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Does Maternal Warmth Moderate the Effects of Birth Weight on Twins' Attention-Deficit/Hyperactivity Disorder (ADHD) Symptoms and Low IQ?

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The moderating effect of maternal warmth on the association between low birth weight and children's attention-deficit/hyperactivity disorder (ADHD) symptoms and low IQ was studied in 2,232 twins. Half of 5-year-old children had low birth weights, below 2,500 g. Maternal warmth, a component of expressed emotion, was coded from mothers' audiotaped descriptions of each child. Both parents and teachers rated children's ADHD symptoms, and the children were administered an IQ test. Results showed a significant interaction between children's birth weight and maternal warmth in predicting mothers' and teachers' ratings of ADHD. The interaction was not significant for IQ. The findings suggest that the effect of children's birth weight on their ADHD symptoms can be moderated by maternal warmth and that enhancing maternal warmth may prevent behavior problems among the increasing population of low-birth-weight children.

In the last 2 decades, significant advances in neonatal intensive care have improved the survival of low-birth-weight (LBW) babies Hack, Friedman, & Fanaroff, 1996). The term LBW is conventionally used to describe babies who are born weighing less than 2,500 g. Compared with normal-birth-weight infants (NBW; $>$ 2,500 g), LBW infants are frequently born prematurely, have greater perinatal morbidity and mortality, and often show long-term neurological, cognitive, and behavioral problems (Breslau, 1995). Twins and higher order multiples are more likely than singletons to be born prematurely and to have LBWs (Gardner et al., 1995; Luke & Keith, 1992), and the birth rate of twins has increased significantly in recent decades, primarily owing to advances in assisted reproductive technologies (Ventura, Martin, Curtin, & Matthews, 1998; Ventura, Martin, Curtin, Menacker, & Hamilton, 2001). The aim of this study was to investigate the outcomes of LBW in a sample of school-age twins and to examine whether maternal warmth can moderate the effect of LBW on attention and cognitive problems.

A number of studies have investigated the long-term sequelae of LBW in singletons and have found that LBW school-age children are more likely to have cognitive difficulties and behavioral problems when compared with NBW children (see Breslau, 1995, and Robinson & Gonzalez, 1999, for reviews). In relation to cognitive difficulties, research has found that LBW children have significantly lower IQ scores and greater educational difficulties than NBW children (e.g., Breslau et al., 1994; Levy-Shiff, Einat, Mogilner, Lerman, & Krikler, 1994; McCormick, Brooks-Gunn, Workman-Daniels, Turner, & Peckham, 1992). According to Breslau's (1995) review, nearly twice the number of LBW children compared with NBW children score one standard deviation below the IQ mean, even after indicators of social class are statistically controlled. The association between LBW and cognitive outcomes does not decrease with age. In fact, research has demonstrated that some groups of very LBW children (VLBW; $<$ 1,501 g) have cognitive and academic problems at 14 years of age (Rickards, Kelly, Doyle, & Callanan, 2001) and even at 20 years of age (Hack et al., 2002).

LBW has also been found to be associated with children's behavioral problems, particularly hyperactivity and inattention. When compared with NBW children, VLBW children have significantly higher levels of hyperactivity and inattention, according to both parents' and teachers' ratings (Hack et al., 1992; Levy-Shiff et al., 1994; McCormick et al., 1992; Rooney, Hay, & Levy, 2003; Szatmari, Saigal, Rosenbaum, & Campbell, 1993; Teplin, Burchinal, Johnson-Martin, Humphry, & Kraybill, 1991). Although there is a gradient effect for birth weight, with the lowest birth weight children showing the poorest outcomes (Breslau, 1995), the effects of birth weight on attention and hyperactivity

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exist for all LBW groups up to 2,500 g (McCormick et al., 1992; Mick, Biederman, Prince, Fischer, & Faraone, 2002). Once again, the association between LBW and behavioral problems persists with age. In one study, 23% of LBW children met the criteria for attention-deficit/hyperactivity disorder (ADHD) at 12 years of age compared with only 6% of NBW controls (Botting, Powls, Cooke, & Marlow, 1997).

Studies that have examined the association between LBW and cognitive and behavioral outcomes have generally focused on singletons and excluded twins from their comparisons, because twins are often thought to be at greater risk for later problems than singletons. Twins are significantly more likely than singletons to be born prematurely and to have LBWs (Gardner et al., 1995; Luke & Keith, 1992), and the rate of twin births has risen by more than 50% since 1980 (Ventura et al., 2001). The increase in multiple births can be attributed to improvements in artificial reproductive technologies and the trend toward delaying childbirth, given that multiple births occur more frequently among older mothers (Luke & Keith, 1992; Ventura et al., 2001). In addition, the effects of LBW may be greater in twins than singletons for two reasons. First, owing to the compromised intrauterine environment, twins may have additional medical problems that are not specifically related to their prematurity or LBW, such as twin-to-twin transfusion syndrome and discordant growth (Cincotta, Gray, Phythian, Rogers, & Chan, 2000; Powers & Kiely, 1994). Second, there is some evidence that parents of twins may experience greater stress, depression, and marital difficulties, owing to the burden of having two children simultaneously (Thorpe, Golding, MacGillivray, & Greenwood, 1991). Thus, compared with families of LBW singletons, families with LBW twins may have additional child and family risk factors that may result in poorer outcomes for these children. For these reasons, twins are an important group to study in relation to the outcomes of LBW.

The etiology of cognitive and behavioral problems in LBW children is largely unknown, although there is some evidence that long-term problems may be a consequence of cerebral damage in the neonatal period (Whitaker et al., 1997). As LBW children are a heterogeneous group and not all children suffer poor outcomes, it is important to identify whether any environmental factors exacerbate or reduce the effect of LBW on children's development. In developmental psychopathology, there is a large body of research that has identified environmental risk and protective factors for behavioral and cognitive problems in children. Family risk factors for child psychopathology and low IQ include exposure to marital violence, stress, harsh discipline, and parental mental illness (Garmezy & Rutter, 1985; Rutter, 1987). Protective factors that are associated with resilience in these psychosocially at-risk children include high parental warmth, positive parent–child relationships, and consistent discipline (Belsky, 1984; Masten et al., 1988; Rutter, 1979, 1983; Werner, 1989, 1990; Wyman et al., 1992). However, whether or not these risk and protective factors also operate for children who are biologically at risk of poor outcomes due to LBW is relatively unknown, given the paucity of research on this topic. Knowledge about these risk and protective factors is crucial for developing effective intervention programs for LBW children.

Only a small number of studies have specifically examined family risk and protective factors for LBW children. Bradley et al. (1994a, 1994b) identified early indicators of resilience in LBW children who were living in poverty. The children who showed signs of resilience received more responsive, accepting, and stimulating care from their parents when compared with nonresilient children. Recently, Laucht, Esser, and Schmidt (2001) conducted a longitudinal study of the effects of mothers' emotional responsivity on inattention and hyperactivity in 347 LBW children. The children were assessed at ages 2, 4, and 8 years old. These researchers found a moderating effect for maternal responsivity. The effects of LBW on attention problems were greater for children whose mothers were emotionally unresponsive to their children when compared with responsive mothers. However, as with most studies on birth weight, this study excluded twins from the sample.

The findings of the aforementioned studies (Bradley et al., 1994a, 1994b; Laucht, Esser, & Schmidt, 2001) suggest that parents' emotional attitudes may be important for LBW children. The role of parental emotional attitudes in the development of child psychopathology has been widely studied (Vostanis & Nicholls, 1995). The construct of *expressed emotion*, measured by the Camberwell Family Interview (Vaughn & Leff, 1976) and the Five-Minute Speech Sample predicts adult psychiatric disorders (Butzlaff & Hooley, 1998) and has also been investigated in relation to childhood disorders (Vaughn, 1989). Research has found that mothers of children with behavioral and emotional disorders express more critical comments, fewer positive comments, and less warmth to their children than control parents (Asarnow, Tompson, Hamilton, & Goldstein, 1994; Hibbs et al., 1991; Scott & Campbell, 2001; Vostanis & Nicholls, 1995; Vostanis, Nicholls, & Harrington, 1994). As maternal warmth is important for children's competence, behavior, and development (Maccoby & Martin, 1983; MacDonald, 1992; Patterson, Cohn, & Kao, 1989), high levels of maternal warmth may be critical for LBW children and may moderate the risk of long-term cognitive and behavioral difficulties.

The aim of the present study was to assess whether LBW is associated with IQ scores and ADHD ratings in school-age twins and to determine if maternal warmth moderates these associations. Two specific hypotheses were tested. First, in keeping with the findings of numerous studies with singletons, it was expected that LBW would predict low IQ scores and mothers' and teachers' ratings of ADHD in this sample of school-age twins. Second, given that one study found maternal responsivity to moderate the effects of birth weight on inattention and hyperactivity (Laucht et al., 2001), we expected that maternal warmth would moderate the effects of birth weight on mothers' and teachers' ratings of ADHD in the present study. As no previous research has examined factors that moderate the effects of LBW on low IQ, this was an exploratory analysis, and no specific hypotheses were formulated.

Method

Sample

Participants are members of the Environmental Risk (E-risk) Longitudinal Twin Study, which investigates how genetic and environmental factors shape children's development. The study follows an epidemiological sample of families with young twins. The E-risk sampling frame was two consecutive birth cohorts (1994 and 1995) in the Twins' Early Development Study, a birth register of twins born in England and Wales (Trouton, Spinath, & Plomin, 2002). The full register is administered by

the government's Office of National Statistics (ONS), which invited parents of all twins born in 1994–1995 to enroll. Of the 15,906 twin pairs born in these two years, 71% joined the register. Our sampling frame excluded opposite-sex twin pairs and began with the 73% of registered families who had same-sex twins.

The E-risk Study sought a sample size of 1,100 families to allow for attrition in future years of the longitudinal study while retaining statistical power. An initial probability sample of 1,210 families was drawn from the register to target for home visits, a 10% oversample to allow for nonparticipation (see Moffitt & The E-risk Study Team, 2002, for a full description of sampling methods). Of the 1,210 families targeted, 7 were discovered to be ineligible for inclusion in our study because the twins had moved overseas, did not speak English, were being reared by neither biological parent, or were of opposite sex. Of the 1,203 eligible families, 1,116 (93%) participated in home-visit assessments when the twins were 5 years old; 4% of families refused, and 3% were lost to tracing or could not be reached after many attempts. The data reported in this article represent the population of mothers having twins in 1994–1995 in the United Kingdom (Bennett, Jarvis, Rowlands, Singleton, & Haselden, 1996).

The sample includes 56% monozygotic and 44% dizygotic twin pairs. Sex is evenly distributed within zygosity (49% male). Birth weight information was obtained for 2,076 children (93% of the sample). The mean birth weight for the sample was 2,436.11 g (SD = 544.95, range = 454.00–4,114.38 g), and the mean gestational age was 36 weeks (SD = 3, range = 24–43 weeks). There were 1,020 (49.9%) children who weighed 2,500 g or more at birth (NBW) and 1,056 (51.1%) who weighed less than 2,500 g at birth (LBW). The mean gestational age for the NBW children was 38 weeks and for the LBW children was 35 weeks. It should be noted that the present study used a continuous measure of birth weight in grams rather than a dichotomous classification of LBW versus NBW, given that these cut-offs have been predominantly used for singletons rather than twins.

Table 1 presents the children's average birth weights according to a number of child variables and family sociodemographic characteristics. There were significant differences between children's average birth weights for the following variables: family social class, zygosity of twins, and gender of twins. Children whose parents were in professional or managerial occupations had higher average birth weights than children whose parents were in skilled manual/nonmanual occupations or were unemployed. Boys had significantly higher average birth weights than girls, and dizygotic twins had significantly higher average birth weights than monozygotic twins. There were no significant birth-weight differences according to twins' ethnicity, family income, or level of maternal warmth. In addition, birth weight was significantly associated with mothers' age and number of children in the family. As mothers' age increased in the sample, children's birth weight also increased (r = .10, $p < .01$). As number of children in the family increased, birth weight also increased (r = .17, $p <$ .01). Thus, five variables (mothers' age, number of children in the family, family social class, twins' zygosity, and twins' gender) were controlled for in subsequent statistical analyses for this study.

There were 23 children in the study who had disability: 16 children had cerebral palsy and 7 had autism. Data analyses were repeated with and without these children, and as their exclusion did not alter the results, these children were included in the final data analyses.

Procedures

Families were interviewed in their homes as close as possible to the twins' 5th birthday. Data were collected within 2 months of the twins' 5th birthday. With mothers' permission, questionnaires were posted to the children's teachers, and teachers returned questionnaires for 94% of cohort children.

Research workers visited each home for 2.5–3 hr, in teams of two. While one interviewed the mother, the other tested the twins in sequence in a different part of the house. Families were given shopping vouchers for their participation, and children were given coloring books and stickers. All research workers had university degrees in behavioral science and experience in psychology, anthropology, or nursing. Each research worker completed a formal 15-day training program on either the mother interview protocol or the child assessment protocol, to attain certification to a rigorous reliability standard. Research workers were blind to information about the twins' birth weights and gestational age.

Table 1
Means, Standard Deviations, t Values, F Values, and p Values for Children's Birth Weights According to Child and Family Variables

Child and family variables	Mean birth weight (*SD*)	*t* value or *F* ratio	*p*
Family social class		3.54	.01
Professional/managerial (39.1%)	2,484.59 (540.21)		
Skilled manual and nonmanual (38.7%)	2,393.02 (538.46)		
Partly skilled and unskilled (13.0%)	2,448.00 (530.99)		
Unemployed (9.2%)	2,297.97 (578.76)		
Zygosity of twins		6.21	.001
Monozygotic (55.7%)	2,396.22 (545.81)		
Dizygotic (44.2%)	2,482.62 (538.35)		
Gender of twins		9.86	.001
Male (48.9%)	2,490.31 (553.05)		
Female (51.1%)	2,382.27 (529.56)		
Ethnicity of twins		0.71	.40
White (90.4%)	2,440.48 (544.09)		
Not White (9.6%)	2,385.43 (541.48)		
Family income		1.00	.37
<£20,000 (47.8%)	2,406.73 (578.01)		
£20,000–£34,999 (29.6%)	2,445.93 (485.77)		
>£35,000 (22.5%)	2,467.04 (537.68)		
Maternal warmth		1.06	.35
Low (20.4%)	2,474.26 (549.48)		
Moderate (37.0%)	2,444.07 (561.53)		
High (42.6%)	2,410.74 (538.36)		

Data from mothers were collected by means of interviews; no self-completion forms were used. Mothers' interviews included structured protocols that were guided by a booklet and more qualitative, open-ended sessions that were audiotaped. Questions about each twin were separated by 1 hr of questions about other topics. Assessment of each child's IQ was part of an engaging 45-min series of games, tasks, and puppet shows.

Measures

Family social class was based on current (or last) occupations of mothers (and their spouses or partners) and was coded using the Office of Population Censuses and Surveys (OPCS, 1991) Standard Occupational Classification. Occupational groups are arranged into six social classes (1 = *professional occupations*; 2 = *managerial and technical occupations*; 3N = *skilled nonmanual occupations*; 3M = *skilled manual occupations*; 4 = *partly skilled occupations*; 5 = *unskilled occupations*). Families were assigned the higher of the occupations held by the mother or her spouse or partner. For analyses, the six social classes were divided into three: (a) professional and managerial, (b) skilled manual and nonmanual, and (c) partly skilled and unskilled.

The zygosity of the twins was determined by a questionnaire administered to the parent about the physical similarities, differences, and confusion between the twins. This questionnaire has been found to accurately classify the zygosity of 95% of twins (Price et al., 2000; Rietveld et al., 2000). In the few cases where the zygosity of the twins was unclear from the questionnaire responses, cheek cells were collected from both children, and zygosity was ascertained using DNA testing.

Family income was established by asking mothers to indicate how much total income the household received from all sources before tax in the previous 12 months. For analyses, income was divided into three categories: less than £20,000, between £20,000 and £34,999, and more than £35,000.

Each twin's birth weight was obtained by means of parental recall when the twins were 1 year old. Although parental recall is less accurate than obtaining birth weight directly from hospital records, a recent study reported that 85% of parents of 12–15-year-old children correctly recalled their children's birth weight to within ± 227 g (Walton et al., 2000). These researchers concluded that parental recall of birth weight is a suitable proxy for recorded birth weight.

Expressed emotion maternal warmth toward each twin was measured using procedures adapted from the Five Minute Speech Sample method (Magana, Goldstein, Karno, & Miklowitz, 1986). Trained interviewers asked the mothers to describe their child ("For the next 5 minutes, I would like you to describe [child] to me, what is [child] like?"). Two trained raters coded the expressed-emotion tapes (see Caspi et al., in press, for details). The raters underwent 2 weeks of training in coding procedures, and the same rater was used to code twins in the same family. Interrater reliability was established by having the raters individually code a test-standard audiotape describing 40 children. The interrater agreement was $r = .90$.

Warmth is a global measure of the whole speech sample and was assessed by the tone of voice, spontaneity, sympathy, and/or empathy toward the child. Warmth was coded on a 6-point scale. *High warmth* (5) and *moderately high warmth* (4) were coded when there was definite warmth, enthusiasm, interest in, and enjoyment of the child. For example, "she is a delight, she is so happy, I love taking her out, she is my ray of sunshine." *Moderate warmth* (3) was coded when there was definite understanding, sympathy, and concern but only limited warmth of tone. For example, "I worried about her when she went to school, I thought she may have difficulty in mixing and I felt sorry for her." *Some warmth* (2) was coded when there was a detached and rather clinical approach, with little or no warmth of tone, but moderate understanding, sympathy, and concern. *Very little warmth* (1) was rated when there was only a slight amount of understanding, sympathy, or concern or enthusiasm about or interest in the child. *No warmth* (0) was reserved for respondents who showed a complete absence of the qualities of warmth as defined. The 6-point scale of warmth was recoded into three groups: *low warmth* (0–2), *moderate warmth* (3), and *high warmth* (4–5). Mothers' expressed emotion ratings were obtained for 2,000 (90%) of the twins in the study. Within the sample, 408 (20%) twins had mothers who expressed low warmth toward them, 739 (37%) had mothers who expressed moderate warmth, and 853 (43%) had mothers who expressed high warmth toward them.

Children's ADHD as rated by parents and teachers was measured with 17 items concerning inattention, impulsivity, and hyperactivity derived from the Rutter Child Scales (Sclare, 1997) and the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association, 1994) diagnostic criteria for Attention Deficit Disorder (e.g., "cannot settle to anything for more than a few moments, quickly moves from one thing to another," and "fidgety or squirmy"). The internal consistency reliabilities of the parent and teacher reports were .90 and .93, respectively. The children in the study had a mean ADHD score of 10.38 for mothers' ratings ($SD = 7.49$, range = 0–34) and 5.02 for teachers' ratings ($SD = 6.55$, range = 0–34). The prevalence rate of *DSM–IV*-diagnosed ADHD in the sample was 5.7% overall, 7.9% among VLBW children (<1,501 g), 5.9% among LBW children (< 2,500 g), and 4.8% among NBW children (> 2,500 g). The high extreme ends of the mother and teacher symptom scales captured the diagnosed cases.

Children's IQ was individually measured using a short form of the Wechsler Preschool and Primary Scale of Intelligence—Revised (WPPSI; Wechsler, 1990). Using two subtests (Vocabulary and Block Design), we computed children's IQs following procedures described by Sattler (1992, Table H-7). The children in the study had an average IQ score of 98 ($SD = 14.40$, range = 52–145). The mean IQ was 93 among VLBW children (< 1,501 g), 98 among LBW children (< 2,501 g), and 100 among NBW children (> 2,500 g).

The mean age for mothers at the Age-5 home visit was 33 years ($SD = 5.8$, range = 19–48). The mean number of children in each family was 3.4 ($SD = 1.3$, range = 2–12).

Data Analysis

Hierarchical regression analyses were used to determine the contributions of birth weight, maternal warmth, and the interaction between birth weight and warmth to children's IQ scores and mothers' and teachers' ratings of ADHD. On the first step of the regression equation, maternal warmth and birth weight were entered simultaneously to test for main effects, after controlling for possible confounding child (children's gender and zygosity) and family variables (mothers' age, number of children in family, and social class). On the second step of the equation, the interaction (multiplication) between birth weight and warmth was entered. A significant interaction between birth weight and warmth would provide evidence of a moderating effect of maternal warmth on children's outcomes. In other words, a significant interaction would indicate that the effect of birth weight on children's IQ scores or ADHD ratings is dependent on the level of maternal warmth. The interaction effect was entered into the last step of the equation to determine its unique contribution to variance after the main effects had already been entered. Power to detect an interaction exceeded .80.

Statistical analyses of data about the study children (e.g., measures of child-specific maternal warmth and measures of children's behavior) were complicated by the fact that our twin study contained two children from each family, leading to nonindependent observations. As such, we analyzed data about the study children using standard regression techniques but with all tests and confidence intervals being based on the sandwich or Huber/White variance estimator (Gould & Sribney, 1999), a method that is available in the statistical package STATA 7.0 (StataCorp, 2001). Application of this technique addresses the assumption of independence of observations; it penalizes estimated standard errors and therefore accounts for the dependence in the data that occurs due to analyzing sets of twins.

Results

Table 2 presents bivariate associations between each predictor variable with mothers' and teachers' ratings of ADHD and children's IQ scores (correlation) and also the associations controlling for confounding child and family variables (unstandardized regression coefficients).

ADHD Ratings

For mothers' ratings of ADHD, there were significant main effects for birth weight, $t(940) = 2.28$, $p < .05$, and maternal warmth, $t(940) = 7.81$, $p < .01$, after controlling for the child and family variables. LBWs and lower levels of maternal warmth were associated with higher mothers' ratings of ADHD. The interaction term (Birth Weight × Warmth) was significant in predicting mothers' ratings of ADHD when entered into Step 2 of the equation, $t(940) = 2.48$, $p < .05$. This interaction suggests that there was a moderating effect of maternal warmth on the association between birth weight and mothers' ratings of ADHD. Illustrative values for the moderating effect of maternal warmth on the association between birth weight and mothers' ratings of ADHD are shown in Figure 1. Among children with LBWs, high maternal warmth was associated with fewer ADHD symptoms, whereas low maternal warmth was associated with more ADHD symptoms. This effect was reduced among children with NBWs. Ten percent of the variance was accounted for by the total model, $F(7, 939) = 23.91$, $p < .01$.

For teachers' ratings of ADHD, there was a significant main effect for maternal warmth, $t(891) = 2.53$, $p < .05$, after controlling for possible confounding child and family variables (see Table 2). Lower levels of maternal warmth were associated with higher teacher ratings of ADHD. However, there was no significant main effect for birth weight on teachers' ADHD ratings. On Step 2 of the regression equation, the interaction term (Birth Weight × Warmth) contributed significantly to the variance in teachers' ADHD ratings, $t(891) = 2.42$, $p < .05$. This significant interaction provided evidence of a moderating effect of maternal warmth. Figure 2 illustrates how maternal warmth moderated the association between children's birth weight and teachers' ratings of ADHD. This figure again suggests that, among children with LBWs, high maternal warmth was associated with fewer ADHD symptoms and low maternal warmth was associated with more ADHD symptoms. However, maternal warmth did not appear to influence teachers' ratings of ADHD among children with NBWs. Six percent of the variance was accounted for by the entire model, $F(7, 891) = 8.86$, $p < .01$.

IQ Scores

For children's IQ, there was a significant main effect for birth weight, $t(936) = 3.70$, $p < .01$, and maternal warmth, $t(936) = 3.66$, $p < .01$, after controlling for possible confounding child and family variables. As maternal warmth and birth weight increased in the sample, children's IQ scores also increased. The interaction term (Birth Weight × Warmth) did not contribute significantly to the variance in IQ when entered into Step 2 of the regression equation. This result suggests that maternal warmth did not moderate the effect of birth weight on children's IQ scores. Fifteen percent of the variance in children's IQ scores was accounted for by the entire model, $F(7, 936) = 31.34$, $p < .01$.

Discussion

The findings of the present study provide support for the hypothesis that twins' LBW predicts their greater ADHD symptoms, as reported by mothers, and their lower IQ scores. The findings of this study also support the hypothesis that maternal warmth moderates the effects of birth weight on ADHD symptoms, and this moderating effect applied whether ADHD symptoms were reported by mothers or teachers. However, maternal warmth did not have a moderating effect on children's IQ scores. Taken together, the findings provide evidence that, like singletons, twins with

Table 2
Regression Models Predicting Mothers' and Teachers' Ratings of ADHD and Children's IQ

	Mothers' ratings of ADHD (n = 1,858)			Teachers' ratings of ADHD (n = 1,749)			IQ (n = 1,844)		
Steps and predictor	r[a]	B[b]	*SE*	r	B	*SE*	r	B	*SE*
Step 1									
Mothers' age	−.15***	−0.17***	0.04	−.06**	−0.04	0.05	.20***	0.30***	0.08
No. of children	.06**	0.34	0.18	.03	0.08	0.18	−.14***	−1.47***	0.40
Family social class	.14***	0.59*	0.24	.09***	0.63*	0.26	−.31***	−4.15***	0.52
Twins' zygosity	.01	0.53	0.42	−.01	0.05	0.43	.06**	0.75	0.84
Twins' gender	−.13***	−1.83***	0.41	−.19***	−2.47***	0.41	−.02	0.11	0.83
Birth weight	−.05*	−0.87*	0.38	.01	−0.22	0.37	.12***	2.86***	0.77
Warmth	−.24***	−2.11***	0.27	−.11***	−0.70*	0.27	.15***	1.88***	0.51
Step 2									
Birth Weight × Warmth	-	1.08*	0.44	-	1.14*	0.47	-	−0.87	0.91

Note. From the full sample of 2,232 twins, the N for specific analyses was reduced by approximately 10% by missing data for birth weight, teacher ratings, and maternal warmth. To calculate the beta weights for birth weight, we converted this variable from grams into kilograms. ADHD = attention-deficit/hyperactivity disorder.

[a] r indicates bivariate Pearson correlation between each predictor and ratings of ADHD and IQ score. [b] Regression coefficients (unstandardized) for predictors' main effects are observed in Step 1, controlling for other variables in the model, but before entering the interaction effect.

* $p < .05$. ** $p < .01$. *** $p < .001$.

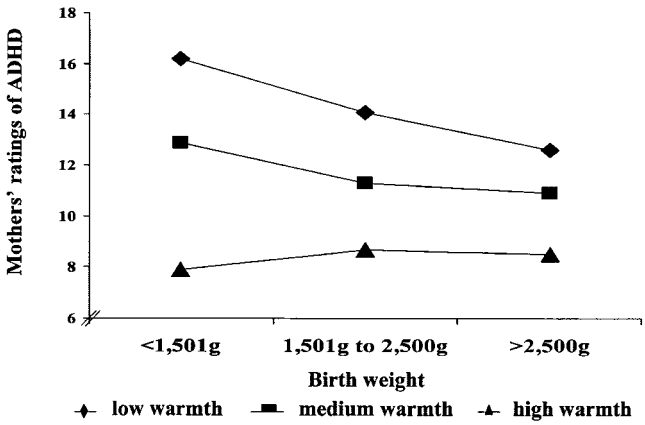

Figure 1. Mothers' ratings of children's attention-deficit/hyperactivity disorder (ADHD) symptoms according to children's birth weight and maternal warmth. For illustrative purposes, we present the interaction effect using groups of birth weight, but the analyses were conducted with a continuous measure of birth weight.

LBWs are biologically susceptible to cognitive difficulties and attention and hyperactivity problems, and these difficulties are apparent as young as 5 years of age. This study also demonstrates that maternal warmth may be important for determining the extent to which birth weight affects children's attention and hyperactivity problems.

The finding that birth weight predicted IQ scores and mother ratings of ADHD supports the findings of numerous studies that have been conducted with singletons of varying ages (Breslau et al., 1994; Breslau et al., 1996; Breslau, Klein, & Allen, 1988; Hack et al., 1992; Levy-Shiff et al., 1994; McCormick et al., 1992; Mick et al., 2002) and extends these findings to twins. Many more twins than singletons are born premature and with LBWs (in fact, half of this nationally representative cohort of twins were LBW), suggesting that as a group of children, twins may be at greater biological risk of cognitive and behavioral problems than singletons. The fact that birth weight did not significantly predict teachers' ratings of ADHD was surprising and contrary to the findings of some previous studies. Szatmari, Saigal, Rosenbaum, Campbell, and King (1990) found that 5-year-old LBW children were at increased risk for ADHD according to teachers' ratings, as did Breslau et al. (1996) with 6-year-old children.

Despite the fact that birth weight did not predict teachers' ratings of ADHD, maternal warmth was found to moderate the effects of LBW on both mothers' and teachers' ratings of ADHD. These findings support those of Laucht et al. (2001), who found that maternal responsivity moderated the effects of LBW on children's inattention and hyperactivity. The Laucht et al. (2001) study took place in Germany, increasing confidence that our findings apply beyond the United Kingdom, although this needs testing. The moderating effect of maternal warmth on the relationship between birth weight and ADHD suggests that high levels of warmth protect LBW children from poor behavioral outcomes and that low levels of warmth exacerbate the behavioral problems associated with LBW. It is possible that mothers who are high in warmth provide a more supportive and caring environment for their LBW twins, which protects them from developing ADHD symptoms. Similarly, LBW children who are exposed to an environment that is low in warmth may receive less positive interaction and stimulation from their mothers, which triggers the development of behavioral problems.

The moderating effect of maternal warmth on the behavioral outcomes of LBW children in the present study is supported by research about the significance of positive parent–child relationships for children generally. Children who experience high levels of warmth or positive interactions with their parents show lower rates of externalizing behavior problems (Bates, Bayles, Bennet, Ridge, & Brown, 1991; Olsen, Bates, Sandy, & Lanthier, 2000; Pettit & Bates, 1989) and ADHD symptoms (Anderson, Hinshaw, & Simmel, 1994; Mash & Johnston, 1982). Thus, it would appear that maternal warmth is no less important for children who are biologically at increased risk of ADHD because of their LBWs and may indeed be crucial for the long-term development of these children.

It is important to note that the present study does not explain how maternal warmth operates as a moderating variable, nor does it address causality of the relationship between birth weight, maternal warmth, and ADHD symptoms. Some unmeasured factor such as prenatal substance abuse may contribute to associations among LBW, low warmth, and ADHD outcome, although this would not negate the protective effect that we observed when LBW coincides with high maternal warmth. It is possible that mothers develop feelings of warmth toward their children in response to the individual characteristics of each child, such as temperamental factors or medical problems that may be associated with LBW. Alternatively, warmth may develop as a result of mothers' preexisting personalities or attitudes (Belsky, 2002). Further research is needed to elucidate the causal relationship between these variables in an effort to understand how maternal warmth moderates the relationship between LBW and children's ADHD symptoms.

In the present study, maternal warmth did not moderate the effect of birth weight on children's IQ scores, suggesting that the

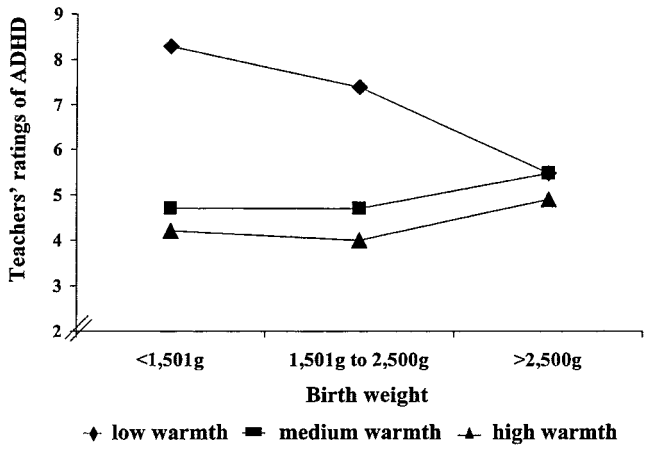

Figure 2. Teachers' ratings of children's attention-deficit/hyperactivity disorder (ADHD) symptoms according to children's birth weight and maternal warmth. For illustrative purposes, we present the interaction effect using groups of birth weight, but the analyses were conducted with a continuous measure of birth weight.

cognitive problems associated with LBW are less influenced by factors in the family environment than are ADHD symptoms. It is possible that for some LBW children, cerebral damage during the neonatal period results in cognitive difficulties that are neither exacerbated nor reduced by maternal attitudes and emotions. However, there may be other factors in the family environment that have a moderating effect on IQ scores, and further research should attempt to identify these. It is important to keep in mind the heterogeneity of LBW children and to recognize that some very premature and small infants have extremely good behavioral and cognitive outcomes. In addition, it is also important to recognize that studies on parenting interventions with LBW infants have demonstrated improvements in children's cognitive abilities (Patteson & Barnard, 1990), suggesting that there are family environmental factors that moderate the relationship between LBW and children's cognitive development.

Despite the lack of research into factors that moderate the effects of LBW on children's development, a large number of early intervention studies have been conducted with premature and LBW infants in recent decades, predominantly during the 1980s. Intervention programs for LBW infants have varied widely in their goals, duration, intensity, format, and theoretical orientation (Dudley, Gyler, Blinkhorm, & Barnett, 1993), but most have shared the same goals: to enhance parents' sensitivity, responsiveness, and care to their vulnerable infants (e.g., Brooks-Gunn, Klabanov, Liaw, & Spiker, 1992; Brooten et al., 1986; Nugent & Brazleton, 1989; Rauh, Achenbach, Nurcombe, Howell, & Teti, 1988). In a review of the literature, Patteson and Barnard (1990) reported that many intervention studies for LBW or premature infants led to significant improvements in children's cognitive development and behavior. These results are encouraging and suggest that interventions for LBW children can be effective. However, advances in neonatal care in recent years have increased the survival rates of even smaller and more vulnerable infants, so samples of LBW children studied presently are likely to differ from those studied in the 1980s. In addition, interventions for LBW children should be based on an empirical evidence base about the factors that exacerbate or reduce the effects of LBW, and, presently, this is not the case. Thus, future research should focus on identifying environmental variables that modify the relationship between LBW and negative long-term outcomes, in order to design effective intervention programs for the current population of LBW children.

Two methodological limitations of the present study must be taken into account when interpreting the findings. The first limitation is that children's birth weights were obtained by means of parental recall and not hospital records. Although one study found parental recall of birth weight to be an adequate proxy for recorded birth weight, it did not include twins, so it is not known whether recall of birth weight for twins is as accurate as it is for singletons (Walton et al., 2000). One study reported very strong reliability for mothers' reports about details of their pregnancies with twins, although twins' birth weight was not studied (Reich, Todd, Joyner, Neuman, & Heath, 2003). Moreover, in Walton et al.'s (2000) study, there was a trend for parents to report their LBW children as being heavier than they actually were, so it is possible that the findings reported in the present study underestimate the true effects of birth weight on children's IQ and ADHD.

The second limitation of the present study is that parental warmth was measured by means of mothers' expressed emotion and not fathers'. It is possible that LBW children with two parents who are high in warmth may show more positive cognitive and behavioral outcomes when compared with children who have only one parent high in warmth. In addition, it is also possible that maternal and paternal warmth have different moderating effects on the relationship between birth weight and children's outcomes. Chen, Liu, and Li (2000) studied a sample of NBW 12-year-olds and found that maternal warmth predicted children's emotional adjustment whereas paternal warmth predicted school achievement. This finding could suggest that paternal warmth may have a different effect on the outcomes of LBW children and that future studies on warmth and birth weight should use a measure of warmth from both mothers and fathers.

The findings of the present study have a number of implications for clinicians working with young children experiencing inattention, hyperactivity, or cognitive difficulties. First, during the assessment interview, clinicians should obtain information about a child's birth weight to determine whether a child is at greater biological risk for long-term problems. Second, for children with LBWs, maternal warmth should be assessed in order to identify children whose biological risk status may be exacerbated by this environmental risk factor. Obtaining information about birth weight and maternal warmth will assist clinicians with hypothesis generation about the factors that cause and maintain a child's problems. Third, families with LBW children whose mothers are low in maternal warmth may benefit from parenting interventions specifically designed to increase the levels of warmth, positive interaction, and responsiveness toward their child. Finally, in order to assess whether the intervention has produced significant improvements in levels of maternal warmth, researchers could conduct the expressed-emotion task used in the present study prior to and following intervention to assess the levels of change in warmth.

In conclusion, the present study demonstrates that LBW has significant effects on IQ and ADHD in school-age twins and that maternal warmth moderates the impact of birth weight on ADHD. Future intervention programs designed to improve behavioral outcomes for LBW children could focus on enhancing maternal warmth as an important goal for intervention. Further research is needed to explore other factors that moderate the impact of LBW on children's cognitive outcomes. Given the increasing survival rates of LBW children and the high health care and educational costs involved in caring for these children, it is essential to continue research that identifies factors in the environment that moderate the relationship between birth weight and poor cognitive and behavioral outcomes. This research is fundamental for designing effective interventions for biologically at-risk children.

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