Original Research Article

Birthweight and Paternal Involvement Predict Early Reproduction in British Women: Evidence from the National Child Development Study

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ABSTRACT There is considerable interest in the mechanisms maintaining early reproduction in the most socioeconomically disadvantaged groups in developed countries. Previous research has suggested that differential exposure to early-life factors such as low birthweight and lack of paternal involvement during childhood may be relevant. Here, we used longitudinal data on the female cohort members from the UK National Child Development Study (n = 3,014–4,482 depending upon variables analyzed) to investigate predictors of early reproduction. Our main outcome measures were having a child by age 20, and stating at age 16 an intended age of reproduction of 20 years or lower. Low paternal involvement during childhood was associated with increased likelihood of early reproduction (O.R. 1.79–2.25) and increased likelihood of early intended reproduction (O.R. 1.38–2.50). Low birthweight for gestational age also increased the odds of early reproduction (O.R. for each additional s.d. 0.88) and early intended reproduction (O.R. for each additional s.d. 0.81). Intended early reproduction strongly predicted actual early reproduction (O.R. 5.39, 95% CI 3.71–7.83). The results suggest that early-life factors such as low birthweight for gestational age, and low paternal involvement during childhood, may affect women's reproductive development, leading to earlier target and achieved ages for reproduction. Differential exposure to these factors may be part of the reason that early fertility persists in socioeconomically disadvantaged groups. We discuss our results with respect to the kinds of interventions likely to affect the rate of teen pregnancy. Am. J. Hum. Biol. 00:00–00, 2009.

While the majority of women in developed countries begin their reproductive careers relatively late, there is a persistent subgroup who become mothers in their teenage years. This early reproduction continues to attract research interest and public policy initiatives in the UK (Arai, 2003; TPIAG, 2008), due to its purported adverse health and socioeconomic consequences for mother and child (Fraser et al., 1995; Furstenberg et al., 1989; Hofferth, 1987; Miller, 2000), though it is unclear to what extent there are negative effects of young motherhood per se, once associated contextual factors are adequately controlled (see Geronimus et al., 1994; Hoffman et al., 1993; Shaw et al., 2006; Smith and Pell, 2001). Recently, an adaptive perspective on early reproduction has begun to develop. The overwhelming predictor of teenage motherhood is socioeconomic deprivation (Imamura et al., 2007; McCulloch, 2001), and socioeconomic deprivation in developed countries is associated with increased mortality and morbidity, particularly in mid-life (Geronimus et al., 1999). By delaying reproduction, individuals run the risk of dying or becoming incapacitated before their offspring are adult (Geronimus, 2003). Thus, we should expect females to match their timing of onset of reproduction to the prevailing mortality and morbidity schedule, starting earlier when these dangers are high (for a review, see Ellis et al., 2009). This hypothesis is extremely successful at explaining differences in age at first birth across species (Promislow and Harvey, 1990) and across human populations (Low et al., 2008), as well as across socioeconomic groups within developed countries (Geronimus, 2003; Geronimus et al., 1999; Wilson and Daly, 1997).

What are the proximate mechanisms which allow human females to alter their reproductive timing in different ecologies? In part, women may be responding to early-life cues that are predictive of their future prospects (Bateson et al., 2004; Belsky et al., 1991; Gluckman et al., 2005). There are a number of lines of evidence of such developmental effects on female reproductive schedules in humans. Low birthweight or thinness at birth, have been shown to predict early menarche in a number of studies (Adair, 2001; Cooper et al., 1996; Ibanez et al., 2006a; Koziel and Jankowska, 2002; Opdahl et al., 2008; Sloboda et al., 2007). Since small size at birth predicts increased risk of mortality, particularly from age 35 onwards (Andersen and Osler, 2004), it makes adaptive sense that there should be calibration of reproductive strategy to size at birth. Note that slow growth after birth has the opposite effect to slow growth before birth, tending to delay menarche (Sloboda et al., 2007). This explains the apparent paradox that at the population level, menarche becomes earlier as nutritional conditions improve, despite the fact that within populations, girls with worse intrauterine growth have earlier menarche (Eveleth and Tanner, 1990).

A second cue which has been intensively studied is paternal involvement. Girls whose fathers are absent or uninvolved in their development reach puberty earlier than average (see Alvergne et al., 2008; Bogaert,

Additional Supporting Information may be found in the online version of this article.

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2008; Ellis, 2004; Quinlan, 2003), have earlier sexual intercourse (Quinlan 2003), and are more likely than average to become mothers young (Chisholm et al., 2005; Ellis et al., 2003; Hogan and Kitagawa, 1985; Vikat et al., 2002). There is some debate about whether low paternal involvement is just one indicator of broad psychosocial adversity during childhood (Belsky et al., 1991), or fathers have a specific causal effect (Draper and Harpending, 1982). Both within and across human societies, men invest less in offspring as conditions become more harsh (Nettle, 2008; Quinlan, 2007), and therefore it is hard to adjudicate between low paternal involvement being a cause of accelerated development, and it being a consequence of the same ecological factors as accelerated development. However, Ellis et al. (2003) find that father absence predicts early sexual activity and teenage pregnancy in two cohorts of girls even once a wide variety of other indicators of stress and adversity are controlled for, suggesting that paternal involvement might indeed have a special causal role.

Although the literature on early-life influences on reproductive development is large and well-developed, there are a number of gaps. Most studies use age at menarche as their outcome variable. While this may be correlated with age at first reproduction, only a much smaller number of studies (e.g. Ellis et al., 2003) have actually gone on to study early parenthood itself. In particular, none of the studies of the association with birthweight has gone beyond menarche to examine early reproduction. There is also relatively sparse information regarding adolescents' consciously held intentions about age at first reproduction. Young women in deprived areas state an earlier target age for reproduction than women in affluent ones (Jewell et al., 2000), and may even make a conscious link between early reproduction and the mortality and morbidity in their environments (Chisholm et al., 2005; Geronimus, 1996). This raises the question of whether birthweight and paternal involvement will be associated with consciously-held desires for early reproduction. Finally, studies of the effects of birthweight have not generally tested for separate effects of short gestational age (preterm birth), as distinct from low birthweight for gestational age (intrauterine growth restriction).

This article investigates the predictors of early reproduction in a large, nationally representative, longitudinally-studied British cohort, the National Child Development Study (NCDS). We concentrate on two outcome variables. The first is becoming a mother before the age of 20. We chose the twentieth birthday (the end of the teenage years) as a cut-off point because it is earlier than the norm for this population, but still yields a sufficient number of cases for good statistical power. However, we have also repeated the main analysis using earlier and later cut-offs (see Supporting Information), and our results are generally similar.

Our second outcome variable concerns reproductive intentions. The NCDS girls were asked, when they were 16, what they felt the ideal age to start a family would be, and some gave an answer less than 20. We can thus examine the relationships between reproductive intentions at 16 and actual outcomes, as well as the relationships between early-life predictors and both intentions and behavior. Our early-life predictor variables are gestational age (henceforth GA), birthweight for gestational age (henceforth BGA), and paternal involvement. Our hypothesis is that low BGA and low paternal involvement will predict both intended early reproduction at age 16, and actual early reproduction. Additionally, we hypothesize that short GA may have an accelerating effect on reproduction independently of the effect of low BGA, since short GA is independently associated with increased mortality and morbidity (Swamy et al., 2008).

Our analytic strategy is three-stage. First, we test whether GA, BGA, and low paternal involvement are associated with the outcome variables, with no other variables controlled. Second, we test whether they continue to have significant relationships with early reproduction once other predictors, such as socio-economic position (SEP) and own mother's age, are included in the model. This is a very conservative test, since SEP could be affecting early reproduction via low paternal involvement, and thus they may not both be significant when entered simultaneously in a multivariate model. However, if they are, it would be suggestive of causal importance. Third, we perform mediation analysis. Since socially deprived groups are characterized by lower birthweight babies and less paternal involvement with children than affluent ones (Mortensen et al., 2008; Nettle, 2008), birthweight and paternal involvement may be among the mechanisms by which low SEP affects reproductive timing.

METHODS

Study population

The NCDS is an ongoing longitudinal investigation of all individuals born in Britain during 1 week in March 1958 (initial $n = 17{,}416$). Extensive medical and sociological information gathered at the time of the cohort members' birth has been supplemented with questionnaires and interviews with parents, teachers, and the cohort members themselves. There have been seven subsequent "sweeps," or surveys of the cohort, most recently in 2004 at cohort age 46. Nearly two thirds of the original cohort members were still in contact at the most recent survey, though some individuals who are still in the study were missed for some intermediate sweeps. Loss to follow-up in this cohort is not random with respect to socioeconomic position at birth. For example, 35.7% of cohort members coming from the highest social class of origin have been lost from the study at age 42, whereas 44.1% of those from the lowest social class of origin have (Nettle, 2003). However, these differences in retention are not dramatic, and the cohort remains large and representative enough for analyses to be robust even at the later ages.

Missing values are treated list-wise, and thus degrees of freedom for analyses are smaller than the number of data points available for individual variables. Only female cohort members are considered here.

Measures

The main measures considered in this study are outlined in Table 1, including their date of gathering, NCDS variable number, and number of valid records. The first outcome variable is having a child before age 20 (early reproduction), derived from responses in 1981. Medical abortion is relatively rare in this cohort (6.4% of first pregnancies end in abortion, a figure which rises to 14.6% for first pregnancies below the age of 20), and so most teenage pregnancies not miscarrying lead to motherhood. The sec-

TABLE I. Description and descriptive statistics of the main measures included in the analyses

Measure	NCDS variable number	Type	Number of valid records	Descriptive statistics
Early reproduction	Derived from ageatfch (1981)	Dichotomous	6,270	No = 5485 Yes = 785
Early intended reproduction	Derived from n2809 (1974)	Dichotomous	5,242	No = 5073 Yes = 169
Age at first pregnancy	Derived from n502023 (1991)	Continuous	4,592	Mean 24.04 (s.d. 4.42)
Father's social class	Derived from n492 (1958), "other" values excluded	5-point scale	7,947	I = 359 II = 1032 III = 4798 IV = 998 V = 760
School socioeconomic composition	n2115 (1974)	10-point scale	5,311	Mean 4.09 (s.d. 2.37)
Mother's age at birth	n553 (1958)	Continuous	8,404	Mean 27.50 (s.d. 5.74)
Birthweight (oz)	n574 (1958)	Continuous	8,143	Mean 113.76 (s.d. 19.99)
Birthweight for gestational age (BGA)	Derived from birthweight	Continuous	7,274	Mean 0.00 (s.d. 1.00)
Gestational age (GA)	n497 (1958)	Continuous	7,502	Mean 280.19 (s.d. 14.71)
Paternal involvement	n1147 (1969)	Four categories	6,705	1 = 3993 2 = 1613 3 = 694 4 = 405

ond outcome variable is stating, at age 16, a desire for a child before age 20 (early intended reproduction). This is derived from responses to the question, "What is the ideal age to have a family?" We also used a different variable, age at first pregnancy, derived from responses in 1991, to produce Figure 1 (see Results).

The predictor variables of interest are the following. Birthweight in ounces was taken by weighing the baby immediately after birth. Gestational age (GA) was recorded at the time of birth from medical records, and is based on mother's last menstrual period. From these, we calculated birthweight for gestational age (BGA). This is the standardized residual from the best-fitting regression relationship of birthweight on gestational age, which was a power function of the form $y = Ax^b$ ($A = 0.001$, $B = 2.305$, $F_{(1,7272)} = 4231.06$, $P < 0.001$, $r^2 = 0.37$). In other words, BGA represents residual variation in birthweight once the effects of gestational age have been partialled out. Its mean is zero, and positive values represent relative heaviness for gestational age, while negative values represent relative lightness for gestational age. Since we are interested in possible effects of both GA and BGA, we enter them both BGA and GA in all multivariate models.

Paternal involvement was assessed in an interview with the mother in 1969 (cohort age 11). Mothers were asked to state the father's role in the management of the child, with the response options "(1) Plays an equal role," "(2) Plays a significant role though less than mother," "(3) Leaves it to the mother," and "(4) Inapplicable." The fourth response usually meant that the child had no contact at all with the father. The modal response to this item was "(1) Plays an equal role." It is implausible that fathers actually played an equal role to mothers in most British families of this generation. Nonetheless, the measure may be valid in a relative sense; in that fathers were doing less in the families where the mother gave a response other than "(1) Plays an equal role." There are also other reasons for trusting that the measure has some validity (see Nettle, 2008), for example that it correlates reasonably well with alternative measures of paternal involvement taken at age 7 (e.g. reading to the child and going on outings). In terms of effects on development, the scale reduces to a dichotomy between heavily involved fathers (Responses 1 and 2) and uninvolved fathers (Responses 3 and 4) (Nettle, 2008). However, here we retain the full four-point scale, except for the mediation analyses and Figure 2, and treat is as a categorical variable. Note that the paternal involvement measure is not exactly equivalent to coresidence, since some coresident fathers scored 3, and some nonresident fathers scored 1 or 2.

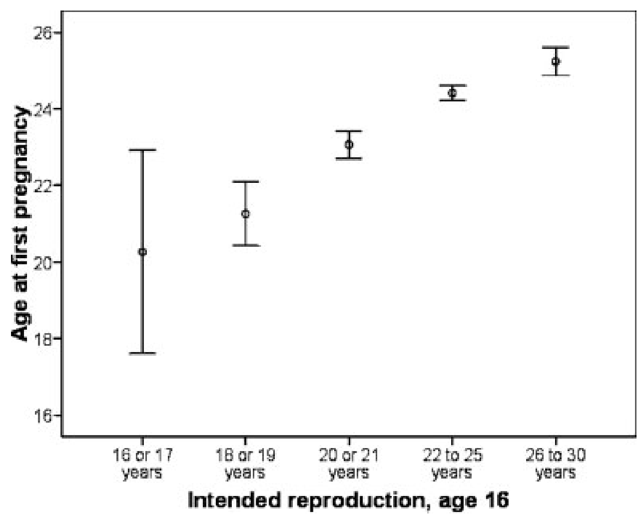

Fig. 1. Actual age of first pregnancy (mean and 95% confidence interval), against intended age at reproduction stated at 16, for women who had been pregnant by age 33. Women who gave an intended age of reproduction of over 30 are excluded.

For SEP, we include one measure based on the cohort member's family background, and based on the neighborhood milieu, since there is some evidence for an effect of neighborhood composition on timing of reproduction above and beyond the effects of family SEP (Brooks-Gunn et al., 1993; Smith and Elander, 2006). The family SEP measure is father's social class, measured in 1958 on the basis of the father or male head of household's most recent job, using the Registrar General's typology of (1) unskilled and routine occupations, (2) partly-skilled occupations, (3) skilled occupations, (4) managerial and technical occupations, and (5) professional occupations. We treat this as an ordered scale of increasing SEP. The neighborhood measure is the proportion of children at the cohort member's current school in 1974 whose fathers are in nonmanual occupations (which equates to Class 4 and 5 and nonmanual jobs in Class 3). This proportion is coded in ten percentage point steps, and is henceforth referred to *as school socioeconomic composition.* Although there is an association between the two SEP measures ($r = 0.32$), this is not sufficient to cause problems of collinearity.

In addition to these variables, we include mother's age at cohort member's birth in the analyses, since there is evidence that women whose mothers were young at their birth are more likely to become young mothers themselves (Meade et al., 2008).

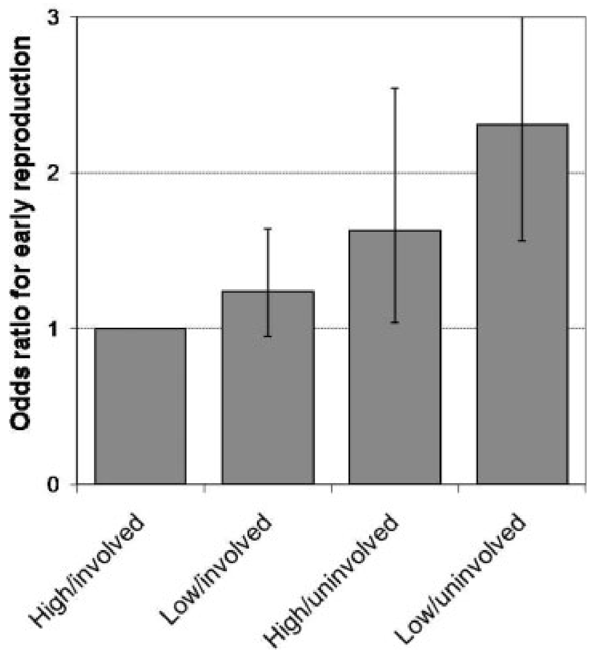

Fig. 2. Odds ratios for early reproduction for all combinations of high and low birthweight for gestational age, and father involved or uninvolved. High and low birthweight for gestational age are defined as above and below the mean respectively, and paternal uninvolvement is defined as the responses "Leaves it to mother" or "Inapplicable." Results are adjusted for gestational age, father's social class, school socioeconomic position, and mother's age at birth.

Analysis

As our main outcome variables (early reproduction and early intended reproduction) are dichotomous, we use logistic regression for our main analyses. Model 1 in each case contains paternal involvement as a factor, and GA and BGA as covariates. Model 2 additionally includes father's social class, school socioeconomic composition, and mother's age at birth as covariates. We considered main effects only in the models. For the mediation analyses, we perform Sobel mediation tests (Sobel, 1982) using the procedures for scaling the coefficients from logistic regression models described in Mackinnon and Dwyer (1993). Since these procedures have only been developed for the case of dichotomous variables, the mediation analysis requires us to collapse our four-category paternal involvement measure to the dichotomy of heavy (1 or 2) versus light (3 or 4). Both previous findings with this measure (Nettle, 2008) and current results (see below) justify this dichotomisation. Ancillary analyses are described as they are presented.

RESULTS

Association between early intended reproduction and early reproduction

Fewer girls stated at 16 a desire to have a baby before 20 than actually did so (3.2% vs. 12.5%). However, early intended reproduction predicted actual early reproduction ($\chi^2 = 95.90$, $P < 0.01$), with those desiring teenage motherhood more likely to actually experience it (OR = 5.39, 95% CI 3.71–7.83). This conclusion is unaffected by excluding those small number of girls who had already given birth or could have been pregnant at the time of the interview at 16 (data not shown). Those who went on to have babies early tended to give low desired ages at parenthood. Of those girls who went on to have a baby before age 20, 29.4% had given an ideal age for first parenthood of 21 or less, whereas only 14.9% of those who did not go on to become teenage mothers did so. Indeed, the relationship between intended fertility pattern stated at age 16 and actual behavior is strong in this cohort. Figure 1 illustrates this by showing the mean age of actual reproduction against the age stated at 16 as ideal, for all the women in the cohort who had had a child by 1991. If anything, those who desired early reproduction actually

TABLE II. Results from logistic regression models predicting early reproduction

	Model 1 (n = 4,482)		Model 2 (n = 3,014)	
Variable	χ^2	Odds ratios	χ^2	Odds ratios
Model overall	42.21*	–	110.41*	–
Paternal involvement	35.80*	Equal to mother 1 Significant 0.88 Leaves it to mother 1.79* Inapplicable 2.25*	14.51*	Equal to mother 1 Significant 1.15 Leaves it to mother 1.87* Inapplicable 1.79**
Birthweight for gestational age	6.13**	One s.d. more 0.88**	3.24§	One s.d. more 0.89§
Gestational age	0.17	–	0.01	–
Father's social class	–	–	23.38*	One class lower 1.41*
School socioeconomic composition	–	–	38.17*	One scale-point fewer 1.21*
Mother's age at birth	–	–	1.02	–

P values are based on the χ^2 log-likelihood ratios for variables overall, and the Wald statistic for individual odds ratios.
*$P < 0.01$.
**$P < 0.05$.
§$P = 0.07$.

TABLE III. Results from logistic regression models predicting early intended reproduction

Variable	Model 1 (n = 3,729) χ^2	Model 1 Odds ratios	Model 2 (n = 3,020) χ^2	Model 2 Odds ratios
Model overall	16.06*	–	29.47*	–
Paternal involvement	11.87*	Equal to mother 1	7.48§	Equal to mother 1
		Significant 1.07		Significant 1.11
		Leaves it to mother 2.50*		Leaves it to mother 2.31*
		Inapplicable 1.38		Inapplicable 1.51
Birthweight for gestational age	4.06**	One s.d. more 0.81**	6.72*	One s.d. more 0.74*
Gestational age	0.30	–	1.05	–
Father's social class	–	–	8.73*	One class lower 1.46*
School socioeconomic composition	–	–	1.19	–
Mother's age at birth	–	–	0.25	–

P values are based on the χ^2 log-likelihood ratios for variables overall, and the Wald statistic for individual odds ratios.
*$P < 0.01$.
**$P < 0.05$.
§$P = 0.06$.

didn't manage to reproduce as early as they would have liked, on average.

Predictors of early reproduction

Table 2 shows the outcomes of the logistic regression analyses with early reproduction as the outcome variable. In Model 1, there is a significant effect of BGA (every extra s.d. reducing the odds, OR = 0.88), but not of GA. Paternal involvement being rated as "leaves to mother" or "inapplicable" significantly raises the odds of early reproduction relative to father having a role "equal to mother" (ORs 1.79 and 2.25, respectively). In Model 2, SEP variables and mother's age at birth are added. There are expected significant effects of father's social class (each class lower compared to professional occupations increasing the odds, OR = 1.41) and school socioeconomic composition (every 10% points fewer professional fathers increasing the odds, OR = 1.21). Mother's age at birth does not significantly predict early reproduction. Even with the control variables in the model, paternal involvement remains a significant predictor of early reproduction, with the odds ratios remaining similar (ORs 1.87 and 1.79). BGA is near-significant (P = 0.07) in Model 2, though the OR is very similar to the significant OR of Model 1 (0.89 vs. 0.88).

We also tested whether the association between father's social class and teenage motherhood was mediated by either BGA or dichotomized paternal involvement (separate analyses). The dichotomization of the paternal involvement variable, which is required for the statistical procedure, seems justified by the fact that the odds ratios for early reproduction never differ significantly between paternal involvement scores of 1 and 2, or between scores of 3 and 4, but they do differ between 1 and 3, and 1 and 4. Dichotomized paternal involvement was a significant mediator of the relationship between father's social class and early reproduction (Sobel test: z = 3.77, $P < 0.01$), as was BGA (Sobel test: z = 1.99, $P < 0.05$).

To explore how BGA and paternal involvement interact with one another to affect reproductive development, we created a synthetic variable with four values (1) above mean BGA and father involved; (2) below mean BGA and father involved; (3) above mean BGA and father uninvolved; and (4) below mean BGA and father uninvolved. We treated this synthetic variable as categorical. In a logistic regression model predicting early reproduction, containing this synthetic variable, and adjusting for GA, father's social class, school socioeconomic position, and mother's age at birth, the synthetic variable is significantly associated with early reproduction (χ^2 = 17.66, $P <$ 0.01). Figure 2 shows the odds ratios associated with each value of the synthetic variable (reference category = above mean BGA and father involved). Below mean BGA and uninvolved father each increase the estimated odds (ORs 1.24 and 1.63, respectively), but the two combine more than additively to give an estimated odds ratio of 2.31 when BGA is low and father is uninvolved.

Predictors of early intended reproduction

Table 3 shows the outcomes of the logistic regression analyses with early intended reproduction, stated at age 16, as the outcome variable. Model 1 found significant effects of BGA (every extra s.d. decreasing the odds of desiring a family before 20, OR 0.81), but not GA. Paternal involvement also affected early intended reproduction in the predicted directed (a rating of "leaves it to mother" increasing the odds of desiring a family before 20, OR 2.50, though the difference between the "Inapplicable" group and the "Equal to mother" group is not significant). In Model 2, where control variables are added, there is a significant effect of father's social class on early intended reproduction, but no effect of school socioeconomic composition or mother's age at birth. The effects of BGA and paternal involvement are largely unchanged from Model 1 to 2. The BGA age effect persists, with a similar odds ratio (ORs 0.74 vs. 0.81), and, while the paternal involvement effect overall becomes marginally significant (P = 0.06), the contrast between the "Equal to mother" and "Leaves it to mother" groups remains significant with a similar odds ratio (ORs 2.31 vs. 2.50). Results are not qualitatively different if girls who might already have been pregnant or have given birth at time of interview at 16 are excluded, and in fact the effects of BGA and paternal involvement are strengthened (data not shown).

The mediation of the relationship between father's social class and early intended reproduction by BGA age was not quite significant (Sobel test, z = 1.80, P = 0.07), but there was a significant mediation effect of paternal involvement (Sobel test, z = 2.60, $P < 0.01$). Thus, part of the association between family SEP and early intended reproduction is explained by lower paternal involvement in low SEP families.

DISCUSSION

The comparison of intended and realized early reproduction suggests that teenage motherhood is often not unanticipated. Ten percent of women who would go on to have babies by age 20 already stated at age 16 that they wished to do so, while almost 40% gave a target age for first reproduction of 21 or lower. As our Figure 1 shows, young people's stated intentions in the domain of life history bear considerable relationship to their actual later behavior, and those who become mothers early are generally women aiming for early reproduction.

We found that low BGA and low paternal involvement in childhood predicted early reproduction. Low paternal involvement was associated with odds of early reproduction increased by 79–125% relative to high paternal involvement, a substantial effect. The BGA effects were weaker (see also Supporting Information), with a standard deviation's reduction in BGA associated with odds around 14% higher. In absolute terms, with no other factors controlled for, girls who went on to reproduce before 20 were on average one and a half ounces (45 g) lighter at birth than those who did not (113.73 oz vs. 115.25 oz). Our Figure 2 suggests that each of the factors has an independent association with early reproduction, but that they combine at least additively, so that girls with low BGA and also fathers who are uninvolved are most liable to reproduce early.

The effects remained around the same size when socioeconomic factors were controlled for, although a substantial reduction in sample size meant that some comparisons moved outside the level of statistical significance. However, more importantly, the data show that both BGA and paternal involvement mediate the relationship between family SEP and early reproduction. Thus, part of the reason for more early reproduction in daughters of lower-SEP families may be that those daughters are differentially likely to be of low BGA, and to receive low paternal involvement.

We also found that these same two factors predicted a desire (stated at age 16) for early reproduction, again with nontrivial effect sizes, which did not change substantially when other variables were controlled for. This is significant, as it suggests that early-life factors might induce changes not just in the schedule of physiological development, but also in motivational characteristics that are accessible at the explicit, conscious level by the time women are 16-year old. Mediation analysis suggest that part of the reason young women in low-SEP families desire earlier reproduction is that they have been differentially exposed to low paternal involvement.

This is the first reported association between low birthweight for gestational age and teenage parenthood later in life. However, it is consistent with findings in other studies that low birthweight or thinness at birth predict early menarche (Adair, 2001; Cooper et al., 1996; Ibanez et al., 2006a; Koziel and Jankowska, 2002; Opdahl et al., 2008; Sloboda et al., 2007). Our study confirms that it is lightness for a given gestational age, rather than being born preterm, which appears to be relevant. Gestational age has no effect on the odds of reproducing young. Why this should be the case is not clear. However, girls born preterm have a reduced probability of ever reproducing, probably due to increased rates of developmental disorders (Swamy et al., 2008). It may be that significantly preterm birth in the ancestral environment was not often enough survived for it to have been employed as a calibrational cue in reproductive development, and thus any effects in contemporary populations are merely disruptive.

Low BGA may thus act as a cue to the developing female to follow a "fast" life history strategy of relatively early maturation and reproduction. Part of this strategy, as these data show, is the development of a conscious motivation to reproduce early. The hormonal mechanisms relating low BGA to accelerated reproductive development are partly understood. Small size at birth predicts increased circulating levels of the estrogen precursor dehydroepiandosterone in childhood and adolescence (Opdahl et al., 2008). Low BGA leads to increased adiposity in childhood (Ibanez et al., 2006b), and adiposity increases estrogen functioning in a number of ways (Frisch, 1987). Low BGA is also associated with hyperinsulinemia and insulin resistance (Ibanez et al., 2006b), and insulin appears to play a major role in pubertal tempo (Ibanez et al., 2006c).

The results for paternal involvement are consistent with a long list of previous studies on age at menarche (for a review, see Ellis, 2004), and a smaller number on teenage childbearing or pregnancy (Ellis et al., 2003; Hogan and Kitagawa, 1985; Vikat et al., 2002). Effects sizes were just as large, or larger, for the "leaves to mother" group of fathers, many of whom were coresident, as for the "Inapplicable" group, where the father had no contact at all with the child by age 11. This supports the contention that the quality of the paternal relationship, not only its mere existence, may be significant (Ellis et al., 1999). Our paternal involvement measure is relatively crude, having only four categories, and our data unfortunately do not allow us to discriminate between fathers who became uninvolved at different ages. Other studies have suggested that father absence before the age of 5 has much stronger effects than father absence beginning later (Ellis et al., 2003), and that there might be different critical periods for age at menarche and age at first sexual activity (Alvergne et al., 2008). Nor can our study shed any light on whether low paternal involvement is just a symptom of general psychosocial adversity, which is the causal factor, or whether there are specific mechanisms responsive to paternal behavior, since we did not have independent measures of psychosocial adversity (but see Ellis et al., 2003).

We found, unsurprisingly, substantial effects of socioeconomic position on teenage motherhood. Both our measure of family SEP and that of neighborhood composition had significant effects on teenage motherhood. This is consistent with the idea that neighborhood characteristics have effects on reproduction above and beyond the effects of family SEP (Brooks-Gunn et al., 1993; Smith and Elander, 2006). However, another possibility is that the neighborhood measure, which was measured at a finer scale than the family one, picked up additional variation in family socioeconomic characteristics, and is predictive for that reason. Our results did not confirm mother-to-daughter intergenerational transmission of early age at reproduction, as reported by Meade et al. (2008). Although maternal age at cohort member's birth does predict cohort members becoming teenage mothers in the NCDS data when no other variables are controlled for, this association disappears as soon as either of the measures of SEP is included in the model (see Supporting Information). Thus, any tendency for women whose mothers had them while young to reproduce early themselves is explained by shared socio-economic position, and there is no evidence for cultural transmission of age at reproduction.

The major limitation of this study is that the design is not genetically informative. Birthweight and paternal involvement could be linked to early reproduction either via developmental plasticity, as we have suggested, or via a genetic correlation between these traits. For example, age at first reproduction might be genetically heritable, and the association with birthweight then simply a side effect of the fact that young mothers are more likely to have low birthweight babies (Borja and Adair, 2003). The lack of a predictive effect of maternal age in our analyses suggests that account is unlikely, but cross-sectional evidence of the kind presented here cannot generally adjudicate between genetic and developmental induction accounts of the same associations. However, we note evidence from a study with a genetically informative design suggesting that at least part of the paternal involvement effect is due to developmental induction rather than genetic heritability (Tither and Ellis, 2008).

The results of this study can be interpreted as suggesting that factors operating early in life induce a motivation for early reproduction, by cuing evolved mechanisms for regulating life-history strategy. If this is the case, current public policy interventions, which aim to reduce teenage pregnancy by educating adolescents about reproduction and contraception, may be of limited effectiveness. For example, Henderson et al. (2007) review the results of a large-scale randomized trial of a program of high-quality sex education for 13- to 15-year-old students, and find that the program had no effect on the rate of teenage conceptions. Evidence is lacking that teenage parents are in fact undereducated about reproduction or contraception (for a discussion, see Arai, 2003), and our data suggest that deep motivational schedules and patterns of expectation may have been set up much earlier in life, including even in utero. Such schedules would in all likelihood remain plastic into adolescence and adulthood, but we don't know how plastic, or to which cues they respond. What is clear, though, is that the long-term route to reducing teenage parenthood is to reduce exposure to the cues of environmental hazard to which young people in deprived areas are disproportionately exposed.

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Supporting Information for Nettle, Coall and Dickins, *Birthweight and paternal involvement predict early reproduction in British women: Evidence from the National Child Development Study*

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May 12, 2009

1 Using different cut-off ages in the definition of early reproduction

We performed the logistic regression analyses with early reproduction as the outcome variable, as described in the main paper, but using different cut-off ages for the definition of early reproduction. The main paper reports the full results for a cut-off of the twentieth birthday. Here we report abbreviated results (odds ratios for key variables only) obtained using the cut-offs of the eighteenth, nineteenth and twenty-first birthdays, for comparison. As in the paper, Model 1 contains only GA, BGA and paternal involvement, whereas Model 2 additionally includes paternal social class, school socio-economic composition, and mother's age at birth. As the cut-off age reduces, the number of cases of early reproduction declines. We did not do the same exercise for early intended reproduction intention, as the numbers of girls giving ages younger than 20 in their answers was small.

The key results are shown in table 1. The results regarding paternal involvement are extremely robust with respect to changes in the cut-off for early reproduction. Regardless of how this is defined, paternal involvement rated as 'Leaves it to mother' or 'Inapplicable' roughly doubles the odds of early reproduction relative to ratings of 'Equal to mother' or 'Significant', which never differ from each other. If there is any trend, it is for the paternal involvement effects to become larger as more extreme early reproduction is considered. The results for BGA are less consistent. The effect is significant with cut-off ages of 20 and 21 (Model 1), and near-significant with a cut-off of 19, but not significant at all with a cut-off of 19. BGA does not reliably remain significant in

Model 2. This is consistent with the smaller effect sizes for BGA than paternal involvement reported in the main paper. GA never has a significant effect.

2 Testing for intergenerational transmission of mother's age

In table 2 we report a logistic regresion with early reproduction as the outcome variable, first with cohort member's mother's age at birth as the sole predictor variable (Model 1), and then adding in father's social class (Model 2), and school socioeconomic position (Model 3). There is a significant effect of mother's age at birth only in Model 1. That is, in this cohort there is no evidence of intergenerational cultural transmission of young reproduction. Similarities between the generations are fully explicable by shared socioeconomic factors, and once these are controlled for, any effect of mother's age disappears.

Cut-off age	18		19		20		21	
Number of cases	275		535		785		1106	
	Model 1	*Model 2*	*Model 1*	*Model 2*	*Model 1*	*Model 2*	*Model 1*	*Model 2*
BGA (+1 s.d.)	0.97	0.94	0.89‡	0.91	0.88†	0.89‡	0.91†	0.94
GA (+1 s.d.)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Paternal involvement	Equal 1 Signif. 1.03 Leaves 2.58⋆ Inapp. 2.32⋆	Equal 1 Signif. 1.78† Leaves 3.01⋆ Inapp. 1.60	Equal 1 Signif. 0.94 Leaves 1.84⋆ Inapp. 2.57⋆	Equal 1 Signif 1.29 Leaves 2.03⋆ Inapp. 2.10⋆	Equal 1 Signif 0.88 Leaves 1.79⋆ Inapp. 2.25⋆	Equal 1 Signif 1.15 Leaves 1.87⋆ Inapp. 1.79⋆	Equal 1 Signif. 0.99 Leaves 1.80⋆ Inapp. 2.26⋆	Equal 1 Signif. 1.17 Leaves 1.82⋆ Inapp. 2.12⋆

Table 1: Odds ratios and significance levels from a logistic regression of early reproduction on birthweight for gestational age, gestational age, and paternal involvement. Model 1 contains only these variables, whereas Model 2 additionally contains the control variables paternal social class, school socioeconomic composition and mother's age at birth (output not shown for these variables).

$\star p < 0.01$

$\dagger p < 0.05$

$\ddagger p < 0.07$

	Model 1 n=5959	Model 2 n=5671	Model 3 n=3896
Variable	χ^2	χ^2	χ^2
Mother's age	$6.99^{\star}$	1.33	0.63
Father's social class	-	$94.96^{\star}$	$39.59^{\star}$
School socioeconomic composition	-	-	$51.82^{\star}$

Table 2: Logistic regression predicting early reproduction by mother's age at birth, father's social class, and school socioeconomic composition.
$\star p < 0.01$