Developmental Trajectories of Body Mass Index in Early Childhood and Their Risk Factors

An 8-Year Longitudinal Study

Laura E. Pryor, MSc; Richard E. Tremblay, PhD; Michel Boivin, PhD; Evelyne Touchette, PhD; Lise Dubois, PhD; Christophe Genolini, PhD; Xuecheng Liu, PhD; Bruno Falissard, MD, PhD; Sylvana M. Côté, PhD

Objectives: To identify groups of children with distinct developmental trajectories of body mass index (BMI), calculated as weight in kilograms divided by height in meters squared, between the ages of 5 months and 8 years and identify early-life risk factors that distinguish children in an atypically elevated BMI trajectory group.

Design: Prospective cohort study.

Setting: Families with a child born between October 1997 and July 1998 in the province of Quebec, Canada.

Participants: A representative sample of children (N=2120) selected through birth registries for the Quebec Longitudinal Study of Child Development. Children for whom BMI data were available for at least 5 time points were retained in the present study (n=1957).

Main Exposures: Early-life factors putatively associated with BMI, assessed by maternal report.

Outcome Measure: Group-based trajectories of children's BMI, identified with a semiparametric modeling method from raw BMI values at each age.

Results: Three trajectories of BMI were identified: low-stable (54.5% of children), moderate (41.0%), and high-rising (4.5%). The high-rising group was characterized by an increasing average BMI, which exceeded international cutoff values for obesity by age 8 years. Two maternal risk factors were associated with the high-rising group as compared with the low-stable and moderate groups combined: maternal BMI (odds ratio, 2.38; 95% confidence interval, 1.38-4.54 for maternal overweight and 6.33; 3.82-11.85 for maternal obesity) and maternal smoking during pregnancy (2.28; 1.49-4.04).

Conclusions: Children continuing on an elevated BMI trajectory leading to obesity in middle childhood can be distinguished from children on a normative BMI trajectory as early as age 3.5 years. Important and preventable risk factors for childhood obesity are in place before birth.

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Author Affiliations are listed at the end of this article.

THE HYPOTHESIS OF THE FEtal origin of obesity has been stated repeatedly during the past 2 decades,[1-5] but results from longitudinal studies are only starting to appear. For instance, in a large cohort study[6] of 8234 children in the United Kingdom, 25 early-life risk factors for obesity were examined. Eight were identified as being associated with an increased risk for obesity at age 7 years, including parental obesity, high birth weight, "catch-up growth," higher weight gain in the child's first year, higher SD score for weight at 8 and 18 months, longer time spent watching television at age 3 years, early adiposity rebound, and short sleep duration.[6] Other studies have identified maternal smoking during pregnancy,[7] the absence or reduced length of breastfeeding,[8,9] and young maternal age[10] as being associated with child obesity. One important limitation that is apparent in many studies examining early-life risk factors for obesity is their lack of a developmental perspective. Indeed, in most studies, the obesity outcome is an assessment of body mass index (BMI) at a single time point.

Studies evaluating the potential heterogeneity in the development of BMI during childhood are needed to describe the normative and atypical patterns that may emerge early in life. To our knowledge, only 1 study has done so while looking at the associated early-life risk factors. Li and colleagues[11] used 6 assessment points (age 2, 4, 6, 8, 10, and 12 years) and identified 3 developmental trajectories of overweight status among a representative US sample (N=1739): early onset (age 2 years, 10.9%), late onset (age 6 years, 5.2%), and never overweight (83.9%). This study provided useful information on the ages at which 2 pathologic BMI trajectories emerged. However, the role of rapid early infancy weight gain was not examined. This is an important factor to consider given evidence of its association with later development of increased levels of adiposity.[12-14]

The aims of the present study were 2-fold. The first was to provide new information on the childhood development of obesity by identifying children with normative vs atypically elevated trajectories of BMI, using repeated measures of height and weight from 5 months to 8 years, among a Canadian population sample. The second was to identify perinatal factors associated with membership in the atypically elevated developmental group.

METHODS

PARTICIPANTS

The present study is a secondary analysis of data drawn from the Quebec Longitudinal Study of Child Development.[15] A random population sample of families with an infant aged approximately 5 months in 1998 was recruited via the Quebec Master Birth registry of the Ministry of Health and Social Services. A stratified 3-stage sampling design was used. The initial target sample of 2917 families was representative of the Quebec population of families with a 5-month-old singleton infant in 1998 residing in each geographic area of Quebec, with the exception of Northern Quebec, Cree territory, and aboriginal reserves. This sample was reduced to 2120 because of nonresponse, inability to contact, or not meeting study criteria. The resulting 2120 families were monitored yearly until the child was aged 8 years. Trained interviewers conducted yearly interviews in the home with the person most knowledgeable about the child (mother in 98.0% of the cases). At every time of data collection, informed written consent was obtained from all participating parents.

Of the 2120 participants in the initial sample, we chose to include in the present study only those with 5 or more time points that included height and weight data. This incurred 7.7% attrition. The 1957 families included in the trajectory group estimations differed from the 163 families that were excluded in the proportions of female children (49.7% vs 41.1%), families with insufficient income (22.1% vs 55.6%), and mothers without a high school diploma (17.1% vs 30.9%).

MEASURES

Outcome Variable: Group-Based Trajectories of BMI

Measures of height and weight were obtained during yearly interviews, through maternal report, when the child was aged 5 months through 5 years and by anthropometric measurement by a trained interviewer[16,17] at ages 6, 7, and 8 years. The BMI was calculated as weight in kilograms divided by height in meters squared.

Independent Variables

Child Characteristics. Birth weight (categorized as <2500 g, 2500-4000 g, or >4000 g)[18,19] and gestational age (categorized as <37 weeks or ≥37 weeks)[6,19] were obtained from hospital records. Birth rank was categorized as first, second, or third or lower.[6,11]

Temperament at 5 months was measured using 7 items from the Infants Characteristics Questionnaire.[20] Mothers' responses were standardized to a 10-point scale, with higher values representing a more difficult child temperament. Early weight gain was expressed as the difference between weight at 5 months and weight at birth, divided by age (5 months). A dichotomous variable for rapid early weight gain coded the highest 40% of these values as 1 and the rest as 0.[21]

Maternal Health Behaviors and Characteristics. Smoking during pregnancy indicated whether the mother reported smoking (1) or not (0) during pregnancy. Maternal BMI was calculated when the baby was aged 17 months and was categorized as normal/low (BMI, <25), overweight (BMI, 25-29.9), or obese (BMI, ≥30).[22] Maternal depressive symptoms at 5 months were assessed using an abbreviated 12-question Center for Epidemiologic Studies Depression Scale.[23,24] Responses were standardized to a 10-point scale, with higher values representing more severe depressive symptoms. Breastfeeding (exclusive or not) was assessed when the child was 17 months, and a 3-category breastfeeding variable was created (did not breastfeed, 2; breastfed for <3 months, 1; and breastfed for ≥3 months, 0).[9,25] Mother's age at the birth of her first child was obtained by maternal report and was kept in its continuous form. Maternal immigrant status was obtained by asking the mother whether she or her child was an immigrant (yes, 1; or no, 0).

Family Socioeconomic Status and Functioning. Maternal education and insufficient household income were measures of family socioeconomic status. Maternal education indicated whether the mother had (0) or did not have (1) a high school diploma. Insufficient household income at 5 months (sufficient, 0; or not sufficient, 1) was calculated according to Statistics Canada's[26] low-income cutoffs, which consider family income in the past year, number of individuals in the household, and family location of residence. Family functioning at 5 months was assessed with the 12-item General Functioning subscale of the McMaster Family Assessment Device[27,28] and was standardized to a 10-point scale, with higher variables on the scale representing less functional households. This scale measures the functionality of the family (eg, "there are lots of bad feelings in our family," "in times of crises, we can turn to each other for support," and "we don't get along well together").

ANALYSES

Group-based developmental trajectories from 5 months to 8 years were identified using a semiparametric mixture model[29] in a trajectory model program (SAS Proc Traj).[30] The Bayesian information criterion was used to select the number of trajectory groups that best fit the data. We chose to estimate each possible combination of trajectory shapes (curvilinear, quadratic, or cubic) in a 2-, 3-, and 4-trajectory model to identify the model maximizing the Bayesian information criterion and maintaining parsimony. The model was determined without a priori hypotheses regarding the existence of distinct trajectories, their number, or shape.

The 2 main outputs from the trajectory model estimation are the shape of each group's trajectory and the probabilities of group membership.[31] The program uses the latter to classify individuals into the trajectory groups.

Trajectory models were estimated separately for each sex, and the resulting curve measurements were examined to identify potential differences in either the levels or the developmental patterns of BMI.

Bivariate associations between trajectory groups and risk factors were estimated with χ^2 tests ($\alpha < .1$) for categorical variables and analysis of variance F tests for continuous variables (**Table 1**). Variables in which a significant bivariate association was found ($P \leq .10$) were retained in the final multivari-

Table 1. Descriptive Data on Maternal and Family Characteristics[a]

Variable	Trajectory Group: Low-Stable (n=1066)	Moderate (n=811)	High-Rising (n=80)	Total Sample (N=1957)	*P* Value[b]	Missing Data, No.
Child characteristics						
Obese child by age, y						
2.5	16 (1.5)	93 (11.5)	21 (26.3)			126
3.5	4 (0.4)	57 (7.0)	26 (32.5)			143
4.5	1 (0.1)	49 (6.0)	31 (38.8)			108
5	7 (0.7)	44 (5.4)	45 (56.3)			734
6	0	9 (1.1)	42 (52.5)			787
7	1 (0.1)	6 (0.7)	61 (76.3)			479
8	0	16 (2.0)	50 (62.5)			612
Race, white	1004 (94.2)	744 (91.7)	72 (90.0)	**1820** (93.0)	.06	8
Female sex	581 (54.5)	350 (43.2)	42 (52.5)	**973** (49.7)	<.001	0
Birth weight, g						
<2500	40 (3.8)	28 (3.5)	1 (1.3)	**69** (3.5)		
2500-4000	943 (88.5)	637 (78.5)	72 (90.0)	**1652** (84.4)	<.001	11
>4000	79 (7.4)	139 (17.1)	7 (8.8)	**225** (11.5)		
Birth rank						
First	476 (44.7)	370 (45.6)	33 (41.3)	**879** (44.9)		
Second	412 (38.6)	325 (40.1)	36 (45.0)	**773** (39.5)	.40	0
≥Third	178 (16.7)	116 (14.3)	11 (13.8)	**305** (15.6)		
Gestational age <37 wk	38 (3.6)	51 (6.3)	4 (5.0)	**93** (4.8)	.02	0
Temperament, mean (SD)[c]	2.73 (1.65)	2.72 (1.59)	2.67 (1.66)	2.72 (1.62)	.93	8
Early weight gain in quintiles						
1, Lowest	238 (22.3)	115 (14.2)	14 (17.5)	**367** (18.8)		
2	235 (22.0)	151 (18.6)	8 (10.0)	**394** (20.1)		
3	216 (20.3)	165 (20.3)	18 (22.5)	**399** (20.4)	<.001	31
4	203 (19.0)	164 (20.2)	15 (18.8)	**382** (19.5)		
5, Highest	159 (14.9)	204 (25.1)	21 (26.3)	**384** (19.6)		
Maternal characteristics/behaviors						
BMI						
<25	787 (73.8)	542 (66.8)	31 (38.8)	**1360** (69.5)		
25-29.9	181 (17.0)	155 (19.1)	21 (26.3)	**357** (18.2)	<.001	44
≥30	75 (7.2)	94 (11.6)	27 (33.8)	**196** (10.0)		
Smoked during pregnancy	251 (23.5)	204 (25.2)	35 (43.8)	**490** (25.0)	<.001	10
Breastfeeding duration						
0	294 (27.6)	232 (28.6)	24 (30.0)	**550** (28.1)		
≤3 mo	320 (30.0)	240 (29.6)	27 (33.8)	**587** (30.0)	.83	11
>3 mo	444 (41.7)	337 (41.6)	28 (35.0)	**809** (41.3)		
Age at first child's birth, mean (SD)[c]	26.93 (9.70)	26.41 (7.60)	26.21 (10.13)	26.69 (8.91)	.41	48
Depression, mean (SD)[c]	1.36 (1.31)	1.40 (1.35)	1.44 (1.16)	**1.38** (1.32)	.77	6
Immigrant	95 (8.9)	85 (10.5)	11 (13.8)	**191** (9.8)	.25	2
SES and family functioning						
Insufficient family income	220 (20.6)	178 (22.0)	28 (35.0)	**426** (21.8)	.01	28
Mother did not complete HS	182 (17.1)	129 (15.9)	24 (30.0)	**335** (17.1)	.01	2
Family functioning, mean (SD)[c]	1.70 (1.49)	1.62 (1.39)	1.98 (1.36)	1.68 (1.45)	.08	15

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); HS, high school; SES, socioeconomic status.
[a] Data are presented as number (percentage) of children unless otherwise indicated.
[b] *P* value determined using χ^2 test or analysis of variance *F* test.
[c] For continuous variables, mean (SD) for each trajectory group and significance from analysis of variance *F* test are reported.

ate basic model. Logistic regression analyses were used to examine the capacity of the risk factors to distinguish membership in the atypically elevated trajectory group vs the other groups while controlling for the levels of the other risk factors. Each variable that had been excluded because of a high *P* value in bivariate analysis was entered one-by-one into the basic logistic model to verify any potential effects. The final logistic regression analysis included 1849 children.

WEIGHTING

Weighted scores were used in the regression model in an attempt to approximate the initial target population in terms of demographic characteristics. Each individual in the sample was given a weight that was inversely proportional to the probability of being drawn from the population given certain demographic characteristics.[15]

RESULTS

BMI TRAJECTORY MODELS

Three distinct groups were identified (**Figure**): low-stable BMI (54.5% of the children), moderate BMI

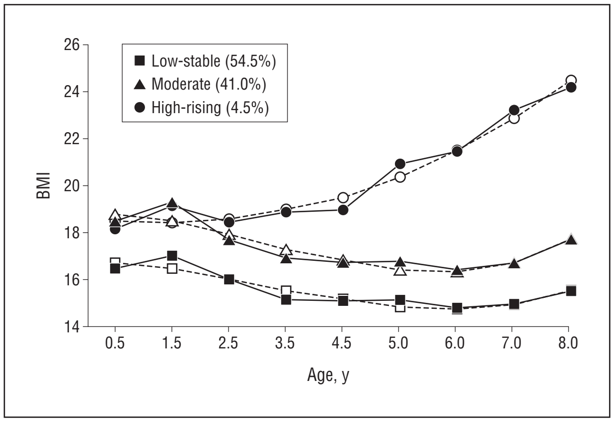

Figure. Body mass index (BMI) trajectory groups (with BMI calculated as weight in kilograms divided by height in meters squared). Solid lines represent observed values, and dashed lines represent expected values.

(41.0%), and high-rising BMI (4.5%). The moderate and low-stable trajectory groups showed a similarly shaped developmental pattern, with BMI values of the moderate group being higher at each time point. The high-rising trajectory was not distinguishable from the other 2 groups between age 5 months and 2.5 years. Between 3.5 and 8 years, children in the high-rising group exhibited increasingly higher BMI, reaching a mean BMI of 24 at 8 years. From 5 years onward, the high-rising group was composed of more than 50% of children with BMI values exceeding the cutoff value for obesity defined by the International Obesity Task Force[22] (Table 1).

We identified differences in the proportions, but not the patterns, of the BMI trajectories modeled separately by sex. As a result, we modeled the development of BMI with the 2 sexes in the same model and controlled for sex in multivariate analyses.

EARLY-LIFE PREDICTORS OF BMI TRAJECTORY GROUP MEMBERSHIP

The children in the present cohort were approximately half girls and predominantly white (93.0%), with 21.8% of families lacking a sufficient income and 17.1% of mothers not completing high school (Table 1). Variables significantly associated with BMI trajectories in bivariate analysis included child's sex, birth weight, gestational age, and average early weight gain; mother's BMI, not completing high school, and smoking during pregnancy; insufficient family income; and low family functioning.

In multivariate logistic regression analyses, 2 maternal characteristics had statistically significant odds ratios (ORs) (**Table 2**). A child with a mother who was overweight or obese or who smoked during pregnancy was more likely to be a member of the high-rising trajectory group compared with the combined low-stable and moderate groups. For maternal BMI, this relationship was graded, with an adjusted OR of 2.38 for overweight and 6.33 for obesity. Maternal smoking during pregnancy had an adjusted OR of 2.28. We did not see a significant difference in the results with the addition of any of the variables that had been excluded from the final model.

Table 2. Logistic Regression Analysis of the Association Between Early Childhood Risk Factors and the High-Rising BMI Trajectory in 1849 Children

	High-Rising vs Other Trajectory
Variable	Adjusted OR (95% CI)
Child	
Early weight gain	
Upper 40%	1.51 (0.93-2.55)
Lower 60%	1 [Reference]
Gestational age, wk	
<37	1.28 (0.51-3.41)
≥37	1 [Reference]
Birth weight, g	
<2500	0.76 (0.22-2.71)
2500-4000	1 [Reference]
>4000	1.08 (0.48-2.44)
Sex	
Boy	0.89 (0.54-1.43)
Girl	1 [Reference]
Maternal	
Smoking in pregnancy	
Yes	2.28 (1.49-4.04)
No	1 [Reference]
BMI	
<25	1 [Reference]
25-29.9	2.38 (1.38-4.54)
≥30	6.33 (3.82-11.85)
Family characteristics and SES	
Income	
Insufficient	1.65 (0.85-2.50)
Sufficient, 1 = no	1 [Reference]
Mother's educational level	
<High school	1.02 (0.61-1.94)
≥High school	1 [Reference]
Functioning	1.07 (0.92-1.23)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CI, confidence interval; OR, odds ratio; SES, socioeconomic status.

COMMENT

Our group-based developmental trajectory model, spanning 9 time points within the first 8 years of children's lives, allowed for the identification of a group of children with an atypically elevated and rising BMI trajectory (4.5%) and 2 groups of children with relatively stable BMI trajectories throughout childhood: the moderate group (41.0%) and the low-stable group (54.5%).

COMPARISON WITH OTHER STUDIES

Our findings indicate that both maternal overweight/obesity and maternal smoking during pregnancy were associated with membership in the high-rising trajectory of BMI. These results are in line with the growing evidence[1-5,32-34] that the perinatal environment has an important influence on later obesity.

The odds of being in the high-rising BMI group were 2.38 and 6.33 times higher than those for being in the other groups when the child's mother was overweight or obese, respectively. Our estimated ORs do not approximate risk ratios[35]; they are further from the reference value (1) than would have been the case if we had chosen to estimate risk ratios.

The finding regarding maternal overweight is in line with reports that identify parental obesity as an important predictor of child[36] and adult[37] obesity. Genetic, epigenetic, and shared environmental characteristics may contribute to this association.[34,38] Furthermore, some evidence relates maternal obesity to future increased cardiovascular disease risk factors[39] and the metabolic syndrome[40] in the offspring through mechanisms related to the fetal origins hypothesis. These mechanisms have the potential to incur a cycle of obesity and related disorders through generations.[32,34,40-42]

We found that having a mother who smoked during pregnancy was associated with an OR of 2.28 for membership in the high-rising group. Several studies have also linked smoking during pregnancy with an increased risk of child[6,43-45] and adult[33] obesity. Maternal smoking is thought to restrict fetal growth,[38] leading to a lower birth weight, which has also been associated with the development of obesity. This may be the result of compensatory rapid postnatal growth[13] or to the programming of appetite regulation.[46] However, a previous study[21] on the present sample found that, among children born to smoking mothers, a normal birth weight placed the child at increased risk for overweight or obesity at 4.5 years. It is clear that the results of the present study cannot disentangle the confounding underlying mechanisms behind low birth weight, rapid growth in infancy, smoking during gestation, and future obesity.

The magnitude of the risk factors identified herein is comparable to that observed in previous studies[7,11,21] on risk factors for obesity. Maternal smoking and maternal BMI are the risk factors most correlated with obesity, but they are not perfectly correlated with it. The results suggest that these early risk factors should not be overlooked when designing preventive interventions, but this possibility requires replication in other studies.

We did not find a statistically significant result for the association between the high-rising trajectory and our assessment of rapid average early weight gain, despite the fact that previous studies[12,13,47] highlight the importance of this factor in predicting overweight. Because a previous study[21] with the same sample found an association between this variable and overweight status at 4.5 years, it is possible that rapid average early weight gain is associated with overweight and obesity in early, but not later, childhood. The significant bivariate association (Table 1) seems to be explained only by the highest quintile of weight gain. A separate analysis (results not presented) examining the ORs for membership in the high-rising vs each of the moderate and low-stable trajectories found that only the high-rising vs low-stable and not the high-rising vs moderate comparison had statistically significant ORs. This suggests that rapid early weight gain may be an important risk factor for overweight or obesity in children, but this may be significant only when looking at extreme comparisons (ie, highest 20% of children for rapid weight gain vs the rest of the children or the highest vs lowest developmental trajectories of BMI).

Our results agree in part with those of a study[11] examining developmental trajectories of BMI in childhood in association with very early risk factors. Our results, as well as those of Li et al,[11] indicate that maternal BMI is one of the most important risk factors for early-onset obesity. Li et al also found other significant risk factors: male sex, black ethnicity, being firstborn, high birth weight, mother without a postsecondary education, and lower middle-class income. However, maternal smoking during pregnancy was not found to be significant in their study. Different trajectory modeling methods and cohort characteristics may explain some of these discrepancies.

LIMITATIONS

Although fundamental in documenting the current obesity epidemic,[48] use of BMI as a proxy measure for adiposity may misclassify certain children.[49] Our study is also limited by the inclusion of 2 different measurement methods for child height and weight and the fact that maternal report of these variables is considered less reliable than direct measurement. In addition, because maternal BMI was measured 17 months after childbirth, we are limited in our ability to draw conclusions related to the influence of maternal overweight during gestation.

The fact that families of lower socioeconomic status were less well represented in our trajectory groups compared with those excluded may constrain our ability to draw conclusions regarding this variable because of a lack of power. We believe that this is unlikely, however, given the small attrition percentage and the fact that weighting was used to attempt to ensure a representative sample.

Another limitation of the study involves the age at which children were assessed during the school years. Beginning in kindergarten (mean age, 6 years), data collection occurred in the spring for all children rather than near their birthdays. Longitudinal attrition did not allow us to control for the age of children in the main analyses. However, in supplementary analyses, we were able to determine that the mean ages of children in the high-rising vs other trajectories were not significantly different during these years.

Finally, we acknowledge that the identified early-life risk factors are not necessarily causal of obesity. Rather, they increase one's probability of following a developmental pattern resembling the high-rising trajectory. It is possible that a third, unexamined variable explains 1 or more of the observed associations.

In conclusion, the results of our study indicate that the most important risk factors for obesity are in place before birth, that they are modifiable, and that an atypically elevated BMI trajectory can be distinguished from the normative BMI trajectory as early as age 3.5 years.

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Author Affiliations: International Laboratory for Child and Adolescent Mental Health, Research Unit on Children's Psychosocial Maladjustment (Groupe de Recherche sur l'inadaptation psychosociale chez l'enfant [GRIP]), University of Montreal, Montreal, Quebec, Canada, and National Institute of Health and Medical Research (Institut national de la santé et de la recherche médicale

[INSERM]) U669, Paris, France (Ms Pryor and Drs Tremblay, Touchette, Falissard, and Côté); Department of Social and Preventive Medicine (Ms Pryor and Dr Côté) and GRIP (Dr Liu), University of Montreal; GRIP, School of Psychology, Laval University, Quebec City, Quebec, Canada (Dr Boivin); INSERM U669, Paris Sud Innovation Group in Adolescent Mental Health Methodology, Université Paris-Sud and Université Paris Descartes, UMR-S0669, Paris, France (Drs Touchette, Genolini, and Falissard); School of Public Health and Population Sciences, University College Dublin, Dublin, Ireland (Dr Tremblay); and Department of Epidemiology and Community Medicine, University of Ottawa, Ottawa, Ontario, Canada (Dr Dubois).
Correspondence: Sylvana M. Côté, PhD, GRIP, Université de Montréal, 3050 Edouard-Montpetit, Montréal, QC H3T 1J7, Canada (sylvana.cote@umontreal.ca).
Author Contributions: The first author had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Drs Tremblay, Falissard, and Côté share senior authorship. *Study concept and design:* Pryor, Tremblay, Boivin, and Côté. *Acquisition of data:* Tremblay, Boivin, and Falissard. *Analysis and interpretation of data:* Pryor, Tremblay, Touchette, Dubois, Genolini, and Liu. *Drafting of the manuscript:* Pryor, Tremblay, and Côté. *Critical revision of the manuscript for important intellectual content:* Pryor, Tremblay, Boivin, Touchette, Dubois, Genolini, Liu, Falissard, and Côté. *Statistical analysis:* Pryor, Tremblay, Genolini, Liu, Falissard, and Côté. *Obtained funding:* Pryor, Tremblay, and Boivin. *Administrative, technical, and material support:* Tremblay and Falissard. *Study supervision:* Tremblay, Touchette, Dubois, and Côté.
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