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## Abstract

**Background**
Researchers have yet to provide a comprehensive explanation of the variability in the development of childhood obesity, owing in part to the dearth of longitudinal studies. Such an understanding would contribute to the improvement of approaches for the primary and secondary prevention of childhood obesity. This study identifies, in a representative sample of Canadian children, age-related patterns of overweight and obesity between toddlerhood and childhood.

**Data and methods**
The data are from cycles 2 through 5 (1996/1997 to 2002/2003) of the National Longitudinal Survey of Children and Youth. The sample comprised children aged 24 to 35 months at baseline, who were followed biennially over six years. Group-based mixture modelling analyses (using SAS PROC TRAJ) were conducted to identify the sex-specific developmental trajectories of body mass index (BMI).

**Results**
Group-based modelling identified four BMI trajectories for the girls (stable normal BMI, early declining BMI, late declining BMI, and an accelerating rise to obesity) and three for the boys (stable normal BMI, transient high BMI, and a J-curve rise to obesity).

**Interpretation**
Identifying distinct, sex-specific BMI trajectories is valuable in understanding pathways through which a child may develop obesity. These findings have implications for further research and practice, in particular, that no single approach can be used to prevent or reduce levels of obesity.

## Keywords
body mass index, child development, trajectories, health surveys, longitudinal studies

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The prevalence of childhood overweight and obesity has been increasing in Canada and globally, among boys and girls of all ages, social classes, ethnic groups and races.[1-3] Based on data from the 1998/1999 Canadian National Longitudinal Survey of Children and Youth, 19% of children aged 2 to 11 were overweight, and 18% were classified as obese.[4] The rising prevalence of obesity in children and adolescents raises concern about conditions and diseases associated with excess weight. Paediatric obesity can affect short- and long-term physical and psychosocial health, and is likely to contribute to adult-onset morbidity.[5-9]

Body mass index (BMI) is the measure used most frequently to classify weight status. Longitudinal epidemiological studies have found that after rapid growth in infancy, BMI-for-age begins to decline at about 1 year of age to a minimum around ages 5 or 6.[10-13] Thereafter, adiposity increases through adolescence. This gradual increase is described as "adiposity rebound," which reflects a normal pattern of growth.[10-13] However, certain patterns of adiposity rebound tend to be related to the development of obesity. For example, early onset of adiposity (younger than age 5) has been associated with higher BMI in adolescence[11] and with an increased risk of adult obesity.[13,14] Dietz,[11] however, suggested that BMI at the time of rebound is a stronger predictor of later BMI—children with high BMI at rebound are more likely to be overweight or obese as adults.

The few longitudinal studies that have been conducted have generally assumed that there is a continuous distribution of BMI trajectories in the population (homogenous population trajectories). This approach has limited understanding of the various pathways that lead to the development of obesity among children. Only two previous studies have explored the variation in BMI in clustered and distinct groups (heterogeneous population trajectories). Mustillo et al.[7]

identified four obesity trajectories: never obese, chronically obese, adolescent obesity, and childhood obesity (obese during childhood, but in the normal weight range during adolescence). However, the children in the study were aged 9 or older at baseline; no data were collected on earlier BMI values, so the researchers could not determine the age at which the chronically obese group developed obesity. A more recent study by Li et al.[15] identified three obesity trajectories in children aged 2 to 12: normal weight, early-onset (obese throughout the data collection period), and late-onset (became overweight after age 8). Both studies combined boys and girls in the trajectory analysis, and both used a dichotomized measure of obesity, which may have resulted in a loss of information and higher rates of misclassification.

Studying BMI trajectories is important to understanding variability in the development of childhood obesity. Such exploration helps explain the role of age, sex, and contextual factors. Hence, the primary purpose of this study was to conduct group-based mixture modelling analyses to identify distinct trajectories in the development of obesity in a representative sample of Canadian children aged 24 to 35 months at baseline, who were followed biennially over six years.

## Methods

### Data source and sample

The analyses were based on data from the master file of the National Longitudinal Survey of Children and Youth.[16] The study followed children aged 24 to 35 months in 1996/1997 for six years until 2002/2003 when they were aged 96 to 107 months. The National Longitudinal Survey of Children and Youth is conducted through a partnership between Statistics Canada and Human Resources and Social Development Canada. Data collection began in 1994/1995 and is repeated at two-year intervals. The survey covers topics such as children's health and cognitive well-being and their social contexts.

The target sample for this study was children aged 24 to 35 months at cycle 2 in 1996/1997. For subsequent cycles (cycles 3 to 5), only children for whom second-cycle data (baseline) were available were selected. The cohort was chosen according to the availability and consistency of other measures pertinent to the broader study objectives (for example, cycle 1 was omitted because it lacked relevant measures). To obtain reliable parameter estimates of trajectories, a minimum of three measurement time-points are needed for each case.[17] Therefore, children from the baseline cohort were retained only if they had at least three biologically plausible BMI measures over the four data collection points. As a result, the final sample was reduced from a possible 1,890 cases to 972 (490 girls and 482 boys).

### Measures

Body mass index (BMI), which is weight in kilograms divided by height in metres squared ($kg/m^2$), is commonly used to classify children, adolescents and adults as normal weight, underweight, overweight and obese.[3] In this study, BMI was the outcome variable in the sex-specific trajectory analyses. The classification of obesity was based on cut-offs established by Cole, Bellizi and Flegal,[18] specific to the child's age and sex. This approach has been used in other studies of Canadian childhood obesity, some of which analyzed data from the National Longitudinal Survey of Children and Youth.[2,4,19,20] The children's BMI was compared with the international cut-off values for BMI for overweight and obesity by sex at ages 24 to 35 months (cycle 2), 48 to 59 months (cycle 3), 72 to 83 months (cycle 4), and 96 to 107 months (cycle 5).

BMI was calculated based on the height and weight of the child reported by the "person most knowledgeable," usually the mother. Height (without shoes) was reported in feet and inches or in metres and centimetres, and weight was reported in pounds and ounces or in kilograms and grams.

The identification of outliers is crucial in the analysis of childhood developmental characteristics. Outliers for height and weight are described as "biologically implausible values."[21] It is assumed that these outliers do not reflect actual growth, but result from inaccurate measurements, data entry errors, or inaccurate reporting by the person most knowledgeable. The outlier analysis was undertaken with a SAS® program that identified extremely low and high BMI values according to the WHO fixed exclusion ranges.[21,22] A total of 392 cases with outlier BMI values were excluded from the study, ranging from 19 cases in cycle 5 to 238 cases in cycle 2. An attrition analysis revealed that the children who were excluded because of outlier values differed significantly from those who were included—they were more likely to be from low-income homes, and the person most knowledgable tended to be younger and less-educated.

### Statistical analysis

Based on Nagin's[17] approach to group-based modelling, obesity trajectories were determined by fitting a semi-parametric mixture model to the data. This strategy was used to identify groups of BMI trajectories from ages 24 to 35 months through to 96 to 107 months. With this method, it is possible to detect distinct classes of BMI change across ages, each class with a specific intercept and slope and estimated population prevalence. The model defined the shape of the trajectory of each group and the estimated percentage of the population belonging to the trajectory group. Group-based modelling assumes that the population is composed of multiple subgroups with different developmental trajectories, but membership at the individual level is unobserved. The parameters of the group-based model are estimated by maximum likelihood; the method utilizes a multi-nomial function to model the relationship between the variables.

The mixture model analysis was conducted by applying PROC TRAJ[23] in SAS® 9.1. Estimation of trajectories was accomplished by using the censored normal model (CNORM). CNORM is typically used to model the conditional distribution of a censored variable where there is a cluster of data at the maximum or minimum values,[23] or for data that are measured on a continuous scale without censoring (for example, BMI).[17] Identifying the distinct groups of developmental trajectories involved: (a) model selection—establishing the optimal number of groups and trajectory shapes that best fit the data, based on the change in the Bayesian Information Criterion (BIC), and (b) estimation of the percentage of individuals in each group. To evaluate the alterations in model fit, the models were compared based on: (a) the change in the log-likelihood BIC, (b) the BIC-based probability approximation, and (c) the BIC log Bayes factor approximation.[17,23] To account for the complex survey design, which incorporated both clustered and stratified sampling, standardized longitudinal sample weights were applied in all analyses. For all 972 cases, the standardized weights were calculated by dividing the cycle 5 longitudinal weight provided by Statistics Canada over the average of that weight.

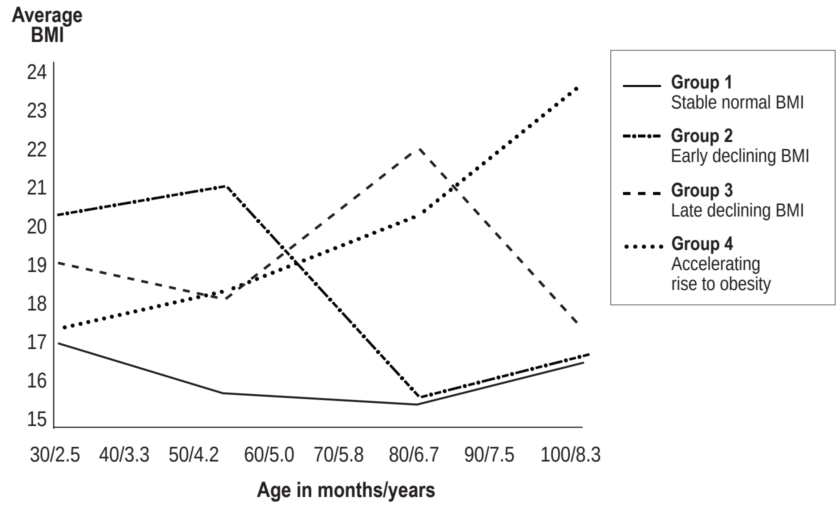
## Results

### Sample description

Descriptive analyses were conducted separately for the boys and girls at baseline (1996/1997) when they were aged 24 to 35 months.

For about 50% of the boys and 46% of the girls, the person most knowledgeable was a college or university graduate; 5.8% of the boys and 9.5% of the girls had a person most knowledgeable with less than secondary graduation. The majority of the children (67.8% of the boys and 60.9% of the girls) were from households where total annual income equalled or exceeded $40,000; about 5% lived in households with less than $15,000 per annum. A large majority of the boys (89%) and girls (93%) were reported to have very good or excellent health; only 2% of the boys and 1% of the girls were reported to have fair or poor health. When the person most knowledgeable was asked about the child's activity level compared with that of other children, 56% of the boys and girls were reported to be "equally active."

**Figure 1**
**Body mass index (BMI) trajectories for girls aged 24 to 35 months at baseline, Canada, 1996/1997 to 2002/2003**




**Source:** National Longitudinal Survey of Children and Youth, 1996/1997 to 2002/2003.

**Table 1**
**Classification of body mass index (BMI) trajectories of girls aged 24 to 35 months at baseline, Canada, 1996/1997 to 2002/2003**

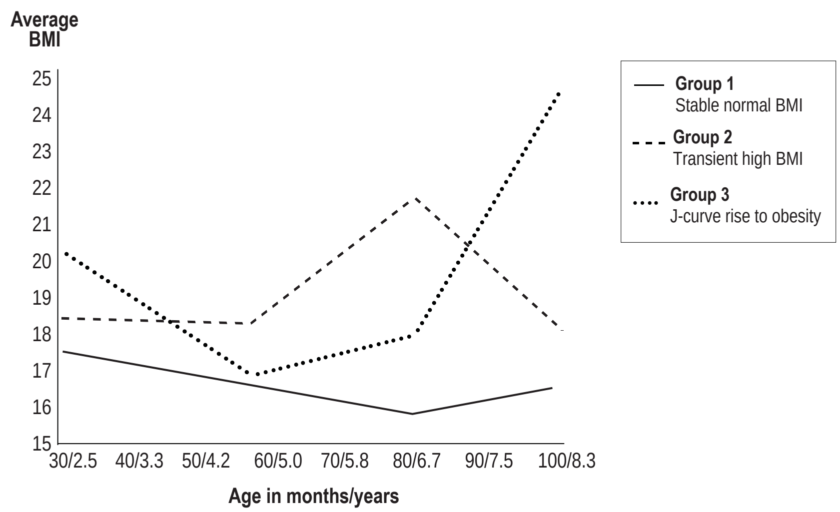
| Average age in months/years (survey year) | Group 1 Stable normal | Group 2 Early-declining | Group 3 Late-declining | Group 4 Accelerating rise to obesity |
|---|---|---|---|---|
| 30 months/2.5 years (1996/1997) | **Normal BMI** (mean BMI = 16.9; 95% confidence interval = 16.3 to 17.6) | **Obese** (mean BMI = 20.4; 95% confidence interval = 17.9 to 22.9) | **Overweight** (mean BMI = 19.1; 95% confidence interval = 17.1 to 21.1) | **Normal BMI** (mean BMI = 17.5; 95% confidence interval = 15.7 to 19.2) |
| 53 months/4.4 years (1998/1999) | **Normal BMI** (mean BMI = 15.8; 95% confidence interval = 15.4 to 16.2) | **Obese** (mean BMI = 21.3; 95% confidence interval = 18.8 to 23.9) | **Overweight** (mean BMI = 18.5; 95% confidence interval = 14.4 to 22.6) | **Overweight** (mean BMI = 18.1; 95% confidence interval = 15.7 to 20.6) |
| 78 months/6.5 years (2000/2001) | **Normal BMI** (mean BMI = 15.5; 95% confidence interval = 14.9 to 16.1) | **Normal BMI** (mean BMI = 15.2; 95% confidence interval = 14.0 to 16.3) | **Obese** (mean BMI = 21.3; 95% confidence interval = 18.1 to 24.4) | **Obese** (mean BMI = 20.8; 95% confidence interval = 18.7 to 22.9) |
| 100 months/8.3 years (2002/2003) | **Normal BMI** (mean BMI =16.4; 95% confidence interval = 15.9 to 16.8) | **Normal BMI** (mean BMI = 16.6; 95% confidence interval = 15.2 to 18.0) | **Normal BMI** (mean BMI = 17.6; 95% confidence interval = 15.1 to 20.1) | **Obese** (mean BMI = 23.2; 95% confidence interval = 21.6 to 24.8) |

**Note:** Based on cut-offs established by Cole, Bellizi and Flegal, specific to child's age and sex.
**Source:** National Longitudinal Survey of Children and Youth, 1996/1997 to 2002/2003.

### BMI trajectory modelling results

Based on the Bayesian Information Criterion (BIC) calculations and the BIC log Bayes factor approximation, the difference in the population distribution of BMI developmental trajectories was best characterized by a four-group model

**Figure 2**
**Body mass index (BMI) trajectories for boys aged 24 to 35 months at baseline, Canada, 1996/1997 to 2002/2003**




**Source:** National Longitudinal Survey of Children and Youth, 1996/1997 to 2002/2003.

**Table 2**
**Classification of body mass index (BMI) trajectories of boys aged 24 to 35 months at baseline, Canada, 1996/1997 to 2002/2003**

| Average age in months/years (survey year) | Group 1 Stable normal | Group 2 Transient high | Group 3 J-curve rise to obesity |
|---|---|---|---|
| 30 months/2.5 years (1996/1997) | **Normal BMI** (mean BMI = 17.2; 95% confidence interval = 16.7 to 17.8) | **Normal BMI** (mean BMI = 18.0; 95% confidence interval = 16.9 to 19.0) | **Overweight** (mean BMI = 19.5; 95% confidence interval = 18.0 to 21.0) |
| 53 months/4.4 years (1998/1999) | **Normal BMI** (mean BMI = 16.4; 95% confidence interval = 15.9 to 16.9) | **Overweight** (mean BMI = 18.5; 95% confidence interval = 17.3 to 19.7) | **Normal BMI** (mean BMI = 16.2; 95% confidence interval = 14.7 to 17.6) |
| 78 months/6.5 years (2000/2001) | **Normal BMI** (mean BMI = 15.7; 95% confidence interval = 15.3 to 16.1) | **Obese** (mean BMI = 21.5; 95% confidence interval = 20.3 to 22.9) | **Overweight** (mean BMI = 17.8; 95% confidence interval = 16.3 to 19.4) |
| 100 months/8.3 years (2002/2003) | **Normal BMI** (mean BMI = 16.4; 95% confidence interval = 15.9 to 17.0) | **Normal BMI** (mean BMI = 17.9; 95% confidence interval = 16.9 to 19.0)) | **Obese** (mean BMI = 24.2; 95% confidence interval = 22.4 to 26.1) |

**Note:** Based on cut-offs established by Cole, Bellizi and Flegal, specific to child's age and sex.
**Source:** National Longitudinal Survey of Children and Youth, 1996/1997 to 2002/2003.

for the girls' data and a three-group model for the boys' data, all with cubic (third-order polynomial) shapes. This was further supported by a comparison between the competing models based on the BIC-based probability of model correctness. For the girls' data, the four-group model had the best BIC value, and the probability of it being the correct model was 0.96. For the boys' data, a three-group solution offered the best fit to the data, and the probability of it being the correct model was 0.56. The correctness of the group membership classifications based on the maximum posterior probability assignment rule indicated strong correspondence of the models with the data. The mean group posterior probability for the girls' data ranged from 0.73 to 0.90, relatively good probabilities, while the mean group posterior probability for the boys' data ranged from 0.80 to 0.91, again, relatively strong classification probabilities.

## BMI classification

BMI values in this study were compared to reference standards that take the child's age and sex into consideration. PROC TRAJ provided a predicted mean BMI by time (or child's age) for each trajectory, so it was possible to describe the changes in BMI for each of the trajectory groups by comparing the predicted BMIs with the cut-offs of Cole et al.[18] To label the various trajectories, the predicted BMI of each group at each time was first compared to the overweight cut-off value, and then, to the obesity cut-off value. Figures 1 and 2 present the BMI trajectories for the girls and the boys, respectively; Tables 1 and 2 show the classification of mean weight status at each measurement time for each trajectory.

## Girls' trajectory groups

The trajectory for each group is described by the probability of BMI membership at each age. Group 1, labelled the "stable normal BMI" group, was estimated to include 64% of the population of girls in the sample. Throughout the six years, their average BMI was normal for their age and sex (Figure 1, Tables 1 and 3).

The girls in the "early declining BMI" group (Group 2) were in the obese category at the first two measurements (1996/1997 and 1998/1999), but they "rebounded" to within normal range at the third measurement (2000/2001) and remained there at the fourth (2002/2003). This group accounted for an estimated 8% of the population.

The average BMI of Group 3 was above the overweight cut-off at the first two measurements, obese at the third, and declined to within normal range at the fourth. This trajectory was labelled the "late declining BMI" group and was estimated to encompass 14% of the sampled population.

Finally, an estimated 14% of the girls' population in the sample belonged to Group 4, the "accelerating rise to obesity" group. From normal at the first

**Table 3**
**Body mass index (BMI) trajectory group membership probabilities for girls and boys aged 24 to 35 months at baseline, Canada, 1996/1997 to 2002/2003**

| Sex/BMI trajectory group | Membership probability % |
|---|---|
| **Girls** | **100** |
| Group 1 (stable normal BMI) | 64 |
| Group 2 (early declining BMI) | 8 |
| Group 3 (late declining BMI) | 14 |
| Group 4 (accelerating rise to obesity) | 14 |
| **Boys** | **100** |
| Group 1 (stable normal BMI) | 70 |
| Group 2 (transient high BMI) | 19 |
| Group 3 (J-curve rise to obesity) | 11 |

**Source:** National Longitudinal Survey of Children and Youth, 1996/1997 to 2002/2003

measurement, their average BMI rose to overweight at the second, and at the third, to obesity, which was sustained at the fourth.

### Boys' trajectory groups

Among the boys in the sample, Group 1, the "stable normal BMI" group, accounted for an estimated 70%. Their average BMI was within the normal range throughout the six years (Figure 2, Tables 2 and 3).

The BMI of the boys in Group 2 changed continuously across the four measurements. Their average BMI was within the normal range at the first measurement; by the second, they were in the overweight range; and by the third, obese. However, at the fourth measurement, they had returned to the normal range. They were labelled the "transient high BMI" group and were estimated to encompass 19% of the sampled population.

Boys in Group 3, the "J-curve rise to obesity" group, were overweight at the first measurement, in the normal BMI range at the second, overweight at the third, and by the fourth, obese. This last group constituted 11% of the population of boys in the sample.

## Discussion

A major finding of this study is the heterogeneity of BMI trajectories—differences that would not have been revealed either in conventional cross-sectional studies or in growth models. The mixed modelling approach identified four subgroups of girls and three subgroups of boys and provided average patterns of change over six years for each subgroup. It is necessary to acknowledge, however, that the results derived from applying the group-based methodology are approximations of population differences in developmental trajectories,[17] and that the BMI trajectories in this study are based on group means over a specific time period.

The longitudinal study by Li et al.[15] also explored the variation in weight status in clustered and distinct groups during early childhood, but the analysis was based on a binary dependent variable rather than a continuous measure of weight status (BMI). Two key differences in the current study are that: (1) a chronically obese or early-onset group was not found, and (2) trajectories for one cluster of boys and two clusters of girls declined from obesity during earlier years to a normal BMI by ages 8 to 9. Li et al. identified groups that were never obese or rose to obesity (early- and late-onset); they did not identify any groups among whom the likelihood of obesity declined over time. However, the trajectory they identified as late-onset obesity for the combined sample of boys and girls is similar to the J-curve rise to obesity trajectory found for some boys in this sample.

### Limitations

The findings of this study should be interpreted cautiously. A major limitation is the reliability of reports of children's height and weight by the person most knowledgeable (typically, the mother), which has implications for the validity of the BMI calculations.

Few studies have assessed the accuracy of parental reporting, and the results have been inconsistent. A comparison of BMI estimates based on parental reports of

## *What is already known on this subject?*

- The prevalence of obesity among children is increasing.
- Certain patterns of adiposity rebound tend to be related to the development of obesity.
- Few longitudinal studies have explored variations in body mass index (BMI) trajectories among children, and those that have done so combined boys and girls.

## *What does this study add?*

- Based on six-year BMI trajectories starting at ages 24 to 35 months, four subgroups of girls and three subgroups of boys were identified.
- The majority of children were in the normal BMI range throughout the six years.
- By the end of the period, 14% of the girls and 11% of the boys were in the obese BMI range.
- Another 22% of the girls and 19% of the boys had been obese at some point in the six years, but by the end of the period were in the normal range for their age and sex.
- Group-based modelling provides an alternative approach to analysing longitudinal BMI data for children.

children's height and weight from the 2002/2003 National Longitudinal Survey of Children and Youth with those based on measured data from the 2004 Canadian Community Health Survey revealed substantial differences, particularly for children aged 2 to 5.[24] When the parents answered for their child, overweight and obesity rates were higher, largely because the parents tended to underestimate their child's height. The author suggested that parents might report the child's last measured height, which could be inaccurate given how quickly children of these ages grow. Davis and Gergen[25] and Huybrechts et al.[26] also reported that parental reports are inaccurate for classifying preschool children into BMI categories. On the other hand, Sekine et al.[27] concluded that parental reports are valid for the study of childhood obesity. Moreover, in the current study, the effects of inaccurate parental reporting may have been reduced by the omission of biologically implausible outliers. As well, children included in this study had parents with significantly higher educational attainment than did the children who were excluded, and according to Baughcum et al.,[28] limited maternal education has been associated with underestimates of children's weight problems. The methods used in this study could also have reduced the impact of inaccurate reporting by analyzing group means over time (group means are considered to be statistically more stable). And finally, the current study is not the only one to use height and weight data from the National Longitudinal Survey of Children and Youth; a number of other empirical studies have relied on these data to estimate obesity prevalence and secular and temporal trends among Canadian children.[2,20,29,30]

To some degree, the generalizability of the findings is limited. The socioeconomic characteristics of the sample on which the analysis was based differed from those of the large population from which it was drawn. This raises the possibility of the existence of other BMI trajectories that may be more prevalent among children in families with lower incomes and lower parental education.

The current study was also limited by the relatively short period—six years—for which data were available at the time of analysis. It was not possible to follow BMI trajectories into adolescence when further changes may occur. For example, using an older sample of 9- to 16-year olds, Mustillo et al.[7] identified a group that experienced obesity during childhood, but whose weight fell to normal during adolescence.

## Conclusion

Group-based modelling provides an alternative approach to analysing longitudinal data. This study has advanced understanding of the various pathways by which young children may develop obesity. Knowledge of the different BMI trajectories may allow health professionals to refine their methods of addressing obesity and obesity-related health problems. For example, a normal-weight child may be overlooked as being at risk for obesity and may not receive proper assessment and counselling.

The increasing prevalence of excess weight among children makes the prevention of obesity a global health priority. Effective prevention requires a comprehensive approach in promoting and supporting healthy living. While this study has identified distinct BMI trajectories and demonstrated substantial differences between girls and boys, it is obviously only a first step. The demographic and socio-economic factors associated with these trajectories remain to be investigated. A better understanding of the risk factors associated with BMI trajectories may improve the effectiveness of programs in identifying and reaching children at the highest risk and maintaining healthful trajectories among other children. The results of such analysis will help to tailor and target programs to specific groups who are at risk of obesity, and perhaps, intervene at an early stage to alter the path of a trajectory. ■

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