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BMI trajectories and risk factors among 2-11-year-old children by their immigrant status: evidence from the Longitudinal Study of Australian Children

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ABSTRACT

Objective This study aimed to identify body mass index (BMI) trajectories and their predictors in Australian children by their maternal immigrant status.

Methods Data on 4142 children aged 2–3 years were drawn from the birth cohort of the Longitudinal Study of Australian Children. BMI was calculated according to the International Obesity Task Force cut-off points. Immigrant status was determined by the Australian Bureau of Statistics and the United Nations Development Programme, Human Development Index criteria. Latent class growth analysis estimated distinct BMI trajectories, and multinomial logistic regression analysis examined factors associated with these BMI trajectories.

Results Two BMI groups and six BMI trajectories were identified. The stable trajectories group included high-risk (10%, n=375), moderate-risk (5%, n=215) and low-risk (68%, n=2861) BMI trajectories. The changing trajectories group included delayed-risk (6%, n=234), gradual-risk (8%, n=314) and declining-risk (3%, n=143) BMI trajectories. We found some evidence that children of immigrants from low-and middle-income countries were more likely to have moderate-risk and high-risk BMI trajectories compared with low-risk BMI trajectory. However, these associations were insignificant in fully adjusted models. The explanatory risk factors for moderate-risk and high-risk BMI trajectory were birth weight, family socioeconomic position, and organised sports participation. Our results also suggest that 4–7 years of age may be important for the prevention of overweight/obesity in children.

Discussion A better understanding of the risk factors associated with distinct BMI trajectories in immigrant children will inform effective preventive strategies. Some of these risk factors such as non-participation in organised sports, and high screen time, may also impede the integration of immigrant children into the host culture. Obesity prevention strategies aimed at increasing physical activities in immigrant children could help deliver a social and health benefit by increasing social integration among children of immigrants and Australians.

Strengths and limitations of this study

- This is the first large-sampled Australian cohort study which identified body mass index trajectories and their predictors in children by their maternal immigrant status.
- Child anthropometric measurements were recorded two-yearly by trained interviewers.
- The 'Longitudinal study of Australian children' under-represented children from non-English-speaking, single-parent families living in disadvantaged areas, and over-represented mothers with year 12 education.
- Sampling weights were used to adjust for unequal probabilities of selection and for non-response.
- There was brevity of diet and physical activities measures, absence of variables to measure health literacy and detailed data on school and neighbourhood attributes.

INTRODUCTION

With over a quarter of children aged 2–17 years either overweight or obese (henceforth referred to overweight/obesity),[1] Australia ranks high among countries with childhood overweight/obesity. Overweight/obese children are more likely to grow up as overweight/obese adults[2] and have increased risk of obesity-related diseases, including cardiometabolic conditions and cancers.[3] The exponential increase in childhood overweight/obesity over the past decade indicates the challenges public health professionals face to implement preventive interventions. As children are increasingly becoming overweight/obese at relatively younger ages,[3] prevention of behavioural risk factors before school age may prove to be essential.

Although the risk of overweight/obesity has plateaued in Australia due to vigorous public health interventions, the prevalence is still high across the whole population, particularly in some ethnic subgroups.[4–6] A recent Australian study showed that overweight/obesity in children from diverse backgrounds such as immigrants increased from 1997 to 2015.[4] Other Australian studies also showed an increase in overweight/obesity among children of immigrants from diverse ethnicities, especially from low-and middle-income countries (LMICs).[5 6] This is puzzling as immigrants from LMICs arrive in host high-income countries (HICs) with low overweight/obesity rates, but overweight/obesity rates in their children born in these HICs surpass the rates in host children.[7] Research suggests that immigrants from LMICs carry over weight-promoting cultural beliefs and practices around diet and physical activities from their origin countries and adopt unhealthy Western lifestyle during acculturation.[7 8] With the global increase in immigration, understanding these practices among immigrants is imperative for obesity prevention.

Similar to other HICs, the drivers of excess overweight/obesity in Australian children are physical inactivity, low fruit and vegetable consumption, and high energy dense food consumption.[9–12] A recent Australian longitudinal study reported high consumption of sugar-sweetened beverages (SSBs) and low physical activity in children aged 4–11 years of immigrants from LMICs. The study indicated that the risk of overweight/obesity over time was higher in children who preferred sedentary activities and had higher screen time.[13] A limitation of this study was that it did not account for developmental variations in children's weight. Recent longitudinal studies centred on developmental heterogeneity in children's weight have demonstrated distinct weight trajectories in children.[14–21] This raises the question of whether the pathways of overweight/obesity onset and development in children of immigrants may differ from hosts.

Within Australia, only a few studies have investigated weight trajectories in children. These studies showed substantial heterogeneity in weight trajectories among Australian children. The predictors of atypical weight trajectories in these studies included child's diet, family socioeconomic status, parental education, parental smoking, child birth weight, breast feeding, maternal obesity, gestational diabetes, and gestational hypertension.[16–18 22] These studies controlled for child immigrant status by using child birthplace,[16] language spoken at home[17] and grandparents' country of birth,[18] but did not consider if weight pathways or risk factors varied by child's immigrant status. Such knowledge is necessary to understand the mechanisms of childhood overweight/obesity among immigrants, a significant first step for culturally sensitive and targeted preventive interventions. Our study addresses this preventative health need by analysing data from the Birth (B) cohort of the Longitudinal Study of Australian Children (LSAC). Based on our literature review, which showed the importance of early life factors and family environment in childhood overweight/obesity, we tested two types of a priori risk factors[14–16 18 22 23]: those specific to the children and those related to the mother and the family environment. Our study aimed to (1) identify distinct body mass index (BMI) trajectories in Australian children aged 2–11 years, and (2) examine whether BMI trajectories differ according to child's immigrant status and other child, maternal or family characteristics at 2–3 years of age.

METHODS

The LSAC is an ongoing cohort study with biennial data collection.[24] The sampling frame for LSAC was drawn from the Medicare Australia enrolment database, which covers all Australian permanent residents. To ensure geographical representation, the database was stratified by both state/territories and metropolitan/non-metropolitan areas. A two-stage clustered design was employed, first randomly selecting postcodes, then children. A total of 311 postcodes were selected with probability proportional to size (approximately 1 in 10). Within postcodes, children had about an equal chance (1 in 25) of selection.[24]

After obtaining informed consent, face-to-face interviews were conducted by trained interviewers primarily with the mother.[24] The LSAC sample comprised two age cohorts. We analysed 10 years of data from the B cohort (n=5017), who were 3–19 months at the first data collection in 2004. Children were aged 10–11 years in 2015, which were the latest available data at the start of the present study. The analysis in this paper is restricted to participants aged 2–11 years as children under 2 years old did not have data on length/height. The proportion of children in the original cohort who participated at each age was 90% (n=4606) at 2–3 years, 86% (n=4386) at 4–5 years, 83% (n=4242) at 6–7 years, 80% (n=4085) at 8–9 years and 74% (n=3764) at 10–11 years.[24] Approximately 73% (n=3372) of children who participated at 2–3 years participated in all five surveys.

Measures

BMI, the outcome variable, was calculated as weight (in light clothing)/height (without shoes) squared (kg/m^2), measured at each visit using standardised equipment.[25] We created a categorical variable to classify children as overweight, obese and not overweight/obese according to the International Obesity Task Force age-specific and sex-specific criteria (overweight and obesity cut-off points of 25 and 30 kg/m^2 in young adults aged 18, extrapolated to children).[26]

Child immigrant status, the exposure variable, was defined using the socioeconomic development of the child's mother and maternal grandparents' birth countries. The father's birth country was not included in determining child immigrant status due to a large number of missing values (n=773, 19%). Socioeconomic development of the birth countries was classified as high-income and low-and middle-income based on the United Nations Development Programme, Human Development Index (HDI) scores of 2015. LMICs included countries with HDI scores of <0.7 and HICs with HDI scores of ≥0.7[27] (online supplementary material S1).

Children were classified as Australian (reference group) if they were born in Australia or born overseas with Australian-born mothers and grandparents. First-generation immigrant children were overseas-born with overseas-born mothers. Second-generation immigrant children were Australian-born with overseas-born mothers and maternal grandparents. Third-generation immigrant children had Australian-born mothers and at least one grandparent born overseas.[28] Immigrant children from LMICs had the mother or at least one maternal grandparent born in that country. Immigrant children from HICs had the mother or at least one maternal grandparent born there. Mixed immigrant background children had one maternal grandparent born in a HIC and the other in a LMIC.

Risk factor data were obtained from the second wave of LSAC data collection when children were aged 2–3 years, which was the baseline for our study.

Child-specific factors which are a priori variables included child sex, child birth weight (<2.5 kg, 2.5–4 kg and >4 kg), whether the child was ever breast fed (yes/no), child's consumption of SSBs (none vs ≥1/day), organised sports activities (yes/no) and screen time (combined television and electronic games on weekdays and weekends) (<3 hours or ≥3 hours on weekdays or weekends). Organised sports participation for children aged 2–3 years old, which included swimming lessons and dancing/movement classes, was used as a proxy for child's physical activities as there were no other reliable measures of child physical activities at this age. Parents reported on the diet, organised sports activities and screen time until the children were 8–9 years.[25]

Maternal and family specific risk factors included maternal gestational diabetes (yes/no), gestational hypertension (yes/no), self-reported maternal weight (overweight/obese or not overweight/obese based on BMI), maternal current smoking (yes/no), maternal age (< 30 years /> 30 years), maternal partnership status (single parent/partnered relationship), magternal work status (full-time/part-time/not in workforce), language spoken at home (non-English/English) and family socioeconomic position (SEP) (low/middle/high).[29] Family SEP was based on a composite measure comprising combined annual family income, employment status and education of both parents,[29] and categorised into the lowest 25%, the middle 50%, and the highest 25%.

Analysis

Sample characteristics were compared by child's immigrant status using the Pearson's χ^2 statistic. BMI trajectories of children from 2 to 11 years were estimated using the latent class growth analysis (LCGA), a type of growth mixture model[30] whereby individuals within a trajectory are treated as a homogeneous group regarding their developmental trajectory. Trajectories were estimated from a latent growth model (LGM), which allows for random effects at the intercept and in the slope of the trajectories. The most appropriate number of trajectories was determined using the Akaike information criterion (AIC) and adjusted Bayesian information criterion (BIC) to assess model fit (smaller value indicates better fit), and the Lo-Mendell-Rubin likelihood ratio test,[31] the adjusted likelihood ratio test (LRT) and the bootstrap likelihood ratio test to compare nested models.[32] We were also guided by parsimony, theoretical justification and interpretability in determining the number of trajectories to extract.[33 34] The level of entropy, reflecting the proportion of participants correctly classified into their respective trajectories, helped determine the utility of additional trajectories. We examined possible non-linear associations in the trajectories of BMI over time by implementing another series of LGM within an LCA framework. These LGMs were estimated with a quadratic slope function. Model fit comparisons were then made with the best fitting model from the linear LGM.

Associations between health-related behaviours and BMI trajectories

The χ^2 statistic was used to compare distributions of risk factors across BMI trajectories. Multinomial logistic regression analysis compared relative risk ratio for BMI trajectories by child immigrant status using Australian children and low-risk BMI trajectory as reference groups. We constructed two models: model 1 adjusted for sex only and model 2 adjusted for all of the explanatory variables of interest described earlier. We also used the goodness-of-fit test to assess the fit of the model. Due to a large number of missing values at baseline for key maternal indicators such as gestational diabetes (22%), gestational hypertension (22%), maternal weight (36%), and maternal current smoking status (31%), these variables were excluded from the primary analysis and assessed in a sensitivity analysis.

LCGAs were undertaken in Mplus V.7.1, while the comparison of differentials between classes was conducted in STATA V.15. Mplus analyses with multiple observations over time include all observations in the longitudinal analysis with the full information maximum likelihood procedure. Survey weights were used for descriptive statistics and modelling. Statistical significance was set at $p<0.05$.

Participants and public involvement

No participants were directly involved in the development of the research question, selection of the outcome measures, design, and implementation of the study, or interpretation of the results.

RESULTS

Sample characteristics

The final sample in our trajectory analysis was 4142 singleton children aged 2–3 years. Children with multiple births (n=155), mixed ethnicities (n=73) and born overseas (n=17) were excluded. The sample included 180 indigenous children.

Approximately 54% of our sample were Australian children, 21% second-generation and 10% third-generation children from HICs. Second-generation and third-generation children from LMICs comprised 12% and 3% of the sample, respectively. We conducted preliminary analysis separately with second-generation and third-generation children, however, found no generational effects. Moreover, due to the low number of third-generation children from LMICs in our sample, we combined these categories. We refer to these combined categories as immigrant children from HICs and LMICs in this paper. The overall prevalence of overweight/obesity was 23% for children aged 2–3 years; a slightly higher percentage of girls and boys from LMICs were obese, compared with the other groups, although this was not statistically significant (table 1).

Number of BMI trajectories: model selection

Based on the model fit indicators, a six-class trajectory model was the most appropriate (online supplementary table 1). Lower AIC and BIC were demonstrated for the six-trajectory model, while the model estimating seven trajectories showed an increase in AIC and BIC. Further, the LRT indicates a significant difference

Table 1 Sociodemographic characteristics of children aged 2–3 years from the birth cohort of the Longitudinal Study of Australian Children

	Australian n (%) 2346 (54)	HICs n (%) 1259 (31)	LMICs n (%) 537 (15)	X^2, p value
Boys	1202 (51)	620 (49)	293 (54)	0.2
Girls	1144 (49)	639 (51)	244 (46)	
Child age (years), mean (SD)	2.3 (0.01)	2.3 (0.01)	2.3 (0.02)	0.8
Low birth weight, <2.5 kg	75 (4)	40 (4)	25 (5)	0.07
Normal birth weight, 2.5–4.0 kg	1929 (82)	1044 (84)	458 (86)	
High birth weight, ≥4.0 kg	337 (14)	169 (13)	48 (8)	
Never breast fed	165 (9)	93 (9)	44 (9)	0.9
Overweight boys	212 (18.3)	106 (18.0)	42 (15.2)	0.8
Obese boys	46 (4.0)	28 (4.7)	14 (5.4)	
Overweight girls	218 (20.6)	115 (17.9)	49 (20.9)	0.3
Obese girls	52 (4.9)	30 (4.9)	19 (7.9)	
Other siblings at home	1922 (82)	987 (78)	413 (77)	0.01
Foreign language spoken at home	21 (1)	155 (14)	386 (78)	<0.001
Overweight/obese mothers	688 (41)	359 (38)	126 (38)	0.2
Mother current smoker	297 (19)	160 (19)	32 (9)	<0.001
Single parent	231 (12)	120 (12)	43 (10)	0.2
Maternal age <30 years	848 (38)	375 (32)	187 (38)	<0.001
Low family SEP	583 (30)	262 (26)	174 (40)	<0.001
Middle family SEP	1182 (49)	668 (52)	223 (39)	
High family SEP	580 (21)	328 (22)	136 (21)	
Mother works full time	385 (16)	221 (18)	112 (19)	<0.001
Mother works part-time	971 (40)	501 (39)	129 (22)	
Mother not in workforce	985 (44)	534 (44)	295 (59)	
SSBs ≥1/day	1622(71)	854(70)	390 (75)	0.2
No organised sports	1248 (56)	668 (56)	393 (77)	<0.001
High screen time (≥3 hours on weekday/ weekend)	702 (32)	361 (31)	194 (38)	0.02
Mother had Gestational diabetes	82 (4)	59 (5)	49 (13)	<0.001
Mother had Gestational hypertension	158 (8)	87 (8)	18 (6)	0.3

All column percentages (except immigrant status which is row %) weighted and rounded.
Numbers may not add due to missing values.
HICs, high-income countries; LMICs, low-income and middle-income countries; SEP, socioeconomic position; SSBs, sugar-sweetened beverages.

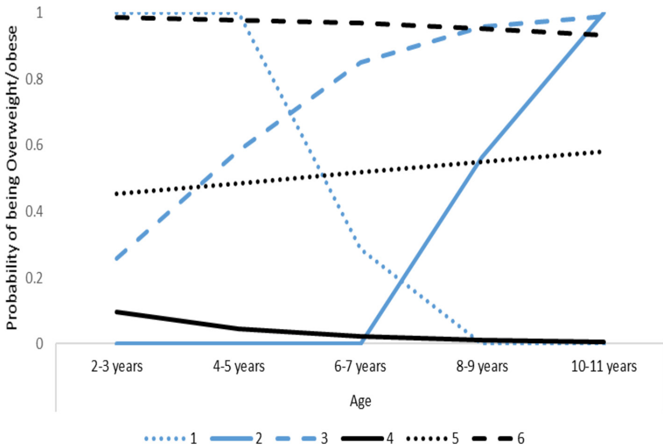

Figure 1 Plot of Body Mass Index (BMI) trajectories from a latent class growth analysis in Australian children aged 2–11 years. Changing trajectories: 1, declining-risk BMI trajectory; 2, delayed-risk BMI trajectory; 3, gradual-risk BMI trajectory; stable trajectories: 4, low-risk BMI trajectory; 5, moderate-risk BMI trajectory; 6, high-risk BMI trajectory. 0 on y axis: no probability of overweight/obesity; 1: high probability of overweight/obesity. .

between nested models for up to the six-trajectory model, but not for the seven-trajectory model, which suggests that the seven-trajectory model does not demonstrate better fit in comparison with the six-trajectory model.

The six trajectories are displayed in figure 1. Three trajectories (4, 5 and 6) reflect stability in BMI category over time. These include a continually high-risk (trajectory 6; 10% of the study sample), moderate-risk (trajectory 5; 5%) and low-risk (trajectory 4; 68%) BMI trajectories. Three trajectories demonstrated substantial change over time. Trajectory 1 (3%) declined in the probability of reporting overweight/obese, from 100% to 0% between 4–5 years and 8–9 years of age. In contrast, there are two trajectories (trajectories 2, 5%; trajectory 3, 8%) where the risk of reporting overweight/obese increased over time and varied only in the rate of their trajectory. Those in trajectory 2 reported no overweight/obesity at baseline, but the probability of reporting overweight/obesity increased substantially in the final two observations (starting at 6–7 years of age), with 100% at the final observation reporting overweight/obesity (delayed-risk). In contrast, trajectory 3 described a rising probability of reporting overweight/obesity from 26% at baseline to 100% by the final observation and reflects a gradual increase in risk.

Association between child immigrant status, child, maternal and family-level risk factors and BMI trajectories

Table 2 shows the distribution of risk factors across BMI trajectory groups at baseline, and table 3 shows the results from the sex-adjusted and fully adjusted regression models. A higher proportion of immigrant children from LMICs were in gradual-risk, moderate-risk and high-risk BMI trajectories, and a lower proportion in low-risk and declining-risk BMI trajectories at 2–3 years of age relative to the Australian children and immigrant children from HICs. This association was not significant in overall comparison across all six trajectories (table 2), but in sex-adjusted models (table 3), relative to the stable low-risk BMI trajectory (reference group), was significant for the high-risk and marginally non-significant for the moderate-risk BMI trajectories. In our multinomial regression models, these risk ratios became insignificant, when we fully adjusted for key risk factors.

In the fully adjusted analysis, the key risk factors significantly associated with BMI trajectories were sex, birth weight, consumption of SSBs, organised sports participation, screen time, and family SEP (table 3). The risk of a moderate-risk BMI trajectory was greater for those with high birth weight and for those with non-participation in organised sports, while the risk of a high-risk BMI trajectory was higher for children with high birth weight and low SEP. Children from high SEP families had a lower chance of being in the high-risk BMI trajectory group.

Girls, rather than boys, and children with high birth weight were more likely to have declining-risk BMI trajectories. Conversely, children from low SEP families, those who consumed SSBs, and those whose mothers were not in the workforce had lower chances of having declining-risk BMI trajectories.

Further, children with high birth weight, high screen time, who did not participate in organised sports, and spoke a foreign language at home were more likely to have a delayed-risk BMI trajectory (although the association was marginally non-significant for those who spoke a foreign language). High screen time, and low family SEP significantly increased and high SEP, and maternal non-participation in the workforce significantly decreased the chances of being in the gradual-risk BMI trajectory.

To further understand the potential (indirect) pathways to children's weight by immigrant status, we created sex-adjusted models with individual risk factors and compared the coefficients for each BMI trajectory by child immigrant status (online supplementary table 2). Our models showed that organised sports participation and family SEP were associated with moderate-risk and high-risk BMI trajectories. Family SEP and high screen time were the only individual risk factors associated with gradual-risk BMI trajectory.

Our sensitivity analysis (online supplementary table 3) showed similar trends as the primary models, with some minor differences, including a significant association for immigrant children from LMICs with the gradual-risk BMI trajectory. These analyses also demonstrated that gestational hypertension and maternal smoking were associated with high-risk BMI trajectory, and maternal overweight/obesity was associated with the declining-risk, delayed-risk, gradual-risk, moderate-risk, and high-risk BMI trajectories.

Table 2 Distribution of risk factors in children aged 2–3 years by BMI trajectories in the birth cohort of the Longitudinal Study of Australian Children

Classes	Changing BMI-trajectories			Stable BMI-trajectories			
	1 Declining-risk n (%)	2 Delayed-risk n (%)	3 Gradual-risk n (%)	4 Low-risk n (%)	5 Moderate-risk n (%)	6 High-risk n (%)	
BMI trajectory classes	**143 (3.2)**	**234 (5.7)**	**314 (7.9)**	**2861 (67.9)**	**215 (5.2)**	**375 (10.2)**	**χ^2, p value**
Children immigrant status							
Australian	85 (3.4)	142 (6.2)	177 (8.0)	1633 (67.9)	111 (4.8)	198 (9.7)	0.170
Immigrant children from HICs	43 (3.1)	65 (5.0)	88 (7.1)	879 (69.8)	69 (5.3)	115 (9.7)	
Immigrant children from LMICs	15 (2.5)	27 (5.4)	49 (9.2)	349 (63.4)	35 (6.8)	62 (12.6)	
Boys	54 (2.2)	126 (5.9)	167 (8.5)	1488 (69.0)	101 (4.7)	179 (9.6)	0.003
Girls	89 (4.2)	108 (5.3)	147 (7.3)	1373 (66.6)	114 (5.8)	196 (10.8)	
Prenatal and neonatal risk factors							
Mother had no Gestational diabetes	126 (3.6)	193 (5.8)	259 (8.1)	2395 (68.4)	182 (5.4)	274 (8.8)	0.022
Mother had Gestational diabetes	7 (3.2)	10 (4.8)	20 (10.6)	117 (59.6)	11 (5.8)	28 (16.2)	
Mother had no Gestationalhypertension	122 (3.5)	192 (5.8)	258 (8.3)	2358 (68.6)	175 (5.2)	264 (8.7)	0.006
Mother had Gestational hypertension	11 (4.3)	12 (5.3)	22 (8.1)	164 (59.2)	18 (7.3)	40 (15.9)	
Low birth weight, <2.5 kg	4 (2.4)	7 (5.1)	9 (5.9)	108 (78.2)	3 (1.9)	9 (6.4)	<0.001
Normal birth weight, 2.5–4.0 kg	106 (2.9)	185 (5.3)	256 (7.8)	2424 (69.2)	176 (5.3)	284 (9.5)	
High birth weight, >4 kg	33 (5.6)	42 (7.9)	49 (8.9)	329 (56.1)	36 (6.0)	82 (15.5)	
Never breast fed	7 (2.7)	23 (6.5)	21 (7.1)	194 (64.1)	13 (3.7)	44 (15.9)	0.023
Ever breast fed	136 (3.3)	211 (5.6)	293 (8.0)	2667 (68.2)	202 (5.4)	331 (9.6)	
Child-level risk factors: diet							
SSBs not at all	58 (4.6)	70 (5.3)	90 (7.8)	889 (68.5)	71 (5.8)	86 (8.0)	0.004
SSBs ≥1/day	85 (2.6)	164 (5.8)	224 (7.8)	1972 (67.6)	144 (5.0)	289 (11.0)	
Physical activity							
No organised sports	70 (2.7)	150 (6.4)	187 (8.3)	1558 (65.4)	136 (6.0)	238 (11.2)	<0.001
Participates in organised sports	73 (3.9)	84 (4.5)	127 (7.4)	1303 (71.4)	79 (4.1)	137 (8.6)	
Low screen time (<3 hours on weekday/weekend)	103 (3.3)	144 (4.9)	195 (7.1)	2048 (69.8)	142 (4.9)	253 (9.9)	0.002
High screen time (≥3 hours on weekday/weekend)	40 (3.0)	90 (7.1)	119 (9.7)	813 (63.9)	73 (5.8)	122 (10.5)	
Maternal and family-level risk factors							
Mother not overweight/obese	64 (3.3)	85 (4.8)	104 (5.9)	1483 (77.1)	67 (3.8)	85 (5.0)	<0.001
Mother overweight/obese	48 (3.8)	95 (7.9)	129 (11.5)	684 (55.8)	84 (7.2)	147 (13.7)	
Mother current smoker	14 (2.4)	35 (6.7)	53 (10.3)	281 (59.2)	36 (6.8)	70 (14.5)	<0.001
Non-smoker	106 (3.8)	150 (5.6)	194 (7.7)	1950 (70.2)	132 (5.0)	185 (7.6)	

Continued

Table 2 Continued

Classes	Changing BMI-trajectories			Stable BMI-trajectories			
	1 Declining-risk n (%)	2 Delayed-risk n (%)	3 Gradual-risk n (%)	4 Low-risk n (%)	5 Moderate-risk n (%)	6 High-risk n (%)	
BMI trajectory classes	**143 (3.2)**	**234 (5.7)**	**314 (7.9)**	**2861 (67.9)**	**215 (5.2)**	**375 (10.2)**	**χ^2, p value**
English spoken at home	128 (3.4)	196 (5.5)	269 (7.9)	2500 (68.7)	185 (4.9)	306 (9.7)	0.044
Foreign language spoken at home	15 (2.4)	38 (6.5)	45 (8.0)	361 (63.4)	34 (7.0)	69 (12.7)	
Low family SEP	16 (1.4)	58 (5.4)	105 (10.1)	627 (61.8)	64 (6.1)	149 (15.1)	<0.001
Medium family SEP	77 (3.6)	124 (6.2)	148 (7.5)	1444 (68.6)	102 (4.8)	178 (9.3)	
High family SEP	50 (4.9)	52 (4.9)	61 (5.7)	785 (74.8)	48 (4.6)	48 (4.9)	
Single parent	9 (1.6)	24 (5.4)	44 (11.0)	247 (63.5)	20 (4.3)	51 (14.1)	0.004
Partnered relationship	134 (3.4)	210 (5.7)	270 (7.5)	2614 (68.4)	195 (5.3)	324 (9.6)	
Mother works full-time	30 (3.9)	37 (4.9)	56 (7.7)	483 (67.8)	42 (5.8)	70 (9.9)	0.025
Mother works Part-time	69 (4.9)	91 (5.7)	132 (8.9)	1109 (68.0)	75 (4.7)	125 (8.5)	
Mother not in the workforce	44 (2.2)	106 (5.8)	126 (7.3)	1269 (68.2)	98 (5.4)	180 (11.2)	

Frequencies (n) and weighted row percentage (%) provided for categorical variables.
Numbers may not add to total sample size due to missing values.
BMI, body mass index; HICs, high-income countries; LMICs, low-income and middle-income countries; SEP, socioeconomic position; SSBs, sugar-sweetened beverages.

DISCUSSION

Using a large, nationally representative cohort data, we identified two distinct groups of BMI trajectories: one where BMI trajectories changed over time and the other where they were stable. The changing trajectories included declining-risk, delayed-risk, and gradual-risk BMI trajectories. The stable trajectories comprised of low-risk, moderate-risk, and high-risk BMI trajectories. Our study revealed some indication that BMI trajectories in Australian children aged 2–11 years varied by their immigrant status. We found that the distribution of immigrant children from HICs was similar to the Australian children across different BMI trajectories. However, there is some evidence that immigrant children from LMICs were less likely to have low-risk and more likely to have moderate-risk and high-risk BMI trajectories; immigrant status was not important for delayed-risk and declining-risk BMI trajectories. In fully adjusted models, the association between immigrant status and moderate-risk and high-risk BMI trajectories was fully attenuated. When we modelled the key maternal variables in our sensitivity analysis, we found that immigrant children from LMICs were also significantly more likely to have a gradual-risk BMI trajectory. Our sensitivity models showed that maternal overweight/obesity was associated with all atypical BMI trajectories, emphasising the importance of genetic, fetal and family environmental factors in childhood obesity.[17] Our finding that approximately 9% of children drastically changed weight between 4 and 7 years (3% in the declining-risk and 6% in the delayed-risk trajectory) suggests that these ages are important for the prevention of childhood overweight/obesity.

To our knowledge, the BMI trajectories we have identified are not reported elsewhere, which makes a comparison with other studies difficult. Nonetheless, we can draw on certain similarities. For example, child immigrant status was a significant risk associated with early-onset BMI trajectory in children aged 6–12 years in a Canadian longitudinal study compared with the late-onset or never overweight/obese trajectory.[15] In a US study, children of new immigrants, especially boys, were more likely to have continuous overweight trajectory compared with a gradual onset or normal weight trajectory from kindergarten through eighth grade when compared with children of Americans and children of longtime or second-generation immigrants.[20] Similarly, in the European context, compared with non-immigrants, children of immigrants aged 4–12 years were more likely to have an increasing BMI trajectory instead of decreasing trajectory.[35] Thus research to date affirms our findings that immigrant children are more likely to have higher BMI trajectories than the host population.[15 20]

Consistent with other studies, we found that sex, birth weight, breast feeding, consumption of SSBs, organised sports participation, screen time, maternal workforce participation and family SEP were associated with atypical BMI trajectories.[14–20 35] We also observed that these risks play out differently for different BMI trajectories. For example, we found that children with SSBs consumption were less likely to have declining-risk BMI trajectory, but

Table 3 Multinomial regression analysis of the association between child immigrant status, risk factors and BMI trajectories in children aged 2–11 years from the birth cohort of the Longitudinal Study of Australian Children

	Changing BMI-trajectories			Stable BMI-trajectories	
	1 Declining-risk*	2 Delayed-risk*	3 Gradual-risk*	5 Moderate-risk*	6 High-risk*
n (%)	**143 (3.3)**	**234 (5.7)**	**314 (7.9)**	**215 (5.3)**	**375 (10.1)**
	RRR (95% CI)	**RRR (95% CI)**	**RRR (95% CI)**	**RRR (95% CI)**	**RRR (95% CI)**
Model 1: adjusted for sex					
Immigrant children from HICs†	0.87 (0.59 to 1.28)	0.79 (0.56 to 1.09)	0.86 (0.64 to 1.14)	1.07 (0.77 to 1.50)	0.9 (0.8 to 1.5)
Immigrant children from LMICs†	0.80 (0.45 to 1.42)	0.92 (0.59 to 1.45)	1.23 (0.86 to 1.75)	1.5 (0.99 to 2.38)$^{(0.051)}$	**1.4 (1.0 to 1.9)**$^{(0.04)}$
Girls	**1.9 (1.3 to 2.7)**$^{(<0.001)}$	0.91 (0.69 to 1.22)	0.89 (0.70 to 1.15)	1.29 (0.96 to 1.75)	1.15 (0.92 to 1.45)
Model 2: fully adjusted					
n (%)	143 (3.2)	231 (5.7)	309 (7.9)	212 (5.2)	371 (10.1)
Immigrant children from HICs†	0.89 (0.59 to 1.32)	0.73 (0.51 to 1.03)	0.90 (0.68 to 1.22)	1.04 (0.74 to 1.45)	0.99 (0.76 to 1.30)
Immigrant children from LMICs†	1.10 (0.54 to 2.24)	0.56 (0.27 to 1.14)	1.49 (0.95 to 2.39)	1.07 (0.56 to 2.06)	1.04 (0.63 to 1.71)
Girls	**2.2 (1.5 to 3.1)**$^{(<0.001)}$	0.98 (0.73 to 1.32)	0.93 (0.72 to 1.19)	1.34 (0.98 to 1.81)	1.22 (0.96 to 1.55)
Never breast fed	0.97 (0.43 to 2.16)	1.16 (0.69 to 1.97)	0.82 (0.49 to 1.35)	0.68 (0.35 to 1.30)	1.43 (0.96 to 2.12)
Low birth weight, <2.5 kg	0.93 (0.33 to 2.65)	0.79 (0.35 to 1.82)	0.65 (0.31 to 1.36)	0.32 (0.09 to 1.12)	0.55 (0.26 to 1.17)
High birth weight, ≥ 4 kg	**2.8 (1.8 to 4.4)**$^{(<0.001)}$	**1.9 (1.3 to 2.8)**$^{(0.002)}$	1.39 (0.96 to 1.99)	**1.6 (1.1 to 2.4)**$^{(0.02)}$	**2.3 (1.7 to 3.1)**$^{(<0.001)}$
High screen time (≥3 hours on weekday/weekend)	1.26 (0.85 to 1.87)	**1.5 (1.1 to 2.0)**$^{(0.01)}$	**1.5 (1.2 to 2.0)**$^{(0.002)}$	1.23 (0.88 to 1.71)	1.03 (0.79 to 1.34)
No organised sports	1.04 (0.73 to 1.49)	**1.6 (1.1 to 2.1)**$^{(0.007)}$	1.08 (0.82 to 1.42)	**1.5 (1.1 to 2.0)**$^{(0.02)}$	1.11 (0.86 to 1.44)
SSBs ≥1/day	**0.64 (0.44 to 0.94)**$^{(0.02)}$	1.01 (0.73 to 1.38)	0.90 (0.68 to 1.20)	0.85 (0.61 to 1.17)	1.18 (0.90 to 1.56)
Foreign language spoken at home	0.85 (0.41 to 1.71)	1.8 (0.99 to 3.6)$^{(0.051)}$	0.83 (0.52 to 1.32)	1.30 (0.71 to 2.40)	1.36 (0.87 to 2.14)
Mother works full-time	1.05 (0.66 to 1.69)	0.87 (0.56 to 1.35)	0.89 (0.62 to 1.27)	1.26 (0.82 to 1.94)	1.13 (0.80 to 1.59)
Mother not in workforce	**0.61 (0.40 to 0.92)**$^{(0.02)}$	1.04 (0.76 to 1.45)	**0.68 (0.50 to 0.91)**$^{(0.009)}$	1.05 (0.74 to 1.48)	1.09 (0.84 to 1.44)
Low family SEP	**0.50 (0.27 to 0.93)**$^{(0.02)}$	0.90 (0.63 to 1.29)	**1.5 (1.1 to 2.0)**$^{(0.02)}$	**1.5 (1.0 to 2.1)**$^{(0.04)}$	**1.6 (1.2 to 2.1)**$^{(<0.001)}$
High family SEP	1.23 (0.81 to 1.84)	0.79 (0.55 to 1.14)	**0.69 (0.49 to 0.98)**$^{(0.03)}$	0.93 (0.63 to 1.36)	**0.49 (0.35 to 0.70)**$^{(<0.001)}$
Single parent	0.88 (0.41 to 1.89)	0.96 (0.56 to 1.63)	1.46 (0.97 to 2.2)	0.83 (0.46 to 1.48)	1.13 (0.78.1.65)

Frequencies (n) and weighted row percentage (%) provided.
Goodness-of-fit test for model 1 (n=4142): (X^2 (10)=11.83, p=–0.29). Goodness-of-fit test for model 2 (n=4096): (X^2 (50)=37.19, p=–0.91).
Values in bold indicate statistically significant results.
RRR is the relative risk ratio for the explanatory variable: that is, the relative risk of being in the specified trajectory, versus the reference trajectory, for the level of the explanatory variable category compared with the reference category.
*Reference group: 4 Low-risk BMI trajectory.
†Reference group: Australian children.
BMI, body mass index; HICs, high income countries; LMICs, low-income and middle-income countries; SEP, socioeconomic position; SSBs, sugar-sweetened beverages.

there was no association with other atypical BMI trajectories. These results are worrisome in showing that quite young children are exposed to SSBs. Our results also confirm that it is not the diet per se that increases the risk of overweight/obesity in children, but rather a combination of factors including sedentary behaviours and physical inactivity.[35]

Immigrant children possibly exhibit an even more inactive lifestyle compared with the host children.[13 36] Immigrant parents may discourage physical activities in their children to promote weight gain due to their favourable cultural views on adiposity.[37] Lack of affordability, religious restrictions and safety concerns are also reasons given by immigrant parents for lower physical activities in children.[38] Additionally, due to low obesity literacy, many immigrant parents consider childhood obesity as a temporary phase, which the child would grow out in adulthood.[38] Irrespective of the causes, non-participation in organised sports and high screen time also impede social integration of immigrant children with host children. Obesity prevention strategies aimed at promoting physical activities in these populations could help deliver a social and health benefit by increasing social integration.

Given that pubertal changes begin early in girls,[39] we expected a higher proportion of girls in changing trajectories. Instead, we found a very similar distribution of boys and girls in all BMI trajectories except delayed-risk BMI trajectory, which was surprising. Higher likelihood of girls in the declining-risk BMI trajectory may indicate social pressure for thinness as the girls grow older.[40] There is no evidence of sex-related differences in BMI trajectories at younger ages[14–16]; however, in older children who are transitioning to adolescence, higher obesity is reported in girls' trajectories.[41] In contrast, among immigrant children, boys are more likely to have higher BMI trajectories than girls in early and middle childhood.[19 20] Sex differences in BMI trajectories among immigrant children warrant further research.

We found that high birth weight was strongly predictive of childhood obesity.[23] The birth weight reflects the influence of early life factors such as maternal (prepregnancy and pregnancy) nutritional status, maternal smoking, and maternal health conditions such as gestational diabetes and hypertension.[23] These early life factors programme appetite and energy expenditure in utero by permanently affecting hormonal, neuronal and autocrine mechanisms contributing to the energy balance.[42] Association of early life risk factors with childhood obesity warrants interventions in prenatal and perinatal periods.

Our study confirms findings which suggest that socioeconomic inequalities related to BMI are present from early childhood and increase with age.[17] We found that socioeconomic disadvantage was more evident for declining-risk, gradual-risk and high-risk BMI trajectories in children from low SEP families. Although due to lack of statistical power we were unable to identify distinct BMI trajectories within each SEP group by immigrant status, a significantly higher proportion of immigrant children from LMICs were from low SEP families, suggesting their high risk. Targeting these children from socially disadvantaged families must be a top intervention priority.

The importance of 4–7 years of age for the prevention of childhood overweight/obesity has also been reported previously.[20 43] At this age, the adiposity rebound occurs and the discrepancies in overweight/obesity emerge in children by their immigrant backgrounds.[20 43] Additionally, at this age, the diet and physical activity of children transform due to schools and peers.[43] Further research to identify factors which result in rapid weight changes of children at these ages will be beneficial for prevention programmes.

To the best of our knowledge, this is the first Australian cohort study to identify distinct BMI trajectories in 2-11-year-old Australian children and then to test whether these trajectories differ by children immigrant status and other child, maternal and family characteristics. The study has high retention rates. In addition, trained interviewers took anthropometric measurements rather than parent-reported.

The major limitation of the study was that the LSAC under-represents children from non-English-speaking, single-parent families living in disadvantaged areas, and over-represents mothers with year 12 education. Sampling weights were used to adjust for unequal probabilities of selection and for non-response.

The second limitation of our study was that we considered immigrant children from LMICs and HICs as homogeneous groups based on the socioeconomic development of their origin country. Although socioeconomic development of origin country influences diet and physical activity practices of immigrants, the cultural meaning of health and healthy weight may still be different in countries with similar socioeconomic development. Therefore, the study results may not be generalisable to all immigrants from countries with similar socioeconomic backgrounds.

A third limitation was that we did not model separate BMI trajectories for boys and girls. Our main focus was to identify BMI trajectories and their risk factors in children by their immigrant status. Our study identified six BMI trajectories and showed the distribution of boys and girls and other risk factors in these BMI trajectories. We found small differences in the distribution of boys and girls in all trajectories except for declining risk. However, to unravel sex-specific puberty-related variations in BMI trajectories for Australian children by their immigrant status, this may be an important future research direction.

Additional limitations included the brevity of diet and physical activities measures, the absence of variables to measure health literacy and detailed data on school and neighbourhood attributes related to obesity in the LSAC data set.

We also acknowledge that our analyses include a large number of hypothesis tests, which will increase the probability of a type I error (incorrectly concluding an association when there is none). In the light of recent criticism and guidelines on the use of p values,[44] and our limited sample size in some subgroups, we have chosen not to adjust p values for multiple testing, but rather to point this out as a limitation of the study.

CONCLUSION

In conclusion, we find that obesity is not always a stable condition and that risk factors may drive quite different BMI trajectories. While for some there can be an improvement, for others there can be a worsening, but the overall pattern for most children (83%) is that their BMI status is stable. This is great news for children with healthy BMI, but of concern for those with high BMI. Our results suggest that immigrant status affects child obesity largely through family socioeconomic disadvantage and child sedentary behaviours. Some of these risk factors may be due to difficulty integrating into the host culture (eg, lack of participation in organised sports and high screen time). Taken together all these may help explain the excess risk of obesity in immigrant children. More research with larger samples is required to explore these factors further. Currently, there is an intense debate in Australia about sugar taxation to curb obesity. However, sugar taxation alone may not be useful in isolation, and efforts to intensify physical activities and discourage sedentary behaviours are also essential. Such interventions should be particularly targeted towards children of immigrants, as it will improve their physical health and result in better mental health outcomes due to improved social integration in Australian society.

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