

# A Population-Based Study of the Effects of Birth Weight on Early Developmental Delay or Disability in Children

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## ABSTRACT

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Improving medical treatment of extremely low-birth-weight infants over the last 20 to 30 years resulted in increased survival rates. The developmental sequela of salvaged infants is of great interest to perinatologists. The primary purposes of the current study were to assess the effect of birth weight (BW) on developmental delay or disability (DDD) in the first three years of life and determine whether there is a BW threshold below which all infants should be evaluated to determine if intervention services for children with DDD should be received. Three statewide databases were merged: 1998 Birth Vital Statistics; 1997–1998 Medicaid eligibility files; and 1998–2001 Children's Medical Services' Early Intervention Program (CMS-EIP) data. Infants who died within the first year of life and plural births were excluded. The final dataset consisted of 170,874 records. A child was determined to have a DDD if a developmental delay, or an established condition, such as sensory impairment, genetic, metabolic, neurological, or severe attachment disorders, was diagnosed through a multidisciplinary evaluation. Logistic regression models were used to relate BW to DDD, controlling for sociodemographic, behavioral, and perinatal variables. Adjusted odds ratios (OR) were calculated to describe the effects of BW on DDD. There was a significant effect of BW on DDD (Adjusted OR = 97.50, 40.01, 15.84, 3.29, 1.39, 1.00, 1.52 for BW categories 450–749, 750–999, 1000–1499, 1500–2499, 2500–2999, 3000–4749, 4750–6050 g, respectively). In these categories, 70%, 56%, 36%, 11%, 4%, 3%, and 6% of surviving singleton infants, respectively, suffered a DDD in their first 3 years of life. Four medical, five sociodemographic, and two behavioral factors were significant in addition to BW. An equation for

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predicting the probability of DDD given these factors was obtained, and its use exemplified. BW is strongly associated with DDD. Over 60% of infants weighing < 1000 g and nearly half (46%) of those weighing < 1500 g at birth are diagnosed with a DDD before 3 years of age. The probability of DDD for a specific infant also varies by sociodemographic, other perinatal, and behavioral factors. The results of this paper suggest that all surviving infants of BW < 1000 g, and perhaps < 1500 g, should be automatically referred for evaluation.

**KEYWORDS:** Low birth weight, morbidity, risk factors

Due to increased survival of low and very low birth weight (BW) infants since 1970, there has been a dramatic decline in infant mortality rates in the United States.<sup>1-3</sup> There is considerable debate about the effect of this increased survival on childhood morbidity rates and also on the wisdom of salvaging the infants who are marginally viable. A question relevant to this debate concerns the relationship of low and very low BWs and the risk of developmental delay or disability (DDD) in early childhood. This issue has been considered previously in the literature but in studies limited by much smaller sample sizes<sup>2-8</sup> or studies considering only a small number of BW groups, not across the entire range of BW values.<sup>3,6,8,9</sup> In this paper, we address this issue in the context of a large population-based cohort study with finely defined BW categories over the entire range of BW values. The goal was to identify a threshold BW, below which, the majority of children suffer a DDD.

Most studies on developmental morbidity have considered one, two, or sometimes, three BW categories<sup>3-6,8,9</sup> but, to the authors' knowledge, none have looked across the entire range of BWs in a fine categorization to determine a threshold for automatic evaluation to determine if services should be received. This paper describes the effect of BW on DDD in early childhood. A suggestion is made for a cut-off BW value under which practitioners should automatically refer infants for evaluation to determine if there is a need for intervention services.

The Individuals with Disabilities Education Act (IDEA-Part C: 20 U.S.C. §§ 1400 et seq.) is a

federal entitlement program that has been implemented in Florida since 1993 via the State Department of Health Children's Medical Services' Early Intervention Program (CMS-EIP). It provides evaluation services for all children, statewide, who are referred by physicians, psychologists, parents, etc., and intervention services for those who are then diagnosed with a DDD in early childhood (birth to 3 years).

Specific questions considered in this study were: (1) What were the population survival percentages by BW? (2) Given survival, what effect did BW have on the odds that a child would have a DDD? (3) What should the threshold BW value be, if any, for all infants to be automatically referred for evaluation to determine if there is a need for intervention services? (4) What effect did certain social demographic, behavioral, and/or perinatal health factors have on a child's chance of developing a DDD?

## POPULATION AND STUDY SAMPLE DESCRIPTION

Three statewide data sets initially were merged to obtain our study population. These data sets were Florida's Birth Vital Statistics (BVS) for 1998, CMS-EIP data for 1998-2001, and Florida Medicaid eligibility data for 1997-1998.

The BVS data set for 1998 contained 195,344 total live births. This data set contains demographic

and perinatal health factors, as well as a measure of tobacco use, for pregnant women who had children born in the state of Florida in 1998.

The CMS-EIP data system maintains information on children who received evaluation or intervention services from Florida's statewide, 16-center referral, evaluation, and early intervention program for children less than or equal to 3 years of age. The CMS-EIP program provides evaluation services to all children referred to them. Evaluators, then, determine whether each referred child is eligible for Part C funded intervention services for those diagnosed with a developmental delay or established disability. Within the CMS-EIP data system there were 9126 children with a diagnosed DDD who were born in 1998.

The Agency for Health Care Administration's Medicaid data set was used for the period of February 15, 1997 to December 31, 1998, that is, the period corresponding to the pregnancy window for births in 1998. Medicaid participation was used as an indicator of poverty. The eligibility standard for Medicaid is 185% of the poverty level, so this determines if a family is classified as "low income."

The three data sets did not contain a common, unique identifier on all records. The BVS data was first merged to the CMS-EIP data and then to the Medicaid data using a deterministic merge strategy developed by Gomatam et al,<sup>10</sup> at the University of Florida. This multi-pass, deterministic merge strategy, with mother's social security number used on the first pass, had a high merge rate when applied to the current data sets. Details of the application of this merge strategy, and a validation of merged results, were discussed in a previous study.<sup>11</sup> The merge rate exceeded 80%. Any BVS record that did not match to a CMS-EIP record or that matched to a record with no DDD diagnosis was assumed to not have a DDD. The final data set that resulted from these merges was the original BVS data set augmented by two attached variables indicating DDD diagnosis (Y/N) and poverty (Y/N).

Three exclusion criteria were applied to this population-based data set: (1) infant deaths, defined as an infant who died within the first year of life; (2)

multiple births; and (3) missing values of BW, sociodemographics, behavioral, or perinatal health factors. Infant deaths were excluded because this study was concerned with morbidity outcomes among survivors. Multiple births, resulting from multiple fetuses of a single pregnancy—for example, twins—and the first of two infants of mothers who gave birth twice in the same year were removed because otherwise assumptions concerning independence between observations would be violated. There were 1514 infant deaths excluded, 5477 observations excluded for dependency, and 17,479 observations excluded because of missing values. After exclusions there were 170,874 mother-infant pairs (87% of the birth cohort) available for analysis. A description of the population and study sample is given in Table 1.

## METHODS

DDD was the early childhood morbidity outcome variable studied. It was defined as a Yes/No indicator of whether a child was diagnosed with a DDD within the 3 three years of life. A positive diagnosis was determined if a child followed one of two paths. Some children were referred for Part C evaluation services if suspected to be at high risk for developmental delay. A referral could be made by anyone (e.g., physician, psychologist, parent) and was followed by an EIP multidisciplinary evaluation, which led to a diagnosed or confirmed DDD (i.e., "Yes"), or no diagnosis of developmental delay (i.e., "No"). A child was determined by an EIP team to have a DDD if the child had a developmental delay (including delayed cognition, physical/motor impairment, lack of communication skills, delayed social/emotional development, or lagging adaptive development) or an established condition placing them at high risk for developmental delay (including sensory impairment, genetic, metabolic, neurological, or severe attachment disorders). Some infants were eligible for evaluation under a different program, that is, Florida's Developmental Evaluation and Intervention program (DEI), if they had been

**Table 1 Comparison of Population and Study Sample**

Variable	Category	N	Total Population				Population of Interest (Total Population Minus IM and Plural Births)				Sample for Statistical Modeling (Population of Interest Minus Missing Values)			
			%	% Survived	% DDD	% Survived and Not DDD	n	%	% DDD	n	%	% DDD	n	%
Total births		195,344	100	99.2	4.7	94.6	188,353	100	4.4	170,874	100	4.2		
PREV	AO	53,658	27.5	99.0	5.3	93.8	51,454	27.3	4.9	42,261	24.7	4.7		
	0	64,306	32.9	99.2	4.3	95.0	62,958	33.4	4.1	61,624	36.1	4.1		
	1-2	65,686	33.6	99.4	4.5	94.9	63,006	33.5	4.2	57,367	33.6	4.1		
	>2	11,689	6.0	99.1	5.0	94.2	10,930	5.8	4.5	9622	5.6	4.2		
PRECARE	No	2202	1.2	95.7	10.0	86.0	2052	1.1	9.8	1618	1.0	9.0		
	Yes	189,892	98.8	99.3	4.6	94.8	183,374	98.9	4.3	169,256	99.0	4.2		
	No	193,555	99.1	99.3	4.5	94.9	186,854	99.2	4.2	169,599	99.3	4.1		
CONG	Yes	1693	0.9	87.5	24.9	63.6	1427	0.8	27.5	1275	0.7	28.3		
COMLAB	No	136,800	70.1	99.5	4.1	95.5	133,343	70.8	3.9	121741	71.2	3.8		
	Yes	58,445	29.9	98.5	6.0	92.6	54,936	29.2	5.5	49,133	28.8	5.3		
MOMEDU	<HS	41,439	21.3	98.9	5.2	93.8	40,179	21.4	4.9	36,391	21.3	4.7		
	HS	67,612	34.8	99.2	4.4	94.9	65,333	34.8	4.2	59,096	34.6	4.1		
	>HS	85,523	43.9	99.5	4.6	94.9	82,167	43.8	4.2	75,387	44.1	4.2		
MSTAT	No	70,917	36.3	98.9	4.9	94.0	68,514	36.4	4.7	61,273	35.9	4.4		
	Yes	124,373	63.7	99.4	4.5	95.0	119,792	63.6	4.2	109,601	64.1	4.1		
MCAID	No	108,645	55.6	99.4	4.4	95.1	104,580	55.5	4.0	95,519	55.9	3.9		
	Yes	86,699	44.4	99.0	5.1	94.0	83,773	44.5	4.8	75,355	44.1	4.6		
MAGE	11-17	9762	5.0	98.4	4.7	93.9	9500	5.0	4.5	8880	5.2	4.3		
	18-19	15,834	8.1	99.0	3.9	95.1	15,420	8.2	3.7	14,119	8.3	3.6		
	20-35	149,767	76.7	99.3	4.6	94.8	144,461	76.7	4.3	131,001	76.6	4.2		
>35	19,929	10.2	99.3	6.0	93.4	18,931	10.1	5.5	16,874	9.9	5.3			

RACE	White	104,186	53.3	99.3	4.8	94.6	100,347	53.3	4.4	91,828	53.8	4.3
	Black	45,835	23.5	98.7	4.9	93.9	43,997	23.3	4.6	39,139	22.9	4.4
	Other	45,323	23.2	99.5	4.2	95.3	44,009	23.4	4.0	39,907	23.3	3.9
SEX	Male	100,189	51.3	99.2	5.8	93.5	96,605	51.3	5.5	87,678	51.3	5.3
	Female	95,154	48.7	99.3	3.5	95.8	91,747	48.7	3.2	83,196	48.7	3.1
BW	450-749	726	0.4	47.5	36.1	13.4	267	0.1	70.4	201	0.1	74.6
	750-999	651	0.3	81.6	51.0	34.1	404	0.2	55.5	306	0.2	57.5
	1000-1499	1545	0.8	93.8	35.7	58.7	1078	0.6	36.4	877	0.5	35.8
	1500-2499	12,624	6.5	98.3	11.2	87.3	9859	5.2	10.8	8571	5.0	10.3
	2500-2999	33,679	17.3	99.5	4.6	95.0	31,862	16.9	4.4	28,632	16.8	4.4
	3000-4749	145,017	74.4	99.8	3.4	96.4	144,044	76.5	3.4	131,573	77.0	3.4
	4750-6050	797	0.4	98.2	5.8	92.5	779	0.4	5.9	714	0.4	5.9
IPI	Means	23.8	23.8	23.8								
CIGPERDAY	Means	1.2	1.2	1.2								

IM, infant mortality; AO, previous "adverse outcome."

cared for in the neonatal intensive care unit of a designated Florida hospital. These children also were evaluated by an EIP team to determine eligibility for Part C intervention services. If the evaluation team diagnosed a DDD, then a "Yes" was indicated in the variable.

BW, sociodemographic factors, prenatal tobacco use, and perinatal factors were studied to assess their effect on a subsequent early childhood DDD. Thirteen variables were chosen for inclusion based on previous studies of the effect of BW or tobacco on developmental or educational outcomes.<sup>12-20</sup> The perinatal health factors were: BW; previous pregnancy experience (PREV); prenatal care (PRECARE); congenital anomalies (CONG); complications of labor or delivery (COMLAB); and interpregnancy interval (IPI). The sociodemographic characteristics included: mother's education level (MOMEDU), mother's marital status (MSTAT), poverty (MCAID), mother's age (MAGE), infant's race (RACE), and infant's sex (SEX). The tobacco variable was the number of cigarettes smoked per day during pregnancy (CIGPERDAY). All of the above variables, except IPI and CIGPERDAY, were considered categorical for this study. PRECARE, CONG, COMLAB, MSTAT, and MCAID were all Yes/No indicator variables. MOMEDU was based on the number of years of completed schooling and had the following categories: less than high school (HS), HS, or greater than HS. PREV had 4 categories: adverse outcome (for women who experienced a previous stillborn or live born that subsequently died, or a previous induced or spontaneous abortion), 0 (= no previous births), 1-2, or > 2 previous births still living and no previous adverse outcomes. MAGE had 4 categories: 11-17, 18-19, 20-35, and greater than 35 years. The categories for RACE were black, white, and other (consisting primarily of Hispanics), and male and female for SEX. BW categories were 450-749, 750-999, 1000-1499, 1500-2499, 3000-4749, and 4750-6050 g. IPI was the number of months from the end of the previous pregnancy to the last menstrual period before the current preg-

nancy. Women with no prior pregnancies were assigned to a separate category, coded in such a way as to allow for separate estimation of the effect of first pregnancy on the DDD outcome.

SAS PROC GENMOD (a procedure in the SAS software package used to model generalized linear models) was utilized to fit a main effects model involving all independent variables with a segmented linear function of IPI with a change point at 60 months. The change point of 60 months was a rounded value obtained from a previous study. It was determined by fitting a sequence of models with change points at 1, 2, . . . , 319 months and choosing the one that provided the best fit to the data (i.e., the one with the minimum deviance).

A binomial error distribution was assumed and a logit link was used to fit the model. Adjusted odds ratios (ORs), defined as a category's estimated odds over the estimated odds of the reference category, were calculated from the main effects model for significant effects. Ninety-five percent confidence intervals were calculated for these adjusted ORs. The following reference categories were used in the calculations: > 2 and an IPI of 60 months for PREV, "Yes" for PRECARE, "No" for CONG, "No" for COMLAB, greater than HS for MOMEDU, "Yes" for MSTAT, "No" for MCAID, 20-35 for MAGE, white for RACE, female for SEX, 0 cigarettes per day for CIGPERDAY, and 3000-4749 g for BW.

## RESULTS

Table 1 shows that the sample for statistical modeling, the population of interest, and the total population had similar profiles with respect to perinatal health factors, sociodemographic characteristics, and BW distribution. Also, descriptive statistics in the population of interest (i.e., surviving singletons) were similar to those in the sample after deletion of missing values. Thus, there is no evidence of a selection bias in the sample for statistical modeling. Note that the percentages of DDD are given for

the sample for statistical modeling, the population of interest, and the total population for comparison purposes; however, the percentages of DDD among the population of interest are most relevant because they are based on the most information.

Table 1 also shows survival percentages and percentages of singleton born survivors with early DDD in each of the three BW categories of particular interest, which were, respectively, 47.5% and 70.4% in the 450–749 g category; 81.6% and 55.5% in the 750–999 g category; 93.8% and 36.4% in the 1000–1499 g category; and 99.8% and 3.4% in the reference category (i.e., 3000–4749 g). Weighted average calculations show that 61% of surviving infants weighing < 1000 g and 46% of those weighing < 1500 g were diagnosed with a DDD in the first 3 years of life. The fitted main effects model and an example for calculating the model-based estimated probability of DDD are given in the Appendix 1.

The model-based estimates of the effects of different BW categories on developmental morbidity are presented in Table 2 in the form of adjusted ORs. It demonstrates a significant increase in morbidity with a decrease in BW. The lowest BW group,

**Table 2 Effects of Birth Weight on DDD**

BW Category	Adjusted Odds Ratio	95% Confidence Interval
450–749	97.50	(70.37, 135.11)
750–999	40.01	(31.59, 50.68)
1000–1499	15.84	(13.66, 18.36)
1500–2499	3.29	(3.04, 3.56)
2500–2999	1.39	(1.30, 1.48)
3000–4749	1.00	Reference Category
4750–6000	1.52	(1.11, 2.08)

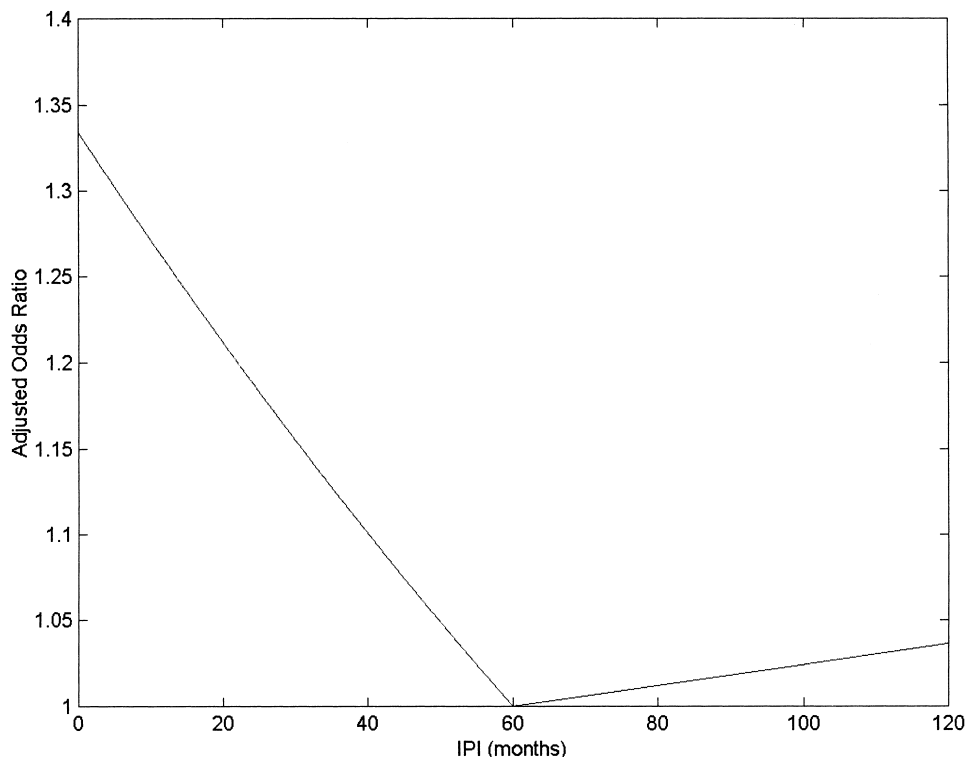
450–749 g, had an adjusted OR of 97.50, compared with the reference BW group, 3000–4749 g.

The OR for measuring the effect of three packs of cigarettes per day was 1.52 (95% confidence interval (CI) = (1.09, 2.12) compared with the reference group of no cigarettes. The OR for measuring the effect of two packs per day was 1.32 (CI = 1.06, 1.65), with a 12.9% incidence of early DDD, compared with the reference group with a 3.8% incidence of early DDD.

Table 3 summarizes the significant effects of perinatal health factors on early developmental morbidity. Perinatal health factors consisting of pre-

**Table 3 Effects of Perinatal Health Factors and Sociodemographics on DDD**

Variable	Category	Reference Category	Adjusted Odds Ratio	95% Confidence Interval
PREV	AO	>2 and IPI = 60	1.12	(1.00, 1.26)
	0	>2 and IPI = 60	1.21	(1.06, 1.38)
	1–2	>2 and IPI = 60	1.11	(1.00, 1.25)
PRECARE	No	Yes	1.51	(1.25, 1.83)
CONG	Yes	No	8.05	(7.06, 9.19)
COMLAB	Yes	No	1.15	(1.09, 1.21)
MOMEDU	<HS	>HS	1.04	(0.96, 1.12)
	HS	>HS	0.91	(0.86, 0.97)
MSTAT	Unmarried	Married	0.98	(0.92, 1.04)
MCAID	Yes	No	1.18	(1.11, 1.25)
RACE	Black	White	0.86	(0.79, 0.92)
	Other	White	0.88	(0.83, 0.94)
SEX	Male	Female	1.86	(1.77, 1.96)
MAGE	11–17	20–35	0.84	(0.74, 0.96)
	18–19	20–35	0.76	(0.69, 0.85)
	>35	20–35	1.25	(1.16, 1.36)



**Figure 1** Effect of IPI on DDD adjusted for BW and sociodemographic variables for women who had more than two children.

natal care, complications of labor and delivery, previous pregnancy experience, and congenital anomalies were all statistically related to DDD. The highest OR was for congenital anomalies (OR = 8.05, CI = 7.06, 9.19). Detrimental effects were observed for no prenatal care (OR = 1.51, CI = 1.25, 1.83) and complications of labor or delivery (OR = 1.15, CI = 1.09, 1.21). The detrimental effect of being first-born was seen in the OR for the level PREV = 0 (OR = 1.21, CI = 1.06, 1.38). A first-born infant had higher odds of having a DDD than an infant whose mother had > 2 previous children and an IPI of 60 months (reference category).

Table 3 also summarizes the significant effects of the sociodemographic characteristics. The significant factors were: male infant (OR = 1.86, CI = 1.77, 1.96) and maternal poverty (OR = 1.18, CI = 1.11, 1.25). Both had detrimental effects. There were protective effects for black race (OR = 0.86, CI = 0.79, 0.92) and other race (OR = 0.88, CI = 0.83, 0.94).

There were protective effects for maternal age 11–17 (OR = 0.84, CI = 0.74, 0.96) and 18–19 (OR = 0.76, CI = 0.69, 0.85), and a detrimental effect for maternal age > 35 (OR = 1.25, CI = 1.16, 1.36). There was a slight protective effect for maternal education level equal to HS (OR = 0.91, CI = 0.86, 0.97). For previous pregnancy experience of > 2 children and an IPI of < 60 months, there was a significant protective effect for each unit increase (i.e., 1 month) in IPI (OR = 0.995, CI = 0.993, 0.997). Adjusted ORs for each value of IPI from 1 to 120 months, relative to 60 months, are plotted in Figure 1.

## DISCUSSION

This study found a dramatic increase in DDDs in children  $\leq$  to 3 years of age with decreasing BW. The high percentages of DDD in the lowest BW

categories (70%, 56%, and 36% for 450–749 g, 750–999 g, and 1000–1499 g, respectively) demonstrate that very low BW is a strong predictor of early childhood morbidity. These results suggest a need for further research to assess morbidity rates among these infants at later ages and their quality of life. As advances in medical technology continue to lower the limits of viability, parallel research on morbidity rates among salvaged survivors will produce valuable information for continuing discussions on prudent guidelines for care of marginally viable infants.

The high percentage of low BW infants diagnosed with DDD also suggests that such infants should be routinely referred for EIP or Part C evaluation services. The current criteria require diagnosis of a developmental delay or an established medical/neurological condition that places the child at high risk for developmental delay. This system is not flawless in catching all children with a DDD. Therefore, there could be a possible underestimation of children with a DDD. The fine gradation of BW categories in this study allowed the identification of a threshold that could be used as a criterion for automatic referral to CMS-EIP for evaluation services. The fact that 61% of all surviving singleton newborns weighing < 1000 g were diagnosed with a DDD indicates that this category of low BW is at high risk for developing DDD and should, at the very least, be automatically evaluated to determine if services should be received. In the next category of low BW, 1000–1499 g, 36% were diagnosed with a DDD, with a total of 46% of surviving singleton infants < 1500 g, having a DDD. Thus, depending on the cut-off percentage for high risk, this group could also be considered at risk for DDD and thus should be automatically evaluated. The overall conclusion is that BWs < 1000 g, and possibly < 1500 g, puts infants at high risk for DDD and therefore automatically should make children eligible for evaluation to determine if EIP intervention services are needed. The determination of this threshold was possible only because this was a large ( $n = 170,874$ ) population-based study using a fine

categorization across all BW values. Although the generalizability of this study's results cannot be guaranteed, the fact that it is a statewide population-based study in the country's fourth largest state enhances that likelihood.

The results of the perinatal, behavioral, and sociodemographic factors were largely as expected. The independent effects of each sociodemographic factor, except for marital status, were statistically significant and in several instances equaled or exceeded those of some perinatal health factors. The expected findings concerning the perinatal factors are still useful to practitioners who can further reinforce the importance of these factors to their patients.

The fitted model in the Appendix to this paper could be used to more specifically estimate the probability of DDD for individual infants, given BW, PREV, PRECARE, CONG, COMLAB, MOMEDU, MSTAT, MCAID, MAGE, RACE, SEX, IPI, and CIGPERDAY. This estimated probability could be used to assess a child's risk of DDD and, with a threshold value, as a guide for referral decisions in a more precise manner than suggested above using BW alone.

A new finding in this paper is that black race had a protective effect on early developmental morbidity. This result is consistent with a similar previous finding of a significant protective effect of black race on physical impairment and nearly significant protective effects for sensory impairment and learning disabilities,<sup>21</sup> and the fact that cognitive developmental delays are not evident early but are acquired with age.<sup>19,22</sup> The protective effect of other race (mostly Hispanic) has been previously documented,<sup>23,24</sup> but contradicts other findings elsewhere in the literature where Hispanic ethnicity is thought to have a detrimental effect.<sup>4</sup> The findings in this paper concerning race were, perhaps, evident only when controlling for many potentially confounding variables. One cannot rule out the possibility that differential referral rates contributed to the protective effect of black and Hispanic rates. It would be interesting to determine in a future study whether white children are

referred for EIP evaluation in higher percentages than blacks or Hispanics.

Contrary to prevailing perception, there was a significant protective effect of young maternal age on early DDD. This result was consistent with the findings of Gueorguieva et al<sup>25</sup> who showed that although teen age appeared to have a detrimental effect on educational disabilities (i.e., special education placement) in kindergarten when related factors (e.g., maternal education level) were not adjusted, it had a protective effect when potentially confounding variables were controlled.

The findings concerning young maternal age and race highlight the advantages of conducting a multivariable analysis. Statistical modeling, such as that employed in this study, allows the investigation of each factor's effect, unconfounded by other factors in the model. This technique allows one to assess the independent effects of interrelated risk factors such as race, poverty, maternal age, maternal education, and marital status. In the current study, the ORs measuring the effects of each factor were adjusted for the effects of all other factors studied.

When controlling for spacing (IPI), mothers with no previous parenting experience carried an elevated risk of a child having a DDD (OR = 1.21, CI = 1.06, 1.38), compared with mothers with more than two children who presumably have greater child-rearing and parenting experience. This result is contrary to the advantageous outcomes usually reported for first-borns, ignoring spacing of births. Figure 1 illustrates that with increasing IPI, the odds of a child having a DDD decreases, up to 60 months. This finding suggests that increasing spacing of pregnancies has a beneficial effect on children's development. The benefit of increased spacing may result from the fact that the older the previous child is, the more attention mothers can devote to the newborn, particularly if the older siblings are of school age.

It is noteworthy that previous pregnancy adverse outcome (AO)—that is, stillborn, induced or spontaneous abortion, a liveborn who died—had only a mild effect on the odds of having a DDD

child. In previous studies<sup>26,27</sup> women who had a previous AO were at higher risk for unfavorable infant birth outcomes (i.e., low BW, very low BW, infant mortality, and postneonatal mortality).

To summarize, a significant association was found between low BW, prenatal tobacco use, interpregnancy interval, perinatal health factors, and sociodemographic characteristics and DDD in children < 3 years of age. Specifically, there were increased odds of a diagnosed DDD among low BW infants and among infants in the heaviest BW category. Nearly half (46%) of very low BW infants (< 1500 g) and almost two thirds (61%) of extremely low BW infants (< 1000 g) were diagnosed with a DDD before the age of 3. Additional research on the sequelae of early DDD should continue as these children move through our health and education systems. Studying the impact of early intervention programs on children's subsequent academic performance is needed. The results of this future research will make important contributions to the ongoing debate on the morbidity, development, and long-term outcome of extremely low, very low, and low BW infants. Furthermore, these results have immediate public health implications because they suggest that extremely low BW, and perhaps even very low BW, should result in automatic referral for IDEA-Part C evaluation services.

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## APPENDIX 1: FORMULA TO CALCULATE PREDICTED PROBABILITY OF DDD FROM FITTED MODEL

### Fitted Model

$\hat{\Pr}(\text{DDD} \mid \text{explanatory variables}) = \frac{e^{\hat{lp}}}{1 + e^{\hat{lp}}}$ , where

$$\begin{aligned} \hat{lp} = & -4.0294 + 0.1130 * I(\text{PREV} = \text{AO}) + \\ & 0.1903 * I(\text{PREV} = 0) + 0.1064 * I(\text{PREV} = 1-2) + \\ & 0.4150 * I(\text{PRECARE} = \text{No}) + 2.0861 * I(\text{CONG} = \\ & \text{Yes}) + 0.1357 * I(\text{COMLAB} = \text{Yes}) + 0.0370 * \\ & I(\text{MOMEDU} = < \text{HS}) - 0.0925 * I(\text{MOMEDU} = \\ & \text{HS}) - 0.0212 * I(\text{MSTAT} = \text{No}) + 0.1628 * \\ & I(\text{MCAID} = \text{Yes}) - 0.1722 * I(\text{MAGE} = 11-17) - \\ & 0.2711 * I(\text{MAGE} = 18-19) + 0.2264 * I(\text{MAGE} \\ & > 35) - 0.1563 * I(\text{RACE} = \text{B}) - 0.1279 * I(\text{RACE} \\ & = \text{O}) + 0.6203 * I(\text{SEX} = \text{M}) + 4.5799 * I(\text{BW} = \\ & 450-749) + 3.6892 * I(\text{BW} = 750-999) + \\ & 2.7623 * I(\text{BW} = 1000-1499) + 1.1907 * I(\text{BW} = \\ & 1500-2499) + 0.3282 * I(\text{BW} = 2500-2999) + \\ & 0.4179 * I(\text{BW} = 4750-6050) - 0.0048 * (I(\text{IPI} < 60) * \\ & I(\text{PREV} \neq 0) * I(\text{IPI} < 60) + 0.0055 * (I(\text{IPI} < 60) * \\ & I(\text{PREV} \neq 0) * I(\text{IPI} \geq 60) + 0.0070 * \text{CIGPERDAY}, \end{aligned}$$

and  $I(\text{“event”}) = 1$  if “event” occurred, 0 otherwise. So, for example,  $I(\text{PREV} = 0) = 1$  when a mother has no previous pregnancy experience, 0 otherwise.

### Example Calculation

The predicted probability of DDD, given BW = 450–749 g, PREV = 0, PRECARE = Yes, CONG = No, COMLAB = No, MOMEDU = HS,

MSTAT = Yes, MCAID = No, MAGE = 11–17, RACE = O, SEX = F, and CIGPERDAY = 60 is calculated as:

$$\hat{\Pr}(\text{DDD} \mid \text{explanatory variables}) = \frac{e^{\hat{lp}}}{1 + e^{\hat{lp}}}, \text{ where}$$

where  $\hat{lp}$  for the given settings of covariates in this example  $\hat{lp}$  is =  $-4.0294 + 0.1130 * 0 + 0.1903 * 1 + 0.1064 * 0 + 0.4150 * 0 + 2.0861 * 0 + 0.1357 * 0 + 0.0370 * 0 - 0.0925 * 1 - 0.0212 * 0 + 0.1628 * 0 - 0.1722 * 1 - 0.2711 * 0 + 0.2264 * 0 - 0.1563 * 0 - 0.1279 * 1 + 0.6203 * 0 + 4.5799 * 1 + 3.6892 * 0 + 2.7623 * 0 + 1.1907 * 0 + 0.3282 * 0 + 0.4179 * 0 - 0.0048 * (I(\text{IPI} < 60) * 0) + 0.0055 * (I(\text{IPI} < 60) * 0 + 0.0070 * 60 = -4.0294 + 0.1903 - 0.0925 - 0.1722 - 0.1279 + 4.5799 + 0.0070 * 60 = 0.77.$

Thus, for this example  $\hat{\Pr}(\text{DDD} \mid \text{explanatory variables}) = \exp(0.77) / [1 + \exp(0.77)] = 0.68.$

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