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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026845
Article Type:	Research
Date Submitted by the Author:	04-Oct-2018

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Keywords:	Immigrants, Low-and-middle-income countries, Pediatric obesity, BMI-trajectories, Australian children

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

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Running head: Overweight/obesity in children of Australian immigrants

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Article summary

- Children of immigrants from low-and-middle-income countries are more likely to have moderate-risk, high-risk or gradual-risk and less likely to have low-risk BMI-trajectories.
- Risk factors associated with these BMI-trajectories in Australian immigrant children are birth weight, family socio-economic-position, language spoken at home and organized sports participation.
- Four to seven year of age is a critical period for developing overweight and obesity in Australian children.

Strengths and limitations of the study

- One strength of our study was that we used data from a large representative sample of children from a country with high immigrant population, with reliable measurements of child weight.
- A limitation of our study was that the "Longitudinal study of Australian children" underrepresents children from non-English speaking, single-parent families living in disadvantaged areas, and over-represents mothers with year 12 education. To adjust for these unequal probabilities of sample selection and for non-response, we used sample weights.

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Introduction

Australia is amongst the most obesogenic countries globally, with over a quarter of children aged 2-17 overweight or obese (henceforth referred to overweight/obesity) (1). Overweight/obese children are more likely to grow up as overweight/obese adults (2) with heightened risk of lifestyle diseases including cardio-metabolic diseases and cancers (3). The exponential increase in childhood overweight/obesity over the past decade indicates the challenges public health professionals face to target preventive interventions (4). As children are increasingly becoming overweight/obese at relatively younger ages (5), prevention of behavioural risk-factors before school age may prove to be essential.

Although the risk of overweight/obesity has plateaued in affluent countries, the prevalence is high within population subgroups (6, 7). A recent Australian longitudinal study identified this high risk in 2-11 year old children of immigrants from low-and-middle-income countries (LMICs), which was independent of family socioeconomic position (8). This is puzzling as immigrants from LMICs arrive in high-income-countries (HICs) with low overweight/obesity rates at immigration, but overweight/obesity rates in their children born in these countries exceed the rates in host children. The difference in overweight/obesity among origin LMICs and host HICs are attributed to the different stages of nutrition transition which closely follow socioeconomic development of the countries (9). Australian studies indicate that the drivers of excess childhood overweight/obesity risk are physical inactivity and low fruit and vegetable and high-energy dense food consumption (10-12). However, there is little evidence about the drivers of overweight/obesity risks in children of immigrants. Evidence suggest that the excess overweight/obesity risk of immigrants are shaped by the cultural and behavioral risk factors around diet and physical activities carried over from the origin countries or those adopted during the process of acculturation (9, 13). Nevertheless, most of this evidence is cross-sectional. Existing longitudinal evidence on children of immigrants is limited and ignores developmental variations in children's weight. However, recently some longitudinal studies focused on developmental heterogeneity in children's weight and demonstrated that there are groups of children who follow distinct weight trajectories (14-22). This raises question whether the pathways of overweight/obesity onset and development differ in children of immigrants from hosts.

Within Australia, only a few studies have investigated weight trajectories in children previously. These studies showed substantial heterogeneity in weight trajectories amongst Australian children. The predictors of atypical weight trajectories in these studies were child's diet, family socioeconomic status, parental education, parental smoking, child birthweight, and maternal obesity (14-16). These studies controlled for child immigrant status using child birthplace (14), language spoken at home (15) and grandparents country of birth (16) 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 necessary first step for culturally sensitive and targeted preventive interventions. Our study addresses this preventative health need by analyzing data from Birth (B) cohort of LSAC. Based on our literature review, we tested two types of *a priori* risk factors associated with childhood overweight/obesity from an early age: those specific to the children and those related to the mother and the family environment. Our study had two aims 1) to identify distinct BMI-trajectories in Australian-children aged 2-11 years, and 2) to 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. (23) The sampling frame for LSAC was drawn from the Medicare Australia enrolment database (which covers all Australian permanent residents), stratified by both state/territories and metropolitan/non-metropolitan areas and approximately one in 10 Australian postcodes were selected (23). Within postcodes children had an approximately equal chance (one in 25) of selection (24).

After obtaining informed consent, face-to-face interviews were conducted by trained interviewers primarily with the parent (23). The LSAC sample comprised two age cohorts. We analyzed 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 was the latest available data at the start of the present study. The analysis in this paper is restricted to child ages of 2-11 as children under two years old did not have data on length/height. The response rate for this cohort 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 year and 74% (n=3764) at 10-11 years (23).

The LSAC has been approved by the Australian Institute of Family Studies Ethics Committee. The current analysis was approved by the Australian National University Human Research Ethics Committee (Protocol No. 2015/421).

Measures

Body Mass Index (BMI), the outcome variable, was calculated as weight (in light clothing) / height (without shoes) squared (kg/m^2), measured at each visit using standardized equipment (23). We created a dichotomous variable to classify children as overweight/obese or not overweight/obese according to the International Obesity Task Force (IOTF) age-and-sex-specific criteria (overweight and obesity cut off points of 25 and 30 kg/m^2 in

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young adults aged 18, extrapolated to children) (25). The decision to combine overweight and obesity as a single category was due to small numbers of children in some categories, particularly from low-and-middle-income-countries and because the two BMI groups shared similar risk-factors at every age (8). This overweight/obesity variable also provides a risk measure for overweight/obesity that is easy to interpret by clinicians and parents (17). We used raw BMI instead of BMI-z score as raw BMI is a more reliable method to measure weight changes in longitudinal studies (26). Raw BMI also allows for comparison with other studies whilst z-scores are standardized to reflect the distribution within a study and it is more complicated to make comparisons between studies which may have different distributions (26).

Child immigrant status, the exposure variable, was defined using the socioeconomic development of child's mother and maternal grandparents birth countries. Father's birth country was not included in determining child immigrant status, due to the 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 (UN) Development Fund (UNDP) 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). (Supplementary material).

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 mother or at least one maternal grandparent born in that country. Immigrant children from HICs had 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 (Supplementary figure 1).

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 risk factors; A *priori* variables included child sex, child birthweight (<2.5 kg, 2.5-4 kg and >4 kg), whether the child was ever breastfed (yes/no); child's consumption of sugar-sweetened-beverages (none versus ≥ 1/day); organized sports activities (yes/no) and screen-time (<3 hours or ≥3 hours on weekdays or weekends). Involvement in organized sports activities for 2-3 year olds, which included swimming lessons and dancing/movement classes, was used as a proxy for child physical activities as there was no other reliable measure of child physical activities at this age. Parents reported on diet, organized-sports activities and screen-time until the children were 8-9 years. (23).

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), language spoken at home (Non-English/English); and family socio-economic position (SEP) (low/middle/high) (29). Family socio-economic position (SEP) was based on a composite measure comprising combined annual family income, employment status and education of both parents (29) and categorized into the lowest 25%, the middle 50%, and the highest 25%.

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Analysis

Sample characteristics were compared by child's immigrant status using the Pearson's chi-square statistic. BMI trajectories of children from 2-11 years were estimated using Latent Class Growth Analysis (LCGA), a type of growth mixture model (30) whereby individuals within a trajectory are treated as a homogeneous group in terms of their developmental trajectory. 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, and Rubin likelihood ratio test (LMR-LRT) (31), the adjusted likelihood ratio test (LRT), and the bootstrap likelihood ratio test (BLRT) 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). Level of entropy, reflecting the proportion of participants correctly classified into their respective trajectories, helped determine the utility of additional trajectories.

Associations between health-related behaviours and BMI trajectories.

The chi-square statistic was used to compare distributions of risk factors across BMI trajectory classes. Multinomial logistic regression analysis then compared BMI trajectories by child immigrant status, risk factors and confounders for children aged 2-3 years (study baseline). We constructed two models: Model 1 adjusted for sex only and Model 2 adjusted for all of the explanatory variables of interest. We also used the goodness of fit test to assess the fit of the model. Due to more than 10% missing values at baseline for gestational diabetes, gestational hypertension, maternal weight and maternal current smoking status, these variables were excluded from the primary analysis, and assessed in a sensitivity analysis.

LCGA analyses were undertaken in MPlus v.7.1 whilst the comparison of differentials between classes was undertaken in STATA v.15. Survey weights were used for descriptive statistics and modeling. Statistical significance was set at $p<0.05$.

Patient and public involvement

No patients 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 comprised of 4312, 2-3 years old singleton children with known birth countries of child, mother and maternal grandparents. Children with mixed ethnicities (n=73), multiple births (n=152) and born-overseas (n=17) were excluded. The sample included 180 indigenous children.

Approximately 55% of our sample were Australian children, 20% second and 10% third generation children from HICs. Second and third generation children from LMIC comprised 12% and 3% of the sample respectively. We conducted preliminary analysis separately with second and third generation children, however found no generational effects. Moreover, due to the low number of third generation children from LMIC in our sample, we combined these categories. We refer to these combined categories as immigrant children from HICs

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and LMICs in this paper. The overall prevalence of overweight/obesity was 22% for children aged 2-3 years; girls were slightly more overweight/obese than boys. (Table 1).

Table 1. Socio-demographic characteristics of 2-3 year old children from Birth Cohort of Longitudinal study of Australian children.

	Australian n (%)	HICs n (%)	LMICs n (%)
Child immigrant status	2481 (55)	1289 (30)	542 (15)
Sons	1274 (51)	633 (49)	296 (54)
Daughters	1207 (49)	656 (51)	246 (46)
Child age (years) (mean SD)	2.3 (0.01)	2.3 (0.01)	2.3 (0.02)
Low birth weight child ≤2.5kg	86 (4)	42 (4)	25 (5)
Normal birth weight (≥2.5 ≤4.0kg)	2029 (82)	1065 (84)	462 (86)
High birth weight child ≥4.0kg	354 (14)	176 (13)	48 (8)
Never breast-fed	182 (9)	96 (9)	44 (9)
Overweight/obese sons	275 (22)	137 (23)	57 (21)
Overweight/obese daughters	281 (25)	148 (22)	68 (29)
Other siblings at home	2028 (82)	1010 (78)	417 (77)*
Foreign Language spoken at home	30 (1)	157 (14)	389 (78)***
Mother current smoker	325 (20)	164 (19)	33 (9)
Overweight/obese mothers	715 (42)	365 (39)	127 (37)
Single mothers	273 (13)	131 (13)	45 (10)
Maternal age <30 years	922 (39)	395 (31)	189 (39)***
Low SEP	673 (34)	277(27)	177 (40)***
Middle SEP	1219 (47)	682 (51)	225 (39)
High SEP	586 (20)	329 (21)	136 (21)
Mother work full time	405 (16)	228 (18)	112 (19)***
Mother work part time	992 (38)	507 (39)	129 (22)
Mother not in workforce	1077 (46)	551 (44)	300 (60)
Sugar-sweetened-beverages ≥ 1/day	1737 (72)	879 (70)	394 (75)
No organised sports	1363 (58)	690 (57)	145 (77)***
High-screen time (≥3 hrs weekday/weekend)	751 (32)	370 (31)	196 (38)*
Gestational diabetes; yes	92 (5)	63 (5)	49 (13)***
Pregnancy hypertension; yes	169 (9)	89 (8)	18 (6)
Mother current smoker	325 (20)	164 (19)	33 (9)***

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SEP=socio-economic-position.
Percentages are weighted and rounded.
*p<0.05, **p<0.01, ***p<0.001

Number of BMI trajectories: Model selection

Based on the model fit indicators a 6-trajectory model was the most appropriate (Table 2). Lower AIC and BIC were demonstrated for the 6- trajectory model, whilst the model estimating 7-trajectories showed an increase in AIC and BIC. Further, the LRT indicates a significant difference between nested models for up to the 6-trajectory model, but not for the 7-trajectory model, which suggests that the 7-trajectory does not demonstrate better fit in comparison with the 6-trajectory model.

The 6-trajectories are displayed in Figure 1. Three trajectories (4, 5 and 6) had stable proportions of overweight/obesity over time and include a high-risk (trajectory 6; 10% of the study sample), moderate-risk (trajectory 5; 5%) and low-risk (trajectory 4; 68 %;) group. Three trajectories demonstrated substantial change over time. One group (trajectory 1; 3%) declined in the proportion reporting overweight/obese, from 100% to

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0% between 4-5 years to 8-9 years. In contrast, there are two groups (trajectories 2; 6% and 3; 8%) which increased in risk over time and varied only in the shape of their trajectory. Those in trajectory 2 reported no overweight/obesity at baseline, but the proportion reporting overweight/obesity increased substantially in the final two observations (starting at 6-7 years) with 100% at the final observation reporting overweight/obesity (delayed-risk). In contrast, trajectory 3 described a rising proportion (26%) of overweight/obesity from baseline to 100% by the final observation (gradual-risk).

Table 2 Model fit indicators for a series of Latent Class Growth Analyses of BMI

# of Classes	AIC	BIC	BIC adjusted sample size	Entropy	LRT*	VLMR p value	Bootstrap p value
2	16227.786	16259.836	16243.948	0.849	4427.276	< 0.001	< 0.001
3	15867.183	15918.463	15893.042	0.724	366.603	< 0.001	< 0.001
4	15647.289	15717.799	15682.845	0.781	225.894	< 0.001	< 0.001
5	15580.958	15689.928	15635.909	0.810	28.119	<0 .001	< 0.001
6	15603.076	15692.817	15648.330	0.848	50.212	0.0057	< 0.001
7	15585.257	15713.458	15649.906	0.792	1.701	0.998	0.667

Abbreviations: AIC= Akaike information criterion; BIC= Bayesian information criterion; LRT=likelihood ratio test; VLMR= Vuong-Lo-Mendel-Rubin Likelihood ratio test; LRT value reflects the “2 times the log-likelihood difference”

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

Table 3 shows the distribution of risk factors across BMI-trajectory groups at baseline and Table 4 shows 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 BMI-trajectory 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 3) but in sex-adjusted models (Table 4), relative to the stable low-risk BMI-trajectory (reference group), was significant for the high-risk and marginally significant for the moderate-risk BMI-trajectory. These risk ratios attenuated in fully adjusted multinomial regression models when we included the explanatory risk factors.

In fully-adjusted analysis, child risk factors significantly associated with BMI-trajectories were sex; birthweight; consumption of sugar-sweetened-beverages; organized sports participation and screen-time (Tables 3 and 4), while maternal and family risk factors were foreign language spoken at home, and family SEP. The risk of a moderate-risk BMI-trajectory was greater for those with high birthweight and for those with non-participation in organized sports, while the risk of a high-risk BMI-trajectory was higher for children with high birthweight 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 birthweight were more likely to have declining-risk BMI-trajectories. Conversely, children from low SEP families, or those who consumed sugared-beverages had lower chances of having declining-risk BMI-trajectories.

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

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Table 3 Distribution of risk factors in children aged 2–3 years by BMI-Trajectories in Birth Cohort of Longitudinal Study of Australian Children.

Classes	Changing Classes			Stable Classes			
BMI-Trajectories classes	Declining-Risk n (%)	Delayed Risk n (%)	Gradual Risk n (%)	Low Risk n (%)	Moderate Risk n (%)	High Risk n (%)	
	143 (3.4)	234 (5.7)	314 (7.6)	2861 (69.1)	215 (5.2)	375 (9.0)	x^2
Child **immigrant status**							
Australian	85 (3.4)	142 (6.2)	177 (8.0)	1633 (67.9)	111 (4.8)	198 (9.7)	
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)	0.170
Sons	54 (2.2)	127 (5.9)	169 (8.5)	1507 (69.0)	102 (4.7)	181 (9.6)	
Daughters	90 (4.2)	108 (5.3)	148 (7.3)	1386 (66.6)	115 (5.8)	200 (10.8)	0.003
Prenatal and neonatal risk-factors							
Gestational diabetes; No	126 (3.6)	193 (5.8)	259 (8.1)	2395 (68.4)	182 (5.4)	274 (8.8)	0.022
Gestational diabetes; yes	7 (3.2)	10 (4.8)	20 (10.6)	117 (59.6)	11 (5.8)	28 (16.2)	
Pregnancy hypertension; No	122 (3.5)	192 (5.8)	258 (8.3)	2358 (68.6)	175 (5.2)	264 (8.7)	0.006
Pregnancy hypertension; yes	11 (4.3)	12 (5.3)	22 (8.1)	164 (59.2)	18 (7.3)	40 (15.9)	
Low birthweight <2.5 kg	4 (2.4)	7 (5.1)	9 (5.9)	111 (78.2)	3 (1.9)	9 (6.4)	
2.5-4.0 kg	107 (2.9)	185 (5.3)	257 (7.8)	2447 (69.2)	178 (5.3)	288 (9.5)	<0.001
>4 kg	33 (5.6)	41 (7.9)	48 (8.9)	324 (56.1)	35 (6.0)	82 (15.5)	
Never Breastfed	8 (2.7)	23 (6.5)	21 (7.1)	198 (64.1)	13 (3.7)	45 (15.9)	0.023
Ever breastfed	136 (3.3)	212 (5.6)	296 (8.0)	2694 (68.2)	204 (5.4)	336 (9.6)	
Child level risk factors: Diet							
Sugar-sweetened-beverages not at all	58 (4.6)	70 (5.3)	90 (7.8)	895 (68.5)	71 (5.8)	87(8.0)	0.004
≥ 1/day	86 (2.6)	164 (5.8)	226 (7.8)	1988 (67.6)	145 (5.0)	292 (11.0)	
Physical activity							
No organised sports	70 (2.7)	151 (6.4)	190 (8.3)	1552 (65.4)	137 (6.0)	241 (11.2)	
Participates in organised sports	74 (3.9)	85 (4.5)	127 (7.4)	1341 (71.4)	80 (4.1)	140 (8.6)	0.000
Low screen time (<3 hrs weekday/weekend)	103 (3.3)	145 (4.9)	198 (7.1)	2067 (69.8)	143 (4.9)	256 (9.9)	0.002
High-screen time (≥3 hrs weekday/weekend)	41(3.0)	90 (7.1)	119 (9.7)	826 (63.9)	74 (5.8)	125 (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)	36 (6.7)	54 (10.3)	295 (59.2)	36 (6.8)	70 (14.5)	<0.001
Non- smoker	106 (3.8)	150 (5.6)	195 (7.7)	1957 (70.2)	132 (5.0)	187 (7.6)	
English spoken at home	129 (3.4)	197 (5.5)	272 (7.9)	2531 (68.7)	183 (4.9)	312 (9.7)	0.044
Foreign language spoken	15 (2.4)	38 (6.5)	45 (8.0)	261 (63.4)	34 (7.0)	69 (12.7)	
Family SEP; Low	17 (1.4)	58 (5.4)	107 (10.1)	646 (61.8)	64 (6.1)	152 (15.1)	
Medium *SEP*	77 (3.6)	125 (6.2)	149 (7.5)	1454 (68.6)	104 (4.8)	181 (9.3)	<0.001
High *SEP*	50 (4.9)	52 (4.9)	61 (5.7)	788 (74.8)	48 (4.6)	48 (4.9)	
Single parent	8 (1.6)	24 (5.4)	44 (11.0)	254 (63.5)	20 (4.3)	53 (14.1)	0.004
Have a partner	136 (3.4)	211 (5.7)	273 (7.5)	2639 (68.4)	197 (5.3)	328 (9.6)	
Maternal full-time work	31 (3.9)	38 (4.9)	57 (7.7)	503 (67.8)	42 (5.8)	73 (9.9)	
Part-time work	70 (4.9)	97 (5.7)	137 (8.9)	1152 (68.0)	79 (4.7)	127 (8.5)	0.025
Not in the workforce	46 (2.2)	105 (5.8)	135 (7.3)	1337 (68.2)	103 (5.4)	187 (11.2)	

a. Legend=1=declining-risk trajectory, 2 = delayed-risk trajectory, 3=gradual-risk trajectory, 4= persistent low-risk trajectory, 5= persistent moderate-risk trajectory, 6= persistent high-risk trajectory
b. Frequency (n) and weighted row percentage (%) provided for categorical variables.

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Table 4. Multinominal Regression Analysis of the association between child Immigrant status, risk factors and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining-Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n (%)	143 (3.3)	234 (5.7)	314 (7.9)	215 (5.3)	375 (10.1)
	RR (95% CI)	RR (95% CI)	RR(95% CI)	RR (95% CI)	RR (95% CI)
Model 1 adjusted for sex					
Immigrant children from HICs[&]	0.87 (0.59,1.28)	0.79 (0.56,1.09)	0.86 (0.64,1.14)	1.07 (0.77,1.50)	0.9 (0.8,1.5)
Immigrant children from LMICs [&]	0.80 (0.45,1.42)	0.92 (0.59,1.45)	1.23 (0.86,1.75)	1.5 (0.99,2.38)[(0.051)]	**1.4 (1.0,1.9)***
Daughters	**1.9 (1.3,2.7)*****	0.91 (0.69,1.22)	0.89 (0.70,1.15)	1.29 (0.96,1.75)	1.15 (0.92,1.45)
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 (0.59,1.32)	0.73 (0.51,1.03)	0.90 (0.68,1.22)	1.04 (0.74,1.45)	0.99 (0.76,1.30)
Immigrant children from LMICs [&]	1.10 (0.54,2.24)	0.56 (0.27,1.14)	1.49 (0.95,2.39)	1.07 (0.56,2.06)	1.04 (0.63,1.71)
Daughters	**2.2 (1.5,3.1) *****	0.98 (0.73,1.32)	0.93 (0.72,1.19)	1.34 (0.98,1.81)	1.22 (0.96,1.55)
Never Breastfed	0.97 (0.43,2.16)	1.16 (0.69,1.97)	0.82 (0.49,1.35)	0.68 (0.35,1.30)	1.43 (0.96,2.12)
birthweight <2.5 kg	0.93 (0.33,2.65)	0.79 (0.35,1.82)	0.65 (0.31,1.36)	0.32 (0.09,1.12)	0.55 (0.26,1.17)
birthweight >4 kg	**2.8 (1.8,4.4) *****	**1.9 (1.3,2.8) ****	1.39 (0.96,1.99)	**1.6 (1.1,2.4) ***	**2.3 (1.7,3.1) *****
High Screen time	1.26 (0.85,1.87)	**1.5 (1.1,2.0) ***	**1.5 (1.2,2.0) ****	1.23 (0.88,1.71)	1.03 (0.79,1.34)
No organised sports	1.04 (0.73,1.49)	**1.6 (1.1,2.1) ****	1.08 (0.82,1.42)	**1.5 (1.1,2.0) ***	1.11 (0.86,1.44)
High sugary-beverages/day	**0.64 (0.44,0.94) ***	1.01 (0.73,1.38)	0.90 (0.68,1.20)	0.85 (0.61,1.17)	1.18 (0.90,1.56)
Foreign language spoken at home	0.85 (0.41,1.71)	1.8 (0.99,3.6)	0.83 (0.52,1.32)	1.30 (0.71,2.40)	1.36 (0.87,2.14)
Mother in full time work	1.05 (0.66,1.69)	0.87 (0.56,1.35)	0.89 (0.62,1.27)	1.26 (0.82,1.94)	1.13 (0.80,1.59)
Mother not in workforce	**0.61 (0.40,0.92) ***	1.04 (0.76,1.45)	**0.68 (0.50,0.91) ***	1.05 (0.74,1.48)	1.09 (0.84,1.44)
Low family SEP	**0.50 (0.27,0.93) ***	0.90 (0.63,1.29)	**1.5 (1.1,2.0) ***	1.40 (0.98,2.10)	**1.6 (1.2,2.1) ****
High family SEP	1.23 (0.81,1.84)	0.79 (0.55,1.14)	**0.69 (0.49,0.98) ***	0.93 (0.63,1.36)	**0.49 (0.35,0.70) *****
Single parent	0.88 (0.41,1.89)	0.96 (0.56,1.63)	1.46 (0.97,2.2)	0.83 (0.46,1.48)	1.13 (0.78.1.65)

[&] Reference group Australian-children
[a] Reference group low-risk BMI-trajectory
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)
*p<0.05, **p<0.01, ***p<0.00

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To further understand the potential (indirect) pathways to children's weight by immigrant status, we created sex-adjusted models with individual explanatory risk factors and compared the coefficients for each BMI-trajectory by child immigrant status (Supplementary Table 1). Our models showed that language spoken at home and organized sports participation and to a lesser degree family SEP explained the high probability of immigrant children from LMICs to have moderate-risk and high-risk BMI-trajectories. None of the individual risk factors explained the potential pathways between children with a gradual-risk BMI-trajectory and their immigrant status.

Our sensitivity analysis (Supplementary Table 2) 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 was associated with declining risk, maternal smoking was associated with the high-risk trajectory, and maternal overweight/obesity was associated with the delayed, gradual, moderate and high-risk trajectories.

Discussion

Using large, nationally representative Australian cohort data, our study revealed that BMI-trajectories in 2-11 year old Australian children varied by their immigrant status, suggestive of differences in child, maternal or family risk factors. For all children in this age range we identified two distinct groups of BMI-trajectories; one where BMI-trajectories changed over time and the other where they were stable. The changing weight group included declining-risk, delayed-risk, and gradual-risk BMI-trajectories. The stable weight group comprised of low-risk, moderate-risk and high-risk BMI-trajectories. We found that the distribution of immigrant children from HICs was similar to the Australian children across different BMI-trajectories. However, the distribution of immigrant children from LMICs across BMI-trajectories varied from both these groups. There is some evidence that these children were less likely to be in a low-risk group and more likely to be in moderate and high-risk groups. They were also more likely to be in the gradual-risk BMI-trajectory whereby children gained weight from 4-7 years of age and were overweight/obese at 10-11 years. This patterning suggests that the ages of 4-7 years are critical for prevention of childhood overweight/obesity especially among immigrant children from LMICs.

To our knowledge, the exact weight-trajectories we have identified are not reported elsewhere, which makes comparison with other studies difficult. However, we can draw on certain similarities. For example, our results are in concordance with international evidence of BMI-trajectories in children of immigrants compared to non-immigrants (17-20, 35, 36). Although there are few of these studies and they report different numbers of BMI-trajectories than in our findings, they still show that immigrant children are more likely to have high (36), or early-onset BMI-trajectories (17, 20).

Consistent with the literature, we found that immigrant status is an important risk for childhood obesity (17, 36). Similar to other risk factors in our models, child's immigrant status also showed differential patterning across BMI-trajectories. Immigrant children from LMICs were more likely to have moderate-risk and high-risk BMI-trajectories and to some extent gradual-risk BMI-trajectory. However, immigrant status was not important for delayed-risk and declining-risk BMI-trajectories. In fully adjusted models for other risk factors, the association of immigrant status for moderate-risk and high-risk BMI-trajectories was fully attenuated. Our sensitivity

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models, including maternal variables with high levels of missing data, showed significant strengthening of this association for immigrant children from LMICs. In this analysis, the heightened likelihood of being in gradual-risk BMI-trajectory for immigrant children from LMICs was not explained by the variables we adjusted for, suggestive of culturally specific influences we were unable to measure such as practices around choice, preparation and eating habits (37). Future research is required to investigate risk factors in this group.

Consistent to other studies, we found that sex, birthweight, breastfeeding, consumption of sugar-sweetened-beverages, organized sports participation, screen-time, language spoken at home, and family SEP explained childhood obesity (35, 36, 38-44). We also observed that these risks play out differently for different BMI-trajectories. For example, girls were more likely to be in declining-risk (significant), moderate-risk and high-risk BMI-trajectories in our sex-adjusted and fully adjusted models, but not in delayed-risk and gradual-risk BMI-trajectories. These findings show that the girls with higher BMI at younger ages were more likely to lose weight as they grew older; an indication of societal pressure on girls for sliminess or thinness in HICs such as Australia. On the contrary, certain subsets of girls such as immigrant girls from LMICs may have indulgent cultural food practices and restrictions on social and after school activities, making weight loss difficult (45). The differential patterning of risks in BMI-trajectories show the complexities of explaining childhood obesity.

Our sex-adjusted models showed that language spoken at home, organized sports participation and family SEP may explain increased likelihood of being in moderate-risk and high-risk BMI-trajectories in immigrant children from LMICs. However, no clear pattern emerged for other BMI-trajectories. Possibly, English as a second language may indicate low health literacy (46) and maternal inability to navigate the health messages in the host country. Higher obesity in immigrant children from LMICs may also be due to parental strategies to promote weight gain due to cultural influences and values, linked to low SEP (19, 42, 47). Children with high birthweight may be particularly at risk of these weight-promoting practices. Low health literacy in mothers who speak a foreign language at home may also be a plausible explanation for the lower proportion of immigrant children from LMICs in stable low-risk BMI-trajectory (19). Targeted culture-specific health promotion messages in simple English or the language of key immigrant communities may lower childhood obesity in these populations.

Among behavioral risk factors, non-participation in organized sports was associated with moderate-risk and high-risk BMI-trajectories in immigrant children from LMICs. Organized sports participation not only promotes healthy weight but may also promote social integration with host children (43). Early introduction of organized sports may be a beneficial strategy for promoting physical activity habits, especially in immigrant children from LMICs.

Our finding that 4-7 year of age is critical for prevention of childhood overweight/obesity has policy implications. This is the age of adiposity rebound and an age where the discrepancies in overweight/obesity emerge between children of immigrants and hosts (48). At this age, the diet and physical activity of children transform due to school-related socialization and regulations (49). Targeted strategies aimed at increasing maternal health literacy and increasing opportunities for physical activities at school may be beneficial for obesity prevention.

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To the best of our knowledge, this is the first Australian cohort study to identify distinct BMI-trajectories in Australian-children aged 2-11 years 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.

We considered immigrant children from LMICs and HICs as homogenous groups based on the socio-economic development of their origin country, which was a limitation of the study. Although socio-economic 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 socio-economic development. The absence of these culturally specific variables in the data restricted us to test for these associations. Other limitations were the brevity of diet and physical activities measures and absence of variables to measure health literacy.

Conclusion

In conclusion, we found that disparities in child weight by children immigrant status are present from early childhood and increases when children transition to school. Importantly, the study shows that obesity is not a stable condition for all and that risk factors may drive quite different BMI-trajectories. Whilst 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 those with good BMI, but of concern for those who report continually moderate to high BMI. Our results are suggestive that socio-economic disadvantage, lack of social integration resulting in sedentary behaviors and low health literacy may be the underlying factors in excess risk of obesity in immigrant children from LMICs. Culture specific preventive strategies to lower obesity rates when the children transition to school may be helpful in increasing maternal health literacy and promote social integration.

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Availability of data and materials

The data that support the findings of this study are available from the Australian Institute of Family Studies, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Australian Institute of Family Studies.

Competing interests

Nil

Funding

Nil

Authors' contributions

TZ developed the original idea and planned the study. RB and TZ conducted data analysis. CDE contributed to analysis. TZ led the writing. RB, CDE, LS contributed to writing and interpretation of results. LS, CDE, RB reviewed and approved the final manuscript.

Acknowledgements

The Longitudinal Study of Australian Children is conducted in partnership between the Department of Families, Housing, Community Services and Indigenous Affairs (FaHCSIA), the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). The findings and views reported in this paper are those of the authors and are not endorsed by FaHCSIA, AIFS or the ABS. We thank all the parents and children for their continuing support and participation in the LSAC.

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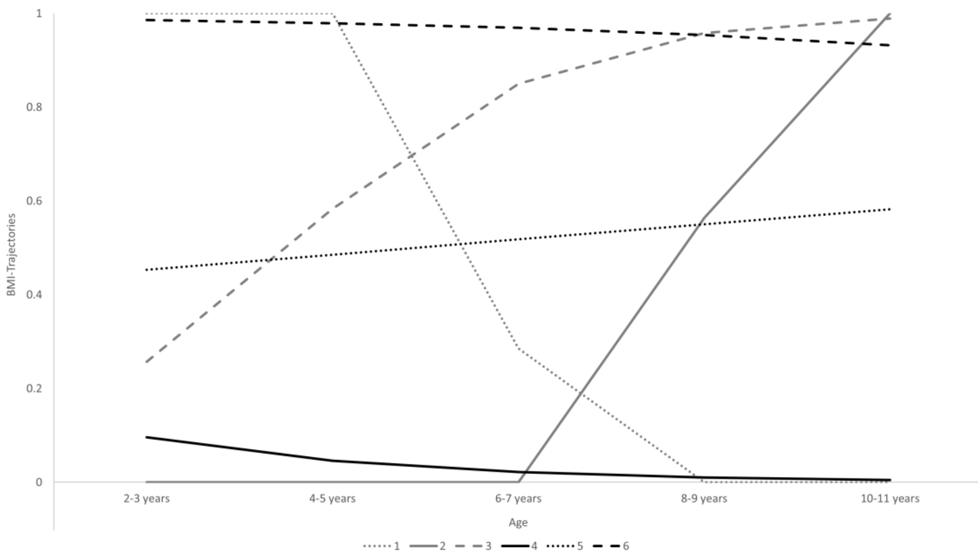

Figure 1. The plot of the trajectories of 6 classes from a Latent Class Growth Analyses of BMI

338x190mm (300 x 300 DPI)

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

List of countries included in Birth Cohort of Longitudinal Study of Australian Children.

The Longitudinal Study of Australian Children reported 96 birth countries. High-income and low-and-middle income countries were classified according to societal development and access to resources by UNDP's Human development Index. High-income-countries had a HD1 score of ≥ 0.70 and low-and-Middle-income-countries scored <0.7.[1]

High-income-countries

Argentina, Albania, Australia, Algeria, Austria, Belgium, Bosnia and Herzegovina, Brunei, Brazil, Canada, Chile, China, Cook Islands, Costa Rica, Croatia, Czech Republic, Denmark, England, Fiji, Republic of Macedonia, France, Germany, Greece, Hong Kong, Hungary, Iran, Ireland, Israel, Italy, Japan Jordan,, South Korea, Lebanon, Libya, Lithuania, Malta, Malaysia, Mauritius, Netherlands, New Caledonia, New Zealand, Peru, Poland, Portugal, Romania, Russian Federation, Samoa, Scotland, Singapore, Slovakia, Spain, Sweden, Switzerland, Taiwan, Thailand, Tonga, Turkey, Ukraine, United Kingdom, United States of America, Uruguay, Wales, Yugoslavia.

Low-and-middle-income-countries

Afghanistan, Bangladesh, Myanmar, Cambodia, East Timor, Egypt, El Salvador, Eritrea, Ethiopia, Ghana, India, Indonesia, Iraq, Kenya, Laos, Liberia, Namibia, Nicaragua, Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Sierra Leone, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Syria, Viet Nam, Zambia, Zimbabwe

1. United Nations Development Programme Human development report 2016. Human development for everyone. United Nations, New York2016.

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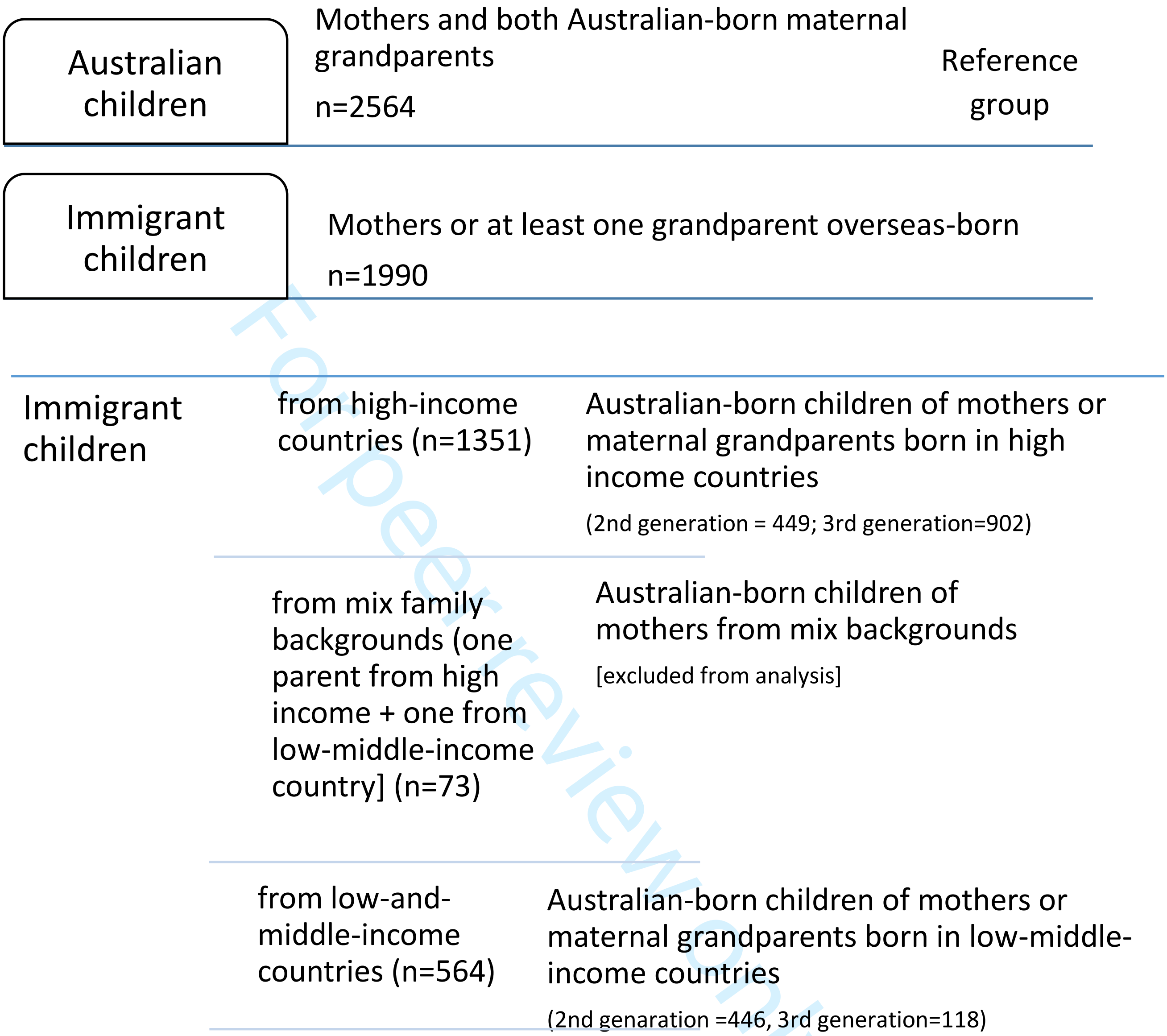
Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

Figure 1. Sample Distribution of 2-3 year old children by Immigrant Status at Baseline of Birth Cohort of Longitudinal Study of Australian Children.



- Final sample was 4312 after excluding first generation children (n=17), multiple births (n=152) and children with mixed immigrant status.

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

Supplementary Table 1. Sex-adjusted and individual risk factors adjusted Multinominal Regression models of the association between child Immigrant status and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			**Stable Classes**	
	Declining-Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n (%)	143 (3.3)	234 (5.7)	314 (7.9)	215 (5.3)	375 (10.1)
	RR (95% CI)	RR (95% CI)	RR(95% CI)	RR (95% CI)	RR (95% CI)
Model 1 adjusted for sex					
Immigrant children from HICs [&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.42)	0.92 (0.59, 1.45)	1.23 (0.86, 1.76)	1.5 (0.99, 2.38)$^{(0.051)T}$	**1.4 (1.0, 1.9)***
Daughters	**1.9 (1.3, 2.7)*****	0.92 (0.69, 1.22)	0.89 (0.70, 1.15)	1.29 (0.96, 1.75)	1.16 (0.92, 1.46)
Model 2 adjusted for sex and Breastfeeding					
Immigrant children from HICs[&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.14)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.44)	0.93 (0.59, 1.46)	1.24 (0.86, 1.77)	**1.5 (1.0, 2.4)***	**1.4 (1.0, 1.9)***
Daughters	**1.9 (1.3, 2.7)*****	0.92 (0.69, 1.23)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.17 (0.92, 1.47)
Never Breast feed	0.73 (0.33, 1.61)	1.25 (0.76, 2.08)	0.95 (0.58, 1.56)	0.75 (0.41, 1.39)	**1.8 (1.2, 2.6)****
Model 3 adjusted for sex and birth-weight					
Immigrant children from HICs[&]	0.89 (0.60, 1.32)	0.79 (0.57, 1.09)	0.87 (0.66, 1.16)	1.08 (0.78, 1.52)	0.98 (0.76, 1.29)
Immigrant children from LMICs [&]	0.86 (0.48, 1.53)	0.97 (0.62, 1.52)	1.23 (0.86, 1.77)	**1.6 (1.0, 2.4)***	**1.4 (1.0, 2.0)***
Daughters	**2.1 (1.5, 3.1)*****	0.96 (0.72, 1.29)	0.92 (0.72, 1.18)	1.34 (0.99, 1.81)	1.25 (0.99, 1.58)
<2.5 kg	0.79 (0.29, 2.21)	0.85 (0.38, 1.93)	0.67 (0.33, 1.39)	0.32 (0.09, 1.10)	0.61 (0.28, 1.28)
>4.0 kg	**2.8 (1.8, 4.4)*****	**1.8 (1.2, 2.7)****	1.37 (0.95, 1.95)	**1.6 (1.0, 2.3)***	**2.2 (1.6, 2.9)*****
Model 4 adjusted for sex and screen time					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.80 (0.45, 1.43)	0.90 (0.58, 1.42)	1.20 (0.84, 1.71)	1.5 (0.98, 2.3)	**1.4 (1.0,1 .9)**$^{(0.050)T}$
Daughters	**1.9 (1.3, 2.7)*****	0.93 (0.70, 1.25)	0.91 (0.71, 1.17)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
High-screen time (≥3 hrs weekday/weekend)	0.99 (0.67, 1.48)	**1.6 (1.2, 2.1)****	**1.5 (1.2, 1.9)****	1.26 (0.92, 1.73)	1.15 (0.90,1.48)
Model 5 adjusted for sex and organised sports					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.85 (0.47, 1.50)	0.84 (0.54, 1.33)	1.19 (0.83, 1.70)	1.41 (0.91, 2.16)	1.31 (0.93, 1.83)
Daughters	**1.9 (1.3, 2.7)****	0.93 (0.70, 1.24)	0.90 (0.70, 1.15)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
No organised sports	0.81(0.57, 1.14)	**1.6 (1.2, 2.1)****	1.17(0.91, 1.50)	**1.57 (1.15, 2.12)****	**1.4 (1.1, 1.8)****
Model 6 adjusted for sex and sugar-sweetened beverages					
Immigrant children from HICs[&]	0.86 (0.58, 1.28)	0.79 (0.57, 1.10)	0.87 (0.65, 1.16)	1.06 (0.76, 1.47)	0.98 (0.75, 1.27)
Immigrant children from LMICs [&]	0.82 (0.46, 1.47)	0.93 (0.59, 1.46)	1.24 (0.87, 1.77)	**1.6 (1.0, 2.4)***	1.38 (0.99, 1.92)
Daughters	**1.9 (1.3, 2.7)****	0.92 (0.69, 1.23)	0.89 (0.69, 1.14)	1.31 (0.97, 1.77)	1.15(0.91, 1.45)

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

Sugar sweetened beverages once or more daily	**0.58 (0.40, 0.82)****	1.10 (0.8, 1.5)	1.02 (0.77, 1.35)	0.97 (0.66, 1.24)	**1.4 (1.1, 1.8)***
Model 7 adjusted for sex and language spoken at home					
Immigrant children from HICs[&]	0.89 (0.59, 1.33)	0.72 (0.51, 1.02)	0.88 (0.66, 1.17)	1.03 (0.74, 1.43)	0.93 (0.71 ,1.23)
Immigrant children from LMICs [&]	0.95 (0.44, 2.02)	0.57 (0.29, 1.13)	1.36 (0.87, 2.13)	1.21 (0.67, 2.2)	1.16 (0.74, 1.83)
Daughters	**1.9 (1.3, 2.7)*****	0.91 (0.69, 1.22)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.15 (0.91, 1.45)
Foreign language spoken at home	0.80 (0.38, 1.68)	**1.8 (1.0, 3.3)***	0.87 (0.56, 1.36)	1.35 (0.76, 2.4)	1.28 (0.84,1 .94)
Model 8 adjusted for sex and family SEP					
Immigrant children from HICs[&]	0.84 (0.57, 1.24)	0.79 (0.57, 1.10)	0.88 (0.66, 1.17)	1.09 (0.78, 1.53)	1.01 (0.78, 1.31)
Immigrant children from LMICs [&]	0.85 (0.48, 1.51)	0.94 (0.60, 1.48)	1.20 (0.84, 1.72)	1.44 (0.93, 2.23)	1.35 (0.97, 1.88)
Daughters	**1.9 (1.3, 2.8)*****	0.92 (0.69, 1.22)	0.89 (0.69, 1.14)	1.27 (0.94, 1.72)	1.13 (0.89, 1.43)
Low SEP	**0.41 (0.23, 0.77)****	0.98 (0.69, 1.39)	**1.5 (1.1, 1.9)****	**1.4 (1.0, 2.0)***	**1.8 (1.4 ,2.3)*****
High SEP	1.30 (0.89, 1.91)	0.73 (0.51, 1.03)	**0.68 (0.49, 0.94)***	0.88 (0.61, 1.29)	**0.4 (0.34, 0.68)*****

[&] Reference group Australian-children
[a] Reference group low-risk BMI-trajectory
Reference group for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English; Family SEP = middle SEP.
[1] all results here are from multinomial analysis.
[T]=0.05, *p<0.05, **p<0.01, ***p<0.001

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Supplementary Table 2. Sensitivity model. Multinominal Regression Analysis of the child Immigrant status, risk factors and group-based BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining-Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n=2746 n (%)	105 (3.7)	161 (6.1)	207 (8.1)	139 (5.3)	200 (8.1)
	RR (95% CI, P)	RR (95% CI, P)	RR(95% CI, P)	RR (95% CI, P)	RR (95% CI, P)
Immigrant children from HICs[&]	0.97 (0.62, 1.52)	0.72 (0.47, 1,08)	1.18 (0.83, 1.68)	1.01 (0.67, 1.54)	1.13 (0.79, 1.62)
Immigrant children from LMICs [&]	1.24 (0.55, 2.80)	0.60 (0.23, 1.56)	**1.9 (1.1, 3.2)***	1.45 (0.71, 2.94)	1.36 (0.71, 2.58)
Daughters	**2.1 (1.4, 3.3)****	0.85 (0.60, 1.21)	1.21 (0.89, 1.66)	1.16 (0.80, 1.70)	1.22 (0.88, 1.68)
Never Breastfed	0.90 (0.32, 2.55)	1.29 (0.67, 2.49)	0.83 (0.43, 1.60)	1.25 (0.60, 2.58)	1.33 (0.73, 2.44)
birthweight <2.5 kg	1.13 (0.36, 3.54)	0.80 (0.26, 2.42)	0.79 (0.31, 1.98)	0.42 (0.09, 1.85)	0.41 (0.13, 1.26)
birthweight >4 kg	**2.1 (1.3, 3.5)****	1.54 (0.96, 2.49)	1.14 (0.73, 1.80)	1.32 (0.89, 2.16)	**1.9 (1.3, 2.9)****
High-screen time (≥3 hrs weekday/weekend)	1.06 (0.66, 1.70)	1.39 (0.97, 2.00)	**1.6 (1.2, 2.3)****	1.13 (0.76, 1.70)	0.88 (0.62, 1.27)
No organised sports	1.09 (0.72, 1.64)	**1.7 (1.2, 2.4)****	1.04 (0.75, 1.44)	1.42 (0.97, 2.06)	1.16 (0.83, 1.62)
High sugary-beverages/day	0.69 (0.45, 1.07)	1.02 (0.70, 1.49)	0.89 (0.64, 1.24)	0.82 (0.55, 1.22)	1.25 (0.87, 1.78)
Foreign language spoken at home	0.73 (0.31, 1.75)	1.67(0.75, 3.73)	0.96 (0.57, 1.62)	1.02 (0.49, 2.09)	1.59 (0.89, 2.8)
Low family SEP	**0.41 (0.18, 0.88)***	0.77 (0.48, 1.24)	**1.7 (1.1, 2.5)****	1.20 (0.73, 1.97)	1.2 (0.8, 1.8)
High family SEP	1.31 (0.83, 2.04)	0.80 (0.53, 1.22)	0.80 (0.54, 1.19)	0.92 (0.58, 1.47)	**0.49 (0.32, 0.76)****
Gestational diabetes	1.11 (0.46, 2.68)	0.80 (0.35, 1.85)	1.37 (0.74, 2.51)	1.09 (0.47, 2.57)	1.40 (0.77, 2.56)
Gestational hypertension	2.07 (0.96, 4.45)	0.92 (0.43, 1.98)	0.94 (0.52, 1.71)	1.6 (0.83, 3.09)	**1.8 (1.1, 2.9)***
Overweight/obese mother	**1.6 (1.0 ,2.5)***	**2.1 (1.45, 2.9)*****	**2.4 (1.7, 3.3)*****	**2.5 (1.7, 3.6)*****	**3.3 (2.3, 4.5)*****
Mother current smoker	0.85 (0.42, 1.73)	1.25 (0.77, 2.06)	1.37 (0.89, 2.09)	1.66 (0.99, 2.77)	**2.2 (1.5, 3.2)*****

Adjusted for gestational diabetes, gestational hypertension, maternal weight, and maternal current smoking status in addition to variables reported in Table 4.
[&] Reference group Australian-children
[a] Reference group low-risk BMI-trajectory
Reference groups for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English language spoken at home; Family SEP = middle SEP; Gestational diabetes = no gestational diabetes; gestational hypertension = no gestational hypertension; overweight/obese mother = mother not overweight/obese; mother current smoker = mother not current smoker.
[T]= 0.05, *p<0.05, **p<0.01, ***p<0.001;
Goodness of Fit test for sensitivity model (n=2746): (X^2 (70)=53.77, p=-0.92)

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	3
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	3-4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	3
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	3, 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	3-4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	4,5
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	5
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	5,6
Outcome data	15*	Report numbers of outcome events or summary measures over time	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	6
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	6
Discussion			
Key results	18	Summarise key results with reference to study objectives	7
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	7
Generalisability	21	Discuss the generalisability (external validity) of the study results	8
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	10

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026845.R1
Article Type:	Research
Date Submitted by the Author:	14-Jan-2019

Complete List of Authors:	Zulfiqar, Tehzeeb; Research School of Population Health - ANU, National Center for Epidemiology and Population Health Burns, Richard; Australian National University, Australia, Center for Research on Ageing, Health & Well being D'Este, Catherine; College of Health and Medicine, The Australian National University, National Center of Epidemiology and Population Health Strazdins, Lyndall; The Australian National University, National Center of Epidemiology and Population Health, The Research School of Population Health, College of Health and Medicine.

Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Paediatrics
Keywords:	Immigrants, Low-and-middle-income countries, Pediatric obesity, BMI-trajectories, Australian children

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status.

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Running head: BMI-trajectories in Australian children by immigrant status

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Article summary

- Relative to children of Australian born parents, children of immigrants from low-and-middle-income countries were significantly more likely to have high-risk and marginally more likely to have moderate-risk BMI-trajectories, rather than stable low-risk BMI-trajectories. These associations became insignificant in fully adjusted models when we added explanatory risk factors.
- Risk factors associated with these BMI-trajectories in Australian immigrant children were birthweight, family socio-economic-position, language spoken at home and organized sports participation. Due to rapid decline of BMI at 4-5 years and rapid increase of BMI at 6-7 years, four to seven year of age was considered as a critical period for developing overweight and obesity in Australian children.

Strengths and limitations of the study

- The study was conducted on a large cohort sample, with reliable measurements of child weight.
- Major limitation was that the "Longitudinal study of Australian children" underrepresents 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.

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Abstract

Objectives: This study aimed to identify BMI-trajectories and their predictors in Australian children by their maternal immigrant status.

Methods: Data on 4606 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 Taskforce cut-off-points. Immigrant status was determined by Australian Bureau of Statistics and UNDP Human Development Index criteria. Latent Class Growth Analysis estimated distinct BMI-trajectories and multinomial logistic regression analysis examined factors associated with BMI-trajectories.

Results: Two BMI groups and Six BMI-trajectories were identified. 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 to 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 birthweight, family socio-economic-position, and organized sports participation. Our results also suggest that 4-7 years of age may be important for prevention of overweight/obesity in children.

Discussion: Better understanding of the risk factors associated with distinct BMI-trajectories in immigrant children will inform effective preventive strategies. Some of these risks factors such as non-participation of organized 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.

Key words: Emigrants and Immigrants, BMI trajectories, Overweight, Paediatric Obesity.

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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 cardio-metabolic conditions and cancers (3). The exponential increase in childhood overweight/obesity over the past decade indicate 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 carryover 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 (SSB) and low physical activity in 4-11-year-old children 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 that there are groups of children who follow distinct weight trajectories (14-21). This raises a question of whether the pathways of overweight/obesity onset and development may differ in children of immigrants from hosts.

Within Australia, only a few studies have investigated weight trajectories in children. These studies showed substantial heterogeneity in weight trajectories amongst Australian children. The predictors of atypical weight trajectories in these studies included child's diet, family socioeconomic status, parental education, parental smoking, child birthweight, breastfeeding, 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 analyzing data from Birth (B) cohort of the longitudinal study of Australian Children (LSAC). Based on our literature review, which showed the importance

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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 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 geographic 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 one in 10). Within postcodes, children had about an equal chance (one in 25) of selection (24).

After obtaining informed consent, face-to-face interviews were conducted by trained interviewers primarily with the parent (24). The LSAC sample comprised of two age cohorts. We analyzed ten 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 was 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 two years old did not have data on length/height. The proportion of children in the original cohort who participated at each age were 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 year and 74% (n=3764) at 10-11 years (24). Approximately 73% children (n=3372) who participated at 2-3 years participated in all five surveys.

The LSAC was approved by the Australian Institute of Family Studies Ethics Committee. The current analysis was approved by the Australian National University Human Research Ethics Committee (Protocol No. 2015/421).

Measures

Body Mass Index (BMI), the outcome variable, was calculated as weight (in light clothing) / height (without shoes) squared (kg/m2), measured at each visit using standardized equipment (25). We created a categorical variable to classify children as overweight, obese and not overweight/obese according to the International Obesity Task Force (IOTF) age-and-sex-specific criteria (overweight and obesity cut off points of 25 and 30 kg/m2 in young adults aged 18, extrapolated to children) (26).

We used raw BMI as it is considered the best measure to assess group-based BMI-trajectories overtime, compared to BMI z-score or BMI-centiles which are best to measure adiposity cross-sectionally (27). BMI-z scores depend on the baseline weight status of the children and are less variable in obese than non-obese children. Therefore, when used longitudinally in trajectory models, they may not allow the identification of distinct groups with various developmental patterns(27, 28). Raw BMI also allows for comparison with other studies whilst z-scores are standardized to reflect the distribution within a study. The easy interpretability of raw BMI also makes it suitable for comparisons between studies with different distributions (27).

Child immigrant status, the exposure variable, was defined using the socioeconomic development of the child's mother and maternal grandparents birth countries. Father's birth country was not included in determining child

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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 (UN) Development Fund (UNDP) Human Development Index (HDI) scores of 2015. LMICs included countries with HDI scores of < 0·7 and HICs with HDI scores of ≥ 0.7 (29). (S1 supplementary material).

Children were classified as Australian (reference group) if they were born in Australia or born-overseas with Australian-born mothers and grandparents. The 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. The third generation immigrant children had Australian-born mothers and at least one grandparent born-overseas (30). 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 an 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 risk factors; A *priori* variables included child sex, child birthweight (<2.5 kg, 2.5-4 kg and >4 kg), whether the child was ever breastfed (yes/no); child's consumption of SSB (none versus ≥ 1/day); organized 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). Organized sports participation for 2-3-year-olds, which included swimming lessons and dancing/movement classes, was used as a proxy for child physical activities as there was no other reliable measure of child physical activities at this age. Parents reported on diet, organized 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), language spoken at home (Non-English/English); and family socio-economic position (SEP) (low/middle/high) (31). Family socioeconomic position (SEP) was based on a composite measure comprising combined annual family income, employment status and education of both parents (31) and categorized 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 chi-square statistic. BMI trajectories of children from 2-11 years were estimated using Latent Class Growth Analysis (LCGA), a type of growth mixture model (32) whereby individuals within a trajectory are treated as a homogeneous group regarding their developmental trajectory. The most appropriate number of trajectories were 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, and Rubin likelihood ratio test (LMR-LRT) (33), the adjusted likelihood ratio test (LRT), and the bootstrap likelihood ratio test (BLRT) to compare nested models (34). We were also guided by parsimony, theoretical justification, and interpretability in determining the number of trajectories to extract (35, 36). Level of entropy, reflecting the proportion of participants correctly classified into their respective trajectories, helped determine the utility of additional trajectories.

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Associations between health-related behaviours and BMI trajectories.

The chi-square statistic was used to compare distributions of risk factors across BMI-trajectories. Multinomial logistic regression analysis compared relative risk (RRR) 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 large number of missing values at baseline for key maternal indicators such as gestational diabetes (22%), gestational hypertension (22%), maternal weight and (36%) maternal current smoking status (31%), these variables were excluded from the primary analysis, and assessed in a sensitivity analysis.

LCGA analyses were undertaken in MPlus v.7.1 whilst the comparison of differentials between classes was conducted in STATA v.15. MPlus analysis 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 modeling. 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 and 10% third generation children from HICs. Second and third generation children from LMIC comprised 12% and 3% of the sample respectively. We conducted preliminary analysis separately with second and third generation children, however, found no generational effects. Moreover, due to the low number of third generation children from LMIC 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 to the other groups, although this was not statistically significant (Table 1).

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Table 1. Socio-demographic characteristics of 2-3 year old children from Birth Cohort of Longitudinal study of Australian children.

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

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position.
Percentages are weighted and rounded.
*p<0.05, **p<0.01, ***p<0.001
Numbers may not add due to missing values

Number of BMI trajectories: Model selection

Based on the model fit indicators a 6-trajectory model was the most appropriate (supplementary Table 1). Lower AIC and BIC were demonstrated for the 6- trajectory model, whilst the model estimating 7-trajectories showed an increase in AIC and BIC. Further, the LRT indicates a significant difference between nested models for up to the 6- trajectory model, but not for the 7-trajectory model, which suggests that the 7-trajectory does not demonstrate better fit in comparison with the 6-trajectory model. Our comparison of models with linear, quadratic and cubic time for our LCGA models showed quadratic and linear models were the most appropriate for our analysis. However, based on higher entropy, we decided that a simpler and more parsimonious linear model was most appropriate.

The 6-trajectories are displayed in Figure 1. Three trajectories (4, 5 and 6) had stable proportions of overweight/obesity over time. These include high-risk (trajectory 6; 10% of the study sample), moderate-risk

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(trajectory 5; 5%) and low-risk (trajectory 4; 68 %;) BMI-trajectories. Three trajectories demonstrated substantial change over time. Trajectory 1 (3%) declined in the proportion reporting overweight/obese, from 100% to 0% between 4-5 years to 8-9 years. In contrast, there are two trajectories (trajectories 2; 5% and 3; 8%) which increased in risk over time and varied only in the shape of their trajectory. Those in trajectory 2 reported no overweight/obesity at baseline, but the proportion reporting overweight/obesity increased substantially in the final two observations (starting at 6-7 years) with 100% at the final observation reporting overweight/obesity (delayed-risk). In contrast, trajectory 3 described a rising proportion (26%) of overweight/obesity from baseline to 100% by the final observation (gradual-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 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-trajectory 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-trajectory. In our multinomial regression models, these risk ratios became insignificant, when we fully-adjusted for key risk factors.

In the fully adjusted analysis, key risk factors significantly associated with BMI-trajectories were sex; birthweight; consumption of SSB; organized sports participation, screen-time and family SEP (Table 3). The risk of a moderate-risk BMI-trajectory was greater for those with high birthweight and for those with non-participation in organized sports, while the risk of a high-risk BMI-trajectory was higher for children with high birthweight 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 birthweight were more likely to have declining-risk BMI-trajectories. Conversely, children from low SEP families, those who consumed SSB and those whose mothers were not in the workforce had lower chances of having declining-risk BMI-trajectories.

Further, children with high birthweight, high screen-time, who did not participate in organized 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 significantly and maternal non-participation in the workforce decreased the chances of being in the gradual-risk BMI-trajectory.

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Table 2 Distribution of risk factors in children aged 2–3 years by BMI-Trajectories in Birth Cohort of Longitudinal Study of Australian Children.

Classes	Changing Trajectories			Stable Trajectories			
BMI-Trajectories classes	1 Declining-Risk n (%)	2 Delayed Risk n (%)	3 Gradual Risk n (%)	4 Low Risk n (%)	5 Moderate Risk n (%)	6 High Risk n (%)	
	143 (3.2)	234 (5.7)	314 (7.9)	2861 (67.9)	215 (5.2)	375(10.2)	x^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							
Gestational diabetes; No	126 (3.6)	193 (5.8)	259 (8.1)	2395 (68.4)	182 (5.4)	274 (8.8)	0.022
Gestational diabetes; yes	7 (3.2)	10 (4.8)	20 (10.6)	117 (59.6)	11 (5.8)	28 (16.2)	
Pregnancy hypertension; No	122 (3.5)	192 (5.8)	258 (8.3)	2358 (68.6)	175 (5.2)	264 (8.7)	0.006
Pregnancy hypertension; yes	11 (4.3)	12 (5.3)	22 (8.1)	164 (59.2)	18 (7.3)	40 (15.9)	
Low birthweight <2.5 kg	4 (2.4)	7 (5.1)	9 (5.9)	108 (78.2)	3 (1.9)	9 (6.4)	<0.001
2.5-4.0 kg	106 (2.9)	185 (5.3)	256 (7.8)	2424 (69.2)	176 (5.3)	284 (9.5)	
>4 kg	33 (5.6)	42 (7.9)	49(8.9)	329 (56.1)	36 (6.0)	82 (15.5)	
Never Breastfed	7 (2.7)	23 (6.5)	21 (7.1)	194 (64.1)	13 (3.7)	44 (15.9)	0.023
Ever breastfed	136 (3.3)	211 (5.6)	293 (8.0)	2667(68.2)	202 (5.4)	331 (9.6)	
Child level risk factors: Diet							
SSB not at all	58 (4.6)	70 (5.3)	90 (7.8)	889 (68.5)	71 (5.8)	86(8.0)	0.004
SSB ≥ 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)	0.000
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 hrs 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 hrs 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)	
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)	
Family SEP; Low	16 (1.4)	58 (5.4)	105 (10.1)	627 (61.8)	64 (6.1)	149 (15.1)	<0.001
Medium *SEP*	77 (3.6)	124 (6.2)	148(7.5)	1444 (68.6)	102 (4.8)	178 (9.3)	
High *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
Have a partner	134 (3.4)	210 (5.7)	270 (7.5)	2614 (68.4)	195(5.3)	324 (9.6)	
Maternal full-time work	30 (3.9)	37(4.9)	56 (7.7)	483 (67.8)	42 (5.8)	70 (9.9)	0.025
Part-time work	69 (4.9)	91 (5.7)	132 (8.9)	1109 (68.0)	75 (4.7)	125 (8.5)	
Not in the workforce	44 (2.2)	106 (5.8)	126 (7.3)	1269 (68.2)	98 (5.4)	180(11.2)	

Legend= Changing-trajectories: 1 = declining-risk trajectory, 2 = delayed-risk trajectory, 3=gradual-risk trajectory, Stable-trajectories: 4= low-risk trajectory, 5= moderate-risk trajectory, 6= high-risk trajectory.
Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened-beverages, SEP=socio-economic-position.
Frequencies (n) and weighted row percentage (%) provided for categorical variables.
Numbers may not add to total sample size due to missing values

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Table 3. Multinominal Regression Analysis of the association between child Immigrant status, risk factors and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Trajectories			Stable Trajectories	
	1 Declining-Risk [a]	2 Delayed Risk [a]	3 Gradual Risk [a]	5 Moderate Risk [a]	6 High Risk [a]
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 (0.59,1.28)	0.79 (0.56,1.09)	0.86 (0.64,1.14)	1.07 (0.77,1.50)	0.9 (0.8,1.5)
Immigrant children from LMICs [&]	0.80 (0.45,1.42)	0.92 (0.59,1.45)	1.23 (0.86,1.75)	1.5 (0.99,2.38)$^{(0.051)}$	**1.4 (1.0,1.9)***
Daughters	**1.9 (1.3,2.7)*** **	0.91 (0.69,1.22)	0.89 (0.70,1.15)	1.29 (0.96,1.75)	1.15 (0.92,1.45)
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 (0.59,1.32)	0.73 (0.51,1.03)	0.90 (0.68,1.22)	1.04 (0.74,1.45)	0.99 (0.76,1.30)
Immigrant children from LMICs [&]	1.10 (0.54,2.24)	0.56 (0.27,1.14)	1.49 (0.95,2.39)	1.07 (0.56,2.06)	1.04 (0.63,1.71)
Daughters	**2.2 (1.5,3.1)** ***	0.98 (0.73,1.32)	0.93 (0.72,1.19)	1.34 (0.98,1.81)	1.22 (0.96,1.55)
Never Breastfed	0.97 (0.43,2.16)	1.16 (0.69,1.97)	0.82 (0.49,1.35)	0.68 (0.35,1.30)	1.43 (0.96,2.12)
birthweight <2.5 kg	0.93 (0.33,2.65)	0.79 (0.35,1.82)	0.65 (0.31,1.36)	0.32 (0.09,1.12)	0.55 (0.26,1.17)
birthweight >4 kg	**2.8 (1.8,4.4)** ***	**1.9 (1.3,2.8)** **	1.39 (0.96,1.99)	**1.6 (1.1,2.4)** *	**2.3 (1.7,3.1)** ***
High Screen time (≥3 hrs weekday/weekend)	1.26 (0.85,1.87)	**1.5 (1.1,2.0)** *	**1.5 (1.2,2.0)** **	1.23 (0.88,1.71)	1.03 (0.79,1.34)
No organised sports	1.04 (0.73,1.49)	**1.6 (1.1,2.1)** **	1.08 (0.82,1.42)	**1.5 (1.1,2.0)** *	1.11 (0.86,1.44)
SSB ≥ 1/day	**0.64 (0.44,0.94)** *	1.01 (0.73,1.38)	0.90 (0.68,1.20)	0.85 (0.61,1.17)	1.18 (0.90,1.56)
Foreign language spoken at home	0.85 (0.41,1.71)	1.8 (0.99,3.6)$^{(0.051)}$	0.83 (0.52,1.32)	1.30 (0.71,2.40)	1.36 (0.87,2.14)
Mother in full time work	1.05 (0.66,1.69)	0.87 (0.56,1.35)	0.89 (0.62,1.27)	1.26 (0.82,1.94)	1.13 (0.80,1.59)
Mother not in workforce	**0.61 (0.40,0.92)** *	1.04 (0.76,1.45)	**0.68 (0.50,0.91)** *	1.05 (0.74,1.48)	1.09 (0.84,1.44)
Low family SEP	**0.50 (0.27,0.93)** *	0.90 (0.63,1.29)	**1.5 (1.1,2.0)** *	1.40 (0.98,2.10)	**1.6 (1.2,2.1)** **
High family SEP	1.23 (0.81,1.84)	0.79 (0.55,1.14)	**0.69 (0.49,0.98)** *	0.93 (0.63,1.36)	**0.49 (0.35,0.70)** ***
Single parent	0.88 (0.41,1.89)	0.96 (0.56,1.63)	1.46 (0.97,2.2)	0.83 (0.46,1.48)	1.13 (0.78.1.65)

& Reference group Australian-children
a Reference group 4 low-risk BMI-trajectory
RRR is the relative risk ratio for the explanatory variable: i.e. the relative risk of being in the specified trajectory, versus the reference trajectory, for the level of the explanatory variable category compared to the reference category
Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened-beverages, SEP=socio-economic-position.
Goodness of Fit test for model 1 (n-4142): (X2 (10) = 11.83, p=-0.29). Goodness of Fit test for model 2 (n=4096): (X2 (50) = 37.19, p=-0.91)
*p<0.05, **p<0.01, ***p<0.001

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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 (Supplementary Table 2). Our models showed that organized 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 (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, delayed, gradual, moderate and high-risk BMI-trajectories.

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 2-11-year-old Australian children 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 modeled the key maternal variables in our sensitivity analysis, we found that immigrant children from LMICs were also somewhat more likely to have a gradual-risk BMI-trajectory. Our sensitivity models showed that maternal overweight/obesity was associated with all atypical BMI-trajectories, emphasizing the importance of genetic, fetal and family environmental factors in childhood obesity (17). Our finding that approximately nine percent of children drastically changed weight between 4-7 years (3% in the declining risk and 6% in the delayed risk trajectory) suggests that these ages are important for 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 to 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 to a gradual onset or normal weight trajectory from kindergarten through eighth grade when compared to children of Americans and children of longtime or second-generation immigrants (20). Similarly, in the European context, compared to non-immigrants, children of immigrants aged 4-12 years were more likely to have an increasing BMI trajectory instead of decreasing trajectory (37). Thus research to date affirms our findings that immigrant children are more likely to have higher BMI-trajectories than the host population (15, 20).

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Consistent with other studies, we found that sex, birthweight, breastfeeding, consumption of sugar-sweetened beverages, organized sports participation, screen-time, maternal workforce participation, and family SEP were associated with atypical BMI-trajectories (14-20, 37). We also observed that these risks play out differently for different BMI-trajectories. For example, we found that children with SSB consumption were less likely to have declining-risk BMI-trajectory, but there was no association with any other atypical BMI-trajectory. These results are worrisome in showing that quite young children are exposed to SSB. 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 behaviors and physical inactivity (37).

Immigrant children possibly exhibit an even more inactive lifestyle compared to the host children (13, 38). Immigrant parents may discourage physical activities in their children to promote weight gain due to their favorable cultural views on adiposity (39). Lack of affordability, religious restrictions and safety concerns are also reasons given by immigrants parents for lower physical activities in children (40). Additionally, due to low obesity literacy, many immigrant parents consider childhood obesity as a temporary phase, which the child would grow out in adulthood (40). Irrespective of the causes, non-participation in organized 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 (41), 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 (42). 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 (43). 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 birthweight was strongly predictive of childhood obesity (23). Birthweight reflects the influence of early life factors such as maternal (pre-pregnancy and pregnancy) nutritional status, maternal smoking, and maternal health conditions such as gestational diabetes and hypertension (23). These early life factors program appetite and energy expenditure in utero by permanently affecting hormonal, neuronal and autocrine mechanisms contributing to the energy balance (44). Association of early life risk factors with childhood obesity warrant interventions in pre- 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 with must be a top intervention priority.

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The importance of 4-7 year of age for prevention of childhood overweight/obesity is reported previously also (20, 45). At this age, the adiposity rebound occurs and the discrepancies in overweight/obesity emerge in children by their immigrant backgrounds (20, 45). Additionally, at this age, the diet and physical activity of children transform due to schools and peers (45). Further research to identify factors which result in rapid weight changes of children at these ages will be beneficial for prevention programs.

To the best of our knowledge, this is the first Australian cohort study to identify distinct BMI-trajectories in Australian-children aged 2-11 years 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 first limitation of our study was that we considered immigrant children from LMICs and HICs as homogenous groups based on the socio-economic development of their origin country. Although socio-economic 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 socio-economic development. Therefore, the study results may not be generalizable to all immigrants from countries with similar socioeconomic backgrounds.

A second 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 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.

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

Conclusion

In conclusion, we find that obesity is not always a stable condition and that risk factors may drive quite different BMI-trajectories. Whilst 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 affect child obesity largely through family socio-economic disadvantage, and child sedentary behaviors. Some of these risk factors may be due to difficulty integrating into the host culture (e.g., lack of participation of organized sports and high screen time). Taken together all this 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 behaviors are also essential. Such interventions should be particularly targeted towards children of immigrants, as it will not only improve their physical health but also result in better mental health outcomes due to improved social integration in Australian society.

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Availability of data and materials

The data of "Longitudinal study of Australian Children" is available from the Australian Institute of Family Studies. However, the data is not publically available. Restrictions apply to the availability of these data, which were used under license for the current study. Data are, however, available from the authors with permission of the Australian Institute of Family Studies.

Competing interests

Nil

Funding

Nil

Authors' contributions

TZ developed the original idea and planned the study. RB and TZ conducted data analysis. CDE contributed to analysis. TZ led the writing. RB, CDE, LS contributed to writing and interpretation of results. LS, CDE, RB reviewed and approved the final manuscript.

Acknowledgements

The Longitudinal Study of Australian Children is conducted in partnership between the Department of Families, Housing, Community Services and Indigenous Affairs (FaHCSIA), the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). The findings and views reported in this paper are those of the authors and are not endorsed by FaHCSIA, AIFS or the ABS. We thank all the parents and children for their continuing support and participation in the LSAC.

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Figure 1- Plot of BMI trajectories from a Latent Class Growth Analyses in Australian children aged 2-11 years.

Legend. 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.

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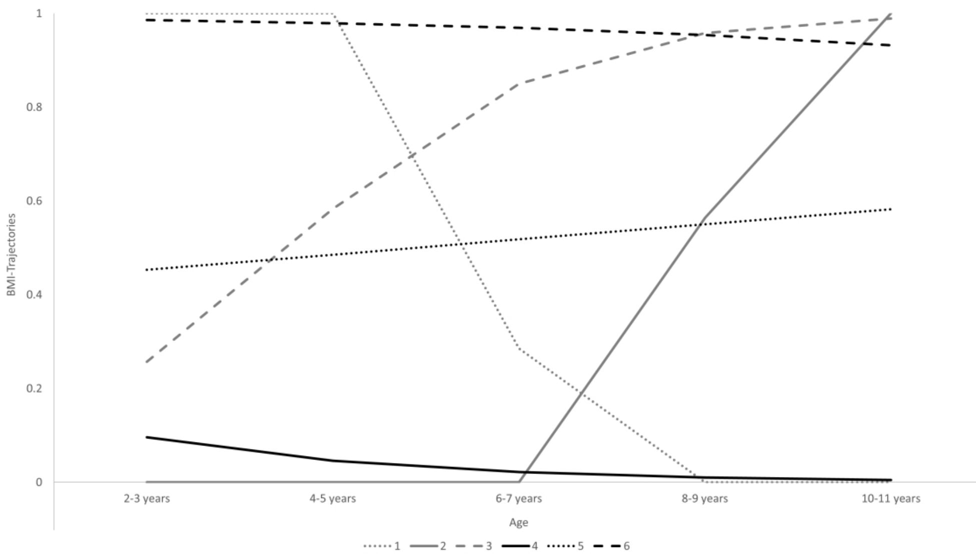

Figure 1- Plot of BMI trajectories from Latent Class Growth Analyses in Australian children aged 2-11 years.

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

S. 1. List of countries included in Birth Cohort of Longitudinal Study of Australian Children.

The Longitudinal Study of Australian Children reported 96 birth countries. High-income and low-and-middle income countries were classified according to societal development and access to resources by UNDP's Human development Index. High-income-countries had a HD1 score of ≥ 0.70 and low-and-Middle-income-countries scored <0.7.[1]

High-income-countries

Argentina, Albania, Australia, Algeria, Austria, Belgium, Bosnia and Herzegovina, Brunei, Brazil, Canada, Chile, China, Cook Islands, Costa Rica, Croatia, Czech Republic, Denmark, England, Fiji, Republic of Macedonia, France, Germany, Greece, Hong Kong, Hungary, Iran, Ireland, Israel, Italy, Japan Jordan,, South Korea, Lebanon, Libya, Lithuania, Malta, Malaysia, Mauritius, Netherlands, New Caledonia, New Zealand, Peru, Poland, Portugal, Romania, Russian Federation, Samoa, Scotland, Singapore, Slovakia, Spain, Sweden, Switzerland, Taiwan, Thailand, Tonga, Turkey, Ukraine, United Kingdom, United States of America, Uruguay, Wales, Yugoslavia.

Low-and-Middle-income-countries

Afghanistan, Bangladesh, Myanmar, Cambodia, East Timor, Egypt, El Salvador, Eritrea, Ethiopia, Ghana, India, Indonesia, Iraq, Kenya, Laos, Liberia, Namibia, Nicaragua, Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Sierra Leone, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Syria, Viet Nam, Zambia, Zimbabwe

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

Supplementary Table 1. Model fit indicators for a series of Latent Class Growth Analyses of BMI

# of Classes	AIC	BIC	BIC adjusted sample size	Entropy	LRT*	VLMR p value	Bootstrap p value
2	16227.786	16259.836	16243.948	0.849	4427.276	< 0.001	< 0.001
3	15867.183	15918.463	15893.042	0.724	366.603	< 0.001	< 0.001
4	15647.289	15717.799	15682.845	0.781	225.894	< 0.001	< 0.001
5	15580.958	15689.928	15635.909	0.810	28.119	<0 .001	< 0.001
6	15603.076	15692.817	15648.330	0.848	50.212	0.0057	< 0.001
7	15585.257	15713.458	15649.906	0.792	1.701	0.998	0.667

Abbreviations: AIC= Akaike information criterion; BIC= Bayesian information criterion; LRT=likelihood ratio test; VLMR= Vuong-Lo-Mendel-Rubin Likelihood ratio test; LRT value reflects the "2 times the log-likelihood difference"

Supplementary Table 2. Sex-adjusted and individual risk factors adjusted Multinominal Regression models of the association between child Immigrant status and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining-Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n (%)	143 (3.3)	234 (5.7)	314 (7.9)	215 (5.3)	375 (10.1)
	RR (95% CI)	RR (95% CI)	RR(95% CI)	RR (95% CI)	RR (95% CI)
Model 1 adjusted for sex					
Immigrant children from HICs [&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.42)	0.92 (0.59, 1.45)	1.23 (0.86, 1.76)	1.5 (0.99, 2.38)(0.051)T	**1.4 (1.0, 1.9)***
Daughters	**1.9 (1.3, 2.7)*****	0.92 (0.69, 1.22)	0.89 (0.70, 1.15)	1.29 (0.96, 1.75)	1.16 (0.92, 1.46)
Model 2 adjusted for sex and Breastfeeding					
Immigrant children from HICs[&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.14)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.44)	0.93 (0.59, 1.46)	1.24 (0.86, 1.77)	**1.5 (1.0, 2.4)***	**1.4 (1.0, 1.9)***
Daughters	**1.9 (1.3, 2.7)*****	0.92 (0.69, 1.23)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.17 (0.92, 1.47)
Never Breastfed	0.73 (0.33, 1.61)	1.25 (0.76, 2.08)	0.95 (0.58, 1.56)	0.75 (0.41, 1.39)	**1.8 (1.2, 2.6)****
Model 3 adjusted for sex and birthweight					
Immigrant children from HICs[&]	0.89 (0.60, 1.32)	0.79 (0.57, 1.09)	0.87 (0.66, 1.16)	1.08 (0.78, 1.52)	0.98 (0.76, 1.29)
Immigrant children from LMICs [&]	0.86 (0.48, 1.53)	0.97 (0.62, 1.52)	1.23 (0.86, 1.77)	**1.6 (1.0, 2.4)***	**1.4 (1.0, 2.0)***
Daughters	**2.1 (1.5, 3.1)*****	0.96 (0.72, 1.29)	0.92 (0.72, 1.18)	1.34 (0.99, 1.81)	1.25 (0.99, 1.58)

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

<2.5 kg	0.79 (0.29, 2.21)	0.85 (0.38, 1.93)	0.67 (0.33, 1.39)	0.32 (0.09, 1.10)	0.61 (0.28, 1.28)
>4.0 kg	**2.8 (1.8, 4.4)***	**1.8 (1.2, 2.7)****	1.37 (0.95, 1.95)	**1.6 (1.0, 2.3)***	**2.2 (1.6, 2.9)*****
Model 4 adjusted for sex and screen time					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.80 (0.45, 1.43)	0.90 (0.58, 1.42)	1.20 (0.84, 1.71)	1.5 (0.98, 2.3)	**1.4 (1.0,1 .9)**[(0.050)T]
Daughters	**1.9 (1.3, 2.7)*****	0.93 (0.70, 1.25)	0.91 (0.71, 1.17)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
High-screen time (≥3 hrs weekday/weekend)	0.99 (0.67, 1.48)	**1.6 (1.2, 2.1)****	**1.5 (1.2, 1.9)****	1.26 (0.92, 1.73)	1.15 (0.90,1.48)
Model 5 adjusted for sex and organised sports					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.85 (0.47, 1.50)	0.84 (0.54, 1.33)	1.19 (0.83, 1.70)	1.41 (0.91, 2.16)	1.31 (0.93, 1.83)
Daughters	**1.9 (1.3, 2.7)****	0.93 (0.70, 1.24)	0.90 (0.70, 1.15)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
No organised sports	0.81(0.57, 1.14)	**1.6 (1.2, 2.1)****	1.17 (0.91, 1.50)	**1.57 (1.15, 2.12)****	**1.4 (1.1, 1.8)****
Model 6 adjusted for sex and SSB					
Immigrant children from HICs[&]	0.86 (0.58, 1.28)	0.79 (0.57, 1.10)	0.87 (0.65, 1.16)	1.06 (0.76, 1.47)	0.98 (0.75, 1.27)
Immigrant children from LMICs [&]	0.82 (0.46, 1.47)	0.93 (0.59, 1.46)	1.24 (0.87, 1.77)	**1.6 (1.0, 2.4)***	1.38 (0.99, 1.92)
Daughters	**1.9 (1.3, 2.7)****	0.92 (0.69, 1.23)	0.89 (0.69, 1.14)	1.31 (0.97, 1.77)	1.15(0.91, 1.45)
SSB ≥ 1/day	**0.58 (0.40, 0.82)****	1.10 (0.8, 1.5)	1.02 (0.77, 1.35)	0.91 (0.66, 1.24)	**1.4 (1.1, 1.8)***
Model 7 adjusted for sex and language spoken at home					
Immigrant children from HICs[&]	0.89 (0.59, 1.33)	0.72 (0.51, 1.02)	0.88 (0.66, 1.17)	1.03 (0.74, 1.43)	0.93 (0.71 ,1.23)
Immigrant children from LMICs [&]	0.95 (0.44, 2.02)	0.57 (0.29, 1.13)	1.36 (0.87, 2.13)	1.21 (0.67, 2.2)	1.16 (0.74, 1.83)
Daughters	**1.9 (1.3, 2.7)*****	0.91 (0.69, 1.22)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.15 (0.91, 1.45)
Foreign language spoken at home	0.80 (0.38, 1.68)	**1.8 (1.0, 3.3)***	0.87 (0.56, 1.36)	1.35 (0.76, 2.4)	1.28 (0.84,1 .94)
Model 8 adjusted for sex and family SEP					
Immigrant children from HICs[&]	0.84 (0.57, 1.24)	0.79 (0.57, 1.10)	0.88 (0.66, 1.17)	1.09 (0.78, 1.53)	1.01 (0.78, 1.31)
Immigrant children from LMICs [&]	0.85 (0.48, 1.51)	0.94 (0.60, 1.48)	1.20 (0.84, 1.72)	1.44 (0.93, 2.23)	1.35 (0.97, 1.88)
Daughters	**1.9 (1.3, 2.8)*****	0.92 (0.69, 1.22)	0.89 (0.69, 1.14)	1.27 (0.94, 1.72)	1.13 (0.89, 1.43)
Low SEP	**0.41 (0.23, 0.77)****	0.98 (0.69, 1.39)	**1.5 (1.1, 1.9)****	**1.4 (1.0, 2.0)***	**1.8 (1.4 ,2.3)*****
High SEP	1.30 (0.89, 1.91)	0.73 (0.51, 1.03)	**0.68 (0.49, 0.94)***	0.88 (0.61, 1.29)	**0.4 (0.34, 0.68)*****

[&] Reference group Australian-children

[a] Reference group low-risk BMI-trajectory

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position

Reference group for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English; Family SEP = middle SEP.

[1] all results here are from multinomial analysis.

[T]=0.05, *p<0.05, **p<0.01, ***p<0.001

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

Supplementary Table 3. Sensitivity model. Multinominal Regression Analysis of the child Immigrant status, risk factors and group-based BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining-Risk [a]	Delayed Risk [a]	Gradual Risk [a]	Moderate Risk [a]	High Risk [a]
n=2746 n (%)	105 (3.7)	161 (6.1)	207 (8.1)	139 (5.3)	200 (8.1)
	RR (95% CI, P)	RR (95% CI, P)	RR(95% CI, P)	RR (95% CI, P)	RR (95% CI, P)
Immigrant children from HICs[&]	0.97 (0.62, 1.52)	0.72 (0.47, 1,08)	1.18 (0.83, 1.68)	1.01 (0.67, 1.54)	1.13 (0.79, 1.62)
Immigrant children from LMICs [&]	1.24 (0.55, 2.80)	0.60 (0.23, 1.56)	**1.9 (1.1, 3.2)***	1.45 (0.71, 2.94)	1.36 (0.71, 2.58)
Daughters	**2.1 (1.4, 3.3)****	0.85 (0.60, 1.21)	1.21 (0.89, 1.66)	1.16 (0.80, 1.70)	1.22 (0.88, 1.68)
Never Breastfed	0.90 (0.32, 2.55)	1.29 (0.67, 2.49)	0.83 (0.43, 1.60)	1.25 (0.60, 2.58)	1.33 (0.73, 2.44)
birthweight <2.5 kg	1.13 (0.36, 3.54)	0.80 (0.26, 2.42)	0.79 (0.31, 1.98)	0.42 (0.09, 1.85)	0.41 (0.13, 1.26)
birthweight >4 kg	**2.1 (1.3, 3.5)****	1.54 (0.96, 2.49)	1.14 (0.73, 1.80)	1.32 (0.89, 2.16)	**1.9 (1.3, 2.9)****
High-screen time (≥3 hrs weekday/weekend)	1.06 (0.66, 1.70)	1.39 (0.97, 2.00)	**1.6 (1.2, 2.3)****	1.13 (0.76, 1.70)	0.88 (0.62, 1.27)
No organised sports	1.09 (0.72, 1.64)	**1.7 (1.2, 2.4)****	1.04 (0.75, 1.44)	1.42 (0.97, 2.06)	1.16 (0.83, 1.62)
SSB ≥ 1/day	0.69 (0.45, 1.07)	1.02 (0.70, 1.49)	0.89 (0.64, 1.24)	0.82 (0.55, 1.22)	1.25 (0.87, 1.78)
Foreign language spoken at home	0.73 (0.31, 1.75)	1.67(0.75, 3.73)	0.96 (0.57, 1.62)	1.02 (0.49, 2.09)	1.59 (0.89, 2.8)
Low family SEP	**0.41 (0.18, 0.88)***	0.77 (0.48, 1.24)	**1.7 (1.1, 2.5)****	1.20 (0.73, 1.97)	1.2 (0.8, 1.8)
High family SEP	1.31 (0.83, 2.04)	0.80 (0.53, 1.22)	0.80 (0.54, 1.19)	0.92 (0.58, 1.47)	**0.49 (0.32, 0.76)****
Gestational diabetes	1.11 (0.46, 2.68)	0.80 (0.35, 1.85)	1.37 (0.74, 2.51)	1.09 (0.47, 2.57)	1.40 (0.77, 2.56)
Gestational hypertension	2.07 (0.96, 4.45)	0.92 (0.43, 1.98)	0.94 (0.52, 1.71)	1.6 (0.83, 3.09)	**1.8 (1.1, 2.9)***
Overweight/obese mother	**1.6 (1.0 ,2.5)***	**2.1 (1.45, 2.9)*****	**2.4 (1.7, 3.3)*****	**2.5 (1.7, 3.6)*****	**3.3 (2.3, 4.5)*****
Mother current smoker	0.85 (0.42, 1.73)	1.25 (0.77, 2.06)	1.37 (0.89, 2.09)	1.66 (0.99, 2.77)	**2.2 (1.5, 3.2)*****

Adjusted for gestational diabetes, gestational hypertension, maternal weight, and maternal current smoking status in addition to variables reported in Table 4.

[&] Reference group Australian-children

[a] Reference group low-risk BMI-trajectory

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position

Reference groups for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English language spoken at home; Family SEP = middle SEP; Gestational diabetes = no gestational diabetes; gestational hypertension = no gestational hypertension; overweight/obese mother = mother not overweight/obese; mother current smoker = mother not current smoker.

[T]= 0.05, *p<0.05, **p<0.01, ***p<0.001;

Goodness of Fit test for sensitivity model (n=2746): (X^2 (70)=53.77, p=0.92)

Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	3
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	3-4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	3
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	3, 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	3-4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	4,5
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	5
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	5,6
Outcome data	15*	Report numbers of outcome events or summary measures over time	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	6
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	6
Discussion			
Key results	18	Summarise key results with reference to study objectives	7
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	7
Generalisability	21	Discuss the generalisability (external validity) of the study results	8
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	10

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026845.R2
Article Type:	Research
Date Submitted by the Author:	01-Mar-2019
Complete List of Authors:	Zulfiqar, Tehzeeb; Research School of Population Health - ANU, National Center for Epidemiology and Population Health Burns, Richard; Australian National University, Australia, Center for Research on Ageing, Health & Well being D'Este, Catherine; College of Health and Medicine, The Australian National University, National Center of Epidemiology and Population Health Strazdins, Lyndall; The Australian National University, National Center of Epidemiology and Population Health, The Research School of Population Health, College of Health and Medicine.
Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Paediatrics
Keywords:	Immigrants, Low-and-middle-income countries, Pediatric obesity, BMI-trajectories, Australian children

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BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children.

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Running head: BMI-trajectories in Australian children by immigrant status

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Strengths and limitations of the study

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

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Abstract

Objectives: This study aimed to identify 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 Taskforce cut-off-points. Immigrant status was determined by Australian Bureau of Statistics and UNDP Human Development Index criteria. Latent Class Growth Analysis estimated distinct BMI-trajectories and multinomial logistic regression analysis examined factors associated with BMI-trajectories.

Results: Two BMI groups and Six BMI-trajectories were identified. 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 to 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 birthweight, family socio-economic-position, and organized sports participation. Our results also suggest that 4-7 years of age may be important for prevention of overweight/obesity in children.

Discussion: Better understanding of the risk factors associated with distinct BMI-trajectories in immigrant children will inform effective preventive strategies. Some of these risks factors such as non-participation of organized 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.

Key words: Emigrants and Immigrants, BMI trajectories, Overweight, Paediatric Obesity.

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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 cardio-metabolic conditions and cancers (3). The exponential increase in childhood overweight/obesity over the past decade indicate 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 carryover 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 (SSB) and low physical activity in 4-11-year-old children 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 a question of whether the pathways of overweight/obesity onset and development may differ in children of immigrants from hosts.

Within Australia, only a few studies have investigated weight trajectories in children. These studies showed substantial heterogeneity in weight trajectories amongst Australian children. The predictors of atypical weight trajectories in these studies included child's diet, family socioeconomic status, parental education, parental smoking, child birthweight, breastfeeding, 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 analyzing data from Birth (B) cohort of the longitudinal study of Australian Children (LSAC). Based on our literature review, which showed the importance

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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 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 geographic 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 one in 10). Within postcodes, children had about an equal chance (one in 25) of selection (24).

After obtaining informed consent, face-to-face interviews were conducted by trained interviewers primarily with the parent (24). The LSAC sample comprised of two age cohorts. We analyzed ten 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 was 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 two years old did not have data on length/height. The proportion of children in the original cohort who participated at each age were 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 year and 74% (n=3764) at 10-11 years (24). Approximately 73% children (n=3372) who participated at 2-3 years participated in all five surveys.

The LSAC was approved by the Australian Institute of Family Studies Ethics Committee. The current analysis was approved by the Australian National University Human Research Ethics Committee (Protocol No. 2015/421).

Measures

Body Mass Index (BMI), the outcome variable, was calculated as weight (in light clothing) / height (without shoes) squared (kg/m2), measured at each visit using standardized equipment (25). We created a categorical variable to classify children as overweight, obese and not overweight/obese according to the International Obesity Task Force (IOTF) age-and-sex-specific criteria (overweight and obesity cut off points of 25 and 30 kg/m2 in young adults aged 18, extrapolated to children) (26).

We used raw BMI as it is considered the best measure to assess group-based BMI-trajectories overtime, compared to BMI z-score or BMI-centiles which are best to measure adiposity cross-sectionally (27). BMI-z scores depend on the baseline weight status of the children and are less variable in obese than non-obese children. Therefore, when used longitudinally in trajectory models, they may not allow the identification of distinct groups with various developmental patterns(27, 28). Raw BMI also allows for comparison with other studies whilst z-scores are standardized to reflect the distribution within a study. The easy interpretability of raw BMI also makes it suitable for comparisons between studies with different distributions (27).

Child immigrant status, the exposure variable, was defined using the socioeconomic development of the child's mother and maternal grandparents birth countries. Father's birth country was not included in determining child

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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 (UN) Development Fund (UNDP) Human Development Index (HDI) scores of 2015. LMICs included countries with HDI scores of < 0·7 and HICs with HDI scores of ≥ 0.7 (29). (S1 supplementary material).

Children were classified as Australian (reference group) if they were born in Australia or born-overseas with Australian-born mothers and grandparents. The 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. The third generation immigrant children had Australian-born mothers and at least one grandparent born-overseas (30). 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 an 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 risk factors; A *priori* variables included child sex, child birthweight (<2.5 kg, 2.5-4 kg and >4 kg), whether the child was ever breastfed (yes/no); child's consumption of SSB (none versus ≥ 1/day); organized 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). Organized sports participation for 2-3-year-olds, which included swimming lessons and dancing/movement classes, was used as a proxy for child physical activities as there was no other reliable measure of child physical activities at this age. Parents reported on diet, organized 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), language spoken at home (Non-English/English); and family socio-economic position (SEP) (low/middle/high) (31). Family socioeconomic position (SEP) was based on a composite measure comprising combined annual family income, employment status and education of both parents (31) and categorized 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 chi-square statistic. BMI trajectories of children from 2-11 years were estimated using Latent Class Growth Analysis (LCGA), a type of growth mixture model (32) whereby individuals within a trajectory are treated as a homogeneous group regarding their developmental trajectory. The most appropriate number of trajectories were 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, and Rubin likelihood ratio test (LMR-LRT) (33), the adjusted likelihood ratio test (LRT), and the bootstrap likelihood ratio test (BLRT) to compare nested models (34). We were also guided by parsimony, theoretical justification, and interpretability in determining the number of trajectories to extract (35, 36). Level of entropy, reflecting the proportion of participants correctly classified into their respective trajectories, helped determine the utility of additional trajectories.

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Associations between health-related behaviours and BMI trajectories.

The chi-square statistic was used to compare distributions of risk factors across BMI-trajectories. Multinomial logistic regression analysis compared relative risk (RRR) 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 large number of missing values at baseline for key maternal indicators such as gestational diabetes (22%), gestational hypertension (22%), maternal weight and (36%) maternal current smoking status (31%), these variables were excluded from the primary analysis, and assessed in a sensitivity analysis.

LCGA analyses were undertaken in MPlus v.7.1 whilst the comparison of differentials between classes was conducted in STATA v.15. MPlus analysis 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 modeling. 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 and 10% third generation children from HICs. Second and third generation children from LMIC comprised 12% and 3% of the sample respectively. We conducted preliminary analysis separately with second and third generation children, however, found no generational effects. Moreover, due to the low number of third generation children from LMIC 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 to the other groups, although this was not statistically significant (Table 1).

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Table 1. Socio-demographic characteristics of 2-3 year old children from Birth Cohort of Longitudinal study of Australian children.

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

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position.
All column percentages (except immigrant status which is row %), weighted and rounded.
*p<0.05, **p<0.01, ***p<0.001
Numbers may not add due to missing values

Number of BMI trajectories: Model selection

Based on the model fit indicators a 6-trajectory model was the most appropriate (supplementary Table 1). Lower AIC and BIC were demonstrated for the 6- trajectory model, whilst the model estimating 7-trajectories showed an increase in AIC and BIC. Further, the LRT indicates a significant difference between nested models for up to the 6- trajectory model, but not for the 7-trajectory model, which suggests that the 7-trajectory does not demonstrate better fit in comparison with the 6-trajectory model. Our comparison of models with linear, quadratic and cubic time for our LCGA models showed quadratic and linear models were the most appropriate for our analysis. However, based on higher entropy, we decided that a simpler and more parsimonious linear model was most appropriate.

The 6-trajectories are displayed in Figure 1. Three trajectories (4, 5 and 6) had stable proportions of overweight/obesity over time. These include high-risk (trajectory 6; 10% of the study sample), moderate-risk

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(trajectory 5; 5%) and low-risk (trajectory 4; 68 %;) BMI-trajectories. Three trajectories demonstrated substantial change over time. Trajectory 1 (3%) declined in the proportion reporting overweight/obese, from 100% to 0% between 4-5 years to 8-9 years. In contrast, there are two trajectories (trajectories 2; 5% and 3; 8%) which increased in risk over time and varied only in the shape of their trajectory. Those in trajectory 2 reported no overweight/obesity at baseline, but the proportion reporting overweight/obesity increased substantially in the final two observations (starting at 6-7 years) with 100% at the final observation reporting overweight/obesity (delayed-risk). In contrast, trajectory 3 described a rising proportion (26%) of overweight/obesity from baseline to 100% by the final observation (gradual-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 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-trajectory 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-trajectory. In our multinomial regression models, these risk ratios became insignificant, when we fully-adjusted for key risk factors.

In the fully adjusted analysis, key risk factors significantly associated with BMI-trajectories were sex; birthweight; consumption of SSB; organized sports participation, screen-time and family SEP (Table 3). The risk of a moderate-risk BMI-trajectory was greater for those with high birthweight and for those with non-participation in organized sports, while the risk of a high-risk BMI-trajectory was higher for children with high birthweight 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 birthweight were more likely to have declining-risk BMI-trajectories. Conversely, children from low SEP families, those who consumed SSB and those whose mothers were not in the workforce had lower chances of having declining-risk BMI-trajectories.

Further, children with high birthweight, high screen-time, who did not participate in organized 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 significantly and maternal non-participation in the workforce decreased the chances of being in the gradual-risk BMI-trajectory.

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Table 2 Distribution of risk factors in children aged 2–3 years by BMI-Trajectories in Birth Cohort of Longitudinal Study of Australian Children.

Classes	Changing Trajectories			Stable Trajectories			
BMI-Trajectories classes	1 Declining-Risk n (%)	2 Delayed Risk n (%)	3 Gradual Risk n (%)	4 Low Risk n (%)	5 Moderate Risk n (%)	6 High Risk n (%)	
	143 (3.2)	234 (5.7)	314 (7.9)	2861 (67.9)	215 (5.2)	375(10.2)	x^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)	
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)	0.170
Boys	54 (2.2)	126 (5.9)	167 (8.5)	1488 (69.0)	101 (4.7)	179 (9.6)	
Girls	89 (4.2)	108 (5.3)	147 (7.3)	1373 (66.6)	114 (5.8)	196 (10.8)	0.003
Prenatal and neonatal risk-factors							
Gestational diabetes; No	126 (3.6)	193 (5.8)	259 (8.1)	2395 (68.4)	182 (5.4)	274 (8.8)	0.022
Gestational diabetes; yes	7 (3.2)	10 (4.8)	20 (10.6)	117 (59.6)	11 (5.8)	28 (16.2)	
Pregnancy hypertension; No	122 (3.5)	192 (5.8)	258 (8.3)	2358 (68.6)	175 (5.2)	264 (8.7)	0.006
Pregnancy hypertension; yes	11 (4.3)	12 (5.3)	22 (8.1)	164 (59.2)	18 (7.3)	40 (15.9)	
Low birthweight <2.5 kg	4 (2.4)	7 (5.1)	9 (5.9)	108 (78.2)	3 (1.9)	9 (6.4)	
2.5-4.0 kg	106 (2.9)	185 (5.3)	256 (7.8)	2424 (69.2)	176 (5.3)	284 (9.5)	<0.001
>4 kg	33 (5.6)	42 (7.9)	49(8.9)	329 (56.1)	36 (6.0)	82 (15.5)	
Never Breastfed	7 (2.7)	23 (6.5)	21 (7.1)	194 (64.1)	13 (3.7)	44 (15.9)	0.023
Ever breastfed	136 (3.3)	211 (5.6)	293 (8.0)	2667(68.2)	202 (5.4)	331 (9.6)	
Child level risk factors: Diet							
SSB not at all	58 (4.6)	70 (5.3)	90 (7.8)	889 (68.5)	71 (5.8)	86(8.0)	
SSB ≥ 1/day	85 (2.6)	164 (5.8)	224 (7.8)	1972 (67.6)	144 (5.0)	289 (11.0)	0.004
Physical activity							
No organised sports	70 (2.7)	150 (6.4)	187 (8.3)	1558(65.4)	136(6.0)	238 (11.2)	
Participates in organised sports	73 (3.9)	84 (4.5)	127 (7.4)	1303 (71.4)	79 (4.1)	137(8.6)	0.000
Low screen time (<3 hrs weekday/weekend)	103 (3.3)	144 (4.9)	195 (7.1)	2048 (69.8)	142 (4.9)	253 (9.9)	
High-screen time (≥3 hrs weekday/weekend)	40(3.0)	90 (7.1)	119 (9.7)	813 (63.9)	73 (5.8)	122 (10.5)	0.002
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)	
English spoken at home	128 (3.4)	196 (5.5)	269 (7.9)	2500 (68.7)	185 (4.9)	306 (9.7)	
Foreign language spoken at home	15 (2.4)	38 (6.5)	45 (8.0)	361 (63.4)	34 (7.0)	69 (12.7)	0.044
Family SEP; Low	16 (1.4)	58 (5.4)	105 (10.1)	627 (61.8)	64 (6.1)	149 (15.1)	
Medium *SEP*	77 (3.6)	124 (6.2)	148(7.5)	1444 (68.6)	102 (4.8)	178 (9.3)	<0.001
High *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)	
Have a partner	134 (3.4)	210 (5.7)	270 (7.5)	2614 (68.4)	195(5.3)	324 (9.6)	0.004
Maternal full-time work	30 (3.9)	37(4.9)	56 (7.7)	483 (67.8)	42 (5.8)	70 (9.9)	
Part-time work	69 (4.9)	91 (5.7)	132 (8.9)	1109 (68.0)	75 (4.7)	125 (8.5)	0.025
Not in the workforce	44 (2.2)	106 (5.8)	126 (7.3)	1269 (68.2)	98 (5.4)	180(11.2)	

Legend= Changing-trajectories: 1 = declining-risk trajectory, 2 = delayed-risk trajectory, 3=gradual-risk trajectory, Stable-trajectories: 4= low-risk trajectory, 5= moderate-risk trajectory, 6= high-risk trajectory.

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened-beverages, SEP=socio-economic-position.

Frequencies (n) and weighted row percentage (%) provided for categorical variables.

Numbers may not add to total sample size due to missing values

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Table 3. Multinominal Regression Analysis of the association between child Immigrant status, risk factors and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Trajectories			Stable Trajectories	
	1 Declining-Risk [a]	**2 Delayed Risk [a]**	**3 Gradual Risk [a]**	**5 Moderate Risk [a]**	**6 High Risk [a]**
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 (0.59,1.28)	0.79 (0.56,1.09)	0.86 (0.64,1.14)	1.07 (0.77,1.50)	0.9 (0.8,1.5)
Immigrant children from LMICs [&]	0.80 (0.45,1.42)	0.92 (0.59,1.45)	1.23 (0.86,1.75)	1.5 (0.99,2.38)[(0.051)]	**1.4 (1.0,1.9)***
Daughters	**1.9 (1.3,2.7)*****	0.91 (0.69,1.22)	0.89 (0.70,1.15)	1.29 (0.96,1.75)	1.15 (0.92,1.45)
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 (0.59,1.32)	0.73 (0.51,1.03)	0.90 (0.68,1.22)	1.04 (0.74,1.45)	0.99 (0.76,1.30)
Immigrant children from LMICs [&]	1.10 (0.54,2.24)	0.56 (0.27,1.14)	1.49 (0.95,2.39)	1.07 (0.56,2.06)	1.04 (0.63,1.71)
Daughters	**2.2 (1.5,3.1)** ***	0.98 (0.73,1.32)	0.93 (0.72,1.19)	1.34 (0.98,1.81)	1.22 (0.96,1.55)
Never Breastfed	0.97 (0.43,2.16)	1.16 (0.69,1.97)	0.82 (0.49,1.35)	0.68 (0.35,1.30)	1.43 (0.96,2.12)
birthweight <2.5 kg	0.93 (0.33,2.65)	0.79 (0.35,1.82)	0.65 (0.31,1.36)	0.32 (0.09,1.12)	0.55 (0.26,1.17)
birthweight >4 kg	**2.8 (1.8,4.4)** ***	**1.9 (1.3,2.8)** **	1.39 (0.96,1.99)	**1.6 (1.1,2.4)** *	**2.3 (1.7,3.1)** ***
High Screen time (≥3 hrs weekday/weekend)	1.26 (0.85,1.87)	**1.5 (1.1,2.0)** *	**1.5 (1.2,2.0)** **	1.23 (0.88,1.71)	1.03 (0.79,1.34)
No organised sports	1.04 (0.73,1.49)	**1.6 (1.1,2.1)** **	1.08 (0.82,1.42)	**1.5 (1.1,2.0)** *	1.11 (0.86,1.44)
SSB ≥ 1/day	**0.64 (0.44,0.94)** *	1.01 (0.73,1.38)	0.90 (0.68,1.20)	0.85 (0.61,1.17)	1.18 (0.90,1.56)
Foreign language spoken at home	0.85 (0.41,1.71)	1.8 (0.99,3.6)[(0.051)]	0.83 (0.52,1.32)	1.30 (0.71,2.40)	1.36 (0.87,2.14)
Mother in full time work	1.05 (0.66,1.69)	0.87 (0.56,1.35)	0.89 (0.62,1.27)	1.26 (0.82,1.94)	1.13 (0.80,1.59)
Mother not in workforce	**0.61 (0.40,0.92)** *	1.04 (0.76,1.45)	**0.68 (0.50,0.91)** *	1.05 (0.74,1.48)	1.09 (0.84,1.44)
Low family SEP	**0.50 (0.27,0.93)** *	0.90 (0.63,1.29)	**1.5 (1.1,2.0)** *	1.40 (0.98,2.10)	**1.6 (1.2,2.1)** **
High family SEP	1.23 (0.81,1.84)	0.79 (0.55,1.14)	**0.69 (0.49,0.98)** *	0.93 (0.63,1.36)	**0.49 (0.35,0.70)** ***
Single parent	0.88 (0.41,1.89)	0.96 (0.56,1.63)	1.46 (0.97,2.2)	0.83 (0.46,1.48)	1.13 (0.78.1.65)

& Reference group Australian-children
a Reference group 4 low-risk BMI-trajectory
Frequencies (n) and weighted row percentage (%) provided.
RRR is the relative risk ratio for the explanatory variable: i.e. the relative risk of being in the specified trajectory, versus the reference trajectory, for the level of the explanatory variable category compared to the reference category
Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened-beverages, SEP=socio-economic-position.
Goodness of Fit test for model 1 (n-4142): (X2 (10) = 11.83, p=-0.29). Goodness of Fit test for model 2 (n=4096): (X2 (50) = 37.19, p=-0.91)
*p<0.05, **p<0.01, ***p<0.001

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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 (Supplementary Table 2). Our models showed that organized 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 (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, delayed, gradual, moderate and high-risk BMI-trajectories.

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 2-11-year-old Australian children 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 modeled the key maternal variables in our sensitivity analysis, we found that immigrant children from LMICs were also somewhat more likely to have a gradual-risk BMI-trajectory. Our sensitivity models showed that maternal overweight/obesity was associated with all atypical BMI-trajectories, emphasizing the importance of genetic, fetal and family environmental factors in childhood obesity (17). Our finding that approximately nine percent of children drastically changed weight between 4-7 years (3% in the declining risk and 6% in the delayed risk trajectory) suggests that these ages are important for 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 to 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 to a gradual onset or normal weight trajectory from kindergarten through eighth grade when compared to children of Americans and children of longtime or second-generation immigrants (20). Similarly, in the European context, compared to non-immigrants, children of immigrants aged 4-12 years were more likely to have an increasing BMI trajectory instead of decreasing trajectory (37). Thus research to date affirms our findings that immigrant children are more likely to have higher BMI-trajectories than the host population (15, 20).

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Consistent with other studies, we found that sex, birthweight, breastfeeding, consumption of sugar-sweetened beverages, organized sports participation, screen-time, maternal workforce participation, and family SEP were associated with atypical BMI-trajectories (14-20, 37). We also observed that these risks play out differently for different BMI-trajectories. For example, we found that children with SSB consumption were less likely to have declining-risk BMI-trajectory, but there was no association with other atypical BMI-trajectories. These results are worrisome in showing that quite young children are exposed to SSB. 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 behaviors and physical inactivity (37).

Immigrant children possibly exhibit an even more inactive lifestyle compared to the host children (13, 38). Immigrant parents may discourage physical activities in their children to promote weight gain due to their favorable cultural views on adiposity (39). Lack of affordability, religious restrictions and safety concerns are also reasons given by immigrants parents for lower physical activities in children (40). Additionally, due to low obesity literacy, many immigrant parents consider childhood obesity as a temporary phase, which the child would grow out in adulthood (40). Irrespective of the causes, non-participation in organized 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 (41), 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 (42). 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 (43). 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 birthweight was strongly predictive of childhood obesity (23). Birthweight reflects the influence of early life factors such as maternal (pre-pregnancy and pregnancy) nutritional status, maternal smoking, and maternal health conditions such as gestational diabetes and hypertension (23). These early life factors program appetite and energy expenditure in utero by permanently affecting hormonal, neuronal and autocrine mechanisms contributing to the energy balance (44). Association of early life risk factors with childhood obesity warrant interventions in pre- 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 with must be a top intervention priority.

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The importance of 4-7 year of age for prevention of childhood overweight/obesity is reported previously also (20, 45). At this age, the adiposity rebound occurs and the discrepancies in overweight/obesity emerge in children by their immigrant backgrounds (20, 45). Additionally, at this age, the diet and physical activity of children transform due to schools and peers (45). Further research to identify factors which result in rapid weight changes of children at these ages will be beneficial for prevention programs.

To the best of our knowledge, this is the first Australian cohort study to identify distinct BMI-trajectories in Australian-children aged 2-11 years 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.

Major limitation of the study was that the LSAC underrepresents 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 homogenous groups based on the socio-economic development of their origin country. Although socio-economic 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 socio-economic development. Therefore, the study results may not be generalizable 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 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.

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

Conclusion

In conclusion, we find that obesity is not always a stable condition and that risk factors may drive quite different BMI-trajectories. Whilst 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 affect child obesity largely through family socio-economic disadvantage, and child sedentary behaviors. Some of these risk factors may be due to difficulty integrating into the host culture (e.g., lack of participation of organized sports and high screen time). Taken together all this 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 behaviors are also essential. Such interventions

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should be particularly targeted towards children of immigrants, as it will not only improve their physical health but also result in better mental health outcomes due to improved social integration in Australian society.

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Availability of data and materials

The data of "Longitudinal study of Australian Children" is available from the Australian Institute of Family Studies. However, the data is not publically available. Restrictions apply to the availability of these data, which were used under license for the current study. Data are, however, available from the authors with permission of the Australian Institute of Family Studies.

Competing interests

Nil

Funding

Nil

Authors' contributions

TZ developed the original idea and planned the study. RB and TZ conducted data analysis. CDE contributed to analysis. TZ led the writing. RB, CDE, LS contributed to writing and interpretation of results. LS, CDE, RB reviewed and approved the final manuscript.

Acknowledgements

The Longitudinal Study of Australian Children is conducted in partnership between the Department of Families, Housing, Community Services and Indigenous Affairs (FaHCSIA), the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). The findings and views reported in this paper are those of the authors and are not endorsed by FaHCSIA, AIFS or the ABS. We thank all the parents and children for their continuing support and participation in the LSAC.

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Figure 1- Plot of BMI trajectories from a Latent Class Growth Analyses in Australian children aged 2-11 years.

Legend. 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.

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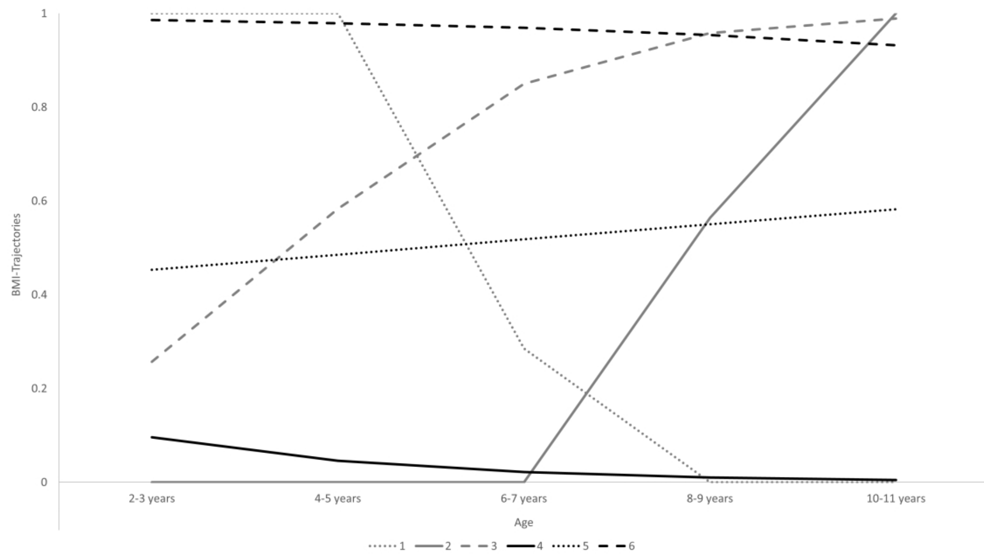

Figure 1- Plot of BMI trajectories from Latent Class Growth Analyses in Australian children aged 2-11 years.

338x190mm (300 x 300 DPI)

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

S. 1. List of countries included in Birth Cohort of Longitudinal Study of Australian Children.

The Longitudinal Study of Australian Children reported 96 birth countries. High-income and low-and-middle income countries were classified according to societal development and access to resources by UNDP's Human development Index. High-income-countries had a HD1 score of ≥ 0.70 and low-and-Middle-income-countries scored <0.7.[1]

High-income-countries

Argentina, Albania, Australia, Algeria, Austria, Belgium, Bosnia and Herzegovina, Brunei, Brazil, Canada, Chile, China, Cook Islands, Costa Rica, Croatia, Czech Republic, Denmark, England, Fiji, Republic of Macedonia, France, Germany, Greece, Hong Kong, Hungary, Iran, Ireland, Israel, Italy, Japan Jordan,, South Korea, Lebanon, Libya, Lithuania, Malta, Malaysia, Mauritius, Netherlands, New Caledonia, New Zealand, Peru, Poland, Portugal, Romania, Russian Federation, Samoa, Scotland, Singapore, Slovakia, Spain, Sweden, Switzerland, Taiwan, Thailand, Tonga, Turkey, Ukraine, United Kingdom, United States of America, Uruguay, Wales, Yugoslavia.

Low-and-Middle-income-countries

Afghanistan, Bangladesh, Myanmar, Cambodia, East Timor, Egypt, El Salvador, Eritrea, Ethiopia, Ghana, India, Indonesia, Iraq, Kenya, Laos, Liberia, Namibia, Nicaragua, Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Sierra Leone, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Syria, Viet Nam, Zambia, Zimbabwe

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Supplementary Table 1. Model fit indicators for a series of Latent Class Growth Analyses of BMI

# of Classes	AIC	BIC	BIC adjusted sample size	Entropy	LRT*	VLMR p value	Bootstrap p value
2	16227.786	16259.836	16243.948	0.849	4427.276	< 0.001	< 0.001
3	15867.183	15918.463	15893.042	0.724	366.603	< 0.001	< 0.001
4	15647.289	15717.799	15682.845	0.781	225.894	< 0.001	< 0.001
5	15580.958	15689.928	15635.909	0.810	28.119	<0 .001	< 0.001
6	15603.076	15692.817	15648.330	0.848	50.212	0.0057	< 0.001
7	15585.257	15713.458	15649.906	0.792	1.701	0.998	0.667

Abbreviations: AIC= Akaike information criterion; BIC= Bayesian information criterion; LRT=likelihood ratio test; VLMR= Vuong-Lo-Mendel-Rubin Likelihood ratio test; LRT value reflects the "2 times the log-likelihood difference"

Supplementary Table 2. Sex-adjusted and individual risk factors adjusted Multinominal Regression models of the association between child Immigrant status and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n (%)	143 (3.3)	234 (5.7)	314 (7.9)	215 (5.3)	375 (10.1)
	RR (95% CI)	RR (95% CI)	RR(95% CI)	RR (95% CI)	RR (95% CI)
Model 1 adjusted for sex					
Immigrant children from HICs [&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.42)	0.92 (0.59, 1.45)	1.23 (0.86, 1.76)	1.5 (0.99, 2.38)[(0.051)T]	**1.4 (1.0, 1.9)***
Daughters	**1.9 (1.3, 2.7)*****	0.92 (0.69, 1.22)	0.89 (0.70, 1.15)	1.29 (0.96, 1.75)	1.16 (0.92, 1.46)
Model 2 adjusted for sex and Breastfeeding					
Immigrant children from HICs[&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.14)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.44)	0.93 (0.59, 1.46)	1.24 (0.86, 1.77)	**1.5 (1.0, 2.4)***	**1.4 (1.0, 1.9)***
Daughters	**1.9 (1.3, 2.7)*****	0.92 (0.69, 1.23)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.17 (0.92, 1.47)
Never Breastfed	0.73 (0.33, 1.61)	1.25 (0.76, 2.08)	0.95 (0.58, 1.56)	0.75 (0.41, 1.39)	**1.8 (1.2, 2.6)****
Model 3 adjusted for sex and birthweight					
Immigrant children from HICs[&]	0.89 (0.60, 1.32)	0.79 (0.57, 1.09)	0.87 (0.66, 1.16)	1.08 (0.78, 1.52)	0.98 (0.76, 1.29)
Immigrant children from LMICs [&]	0.86 (0.48, 1.53)	0.97 (0.62, 1.52)	1.23 (0.86, 1.77)	**1.6 (1.0, 2.4)***	**1.4 (1.0, 2.0)***
Daughters	**2.1 (1.5, 3.1)*****	0.96 (0.72, 1.29)	0.92 (0.72, 1.18)	1.34 (0.99, 1.81)	1.25 (0.99, 1.58)

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<2.5 kg	0.79 (0.29, 2.21)	0.85 (0.38, 1.93)	0.67 (0.33, 1.39)	0.32 (0.09, 1.10)	0.61 (0.28, 1.28)
>4.0 kg	**2.8 (1.8, 4.4)*****	**1.8 (1.2, 2.7)****	1.37 (0.95, 1.95)	**1.6 (1.0, 2.3)***	**2.2 (1.6, 2.9)*****
Model 4 adjusted for sex and screen time					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.80 (0.45, 1.43)	0.90 (0.58, 1.42)	1.20 (0.84, 1.71)	1.5 (0.98, 2.3)	**1.4 (1.0,1 .9)**[(0.050)T]
Daughters	**1.9 (1.3, 2.7)*****	0.93 (0.70, 1.25)	0.91 (0.71, 1.17)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
High-screen time (≥3 hrs weekday/weekend)	0.99 (0.67, 1.48)	**1.6 (1.2, 2.1)****	**1.5 (1.2, 1.9)****	1.26 (0.92, 1.73)	1.15 (0.90,1.48)
Model 5 adjusted for sex and organised sports					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.85 (0.47, 1.50)	0.84 (0.54, 1.33)	1.19 (0.83, 1.70)	1.41 (0.91, 2.16)	1.31 (0.93, 1.83)
Daughters	**1.9 (1.3, 2.7)****	0.93 (0.70, 1.24)	0.90 (0.70, 1.15)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
No organised sports	0.81(0.57, 1.14)	**1.6 (1.2, 2.1)****	1.17 (0.91, 1.50)	**1.57 (1.15, 2.12)****	**1.4 (1.1, 1.8)****
Model 6 adjusted for sex and SSB					
Immigrant children from HICs[&]	0.86 (0.58, 1.28)	0.79 (0.57, 1.10)	0.87 (0.65, 1.16)	1.06 (0.76, 1.47)	0.98 (0.75, 1.27)
Immigrant children from LMICs [&]	0.82 (0.46, 1.47)	0.93 (0.59, 1.46)	1.24 (0.87, 1.77)	**1.6 (1.0, 2.4)***	1.38 (0.99, 1.92)
Daughters	**1.9 (1.3, 2.7)****	0.92 (0.69, 1.23)	0.89 (0.69, 1.14)	1.31 (0.97, 1.77)	1.15(0.91, 1.45)
SSB ≥ 1/day	**0.58 (0.40, 0.82)****	1.10 (0.8, 1.5)	1.02 (0.77, 1.35)	0.91 (0.66, 1.24)	**1.4 (1.1, 1.8)***
Model 7 adjusted for sex and language spoken at home					
Immigrant children from HICs[&]	0.89 (0.59, 1.33)	0.72 (0.51, 1.02)	0.88 (0.66, 1.17)	1.03 (0.74, 1.43)	0.93 (0.71 ,1.23)
Immigrant children from LMICs [&]	0.95 (0.44, 2.02)	0.57 (0.29, 1.13)	1.36 (0.87, 2.13)	1.21 (0.67, 2.2)	1.16 (0.74, 1.83)
Daughters	**1.9 (1.3, 2.7)*****	0.91 (0.69, 1.22)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.15 (0.91, 1.45)
Foreign language spoken at home	0.80 (0.38, 1.68)	**1.8 (1.0, 3.3)***	0.87 (0.56, 1.36)	1.33 (0.76, 2.4)	1.28 (0.84,1 .94)
Model 8 adjusted for sex and family SEP					
Immigrant children from HICs[&]	0.84 (0.57, 1.24)	0.79 (0.57, 1.10)	0.88 (0.66, 1.17)	1.09 (0.78, 1.53)	1.01 (0.78, 1.31)
Immigrant children from LMICs [&]	0.85 (0.48, 1.51)	0.94 (0.60, 1.48)	1.20 (0.84, 1.72)	1.44 (0.93, 2.23)	1.35 (0.97, 1.88)
Daughters	**1.9 (1.3, 2.8)*****	0.92 (0.69, 1.22)	0.89 (0.69, 1.14)	1.27 (0.94, 1.72)	1.13 (0.89, 1.43)
Low SEP	**0.41 (0.23, 0.77)****	0.98 (0.69, 1.39)	**1.5 (1.1, 1.9)****	**1.4 (1.0, 2.0)***	**1.8 (1.4 ,2.3)*****
High SEP	1.30 (0.89, 1.91)	0.73 (0.51, 1.03)	**0.68 (0.49, 0.94)***	0.88 (0.61, 1.29)	**0.4 (0.34, 0.68)*****

Frequencies (n) and weighted row percentage (%) provided.
[&] Reference group Australian-children
[a] Reference group low-risk BMI-trajectory
Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position
Reference group for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English; Family SEP = middle SEP.
[1] all results here are from multinomial analysis.
[T]=0.05, *p<0.05, **p<0.01, ***p<0.001

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Supplementary Table 3. Sensitivity model. Multinominal Regression Analysis of the child Immigrant status, risk factors and group-based BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n=2746 n (%)	105 (3.7)	161 (6.1)	207 (8.1)	139 (5.3)	200 (8.1)
	RR (95% CI, P)	RR (95% CI, P)	RR(95% CI, P)	RR (95% CI, P)	RR (95% CI, P)
Immigrant children from HICs[&]	0.97 (0.62, 1.52)	0.72 (0.47, 1,08)	1.18 (0.83, 1.68)	1.01 (0.67, 1.54)	1.13 (0.79, 1.62)
Immigrant children from LMICs [&]	1.24 (0.55, 2.80)	0.60 (0.23, 1.56)	**1.9 (1.1, 3.2)***	1.45 (0.71, 2.94)	1.36 (0.71, 2.58)
Daughters	**2.1 (1.4, 3.3)****	0.85 (0.60, 1.21)	1.21 (0.89, 1.66)	1.16 (0.80, 1.70)	1.22 (0.88, 1.68)
Never Breastfed	0.90 (0.32, 2.55)	1.29 (0.67, 2.49)	0.83 (0.43, 1.60)	1.25 (0.60, 2.58)	1.33 (0.73, 2.44)
birthweight <2.5 kg	1.13 (0.36, 3.54)	0.80 (0.26, 2.42)	0.79 (0.31, 1.98)	0.42 (0.09, 1.85)	0.41 (0.13, 1.26)
birthweight >4 kg	**2.1 (1.3, 3.5)****	1.54 (0.96, 2.49)	1.14 (0.73, 1.80)	1.32 (0.89, 2.16)	**1.9 (1.3, 2.9)****
High-screen time (≥3 hrs weekday/weekend)	1.06 (0.66, 1.70)	1.39 (0.97, 2.00)	**1.6 (1.2, 2.3)****	1.13 (0.76, 1.70)	0.88 (0.62, 1.27)
No organised sports	1.09 (0.72, 1.64)	**1.7 (1.2, 2.4)****	1.04 (0.75, 1.44)	1.42 (0.97, 2.06)	1.16 (0.83, 1.62)
SSB ≥ 1/day	0.69 (0.45, 1.07)	1.02 (0.70, 1.49)	0.89 (0.64, 1.24)	0.82 (0.55, 1.22)	1.25 (0.87, 1.78)
Foreign language spoken at home	0.73 (0.31, 1.75)	1.67(0.75, 3.73)	0.96 (0.57, 1.62)	1.02 (0.49, 2.09)	1.59 (0.89, 2.8)
Low family SEP	**0.41 (0.18, 0.88)***	0.77 (0.48, 1.24)	**1.7 (1.1, 2.5)****	1.20 (0.73, 1.97)	1.2 (0.8, 1.8)
High family SEP	1.31 (0.83, 2.04)	0.80 (0.53, 1.22)	0.80 (0.54, 1.19)	0.92 (0.58, 1.47)	**0.49 (0.32, 0.76)****
Gestational diabetes	1.11 (0.46, 2.68)	0.80 (0.35, 1.85)	1.37 (0.74, 2.51)	1.09 (0.47, 2.57)	1.40 (0.77, 2.56)
Gestational hypertension	2.07 (0.96, 4.45)	0.92 (0.43, 1.98)	0.94 (0.52, 1.71)	1.6 (0.83, 3.09)	**1.8 (1.1, 2.9)***
Overweight/obese mother	**1.6 (1.0 ,2.5)***	**2.1 (1.45, 2.9)*****	**2.4 (1.7, 3.3)*****	**2.5 (1.7, 3.6)*****	**3.3 (2.3, 4.5)*****
Mother current smoker	0.85 (0.42, 1.73)	1.25 (0.77, 2.06)	1.37 (0.89, 2.09)	1.66 (0.99, 2.77)	**2.2 (1.5, 3.2)*****

Adjusted for gestational diabetes, gestational hypertension, maternal weight, and maternal current smoking status in addition to variables reported in Table 4.

Frequencies (n) and weighted row percentage (%) provided.

[&] Reference group Australian-children

[a] Reference group low-risk BMI-trajectory

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position

Reference groups for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English language spoken at home; Family SEP = middle SEP; Gestational diabetes = no gestational diabetes; gestational hypertension = no gestational hypertension; overweight/obese mother = mother not overweight/obese; mother current smoker = mother not current smoker.

[T]= 0.05, *p<0.05, **p<0.01, ***p<0.001;

Goodness of Fit test for sensitivity model (n=2746): (X^2 (70)=53.77, p=0.92)

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Growing up in Australia: BMI trajectories and risk factors among Australian children aged 2-11 years by immigrant status. Supplementary material

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	3
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	3-4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	3
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	3, 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	3-4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	4,5
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	5
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	5,6
Outcome data	15*	Report numbers of outcome events or summary measures over time	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	6
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	6
Discussion			
Key results	18	Summarise key results with reference to study objectives	7
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	7
Generalisability	21	Discuss the generalisability (external validity) of the study results	8
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	10

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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BMJ Open

BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026845.R3
Article Type:	Research
Date Submitted by the Author:	14-May-2019
Complete List of Authors:	Zulfiqar, Tehzeeb; Research School of Population Health - ANU, National Center for Epidemiology and Population Health Burns, Richard; Australian National University, Australia, Center for Research on Ageing, Health & Well being D'Este, Catherine; College of Health and Medicine, The Australian National University, National Center of Epidemiology and Population Health Strazdins, Lyndall; The Australian National University, National Center of Epidemiology and Population Health, The Research School of Population Health, College of Health and Medicine.
Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Paediatrics
Keywords:	Immigrants, Low-and-middle-income countries, Pediatric obesity, BMI-trajectories, Australian children

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BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children.

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Running head: BMI-trajectories in Australian children by immigrant status

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Strengths and limitations of the study

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

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Abstract

Objectives: This study aimed to identify 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 Taskforce cut-off-points. Immigrant status was determined by Australian Bureau of Statistics and UNDP Human Development Index criteria. Latent Class Growth Analysis estimated distinct BMI-trajectories and multinomial logistic regression analysis examined factors associated with BMI-trajectories.

Results: Two BMI groups and Six BMI-trajectories were identified. 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 to 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 birthweight, family socio-economic-position, and organized sports participation. Our results also suggest that 4-7 years of age may be important for prevention of overweight/obesity in children.

Discussion: Better understanding of the risk factors associated with distinct BMI-trajectories in immigrant children will inform effective preventive strategies. Some of these risks factors such as non-participation of organized 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.

Key words: Emigrants and Immigrants, BMI trajectories, Overweight, Paediatric Obesity.

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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 cardio-metabolic conditions and cancers (3). The exponential increase in childhood overweight/obesity over the past decade indicate 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 carryover 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 (SSB) and low physical activity in 4-11-year-old children 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 a question of whether the pathways of overweight/obesity onset and development may differ in children of immigrants from hosts.

Within Australia, only a few studies have investigated weight trajectories in children. These studies showed substantial heterogeneity in weight trajectories amongst Australian children. The predictors of atypical weight trajectories in these studies included child's diet, family socioeconomic status, parental education, parental smoking, child birthweight, breastfeeding, 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 analyzing data from Birth (B) cohort of the longitudinal study of Australian Children (LSAC). Based on our literature review, which showed the importance

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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 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 geographic 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 one in 10). Within postcodes, children had about an equal chance (one in 25) of selection (24).

After obtaining informed consent, face-to-face interviews were conducted by trained interviewers primarily with the parent (24). The LSAC sample comprised of two age cohorts. We analyzed ten 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 was 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 two years old did not have data on length/height. The proportion of children in the original cohort who participated at each age were 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 year and 74% (n=3764) at 10-11 years (24). Approximately 73% children (n=3372) who participated at 2-3 years participated in all five surveys.

The LSAC was approved by the Australian Institute of Family Studies Ethics Committee. The current analysis was approved by the Australian National University Human Research Ethics Committee (Protocol No. 2015/421).

Measures

Body Mass Index (BMI), the outcome variable, was calculated as weight (in light clothing) / height (without shoes) squared (kg/m2), measured at each visit using standardized equipment (25). We created a categorical variable to classify children as overweight, obese and not overweight/obese according to the International Obesity Task Force (IOTF) age-and-sex-specific criteria (overweight and obesity cut off points of 25 and 30 kg/m2 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. 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 (UN) Development Fund (UNDP) 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). (S1 supplementary material).

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Children were classified as Australian (reference group) if they were born in Australia or born-overseas with Australian-born mothers and grandparents. The 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. The 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 an 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 risk factors; A *priori* variables included child sex, child birthweight (<2.5 kg, 2.5-4 kg and >4 kg), whether the child was ever breastfed (yes/no); child's consumption of SSB (none versus ≥ 1/day); organized 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). Organized sports participation for 2-3-year-olds, which included swimming lessons and dancing/movement classes, was used as a proxy for child physical activities as there was no other reliable measure of child physical activities at this age. Parents reported on diet, organized 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), language spoken at home (Non-English/English); and family socio-economic position (SEP) (low/middle/high) (29). Family socioeconomic position (SEP) was based on a composite measure comprising combined annual family income, employment status and education of both parents (29) and categorized 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 chi-square statistic. BMI trajectories of children from 2-11 years were estimated using 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 were 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, and Rubin likelihood ratio test (LMR-LRT) (31), the adjusted likelihood ratio test (LRT), and the bootstrap likelihood ratio test (BLRT) 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). 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 a LCA framework. These LGM were estimated with a quadratic slope function. Model fit comparisons were then made with the best fitting model from the linear LGM.

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Associations between health-related behaviours and BMI trajectories.

The chi-square statistic was used to compare distributions of risk factors across BMI-trajectories. Multinomial logistic regression analysis compared relative risk (RRR) 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 large number of missing values at baseline for key maternal indicators such as gestational diabetes (22%), gestational hypertension (22%), maternal weight and (36%) maternal current smoking status (31%), these variables were excluded from the primary analysis, and assessed in a sensitivity analysis.

LCGA analyses were undertaken in MPlus v.7.1 whilst the comparison of differentials between classes was conducted in STATA v.15. MPlus analysis 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 modeling. 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 and 10% third generation children from HICs. Second and third generation children from LMIC comprised 12% and 3% of the sample respectively. We conducted preliminary analysis separately with second and third generation children, however, found no generational effects. Moreover, due to the low number of third generation children from LMIC 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 to the other groups, although this was not statistically significant (Table 1).

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Table 1. Socio-demographic characteristics of 2-3-year-old children from Birth Cohort of Longitudinal study of Australian children.

	Australian **n (%)** 2346 (54)	**HICs** **n (%)** 1259 (31)	**LMICs** **n (%)** 537 (15)	x^2 P value
Sons	1202 (51)	620 (49)	293 (54)	0.2
Daughters	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 birthweight child ≤2.5kg	75 (4)	40 (4)	25 (5)	0.07
Normal birthweight (≥2.5 ≤4.0kg)	1929 (82)	1044 (84)	458 (86)	
High birthweight child ≥4.0kg	337 (14)	169 (13)	48 (8)	
Never breast-fed	165 (9)	93 (9)	44 (9)	0.9
Overweight sons	212 (18.3)	106 (18.0)	42 (15.2)	0.8
Obese sons	46 (4.0)	28 (4.7)	14 (5.4)	
Overweight daughters	218 (20.6)	115 (17.9)	49 (20.9)	0.3
Obese daughters	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 mothers	231 (12)	120 (12)	43 (10)	0.2
Maternal age <30 years	848 (38)	375 (32)	187 (38)	<0.001
Low SEP	583 (30)	262(26)	174 (40)	<0.001
Middle SEP	1182 (49)	668 (52)	223 (39)	
High SEP	580 (21)	328 (22)	136 (21)	
Mother work full time	385 (16)	221 (18)	112 (19)	<0.001
Mother work part time	971 (40)	501 (39)	129 (22)	
Mother not in workforce	985 (44)	534 (44)	295 (59)	
SSB ≥ 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 hrs weekday/weekend)	702 (32)	361 (31)	194 (38)	0.02
Gestational diabetes; yes	82 (4)	59 (5)	49 (13)	<0.001
Pregnancy hypertension; yes	158 (8)	87 (8)	18 (6)	0.3

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position.
All column percentages (except immigrant status which is row %), weighted and rounded.
Numbers may not add due to missing values

Number of BMI trajectories: Model selection

Based on the model fit indicators a 6-class trajectory model was the most appropriate (supplementary Table 1). Lower AIC and BIC were demonstrated for the 6- trajectory model, whilst the model estimating 7-trajectories showed an increase in AIC and BIC. Further, the LRT indicates a significant difference between nested models for up to the 6- trajectory model, but not for the 7-trajectory model, which suggests that the 7-trajectory does not demonstrate better fit in comparison with the 6-trajectory model.

The 6-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 to 8-9 years of age. In contrast, there are two trajectories (trajectories 2; 5% and 3; 8%) which increased

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in risk of reporting overweight/obese over time and varied only 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 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-trajectory 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-trajectory. In our multinomial regression models, these risk ratios became insignificant, when we fully-adjusted for key risk factors.

In the fully adjusted analysis, key risk factors significantly associated with BMI-trajectories were sex; birthweight; consumption of SSB; organized sports participation, screen-time and family SEP (Table 3). The risk of a moderate-risk BMI-trajectory was greater for those with high birthweight and for those with non-participation in organized sports, while the risk of a high-risk BMI-trajectory was higher for children with high birthweight 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 birthweight were more likely to have declining-risk BMI-trajectories. Conversely, children from low SEP families, those who consumed SSB and those whose mothers were not in the workforce had lower chances of having declining-risk BMI-trajectories.

Further, children with high birthweight, high screen-time, who did not participate in organized 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 significantly and maternal non-participation in the workforce decreased the chances of being in the gradual-risk BMI-trajectory.

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Table 2 Distribution of risk factors in children aged 2–3 years by BMI-Trajectories in Birth Cohort of Longitudinal Study of Australian Children.

Classes	Changing Trajectories			Stable Trajectories			
BMI-Trajectories classes	1 Declining-Risk n (%)	2 Delayed Risk n (%)	3 Gradual Risk n (%)	4 Low Risk n (%)	5 Moderate Risk n (%)	6 High Risk n (%)	
	143 (3.2)	234 (5.7)	314 (7.9)	2861 (67.9)	215 (5.2)	375(10.2)	x^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)	
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)	0.170
Boys	54 (2.2)	126 (5.9)	167 (8.5)	1488 (69.0)	101 (4.7)	179 (9.6)	
Girls	89 (4.2)	108 (5.3)	147 (7.3)	1373 (66.6)	114 (5.8)	196 (10.8)	0.003
Prenatal and neonatal risk-factors							
Gestational diabetes; No	126 (3.6)	193 (5.8)	259 (8.1)	2395 (68.4)	182 (5.4)	274 (8.8)	0.022
Gestational diabetes; yes	7 (3.2)	10 (4.8)	20 (10.6)	117 (59.6)	11 (5.8)	28 (16.2)	
Pregnancy hypertension; No	122 (3.5)	192 (5.8)	258 (8.3)	2358 (68.6)	175 (5.2)	264 (8.7)	0.006
Pregnancy hypertension; yes	11 (4.3)	12 (5.3)	22 (8.1)	164 (59.2)	18 (7.3)	40 (15.9)	
Low birthweight <2.5 kg	4 (2.4)	7 (5.1)	9 (5.9)	108 (78.2)	3 (1.9)	9 (6.4)	
2.5-4.0 kg	106 (2.9)	185 (5.3)	256 (7.8)	2424 (69.2)	176 (5.3)	284 (9.5)	<0.001
>4 kg	33 (5.6)	42 (7.9)	49(8.9)	329 (56.1)	36 (6.0)	82 (15.5)	
Never Breastfed	7 (2.7)	23 (6.5)	21 (7.1)	194 (64.1)	13 (3.7)	44 (15.9)	0.023
Ever breastfed	136 (3.3)	211 (5.6)	293 (8.0)	2667(68.2)	202 (5.4)	331 (9.6)	
Child level risk factors: Diet							
SSB not at all	58 (4.6)	70 (5.3)	90 (7.8)	889 (68.5)	71 (5.8)	86(8.0)	
SSB ≥ 1/day	85 (2.6)	164 (5.8)	224 (7.8)	1972 (67.6)	144 (5.0)	289 (11.0)	0.004
Physical activity							
No organised sports	70 (2.7)	150 (6.4)	187 (8.3)	1558(65.4)	136(6.0)	238 (11.2)	
Participates in organised sports	73 (3.9)	84 (4.5)	127 (7.4)	1303 (71.4)	79 (4.1)	137(8.6)	<0.001
Low screen time (<3 hrs 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 hrs 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)	
English spoken at home	128 (3.4)	196 (5.5)	269 (7.9)	2500 (68.7)	185 (4.9)	306 (9.7)	
Foreign language spoken at home	15 (2.4)	38 (6.5)	45 (8.0)	361 (63.4)	34 (7.0)	69 (12.7)	0.044
Family SEP; Low	16 (1.4)	58 (5.4)	105 (10.1)	627 (61.8)	64 (6.1)	149 (15.1)	
Medium *SEP*	77 (3.6)	124 (6.2)	148(7.5)	1444 (68.6)	102 (4.8)	178 (9.3)	<0.001
High *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)	
Have a partner	134 (3.4)	210 (5.7)	270 (7.5)	2614 (68.4)	195(5.3)	324 (9.6)	0.004
Maternal full-time work	30 (3.9)	37(4.9)	56 (7.7)	483 (67.8)	42 (5.8)	70 (9.9)	
Part-time work	69 (4.9)	91 (5.7)	132 (8.9)	1109 (68.0)	75 (4.7)	125 (8.5)	0.025
Not in the workforce	44 (2.2)	106 (5.8)	126 (7.3)	1269 (68.2)	98 (5.4)	180(11.2)	

Legend= Changing-trajectories: 1 = declining-risk trajectory, 2 = delayed-risk trajectory, 3=gradual-risk trajectory, Stable-trajectories: 4= low-risk trajectory, 5= moderate-risk trajectory, 6= high-risk trajectory.
Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened-beverages, SEP=socio-economic-position.
Frequencies (n) and weighted row percentage (%) provided for categorical variables.
Numbers may not add to total sample size due to missing values

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Table 3. Multinominal Regression Analysis of the association between child Immigrant status, risk factors and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

& Reference group Australian-children

	Changing Trajectories			Stable Trajectories	
	1 Declining-Risk [a]	2 Delayed Risk [a]	3 Gradual Risk [a]	5 Moderate Risk [a]	6 High Risk [a]
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 (0.59,1.28)	0.79 (0.56,1.09)	0.86 (0.64,1.14)	1.07 (0.77,1.50)	0.9 (0.8,1.5)
Immigrant children from LMICs [&]	0.80 (0.45,1.42)	0.92 (0.59,1.45)	1.23 (0.86,1.75)	1.5 (0.99,2.38)[(0.051)]	**1.4 (1.0,1.9)[(0.04)]**
Daughters	**1.9 (1.3,2.7)**[(<0.001)]	0.91 (0.69,1.22)	0.89 (0.70,1.15)	1.29 (0.96,1.75)	1.15 (0.92,1.45)
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 (0.59,1.32)	0.73 (0.51,1.03)	0.90 (0.68,1.22)	1.04 (0.74,1.45)	0.99 (0.76,1.30)
Immigrant children from LMICs [&]	1.10 (0.54,2.24)	0.56 (0.27,1.14)	1.49 (0.95,2.39)	1.07 (0.56,2.06)	1.04 (0.63,1.71)
Daughters	**2.2 (1.5,3.1)** [(<0.001)]	0.98 (0.73,1.32)	0.93 (0.72,1.19)	1.34 (0.98,1.81)	1.22 (0.96,1.55)
Never Breastfed	0.97 (0.43,2.16)	1.16 (0.69,1.97)	0.82 (0.49,1.35)	0.68 (0.35,1.30)	1.43 (0.96,2.12)
birthweight <2.5 kg	0.93 (0.33,2.65)	0.79 (0.35,1.82)	0.65 (0.31,1.36)	0.32 (0.09,1.12)	0.55 (0.26,1.17)
birthweight >4 kg	**2.8 (1.8,4.4)** [(<0.001)]	**1.9 (1.3,2.8) [(0.002)]**	1.39 (0.96,1.99)	**1.6 (1.1,2.4) [(0.02)]**	**2.3 (1.7,3.1)** [(<0.001)]
High Screen time (≥3 hrs weekday/weekend)	1.26 (0.85,1.87)	**1.5 (1.1,2.0) [(0.01)]**	**1.5 (1.2,2.0) [(0.002)]**	1.23 (0.88,1.71)	1.03 (0.79,1.34)
No organised sports	1.04 (0.73,1.49)	**1.6 (1.1,2.1) [(0.007)]**	1.08 (0.82,1.42)	**1.5 (1.1,2.0) [(0.02)]**	1.11 (0.86,1.44)
SSB ≥ 1/day	**0.64 (0.44,0.94) [(0.02)]**	1.01 (0.73,1.38)	0.90 (0.68,1.20)	0.85 (0.61,1.17)	1.18 (0.90,1.56)
Foreign language spoken at home	0.85 (0.41,1.71)	1.8 (0.99,3.6)[(0.051)]	0.83 (0.52,1.32)	1.30 (0.71,2.40)	1.36 (0.87,2.14)
Mother in full time work	1.05 (0.66,1.69)	0.87 (0.56,1.35)	0.89 (0.62,1.27)	1.26 (0.82,1.94)	1.13 (0.80,1.59)
Mother not in workforce	**0.61 (0.40,0.92) [(0.02)]**	1.04 (0.76,1.45)	**0.68 (0.50,0.91) [(0.009)]**	1.05 (0.74,1.48)	1.09 (0.84,1.44)
Low family SEP	**0.50 (0.27,0.93) [(0.02)]**	0.90 (0.63,1.29)	**1.5 (1.1,2.0) [(0.02)]**	**1.5 (1.0,2.1)[(0.04)]**	**1.6 (1.2,2.1)** [(<0.001)]
High family SEP	1.23 (0.81,1.84)	0.79 (0.55,1.14)	**0.69 (0.49,0.98) [(0.03)]**	0.93 (0.63,1.36)	**0.49 (0.35,0.70)** [(<0.001)]
Single parent	0.88 (0.41,1.89)	0.96 (0.56,1.63)	1.46 (0.97,2.2)	0.83 (0.46,1.48)	1.13 (0.78.1.65)

a Reference group 4 low-risk BMI-trajectory

Frequencies (n) and weighted row percentage (%) provided.

RRR is the relative risk ratio for the explanatory variable: i.e. the relative risk of being in the specified trajectory, versus the reference trajectory, for the level of the explanatory variable category compared to the reference category

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened-beverages, SEP=socio-economic-position.

Goodness of Fit test for model 1 (n-4142): (X2 (10) = 11.83, p=-0.29). Goodness of Fit test for model 2 (n=4096): (X2 (50) = 37.19, p=-0.91)

Values in bold indicate statistically significant results.

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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 (Supplementary Table 2). Our models showed that organized 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 (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, delayed, gradual, moderate and high-risk BMI-trajectories.

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 2-11-year-old Australian children 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 modeled 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, emphasizing the importance of genetic, fetal and family environmental factors in childhood obesity (17). Our finding that approximately nine percent of children drastically changed weight between 4-7 years (3% in the declining risk and 6% in the delayed risk trajectory) suggests that these ages are important for 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 to 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 to a gradual onset or normal weight trajectory from kindergarten through eighth grade when compared to children of Americans and children of longtime or second-generation immigrants (20). Similarly, in the European context, compared to 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).

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Consistent with other studies, we found that sex, birthweight, breastfeeding, consumption of sugar-sweetened beverages, organized 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 SSB consumption were less likely to have declining-risk BMI-trajectory, but there was no association with other atypical BMI-trajectories. These results are worrisome in showing that quite young children are exposed to SSB. 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 behaviors and physical inactivity (35).

Immigrant children possibly exhibit an even more inactive lifestyle compared to the host children (13, 36). Immigrant parents may discourage physical activities in their children to promote weight gain due to their favorable cultural views on adiposity (37). Lack of affordability, religious restrictions and safety concerns are also reasons given by immigrants 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 organized 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 birthweight was strongly predictive of childhood obesity (23). Birthweight reflects the influence of early life factors such as maternal (pre-pregnancy and pregnancy) nutritional status, maternal smoking, and maternal health conditions such as gestational diabetes and hypertension (23). These early life factors program 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 warrant interventions in pre- 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 with must be a top intervention priority.

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The importance of 4-7 year of age for prevention of childhood overweight/obesity is reported previously also (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 programs.

To the best of our knowledge, this is the first Australian cohort study to identify distinct BMI-trajectories in Australian-children aged 2-11 years 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.

Major limitation of the study was that the LSAC underrepresents 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 homogenous groups based on the socio-economic development of their origin country. Although socio-economic 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 socio-economic development. Therefore, the study results may not be generalizable 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 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 neighborhood 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. Whilst 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

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healthy BMI, but of concern for those with high BMI. Our results suggest that Immigrant status affect child obesity largely through family socio-economic disadvantage, and child sedentary behaviors. Some of these risk factors may be due to difficulty integrating into the host culture (e.g., lack of participation of organized sports and high screen time). Taken together all this 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 behaviors are also essential. Such interventions should be particularly targeted towards children of immigrants, as it will not only improve their physical health but also result in better mental health outcomes due to improved social integration in Australian society.

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Availability of data and materials

The data of "Longitudinal study of Australian Children" is available from the Australian Institute of Family Studies. However, the data is not publically available. Restrictions apply to the availability of these data, which were used under license for the current study. Data are, however, available from the authors with permission of the Australian Institute of Family Studies.

Competing interests

Nil

Funding

Nil

Authors' contributions

TZ developed the original idea and planned the study. RB and TZ conducted data analysis. CDE contributed to analysis. TZ led the writing. RB, CDE, LS contributed to writing and interpretation of results. LS, CDE, RB reviewed and approved the final manuscript.

Acknowledgements

The Longitudinal Study of Australian Children is conducted in partnership between the Department of Families, Housing, Community Services and Indigenous Affairs (FaHCSIA), the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). The findings and views reported in this paper are those of the authors and are not endorsed by FaHCSIA, AIFS or the ABS. We thank all the parents and children for their continuing support and participation in the LSAC.

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Figure 1- Plot of BMI trajectories from a Latent Class Growth Analyses in Australian children aged 2-11 years.

Legend. 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

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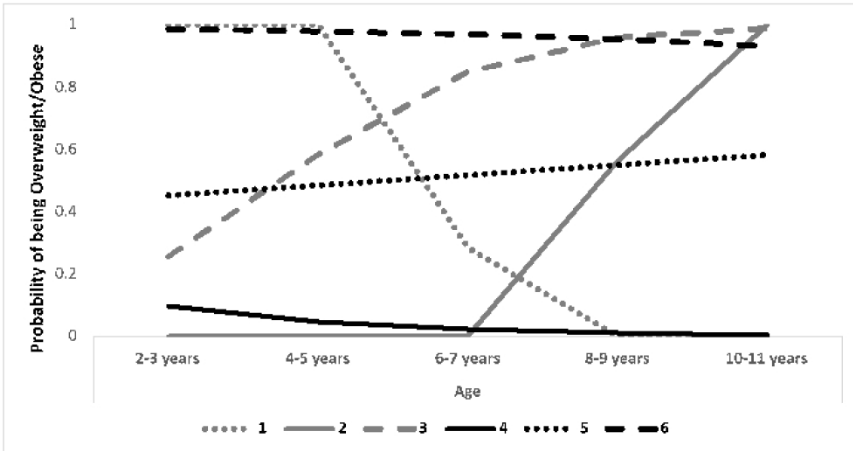

Figure 1- Plot of BMI trajectories from a Latent Class Growth Analyses in Australian children aged 2-11 years.

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BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children. Supplementary material

S. 1. List of countries included in Birth Cohort of Longitudinal Study of Australian Children.

The Longitudinal Study of Australian Children reported 96 birth countries. High-income and low-and-middle income countries were classified according to societal development and access to resources by UNDP's Human Development Index. High-income-countries had a HD1 score of ≥ 0.70 and low-and-Middle-income-countries scored <0.7.[1]

High-income-countries

Argentina, Albania, Australia, Algeria, Austria, Belgium, Bosnia and Herzegovina, Brunei, Brazil, Canada, Chile, China, Cook Islands, Costa Rica, Croatia, Czech Republic, Denmark, England, Fiji, Republic of Macedonia, France, Germany, Greece, Hong Kong, Hungary, Iran, Ireland, Israel, Italy, Japan Jordan,, South Korea, Lebanon, Libya, Lithuania, Malta, Malaysia, Mauritius, Netherlands, New Caledonia, New Zealand, Peru, Poland, Portugal, Romania, Russian Federation, Samoa, Scotland, Singapore, Slovakia, Spain, Sweden, Switzerland, Taiwan, Thailand, Tonga, Turkey, Ukraine, United Kingdom, United States of America, Uruguay, Wales, Yugoslavia.

Low-and-Middle-income-countries

Afghanistan, Bangladesh, Myanmar, Cambodia, East Timor, Egypt, El Salvador, Eritrea, Ethiopia, Ghana, India, Indonesia, Iraq, Kenya, Laos, Liberia, Namibia, Nicaragua, Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Sierra Leone, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Syria, Viet Nam, Zambia, Zimbabwe

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1. United Nations Development Programme Human development report 2016. Human development for everyone. United Nations, New York2016.

BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children. Supplementary material

Supplementary Table 1. Model fit indicators for a series of Latent Class Growth Analyses of BMI

# of Classes	AIC	BIC	BIC adjusted sample size	Entropy	LRT*	VLMR p value	Bootstrap p value
2	16227.786	16259.836	16243.948	0.849	4427.276	< 0.001	< 0.001
3	15867.183	15918.463	15893.042	0.724	366.603	< 0.001	< 0.001
4	15647.289	15717.799	15682.845	0.781	225.894	< 0.001	< 0.001
5	15580.958	15689.928	15635.909	0.810	28.119	<0 .001	< 0.001
6	15603.076	15692.817	15648.330	0.848	50.212	0.0057	< 0.001
7	15585.257	15713.458	15649.906	0.792	1.701	0.998	0.667

Abbreviations: AIC= Akaike information criterion; BIC= Bayesian information criterion; LRT=likelihood ratio test; VLMR= Vuong-Lo-Mendel-Rubin Likelihood ratio test; LRT value reflects the “2 times the log-likelihood difference”

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BMI trajectories and risk factors among children aged 2-11 years by maternal immigrant status: Evidence from Longitudinal Study of Australian children. Supplementary material

Supplementary Table 2. Sex-adjusted and individual risk factors adjusted Multinominal Regression models of the association between child Immigrant status and BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

Frequencies (n) and weighted row percentage (%) provided.

	Changing Classes			Stable Classes	
	Declining Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
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, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.42)	0.92 (0.59, 1.45)	1.23 (0.86, 1.76)	1.5 (0.99, 2.38) (0.051)T	**1.4 (1.0, 1.9) (0.04)**
Daughters	**1.9 (1.3, 2.7) (<0.001)**	0.92 (0.69, 1.22)	0.89 (0.70, 1.15)	1.29 (0.96, 1.75)	1.16 (0.92, 1.46)
Model 2 adjusted for sex and Breastfeeding					
Immigrant children from HICs[&]	0.87 (0.59, 1.28)	0.79 (0.56, 1.09)	0.86 (0.65, 1.14)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.81 (0.45, 1.44)	0.93 (0.59, 1.46)	1.24 (0.86, 1.77)	**1.5 (1.0, 2.4) (0.04)**	**1.4 (1.0, 1.9) (0.048)**
Daughters	**1.9 (1.3, 2.7) (0.001)**	0.92 (0.69, 1.23)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.17 (0.92, 1.47)
Never Breastfed	0.73 (0.33, 1.61)	1.25 (0.76, 2.08)	0.95 (0.58, 1.56)	0.75 (0.41, 1.39)	**1.8 (1.2, 2.6) (0.003)**
Model 3 adjusted for sex and birthweight					
Immigrant children from HICs[&]	0.89 (0.60, 1.32)	0.79 (0.57, 1.09)	0.87 (0.66, 1.16)	1.08 (0.78, 1.52)	0.98 (0.76, 1.29)
Immigrant children from LMICs [&]	0.86 (0.48, 1.53)	0.97 (0.62, 1.52)	1.23 (0.86, 1.77)	**1.6 (1.0, 2.4)(0.03)**	**1.4 (1.0, 2.0)(0.04))**
Daughters	**2.1 (1.5, 3.1)(<0.001)**	0.96 (0.72, 1.29)	0.92 (0.72, 1.18)	1.34 (0.99, 1.81)	1.25 (0.99, 1.58)
<2.5 kg	0.79 (0.29, 2.21)	0.85 (0.38, 1.93)	0.67 (0.33, 1.39)	0.32 (0.09, 1.10)	0.61 (0.28, 1.28)
>4.0 kg	**2.8 (1.8, 4.4)(<0.001)**	**1.8 (1.2, 2.7)(0.002)**	1.37 (0.95, 1.95)	**1.6 (1.0, 2.3)(0.03)**	**2.2 (1.6, 2.9)(<0.001)**
Model 4 adjusted for sex and screen time					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.80 (0.45, 1.43)	0.90 (0.58, 1.42)	1.20 (0.84, 1.71)	1.5 (0.98, 2.3)	**1.4 (1.0,1 .9)(0.050)T**
Daughters	**1.9 (1.3, 2.7) (<0.001)**	0.93 (0.70, 1.25)	0.91 (0.71, 1.17)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
High-screen time (≥3 hrs weekday/weekend)	0.99 (0.67, 1.48)	**1.6 (1.2, 2.1) (0.003)**	**1.5 (1.2, 1.9) (0.002)**	1.26 (0.92, 1.73)	1.15 (0.90,1.48)
Model 5 adjusted for sex and organised sports					
Immigrant children from HICs[&]	0.87 (0.59, 1.29)	0.79 (0.57, 1.09)	0.86 (0.65, 1.15)	1.08 (0.77, 1.50)	0.97 (0.75, 1.26)
Immigrant children from LMICs [&]	0.85 (0.47, 1.50)	0.84 (0.54, 1.33)	1.19 (0.83, 1.70)	1.41 (0.91, 2.16)	1.31 (0.93, 1.83)
Daughters	**1.9 (1.3, 2.7) (0.001)**	0.93 (0.70, 1.24)	0.90 (0.70, 1.15)	1.31 (0.97, 1.77)	1.16 (0.92, 1.47)
No organised sports	0.81(0.57, 1.14)	**1.6 (1.2, 2.1)(0.002)**	1.17 (0.91, 1.50)	**1.57 (1.15, 2.12)(0.005)**	**1.4 (1.1, 1.8)(0.004)**
Model 6 adjusted for sex and SSB					

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Immigrant children from HICs&	0.86 (0.58, 1.28)	0.79 (0.57, 1.10)	0.87 (0.65, 1.16)	1.06 (0.76, 1.47)	0.98 (0.75, 1.27)
Immigrant children from LMICs &	0.82 (0.46, 1.47)	0.93 (0.59, 1.46)	1.24 (0.87, 1.77)	**1.6 (1.0, 2.4)(0.04)**	1.38 (0.99, 1.92)
Daughters	**1.9 (1.3, 2.7)(0.001)**	0.92 (0.69, 1.23)	0.89 (0.69, 1.14)	1.31 (0.97, 1.77)	1.15(0.91, 1.45)
SSB ≥ 1/day	**0.58 (0.40, 0.82)(0.003)**	1.10 (0.8, 1.5)	1.02 (0.77, 1.35)	0.9 (0.66, 1.24)	**1.4 (1.1, 1.8)(0.02)**
Model 7 adjusted for sex and language spoken at home					
Immigrant children from HICs&	0.89 (0.59, 1.33)	0.72 (0.51, 1.02)	0.88 (0.66, 1.17)	1.03 (0.74, 1.43)	0.93 (0.71 ,1.23)
Immigrant children from LMICs &	0.95 (0.44, 2.02)	0.57 (0.29, 1.13)	1.36 (0.87, 2.13)	1.21 (0.67, 2.2)	1.16 (0.74, 1.83)
Daughters	**1.9 (1.3, 2.7)(0.000)**	0.91 (0.69, 1.22)	0.90 (0.70, 1.15)	1.29 (0.96, 1.75)	1.15 (0.91, 1.45)
Foreign language spoken at home	0.80 (0.38, 1.68)	**1.8 (1.0, 3.3)(0.04)**	0.87 (0.56, 1.36)	1.35 (0.76, 2.4)	1.28 (0.84,1 .94)
Model 8 adjusted for sex and family SEP					
Immigrant children from HICs&	0.84 (0.57, 1.24)	0.79 (0.57, 1.10)	0.88 (0.66, 1.17)	1.09 (0.78, 1.53)	1.01 (0.78, 1.31)
Immigrant children from LMICs &	0.85 (0.48, 1.51)	0.94 (0.60, 1.48)	1.20 (0.84, 1.72)	1.44 (0.93, 2.23)	1.35 (0.97, 1.88)
Daughters	**1.9 (1.3, 2.8)(<0.001)**	0.92 (0.69, 1.22)	0.89 (0.69, 1.14)	1.27 (0.94, 1.72)	1.13 (0.89, 1.43)
Low SEP	**0.41 (0.23, 0.77)(0.003)**	0.98 (0.69, 1.39)	**1.5 (1.1, 1.9)(0.009)**	**1.4 (1.0, 2.0)(0.04)**	**1.8 (1.4 ,2.3)(<0.001)**
High SEP	1.30 (0.89, 1.91)	0.73 (0.51, 1.03)	**0.68 (0.49, 0.94) (0.02)**	0.88 (0.61, 1.29)	**0.4 (0.34, 0.68)(<0.001)**

& Reference group Australian-children

a Reference group low-risk BMI-trajectory

RRR is the relative risk ratio for the explanatory variable: i.e. the relative risk of being in the specified trajectory, versus the reference trajectory, for the level of the explanatory variable category compared to the reference category

Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position

Reference group for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English; Family SEP = middle SEP.

all results here are from multinomial analysis.

Values in bold show significant results

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Supplementary Table 3. Sensitivity model. Multinominal Regression Analysis of the child Immigrant status, risk factors and group-based BMI-Trajectories in children aged 2-11 years from Birth Cohort of Longitudinal Study of Australian Children.

	Changing Classes			Stable Classes	
	Declining Risk [a]	**Delayed Risk [a]**	**Gradual Risk [a]**	**Moderate Risk [a]**	**High Risk [a]**
n=2746 n (%)	105 (3.7)	161 (6.1)	207 (8.1)	139 (5.3)	200 (8.1)
	RRR (95% CI, P)	RRR (95% CI, P)	RRR(95% CI, P)	RRR (95% CI, P)	RRR (95% CI, P)
Immigrant children from HICs[&]	0.97 (0.62, 1.52)	0.72 (0.47, 1,08)	1.18 (0.83, 1.68)	1.01 (0.67, 1.54)	1.13 (0.79, 1.62)
Immigrant children from LMICs [&]	1.24 (0.55, 2.80)	0.60 (0.23, 1.56)	**1.9 (1.1, 3.2)[(0.02)]**	1.45 (0.71, 2.94)	1.36 (0.71, 2.58)
Daughters	**2.1 (1.4, 3.3)[(0.001)]**	0.85 (0.60, 1.21)	1.21 (0.89, 1.66)	1.16 (0.80, 1.70)	1.22 (0.88, 1.68)
Never Breastfed	0.90 (0.32, 2.55)	1.29 (0.67, 2.49)	0.83 (0.43, 1.60)	1.25 (0.60, 2.58)	1.33 (0.73, 2.44)
birthweight <2.5 kg	1.13 (0.36, 3.54)	0.80 (0.26, 2.42)	0.79 (0.31, 1.98)	0.42 (0.09, 1.85)	0.41 (0.13, 1.26)
birthweight >4 kg	**2.1 (1.3, 3.5)[(0.005)]**	1.54 (0.96, 2.49)	1.14 (0.73, 1.80)	1.32 (0.89, 2.16)	**1.9 (1.3, 2.9)[(0.001)]**
High-screen time (≥3 hrs weekday/weekend)	1.06 (0.66, 1.70)	1.39 (0.97, 2.00)	**1.6 (1.2, 2.3)[(0.003)]**	1.13 (0.76, 1.70)	0.88 (0.62, 1.27)
No organised sports	1.09 (0.72, 1.64)	**1.7 (1.2, 2.4)[(0.006)]**	1.04 (0.75, 1.44)	1.42 (0.97, 2.06)	1.16 (0.83, 1.62)
SSB ≥ 1/day	0.69 (0.45, 1.07)	1.02 (0.70, 1.49)	0.89 (0.64, 1.24)	0.82 (0.55, 1.22)	1.25 (0.87, 1.78)
Foreign language spoken at home	0.73 (0.31, 1.75)	1.67(0.75, 3.73)	0.96 (0.57, 1.62)	1.02 (0.49, 2.09)	1.59 (0.89, 2.8)
Low family SEP	**0.41 (0.18, 0.88)[(0.02)]**	0.77 (0.48, 1.24)	**1.7 (1.1, 2.5)[(0.009)]**	1.20 (0.73, 1.97)	1.2 (0.8, 1.8)
High family SEP	1.31 (0.83, 2.04)	0.80 (0.53, 1.22)	0.80 (0.54, 1.19)	0.92 (0.58, 1.47)	**0.49 (0.32, 0.76)[(0.002)]**
Gestational diabetes	1.11 (0.46, 2.68)	0.80 (0.35, 1.85)	1.37 (0.74, 2.51)	1.09 (0.47, 2.57)	1.40 (0.77, 2.56)
Gestational hypertension	2.07 (0.96, 4.45)	0.92 (0.43, 1.98)	0.94 (0.52, 1.71)	1.6 (0.83, 3.09)	**1.8 (1.1, 2.9)[(0.03)]**
Overweight/obese mother	**1.6 (1.0 ,2.5)[(0.04)]**	**2.1 (1.45, 2.9)[(<0.001)]**	**2.4 (1.7, 3.3)[(<0.001)]**	**2.5 (1.7, 3.6)[(<0.001)]**	**3.3 (2.3, 4.5)[(<0.001)]**
Mother current smoker	0.85 (0.42, 1.73)	1.25 (0.77, 2.06)	1.37 (0.89, 2.09)	1.66 (0.99, 2.77)	**2.2 (1.5, 3.2)[(<0.001)]**

Adjusted for gestational diabetes, gestational hypertension, maternal weight, and maternal current smoking status in addition to variables reported in Table 4.
Frequencies (n) and weighted row percentage (%) provided.
& Reference group Australian-children
a Reference group low-risk BMI-trajectory
RRR is the relative risk ratio for the explanatory variable: i.e. the relative risk of being in the specified trajectory, versus the reference trajectory for the level of the explanatory variable category compared to the reference category
Abbreviations: HICs=high-income-countries, LMICs= Low-and-middle-income-countries, SSB=Sugar-sweetened beverages, SEP=socio-economic-position
Reference groups for sex = boys; breastfeeding = ever-breastfed; birth weight = 2.5-4.0 kg; screen time = low screen time (<3 hrs weekday/weekend); organised-sports = participated in organised sports last year; sugar-sweetened-beverages = no sugar sweetened beverages in last 24 hours; language spoken at home = English language spoken at home; Family SEP = middle SEP; Gestational diabetes = no gestational diabetes; gestational hypertension = no gestational hypertension; overweight/obese mother = mother not overweight/obese; mother current smoker = mother not current smoker.
Values in bold show significant results
Goodness of Fit test for sensitivity model (n=2746): (X2 (70)=53.77, p=0.92)

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	3
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	3-4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	3
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	3, 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	3-4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	4,5
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	5
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	5,6
Outcome data	15*	Report numbers of outcome events or summary measures over time	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	6
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	6
Discussion			
Key results	18	Summarise key results with reference to study objectives	7
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	7
Generalisability	21	Discuss the generalisability (external validity) of the study results	8
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	10

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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