60	31.6 (5.4)	31.4 (5.6)
Father absence at 10 years	3,614 (93.2%)	Present	2,978 (82.4%)	1,989 (83.9%)	989 (79.5%)
		Absent	636 (17.6%)	381 (16.1%)	255 (20.5%)
Index of Multiple Deprivation	3,878 (100%)	Composite score	13.7 (11.2); range = 1.4 – 70.4	13.6 (11.2)	13.7 (11.1)
Extraversion	2,995 (77.2%)	IPIP score	35.2 (6.9); range = 10 – 50	35.4 (6.9)	34.7 (6.9)
Agreeableness	2,938 (75.8%)	IPIP score	38.1 (5.1); range = 18 – 50	38.7 (4.9)	36.9 (5.1)
Conscientiousness	2,861 (73.8%)	IPIP score	32.1 (5.7); range = 14 – 50	32.4 (5.8)	31.5 (5.4)
Emotional stability	2,889 (74.5%)	IPIP score	31.8 (6.5); range = 10 – 50	32.1 (6.4)	31.3 (6.5)
Openness	2,924 (75.4%)	IPIP score	36.0 (5.7); range = 14 – 50	36.1 (5.5)	35.7 (6.0)

Table 89. Pairwise correlations between variables used in mother-rated prosocial score model

	tcp_7o~r	sex	matedu	patedu	FDiff85	HomeQ_~d	mumse~16
tcp_7orlower	1.0000						
sex	0.0801	1.0000					
	0.0000						
matedu	0.0429	-0.0200	1.0000				
	0.0082	0.2168					
patedu	0.0336	-0.0348	0.5133	1.0000			
	0.0408	0.0341	0.0000				
FDiff85	-0.0912	-0.0158	-0.1726	-0.2022	1.0000		
	0.0000	0.3478	0.0000	0.0000			
HomeQ_ref_~d	0.0128	-0.0034	0.1779	0.1774	-0.1575	1.0000	
	0.4452	0.8420	0.0000	0.0000	0.0000		
mumsexU16	-0.0405	-0.0050	-0.1411	-0.1026	0.0909	-0.1008	1.0000
	0.0177	0.7716	0.0000	0.0000	0.0000	0.0000	
matfirstpreg	0.0101	-0.0151	0.3198	0.2783	-0.1532	0.2306	-0.2525
	0.5313	0.3495	0.0000	0.0000	0.0000	0.0000	0.0000
matmenarche	-0.0473	0.0166	-0.0271	-0.0035	-0.0059	0.0148	-0.1253
	0.0059	0.3346	0.1169	0.8437	0.7415	0.4108	0.0000
patagepreg	0.0150	-0.0346	0.1763	0.1797	-0.0685	0.1951	-0.1015
	0.3665	0.0372	0.0000	0.0000	0.0001	0.0000	0.0000
biodadab~10y	-0.0552	0.0205	-0.1029	-0.1346	0.2579	-0.1914	0.0806
	0.0009	0.2182	0.0000	0.0000	0.0000	0.0000	0.0000
logimd201~08	-0.0087	0.0306	-0.2131	-0.2382	0.1675	-0.2081	0.0661
	0.5861	0.0568	0.0000	0.0000	0.0000	0.0000	0.0001
Extraversi~G	0.0507	0.1125	-0.0016	-0.0051	-0.0077	-0.0450	0.0274
	0.0055	0.0000	0.9312	0.7838	0.6830	0.0172	0.1569
Agreeablen~G	0.1722	0.3090	0.1260	0.1028	-0.0277	0.0439	-0.0355
	0.0000	0.0000	0.0000	0.0000	0.1483	0.0215	0.0693
Conscienti~G	0.0780	-0.0706	-0.0285	0.0114	-0.0431	-0.0067	-0.0159
	0.0000	0.0002	0.1308	0.5502	0.0263	0.7285	0.4226
EmotionalS~G	0.0614	-0.2528	0.0559	0.0541	-0.0618	0.0256	-0.0556
	0.0010	0.0000	0.0028	0.0043	0.0014	0.1838	0.0047
IntellectI~G	0.0314	-0.0648	0.1623	0.1807	-0.0465	0.0347	-0.0230
	0.0893	0.0005	0.0000	0.0000	0.0154	0.0696	0.2401

	matfir~g	matmen~e	patage~g	biod~10y	logim~08	Extrav~G	Agreea~G
matfirstpreg	1.0000						
matmenarche	0.0498 0.0038	1.0000					
patagepreg	0.3602 0.0000	0.0042 0.8126	1.0000				
biodadab~10y	-0.1721 0.0000	0.0040 0.8204	-0.1485 0.0000	1.0000			
logimd201~08	-0.2029 0.0000	0.0321 0.0613	-0.1020 0.0000	0.1192 0.0000	1.0000		
Extraversi~G	-0.0537 0.0034	-0.0035 0.8565	-0.0184 0.3299	0.0181 0.3362	-0.0215 0.2400	1.0000	
Agreeablen~G	0.0707 0.0001	-0.0063 0.7492	0.0740 0.0001	-0.0544 0.0041	-0.0692 0.0002	0.2496 0.0000	1.0000
Conscienti~G	0.0281 0.1344	0.0171 0.3908	-0.0193 0.3177	-0.0564 0.0034	-0.0089 0.6334	-0.0125 0.5058	0.2000 0.0000
EmotionalS~G	0.0470 0.0119	0.0063 0.7509	0.0141 0.4617	-0.0626 0.0011	-0.0347 0.0621	0.1794 0.0000	0.0144 0.4449
IntellectI~G	0.1219 0.0000	0.0003 0.9877	0.1115 0.0000	-0.0200 0.2938	-0.0574 0.0019	0.1538 0.0000	0.4131 0.0000

	Consci~G	Emotio~G	Intell~G
Conscienti~G	1.0000		
EmotionalS~G	0.2961 0.0000	1.0000	
IntellectI~G	0.3196 0.0000	0.0797 0.0000	1.0000

A4.2.5 Mother-rated conduct problems

Table 90. Descriptive statistics for variables used in mother-rated conduct problems model

			All	High conduct problems	Low conduct problems
Variables	**n (% of sample)**	**Units *or* categories**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**	**Mean (SD) or distribution across categories (%)**
Mother-rated conduct problems	3,879 (100%)	Low	2,844 (73.3%)	0 (0%)	2,844 (100%)
		High	1,035 (26.7%)	1,035 (100%)	0 (0%)
Sex	3,879 (100%)	Male	1,858 (47.9%)	462 (44.6%)	1,396 (49.1%)
		Female	2,021 (52.1%)	573 (55.4%)	1,448 (50.9%)
Maternal education	3,798 (97.9%)	None/CSE	451 (11.9%)	146 (14.5%)	305 (10.9%)
		Vocational	334 (8.8)	104 (10.3%)	230 (8.2%)
		O-levels	1,440 (37.9%)	381 (37.9%)	1,059 (37.9%)
		A-levels	1,007 (26.5%)	248 (24.7%)	759 (27.2%)
		Degree	566 (14.9%)	127 (12.6%)	439 (15.7%)
Paternal education	3,706 (95.5%)	None/CSE	715 (19.3%)	215 (21.9%)	500 (18.4%)
		Vocational	323 (8.7%)	98 (10.0%)	225 (8.3%)
		O-levels	857 (23.1%)	230 (23.5%)	627 (23.0%)
		A-levels	1,084 (29.3%)	273 (27.8%)	811 (29.8%)
		Degree	727 (19.6%)	165 (16.8%)	562 (20.6%)
Financial difficulties	3,544 (91.4%)	None	1,760 (49.7%)	394 (42.4%)	1,366 (52.3%)
		Some	1,361 (38.4%)	392 (42.2%)	969 (37.1%)
		Many	423 (11.9%)	144 (15.5%)	279 (10.7%)
Home ownership status	3,534 (91.1%)	Rented	285 (8.1%)	102 (11.1%)	183 (7.0%)
		Mortgaged	3,005 (85.0%)	757 (82.1%)	2,248 (86.1%
		Owned	244 (6.9%)	63 (6.8%)	181 (6.9%)
Mother had sex with boyfriend when <16	3,439 (88.7%)	No	2,928 (85.1%)	759 (83.6%)	2,169 (85.7%)
		Yes	511 (14.9%)	149 (16.4%)	362 (14.3%)
Maternal age at first pregnancy	3,839 (99.0%)	Years	25.7 (4.7); range = 3 – 44	25.4 (5.0)	25.8 (4.6)
Maternal age at menarche	3,397 (87.6%)	Years	12.8 (1.5); range = 8 – 22	12.9 (1.5)	12.8 (1.5)
Paternal age at index pregnancy	3,631 (93.6%)	Years	31.5 (5.4); range = 7 – 60	31.3 (5.6)	31.6 (5.4)
Father absence at 10 years	3,613 (93.1%)	Present	2,979 (82.5%)	821 (81.5%)	1,397 (84.4%)
		Absent	634 (17.6%)	187 (18.6%)	259 (15.6%)
Index of Multiple Deprivation	3,879 (100%)	Composite score	13.7 (11.2); range 1.4 – 70.4	14.4 (11.7)	13.4 (11.0)
Extraversion	2,996 (77.2%)	IPIP score	35.2 (6.9); range = 10 – 50	35.9 (6.9)	35.0 (6.9)
Agreeableness	2,938 (75.7%)	IPIP score	38.1 (5.1); range = 15 – 50	37.6 (5.4)	38.2 (5.0)
Conscientiousness	2,862 (73.8%)	IPIP score	32.1 (5.7); range = 14 – 50	31.1 (5.5)	32.4 (5.7)
Emotional stability	2,890 (74.5%)	IPIP score	31.8 (6.5); range = 10 – 50	30.4 (6.5)	32.3 (6.4)
Openness	2,925 (75.4%)	IPIP score	36.0 (5.7); range = 14 – 50	35.8 (6.0)	36.1 (5.5)

Table 91. Pairwise correlations between variables used in mother-rated conduct problems model

	tcpcon~r	sex	matedu	patedu	FDiff85	HomeQ_~d	mumse~16
tcpconduct~r	1.0000						
sex	0.0394	1.0000					
	0.0142						
matedu	-0.0680	-0.0186	1.0000				
	0.0000	0.2522					
patedu	-0.0591	-0.0366	0.5171	1.0000			
	0.0003	0.0259	0.0000				
FDiff85	0.0940	-0.0161	-0.1727	-0.2031	1.0000		
	0.0000	0.3381	0.0000	0.0000			
HomeQ_ref_~d	-0.0472	-0.0026	0.1788	0.1786	-0.1570	1.0000	
	0.0050	0.8761	0.0000	0.0000	0.0000		
mumsexU16	0.0261	-0.0057	-0.1422	-0.1006	0.0919	-0.1028	1.0000
	0.1257	0.7398	0.0000	0.0000	0.0000	0.0000	
matfirstpreg	-0.0379	-0.0163	0.3221	0.2775	-0.1537	0.2328	-0.2528
	0.0189	0.3115	0.0000	0.0000	0.0000	0.0000	0.0000
matmenarche	0.0306	0.0184	-0.0270	-0.0019	-0.0039	0.0140	-0.1243
	0.0749	0.2847	0.1180	0.9128	0.8271	0.4360	0.0000
patagepreg	-0.0207	-0.0339	0.1760	0.1798	-0.0690	0.1947	-0.1012
	0.2123	0.0408	0.0000	0.0000	0.0001	0.0000	0.0000
biodadab~10y	0.0355	0.0207	-0.1039	-0.1342	0.2568	-0.1930	0.0833
	0.0328	0.2138	0.0000	0.0000	0.0000	0.0000	0.0000
logimd201~08	0.0365	0.0311	-0.2149	-0.2373	0.1695	-0.2082	0.0679
	0.0230	0.0525	0.0000	0.0000	0.0000	0.0000	0.0001
Extraversi~G	0.0578	0.1138	-0.0044	-0.0055	-0.0091	-0.0456	0.0305
	0.0015	0.0000	0.8114	0.7669	0.6305	0.0158	0.1144
Agreeablen~G	-0.0566	0.3108	0.1236	0.1003	-0.0308	0.0454	-0.0338
	0.0021	0.0000	0.0000	0.0000	0.1079	0.0173	0.0836
Conscienti~G	-0.1031	-0.0709	-0.0266	0.0133	-0.0405	-0.0060	-0.0182
	0.0000	0.0001	0.1578	0.4865	0.0372	0.7573	0.3586
EmotionalS~G	-0.1263	-0.2510	0.0560	0.0532	-0.0637	0.0262	-0.0584
	0.0000	0.0000	0.0028	0.0050	0.0010	0.1727	0.0030
IntellectI~G	-0.0215	-0.0674	0.1643	0.1801	-0.0471	0.0360	-0.0193
	0.2453	0.0003	0.0000	0.0000	0.0141	0.0593	0.3245

	matfir~g	matmen~e	patage~g	biod~10y	logim~08	Extrav~G	Agreea~G
matfirstpreg	1.0000						
matmenarche	0.0505	1.0000					
	0.0033						
patagepreg	0.3605	0.0030	1.0000				
	0.0000	0.8653					
biodadab~10y	-0.1733	0.0036	-0.1480	1.0000			
	0.0000	0.8384	0.0000				
logimd201~08	-0.2036	0.0320	-0.1027	0.1200	1.0000		
	0.0000	0.0620	0.0000	0.0000			
Extraversi~G	-0.0537	-0.0026	-0.0181	0.0204	-0.0191	1.0000	
	0.0034	0.8917	0.3362	0.2777	0.2950		
Agreeablen~G	0.0708	-0.0019	0.0749	-0.0541	-0.0678	0.2535	1.0000
	0.0001	0.9238	0.0001	0.0044	0.0002	0.0000	
Conscienti~G	0.0275	0.0173	-0.0190	-0.0571	-0.0113	-0.0133	0.1980
	0.1425	0.3854	0.3241	0.0030	0.5453	0.4803	0.0000
EmotionalS~G	0.0480	0.0045	0.0139	-0.0636	-0.0372	0.1795	0.0170
	0.0102	0.8198	0.4690	0.0009	0.0456	0.0000	0.3667
IntellectI~G	0.1213	-0.0011	0.1116	-0.0201	-0.0567	0.1542	0.4115
	0.0000	0.9572	0.0000	0.2904	0.0022	0.0000	0.0000

	Consci~G	Emotio~G	Intell~G
Conscienti~G	1.0000		
EmotionalS~G	0.2947	1.0000	
	0.0000		
IntellectI~G	0.3179	0.0777	1.0000
	0.0000	0.0000	

A4.3 Pairwise correlations between cooperation measures

Table 92. Pairwise correlations between cooperation variables used as outcomes in chapter 3

	1	2	3	4
1: Returned 'You and your Friends'	1			
2: Attended Teen Focus 4	0.3649***	1		
3: Teacher-rated prosocial score	0.0875***	0.0775***	1	
4: Mother-rated prosocial score	0.0467*	0.0421*	0.1147***	1
5: Mother-rated conduct problems	-0.0652***	-0.0191	-0.1097***	-0.3528***

A4.4 Social classification group sizes

Table 93. Group sizes for different classifications for cooperation models in chapter 3

	Neighbourhoods		**Schools**		**Friendship networks**	
Measure of cooperation	*Total #*	*Mean # individuals per group*	*Total #*	*Mean # individuals per group*	*# Friendship networks with 2 or more members*	*Mean # individuals per group (if 2 or more members)*
Returned 'You and Your Friends'	576	9.7	108	51.7	NA	NA
Attended Teen Focus 4	576	8.7	103	48.7	NA	NA
Teacher-rated prosocial score	568	8.5	148	32.7	614	2.4
Mother-rated prosocial score	572	6.8	98	39.6	587	2.5
Mother-rated conduct problems	571	6.8	97	40.0	587	2.5

Appendix to chapter 6

A6.1 Additional tables for girls

Table 94 provides descriptive statistics for the sample of girls featured in the APV and PV models in chapter 6. Pairwise correlations between pubertal development variables (apart from age at menarche) and the independent variables can be found in Table 95. Table 96 contains pairwise correlations between pubertal development measures. Finally, Table 97 shows a comparison of baseline characteristics for analysis and attrition samples for the analyses based on pubertal progression measures (rather than developmental trajectories).

Table 94. Descriptive statistics for the sample of girls used for APV and PV models

Variables	n (% of sample)	Units or categories	Mean (SD) or distribution across categories (%)
Maternal age at menarche	2,069 (88.0%)	Years	12.87 (1.49); range = 9 – 24
BMI at Focus@7	2,126 (90.5%)	kg/m^2	16.25 (2.03); range = 10.85 – 31.65
Maternal education	2,315 (98.5%)	None/CSE	244 (10.5%)
		Vocational	154 (6.7%)
		O-levels	801 (34.6%)
		A-levels	646 (27.9%)
		Degree	470 (20.3%)
Paternal education	2,273 (96.7%)	None/CSE	397 (17.5%)
		Vocational	170 (7.5%)
		O-levels	454 (20.0%)
		A-levels	683 (30.1%)
		Degree	569 (25.0%)
Financial difficulties	2,218 (94.4%)	None	914 (41.2%)
		Some	918 (41.4%)
		Many	386 (17.4%)
Home ownership status	2,199 (93.6%)	Rented	245 (11.1%)
		Mortgaged	1,900 (86.4%)
		Owned	54 (2.5%)
Father absence by 5 years	2,333 (99.3%)	Present	2,031 (87.1%)
		Absent	302 (21.9%)
Index of Multiple Deprivation	2,217 (94.3%)	Composite score	18.18 (13.64); range = 3.87 – 66.80
	2,217 (94.3%)	Log-transformed	2.64 (0.72); range = 1.35 – 4.20

Table 95. Pairwise correlations between pubertal development variables and independent variables for girls. M_{APV} = APV for menarche; B_3 = breast development: Tanner stage III reached; B_{APV} = APV for breast development; B_{PV} = PV for breast development; P_3 = pubic hair growth: Tanner stage III reached; P_{APV} = APV for pubic hair growth; P_{PV} = PV for pubic hair growth; A_{APV} = APV for pubic hair growth

	M_{APV}	B_3	B_{APV}	B_{PV}	P_3	P_{APV}	P_{PV}	A_{APV}
Maternal age at menarche	0.28***	-0.19***	0.26***	0.01	-0.22***	0.25***	-0.07*	0.15***
BMI at Focus@7	-0.27***	0.25***	-0.36***	-0.18***	0.18***	-0.24***	0.06*	-0.25***
Maternal education	0.02	-0.04*	0.05	-0.04	-0.01	0.04	-0.04	0.03
Paternal education	0.02	-0.05*	0.05*	-0.05	0.00	0.02	-0.08**	0.01
Financial difficulties	-0.03	0.04	-0.06*	0.05*	0.02	-0.04	0.06*	-0.00
Home ownership status	0.02	-0.03	0.05*	-0.02	-0.00	-0.02	-0.01	-0.01
Father absence by 5 years	-0.03	-0.02	0.00	0.05*	0.01	-0.00	0.03	0.01
Index of Multiple Deprivation	-0.03	0.02	-0.01	0.05	-0.01	0.00	0.02	-0.01

*** p < 0.001, ** p < 0.01, * p < 0.05

Table 96. Pairwise correlations between pubertal development variables for girls – sample used for mixed effects models)

	1	2	3	4	5	6	7	8	9	10	11	12
1: Age at menarche	1***											
2: Menarche: APV	0.82***	1										
3: Breast development	-0.63***	-0.61***	1									
4: Breast development (T3)	-0.52***	-0.51***	0.84***	1								
5: Breast development: APV	0.63***	0.62***	-0.84***	-0.73***	1							
6: Breast development: PV	0.01	-0.01	-0.04	-0.10***	-0.17***	1						
7: Pubic hair growth (T1-5)	-0.58***	-0.55***	0.63***	0.53***	-0.59***	-0.03	1					
8: Pubic hair growth (T3)	-0.52***	-0.49***	0.55***	0.51***	-0.52***	-0.06*	0.86***	1				
9: Pubic hair growth: APV	0.60***	0.60***	-0.62***	-0.53***	0.64***	-0.02	-0.87***	-0.75***	1			
10: Pubic hair growth: PV	-0.13***	-0.14***	0.12***	0.09***	-0.19***	0.24***	0.09***	0.01	-0.28***	1		
11: Armpit hair growth (T3)	-0.28***	-0.26***	0.29***	0.24***	-0.30***	-0.04	0.44***	0.36***	-0.46***	-0.04	1	
12: Armpit hair growth: APV	0.41***	0.40***	-0.43***	-0.38***	0.43***	0.05*	-0.57***	-0.48***	0.61***	0.00	-0.81***	1

Table 97. Comparison of baseline characteristics – maternal education, paternal education, home ownership status, neighbourhood deprivation, maternal age at menarche – for analysis (n = 4,321) and attrition (n = 2,273) samples for girls

Variables	**Units *or* categories**	**Analysis sample**	**Attrition sample**	**Test for difference**
Maternal education	None/CSE	636 (15.4%)	527 (30.4%)	$X^2 = 247.0$, $p < 0.001$
	Vocational	371 (9.0%)	204 (11.8%)	
	O-levels	1,452 (35.1%)	579 (33.5%)	
	A-levels	1,040 (25.1%)	291 (16.8%)	
	Degree	640 (15.5%)	130 (7.5%)	
	Total	4,139	1,731	
Paternal education	None/CSE	906 (22.5%)	572 (35.1%)	$X^2 = 140.9$, $p < 0.001$
	Vocational	331 (8.2%)	157 (9.6%)	
	O-levels	842 (20.9%)	337 (20.7%)	
	A-levels	1,123 (27.9%)	384 (23.6%)	
	Degree	827 (20.5%)	179 (11.0%)	
	Total	4,029	1,629	
Home ownership (T = pregnancy)	Rented	668 (16.6%)	729 (39.0%)	$X^2 = 359.1$, $p < 0.001$
	Mortgaged	3,287 (81.5%)	1102 (58.9%)	
	Owned	77 (1.9%)	39 (2.1%)	
	Total	4,032	1,870	
Index of Multiple Deprivation (ward at birth)	Composite score	20.0 (14.8)	25.6 (16.4)	Mann-Whitney test: $z = 13.6$, $p < 0.001$
	Total	4,100	2,090	
Maternal age at menarche	Years	12.8 (1.5)	12.8 (1.6)	$t = -1.3$, $p = 0.18$
	Total	3,725	1,557	

A6.2 Additional tables for boys

Table 98 provides descriptive statistics for the sample of boys featured in the APV and PV models in chapter 6. Pairwise correlations between pubertal development variables (apart from binary voice breaking measure) and the independent variables can be found in Table 99. Table 100 contains pairwise correlations between pubertal development measures. Finally, Table 101 shows a comparison of baseline characteristics for analysis and attrition samples for the analyses based on pubertal progression measures (rather than developmental trajectories).

Table 98. Descriptive statistics for the sample of boys used for APV and PV models

Variables	n (% of sample)	Units or categories	Mean (SD) or distribution across categories (%)
Maternal age at menarche	1,275 (89.2%)	Years	12.86 (1.46); range = 9 – 18
BMI at Focus@7	1,308 (91.5%)	kg/m^2	16.00 (1.84); range = 12.50 – 26.71
Maternal education	1,416 (99.1%)	None/CSE	122 (8.6%)
		Vocational	89 (6.3%)
		O-levels	479 (33.8%)
		A-levels	430 (30.4%)
		Degree	296 (20.9%)
Paternal education	1,387 (97.1%)	None/CSE	189 (13.6%)
		Vocational	84 (6.1%)
		O-levels	288 (20.8%)
		A-levels	416 (30.0%)
		Degree	410 (29.6%)
Financial difficulties	1,387 (97.1%)	None	570 (41.7%)
		Some	584 (42.8%))
		Many	212 (15.5%)
Home ownership status	1,342 (93.9%)	Rented	119 (8.9%)
		Mortgaged	1,197 (89.2%)
		Owned	26 (1.9%)
Father absence by 5 years	1,422 (99.5%)	Present	1,269 (89.2%)
		Absent	153 (10.8%)
Index of Multiple Deprivation	1,323 (92.6%)	Composite score	17.15 (12.72); range = 3.87 – 66.80
	1,323 (92.6%)	Log-transformed	2.60 (0.69); range = 1.35 – 4.20

Table 99. Pairwise correlations between pubertal development variables and independent variables for boys. V_{APV} = APV for voice breaking; V_{PV} = PV for voice breaking; G_3 = genital development: Tanner stage III reached; G_{APV} = APV for genital development; G_{PV} = PV for genital development; P_3 = pubic hair growth: Tanner stage III reached; P_{APV} = APV for pubic hair growth; P_{PV} = PV for pubic hair growth; A_{APV} = APV for pubic hair growth

	V_{APV}	V_{PV}	G_3	G_{APV}	G_{PV}	P_3	P_{APV}	P_{PV}	A_{APV}
Maternal age at menarche	0.16***	0.03	-0.06**	0.10**	-0.06	-0.11***	0.20**	-0.03	0.12***
BMI at Focus@7	-0.06	-0.03	-0.05*	0.04	0.03	0.11***	-0.17***	0.08*	-0.18***
Maternal education	-0.08*	0.04	-0.07**	0.08*	0.12***	0.01	0.00	-0.03	-0.02
Paternal education	-0.04	0.02	-0.04	0.08*	0.07*	0.02	0.05	-0.05	0.03
Financial difficulties	-0.02	-0.02	0.02	-0.08*	-0.05	0.05*	-0.08*	0.01	0.00
Home ownership status	0.01	0.01	-0.02	0.03	0.00	-0.04	0.05	-0.08*	0.03
Father absence by 5 years	0.03	0.00	0.07***	-0.10**	-0.04	0.01	-0.03	0.03	-0.02
Index of Multiple Deprivation	-0.03	0.01	0.03	-0.10**	-0.07*	0.03	-0.05	-0.01	0.01

Table 100. Pairwise correlations between pubertal development variables for boys – sample used for mixed effects models

	1	2	3	4	5	6	7
1: Voice breaking	1						
2: Voice breaking: APV	-0.71***	1					
3: Voice breaking: PV	-0.31***	-0.07*	1				
4: Genital development	0.29***	-0.36***	-0.01	1			
5: Genital development (T3)	0.23***	-0.27***	-0.02	0.85***	1		
6: Genital development: APV	-0.30***	0.44***	0.00	-0.75***	-0.64***	1	
7: Genital development: PV	0.03	-0.05	0.13**	-0.36***	-0.37***	0.41***	1
8: Pubic hair growth	0.50***	-0.58***	0.03	0.37***	0.30***	-0.46***	0.08*
9: Pubic hair growth: T3	0.40***	-0.48***	-0.01	0.30***	0.27***	-0.39***	0.06
10: Pubic hair growth: APV	-0.46***	0.62***	-0.02	-0.44***	-0.36***	0.57***	-0.06
11: Pubic hair growth: PV	0.09**	-0.11**	0.16***	-0.07*	-0.10**	0.00	0.33***
12: Armpit hair growth armpitb5	0.40***	-0.44***	0.00	0.27***	0.24***	-0.30***	0.01
13: Armpit hair growth: APV	-0.34***	0.48***	0.02	-0.28***	-0.24***	0.34***	-0.06
	8	9	10	11	12	13	
8: Pubic hair growth	1						
9: Pubic hair growth: T3	0.85***	1					
10: Pubic hair growth: APV	-0.86***	-0.75***	1				
11: Pubic hair growth: PV	0.03	-0.08**	-0.03	1			
12: Armpit hair growth armpitb5	0.50***	0.40***	-0.54***	0.06	1		
13: Armpit hair growth: APV	-0.53***	-0.44***	0.63***	-0.04	-0.77***	1	

Table 101. Comparison of baseline characteristics – maternal education, paternal education, home ownership status, neighbourhood deprivation, maternal age at menarche – for analysis (n = 3,330) and attrition (n = 3,693) samples for boys

Variables	**Units *or* categories**	**Analysis sample**	**Attrition sample**	**Test for difference**
Maternal education	None/CSE	400 (12.3%)	876 (29.3%)	$X^2 = 364.4$, $p < 0.001$
	Vocational	275 (8.5%)	346 (11.6%)	
	O-levels	1180 (36.4%)	974 (32.6%)	
	A-levels	858 (26.5%)	539 (18.0%)	
	Degree	529 (16.3%)	255 (8.5%)	
	Total	3,242	2,990	
Paternal education	None/CSE	570 (18.1%)	990 (35.1%)	$X^2 = 296.5$, $p < 0.001$
	Vocational	243 (7.7%)	254 (9.0%)	
	O-levels	690 (21.9%)	593 (21.0%)	
	A-levels	887 (28.2%)	639 (22.6%)	
	Degree	757 (24.1%)	347 (12.3%)	
	Total	3,147	2,823	
Home ownership (T = pregnancy)	Rented	454 (14.3%)	1094 (34.4%)	$X^2 = 362.0$, $p < 0.001$
	Mortgaged	2651 (83.5%)	1991 (62.7%)	
	Owned	69 (2.2%)	93 (2.9%)	
	Total	3,174	3,178	
Index of Multiple Deprivation (ward at birth)	Composite score	19.2 (14.0)	24.5 (16.8)	Mann-Whitney test: $z = 12.8$, $p < 0.001$
	Total			
Maternal age at menarche	Years	12.9 (1.5)	12.8 (1.6)	$t = -0.9$, $p = 0.37$
	Total			