

Individual development and potential determinants of excess weight in children and adolescents: a longitudinal study

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Summary

OBJECTIVES: Excess body weight is a major public health concern already at a young age. The aim of this study was to track weight status among pupils aged 6–14 years in the City of Zurich, to examine the association between sociodemographic and environmental factors and excess weight at school entry and excess weight gain thereafter.

DESIGN: Longitudinal study.

SETTING: Data were from the medical examinations routinely performed at public schools in Zurich, the largest city in Switzerland. Weight and height were measured in kindergarten (mean age: 5.9 years), grade 1 (7.2 years), grade 4 (10.1 years) and grade 8 (14.2 years).

PARTICIPANTS: The study included 7145 children who enrolled in kindergarten in 2003/04 or 2004/05 and had more than one measurement of weight and height.

OUTCOME MEASURES: Body weight and height were measured by physicians or nurses during the medical examinations at schools. For each measurement point, body mass index (BMI) was calculated and converted to the age- and sex-specific BMI z-scores and BMI percentiles. The stability of children's weight status categories, sociodemographic and environmental factors associated with excess weight gain and with overweight/obesity at school entry were investigated using multiple linear and logistic regression models.

RESULTS: The prevalence of overweight/obesity increased between kindergarten and grade 8 (from 17.6 to 26.0%). Overall, 86.2% of the children remained in the same weight category; 10.8% shifted to a higher and 3% to a lower category. There was a strong correlation between migration background and overweight/obesity at school entry (odds ratios between 1.62 and 3.42, all $p < 0.05$). In addition, boys with Southern/Eastern European background (+2.29 BMI percentile, $p = 0.023$) and girls in lower level school type (+12.98 BMI percentile, $p < 0.001$)

had the highest risk for excess weight gain over a school period.

CONCLUSIONS: Overweight/obesity developed prior to school entry and mostly persisted through childhood. In order to better exploit obesity prevention potential, measures to prevent the development of the excess weight need to be implemented at a very early stage in life.

Keywords: childhood obesity, trajectories, sociodemographic determinants, record linkage study, school setting

Introduction

Excess body weight is a major public health burden worldwide. More than two billion people are expected to be overweight or obese and the prevalence is still increasing in most countries [1]. Excess weight develops at a young age. Thus, besides adults, a large number of children and adolescents are affected [2]. In rapidly developing countries such as India or China, childhood obesity is on the rise [3] whereas in developed countries, there is currently a trend towards stagnation at a high level [4, 5].

Several factors, such as low physical activity [6], sedentary behaviour [7] and unfavourable eating habits [8, 9], probably influence the development of childhood obesity. Lifestyle behaviours are driven by individual and environmental factors, including age, gender, ethnicity and parental socioeconomic position [10], access to recreational facilities, vegetation density and traffic exposure [11].

Overweight children are much more likely than normal weight children to become overweight adults [12]. The early school years might be a critical time for the excess body mass index (BMI) gains. Datar et al. [13] found the largest BMI gains in a nationally representative cohort of children in the United States between 1st and 3rd school grades. In Switzerland, previous data also suggest that the school years might be a critical period for excess weight gain [14]. In this country, in 2012, 14.0% of individuals aged 6 to 12 years were overweight and 3.4% were obese according to the International Obesity Task Force (IOTF) criteria [15]. Data from the same time period for adolescents

Author contributions

DF conceived the study and assisted in data analysis, design of figures and tables and writing. AP mainly performed statistical analyses, designed tables and figures and wrote the manuscript. JB assisted in data modelling and analysis and writing of the Methods section. MB and KS added important background knowledge and improved the manuscript by repeated readings and rephrasing as well as critical discussions of the intellectual content. All authors contributed to the final version of the manuscript.

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(average age: 14.7 years) showed that 15.9% were overweight and 4.9% were obese, with boys having higher rates of overweight and obesity combined than girls (23.1 vs 17.5%) [14]. However, as in most cases, in these studies there was no individual follow-up – the same individuals could not be tracked over time. Only individual longitudinal data allow proper study of critical periods and possible triggers for excess weight gain and thorough study of coincidence with sociodemographic, environmental and behavioural factors.

In order to define potential target groups, appropriate settings and life periods for preventive public health measures, it is essential to assess children who are already overweight/obese at school entry separately from those who gain excess weight during school years. In this study, we aimed to use routine data from medical examinations in the public schools of Zurich to track individual changes in BMI, to investigate the stability of children's weight status and to examine the sociodemographic and environmental factors associated with excess weight gain and with overweight/obesity at school entry.

Methods

Ethics approval

The study procedure was reviewed and classified as un-critical by the ethics committee of the canton of Zurich, Switzerland (Unbedenklichkeitserklärung-Nr. 18-2015).

Study population

Data were obtained from the routine medical examinations at public schools undertaken by physicians of the School Health Services of Zurich, the largest city in Switzerland. Examinations usually occur in kindergarten (children aged 5–6 years), grade 4 (10 years) and 8 (14 years) and are aimed at monitoring children's development (including height and weight), examining function of the sensory organs and checking vaccination status. In addition, weight and height data from the first school grade (7 years) are used for the motor function examination of the Federal Institute of Technology (ETHZ). Also, because routine medical examinations are conducted only at public schools, children who switched to a baccalaureate school after grade 6 did not attend a medical examination at grade 8. Data were gathered between the school years 2003/04 and 2013/14. Only children who were enrolled in kindergarten in 2003/04 or 2004/05, who had more than one weight and height measurement and for whom information on sex was available were considered for analyses.

To ensure the validity of comparing the overweight/obesity prevalence between the kindergarten and the 8th grade, a subsample consisting of children who participated at least in the kindergarten and in the 8th grade examination was used for the analyses shown in [table S1](#), [figure 2](#) and [figure 4](#). In all other analyses, the entire study sample was used. However, the number of children used for analyses leading to the result tables varies owing to the incompleteness of data regarding the variables included.

Different data sources were linked by the Statistics Office of the City of Zurich (SSZ). After linkage, identification information (date of birth, identification number, building and residence indicators) was removed from the data file

prior to analysis to ensure the privacy of all examined subjects.

Measures

Anthropometric measures

Body weight and height were measured by physicians or nurses during the medical examinations at schools with calibrated scales and fixed tape measures. Children's weight was measured in light clothing and without shoes to the nearest of 100 g and height to the nearest of 0.5 cm. The protocol and equipment were standardised.

Body mass index

For each measurement point, BMI was calculated (kg/m^2) and converted to the age- and sex-specific BMI z-scores by using the STATA "zanthro" command and to BMI percentiles by using the definition of the International Obesity Task Force (IOTF) [16, 17]. Individuals were classified according to Cole et al. [16, 17]: normal weight (equivalent to $\text{BMI} < 25 \text{ kg}/\text{m}^2$ at age ≥ 18), overweight ($25 \text{ kg}/\text{m}^2 \leq \text{BMI} < 30 \text{ kg}/\text{m}^2$), obese ($\geq 30 \text{ kg}/\text{m}^2$). In light of the scope of this study (excess weight and not underweight), children with $\text{BMI} < 18.5 \text{ kg}/\text{m}^2$ were classified as normal weight. The mean of the BMI percentiles for the observed children is indicated as mean BMI percentiles.

Weight status trajectories

All children included in the study were classified into four groups of weight status trajectories: (1) children who were of normal weight most of the time i.e., these children were never or in only one examination overweight/obese (normal weight \rightarrow normal weight); (2) children who were overweight/obese for most or all points of available examination (overweight/obese \rightarrow overweight/obese); (3) children who were in the normal weight category at the first available measurement and became overweight/obese over time and whose their BMI percentile rose ≥ 10 percentiles (normal weight \rightarrow overweight/obese); (4) children who changed weight status category from overweight/obese to normal weight over time and whose BMI percentile reduced ≥ 10 percentiles (overweight/obese \rightarrow normal weight). Trajectories depend on the individually available measurements and therefore the length of observation time may vary between children.

Excess BMI gain

Additionally, children were classified according to whether their BMI percentile increased over the school years studied by ≥ 20 percentiles and ended up ≥ 85 th percentile (at last available measurement). The excess BMI gain was not included in multivariate models because there were no results that were statistically significant (lack of power due to the categorisation of variables).

Sociodemographic characteristics

The sociodemographic characteristics of the children were provided by the school department of the city of Zurich from their administrative databases and included sex, exact date of birth, nationality, main language, district of residence, type of secondary school, household size including the number of children in the household, father's and mother's marital status, parental year of birth and an indicator of taxable household income.

Child's migration background

Migration background was based on the child's nationality and his/her main language. Children with German as their main language and Swiss nationality at all existing measurement points were categorized as Swiss. In light of the small samples of specific nationalities, all other children were categorized according to their main language and their nationality at baseline into the following groups: northern and western Europe (including Germany), southern and eastern Europe and countries outside Europe.

Based on the rates found in adults living in Switzerland [18], nationality was dichotomised into; (1) Switzerland or northern and western Europe and (2) southern and eastern Europe and countries outside Europe. These two groups were used for regression analyses presented in table 4 and for the city maps.

Taxable income

The taxable family income was indicated by a letter (A–E). The letters were originally used to determine if a family is entitled to some subsidies for specific services from the city of Zurich and if so what the subsidised amount is. Therefore the income is not linearly distributed over the A–E groups. Families in the B–E groups received some subsidies for specific services from the city of Zurich, because they all had a low taxable income. Families in group A had a medium to high income and therefore do not receive any subsidies. The family income was dichotomised as low or high: the letter A was defined as high income, whereas the letters B–E were defined as low income.

Secondary school type

In Zurich, secondary school comprises of grade 7 to 9. In secondary school, pupils are divided according to their capacities and career intentions in three school types: (1) upper level for students who aspire to a university education and entry to baccalaureate school; (2) intermediate level for students reaching an intermediate level of education and intending to pursue a trade or vocation; (3) lower level for students reaching a basic level of education and intending to pursue a trade or vocation.

Environment

Environmental data were available for 2010 from the Statistik Stadt Zurich (SSZ). Land use was categorised as buildings, land surrounding buildings, traffic, parks and sports grounds, meadows and farming, woodland and water bodies. The categories “parks and sports facilities” and “meadows and farming areas” and “woodland” were combined to form a new category “green area”. Proportions of land use categories were calculated for every city district.

Statistical analysis

For descriptive analyses, we calculated means, standard deviations and proportions. Cross-tabulation was used to investigate the changes in anthropometric variables over time. Differences between groups were detected in the independent samples t-test and Pearson's chi-square test. In order to examine individual predictors for the existence of overweight/obesity at school entry, multiple logistic regression models were calculated and adjusted for sex, district of residence, family income and father's marital status. Murer et al. [19] detected risk factors (such as parental nationality) that play an important role in the development of childhood obesity and showed that these risk factors affect boys and girls differently. In order to evaluate the

role of these protective and risk factors in the potential target population, we stratified for sex and migration background. Three separate population groups were considered: (1) models including all examined children and separate models to look individually at children with (2) Western and Northern European background and (3) non-Western and non-Northern European background were calculated. Gain in BMI percentiles over time was examined with multiple linear regression models. The dependent variable was the difference in BMI percentile between the first and the last available measurement. Since the date of birth and examination date were available and the time spans between measurements were unequal, we used years (and not school period) as time metric. The multiple linear regression models were adjusted for time (in years) between the first and the last available BMI value and for age and BMI percentile at the first available measurement. The variables in the final models were selected with a stepwise procedure based on the Bayesian Information Criterion (BIC). As father's and the mother's marital status are alike in many cases (both married, both divorced...), including both in the models would induce a high danger of multicollinearity and not add much additional information to the model. For this reason, only one of the two variables was included in the model. Individuals with missing information were excluded from the respective analyses. In some analyses, samples are small (e.g., a sample of children with a Western and Northern European background, children living in district 1), precluding robust results. Data were analysed using Stata V.13.0 (StataCorp, Texas, USA). In all cases, the results were considered to be statistically significant if $p < 0.05$.

Results

Study sample

Of the 56 580 children who had ≥ 1 examination during the school years 2003/04 and 2013/14, 7145 fulfilled the inclusion criteria. A total of 49 408 children were either not enrolled in kindergarten in 2003/04 or 2004/05 or had no or only one weight and/or height measurement and were therefore excluded. In addition, 27 children were excluded because of incomplete information on sex (fig. 1).

Of the 7145 remaining children, 3542 participated at least in the kindergarten and in the 8th grade examination, 641 children left elementary school after the 6th grade and went to baccalaureate school, 1203 children moved into or away from the city of Zurich and 1759 had some missing data owing to school absence on the examination day (table 1).

Study population characteristics

The demographic characteristics of the 3542 children who participated at least in the kindergarten and in the 8th grade examinations are shown in table S1 (appendix 1). Equivalent data based on the entire analysed sample ($n = 7145$) is shown in table S2. Of the 3542 children who participated in the kindergarten and 8th grade examinations, 51.8% were male. At school entry, half of the children (50.3%) were foreign nationals. This proportion decreased over the school career. However, >60% of the children had a migration background.

In the same group of children, the mean BMI percentiles at grade 1 (+5.5, $p < 0.001$), 4 (+8.9, $p < 0.001$) and 8 (+12.8, $p < 0.001$) were significantly higher than the mean percentiles at kindergarten. Accordingly, the number of children who were classified as overweight/obese increased significantly ($p < 0.001$) from kindergarten (17.6%) to grade 8 (26.0%). The prevalence of overweight/obesity was higher for girls than boys in grade 1 ($p = 0.035$). In contrast, in grade 8, boys were more often overweight/obese than girls ($p = 0.031$; [fig. 2](#)). At all school grades, children with a migration background from southern and eastern Europe were more often overweight/obese than the Swiss children. The highest difference could be found at school entry, where 25.5% of children with southern and eastern European background were overweight/obese, as compared with 9.9% of the Swiss children. Over the school grades considered, overweight and obesity increased similarly among both nationality groups and amounted at grade 8 to 32.5% and 18.8%, respectively. Children with a northern and western European background (including Germany) had a prevalence of overweight/obesity comparable to that of Swiss children (12.6% in kindergarten; 16.8% in grade 8). Over the school grades, the number of overweight/obese children increased most among children with a migration background from outside Europe (15.4% in kindergarten; 27.9% in grade 8).

[Figure 3a](#) shows the proportions of all included children in the study ($n = 7145$) with excess BMI gain by city district.

Overall, in 7.5% the BMI percentiles increased over the school years considered by >20 percentiles and ended up ≥ 85 th percentile. Districts coloured dark red had the highest prevalence of excess BMI gain, whereas districts in the lightest colour had the lowest. Differences in districts were compared also among other variables such as the proportion of children with a migration background from southern and eastern Europe or a country outside Europe ([fig. 3b](#)), low income of the parents ([fig. 3c](#)), low education level of the children ([fig. 3d](#)) and environmental characteristics ([fig. 3e, 3f, 3g](#)). District 4 showed the highest proportion of children with excess BMI gain as well as the highest proportion of children with a migration background from southern and eastern Europe or a country outside Europe, low income of the parents and low education levels of the children. In addition, this district had a low proportion of green areas and a relatively high proportion of traffic and buildings.

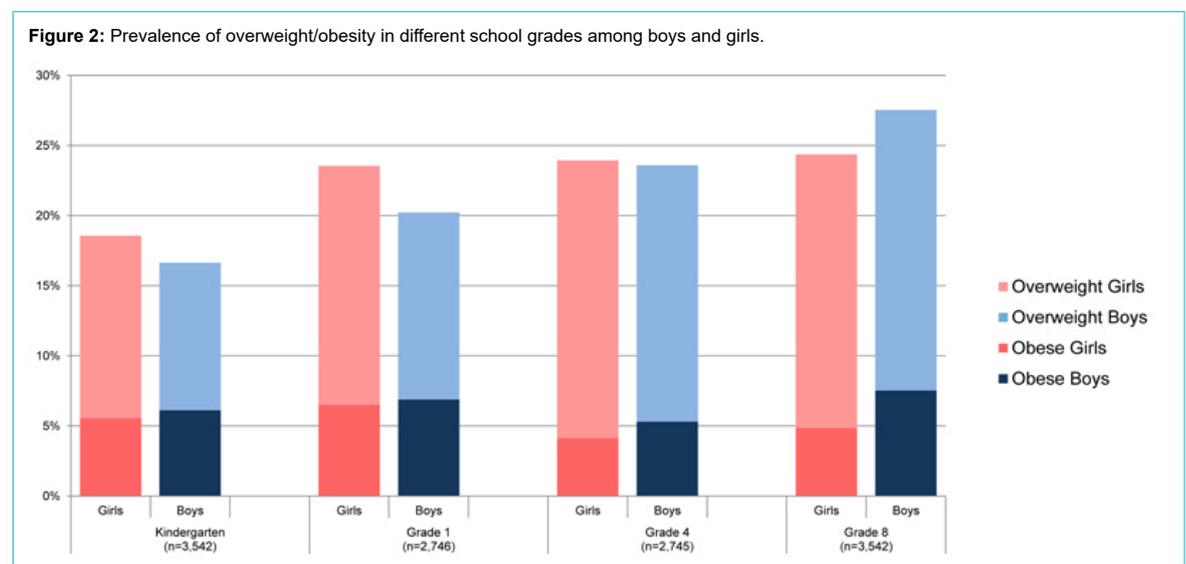
Weight status trajectories over school grades

[Table 2](#) presents the prevalence of the four groups of weight status trajectories in all children included in the study ($n = 7145$) and in the important sociodemographic subpopulation. Most of the children remained in the same weight category over the school grades studied. One-tenth of the children showed an ascending trajectory, whereas only 3% were found in the descending trajectory. Differences in the weight status trajectories were observed with

Table 1: Study sample: participation of the children in the various examinations and reasons for missing data.

Kindergarten	Grade 1	Grade 4	Grade 8	Study sample*	Reasons for missing data
X	(x)	(x)	X	3542	
X	(x)	(x)		2466	538 children switched to baccalaureate school after grade 6 563 children moved away from the City of Zurich after kindergarten 1365 children were absent from school or refused to participate at least in grade 8
	(x)	(x)	X	848	501 children moved into the City of Zurich after kindergarten 347 children were absent from school or refused to participate at least in kindergarten
	X	X		289	103 children switched to baccalaureate school after grade 6 139 children moved into or away from the City of Zurich 47 were absent from school or refused to participate in kindergarten and in grade 8
			Total	7145	

x = children participating in the respective examination (x) = children participating either in the 1st grade examination or in the 4th grade examination or in both examinations * n = children participating in examination in the respective grade (kindergarten, 1, 4, 8)



respect to the migration background of the children, the age of the parents at childbirth and the taxable income. No sex differences were observed.

Stability of children’s weight status categories over time

To examine the proportion of children who changed weight categories between kindergarten and grade 8, weight status categories were cross-tabulated. Among the children who had normal weight in kindergarten, the weight status was relatively stable over the 8 school years (fig. 4). Most children (83.8%) with normal weight remained in that category between kindergarten and grade 8. Only 16.2% of the children who were not overweight/obese in kindergarten changed weight category to overweight/obese. Larger changes occurred among the overweight/obese children. Of the 415 children who were overweight in kindergarten,

nearly 40% were classified as normal weight 8 years later, whereas 14.5% had become obese. Among those who were obese in kindergarten only 7.3% moved into the normal weight category. However, nearly 50% changed to the overweight category.

Factors associated with overweight/obesity at school entry

A multivariate logistic regression analysis found that the odds ratio of being overweight/obese at school entry is strikingly elevated in children with a migration background compared with Swiss children after adjustment for sex, district of residence, family income and father’s marital status (table 3). Analyses were also stratified by migration background. In children with a migration background from southern and eastern Europe or a country outside Europe, there was a significant association between district of residence and weight status in kindergarten. In children

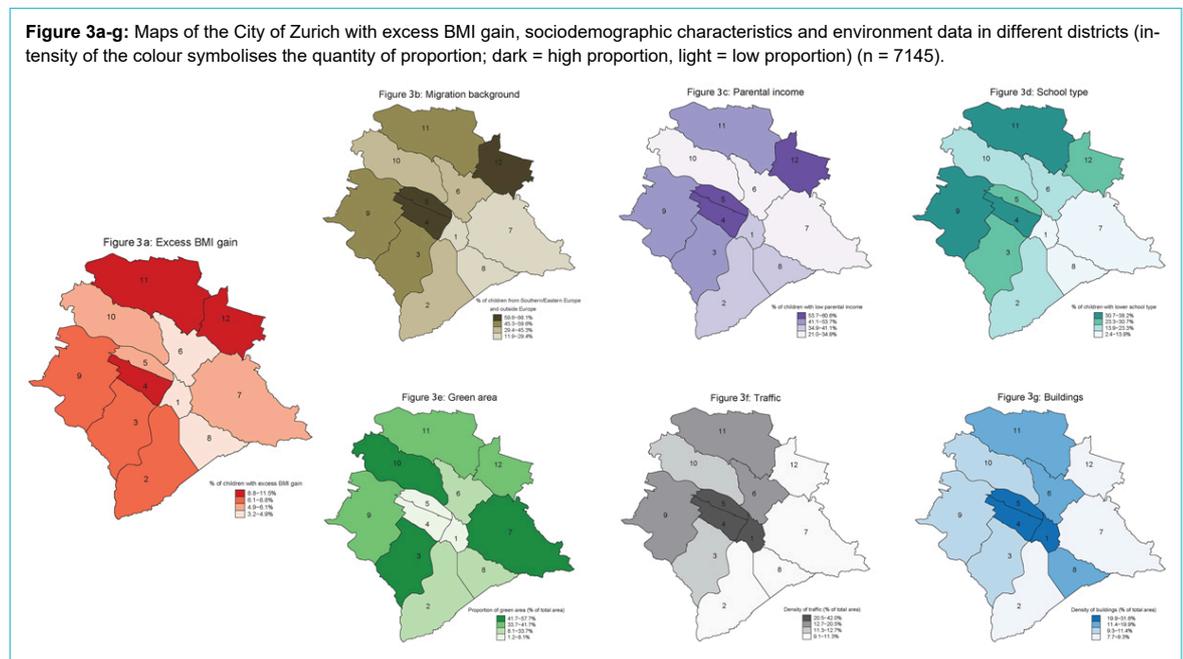


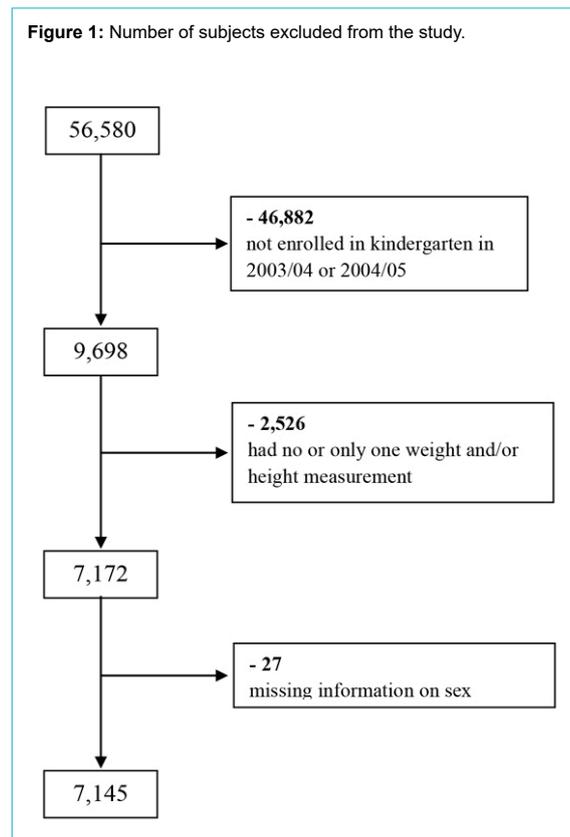
Table 2: Weight status trajectories in all children (n = 7145) and in specific strata.

		normal weight → normal weight	overweight/obese → overweight/obese	normal weight → overweight/obese	overweight/obese → normal weight
All children		5130 (71.8%)	1027 (14.4%)	774 (10.8%)	214 (3.0%)
Sex	Girls	2514 (71.8%)	496 (14.2%)	364 (10.4%)	129 (3.7%)
	Boys	2616 (71.8%)	531 (14.6%)	410 (11.3%)	85 (2.3%)
Migration background	None	2662 (81.1%)	272 (8.3%)	284 (8.7%)	64 (1.9%)
	Northern and western Europe (incl. Germany)	255 (81.5%)	29 (9.3%)	21 (6.7%)	8 (2.6%)
	Southern and eastern Europe	1529 (60.6%)	559 (22.1%)	326 (12.9%)	111 (4.4%)
	Outside Europe	684 (66.8%)	166 (16.2%)	143 (14.0%)	31 (3.0%)
	Missing data (n)			1	
Age of mother at child’s birth	<25	819 (64.6%)	245 (19.3%)	160 (12.6%)	44 (3.5%)
	>25	4311 (73.4%)	781 (13.3%)	614 (10.5%)	170 (2.9%)
	Missing data (n)				
Age of father at child’s birth	<25	305 (63.0%)	96 (19.8%)	68 (14.1%)	15 (3.1%)
	>25	4825 (72.4%)	931 (14.0%)	706 (10.6%)	199 (3.0%)
Taxable income	Low	1929 (68.1%)	459 (16.2%)	358 (12.6%)	88 (3.1%)
	High	2697 (74.8%)	458 (12.7%)	344 (9.5%)	107 (3.0%)
	Missing data (n)	504	110	72	19

Trajectories depend on the individually available measurements and may vary therefore between children in time length.

with a western and northern European background, girls had a greater risk of being overweight/obese at school en-

try than boys (table 3). No sex differences were found among children with a non-western and non-northern European background.



Factors associated with an excess BMI increase during school years

Table 4 shows the results of the linear regression analysis for all children and stratified by sex. The increase in BMI percentile was strongly associated with migration background. Children with a migration background from southern and eastern Europe or a country outside Europe gained on average 1.66 or 1.97 percentiles, respectively, more per year than Swiss children. In addition, the difference in BMI percentiles was significantly associated with sex, indicating a greater gain in BMI percentiles in boys than girls. Boys with southern and eastern European background

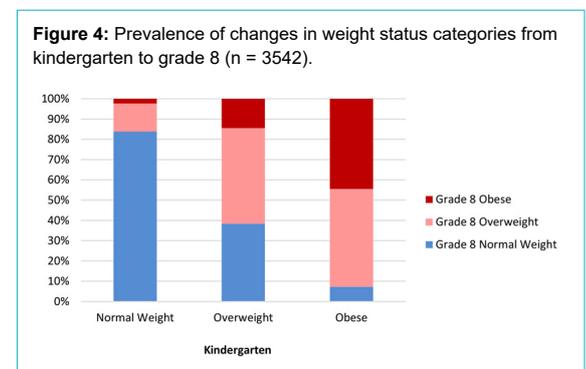


Table 3: Odds ratios (95% confidence intervals) for children being overweight/obese at school entry, based on sociodemographic variables and stratified for migration background.

	All Children			Migration background: southern, eastern and outside Europe*			Migration background: western and northern Europe**		
	OR	95% CI	p-value	OR	95% CI	p-value	OR	95% CI	p-value
	n = 5199			n = 2597			n = 2598		
Sex ¹									
Girls	1.15	0.99–1.34	0.064	1.03	0.86–1.24	0.745	1.44	1.10–1.89	0.008
Migration background ²									
Northern and western Europe (incl. Germany)	1.60	1.02–2.49	0.040	–			1.67	1.08–2.66	0.026
Southern and eastern Europe	3.39	2.81–4.09	<0.001	–			–		
Outside Europe	1.95	1.49–2.55	<0.001	0.60	0.47–0.77	<0.001	–		
Taxable income ⁴									
Low	1.00	0.85–1.18	0.956	0.89	0.73–1.08	0.225	1.33	0.97–1.77	0.062
Father's marital status ⁵									
Unmarried	1.05	0.69–1.59	0.818	0.67	0.28–1.63	0.378	1.18	0.74–1.93	0.492
Divorced/separated/widowed	1.04	0.77–1.40	0.804	1.24	0.83–1.84	0.295	0.78	0.56–1.47	0.311
District of residence ³									
District 1	1.18	0.34–4.10	0.796	–			1.43	0.40–5.23	0.585
District 3	1.55	1.04–2.33	0.033	1.66	0.94–2.92	0.079	1.57	0.87–2.85	0.133
District 4	1.35	0.86–2.12	0.188	1.45	0.81–2.60	0.208	2.18	0.81–5.91	0.125
District 5	2.19	1.33–3.63	0.002	2.91	1.52–5.57	0.001	1.02	0.36–2.87	0.973
District 6	1.74	1.12–2.71	0.014	2.58	1.37–4.87	0.003	1.20	0.64–2.27	0.569
District 7	1.42	0.89–2.25	0.138	1.15	0.54–2.44	0.716	1.58	0.87–2.86	0.134
District 8	0.90	0.48–1.67	0.731	1.49	0.64–3.45	0.350	0.51	0.19–1.42	0.188
District 9	1.57	1.05–2.34	0.028	1.77	1.02–3.09	0.044	1.40	0.76–2.60	0.290
District 10	1.50	0.97–2.32	0.065	1.64	0.88–3.03	0.117	1.42	0.77–2.62	0.264
District 11	1.29	0.87–1.90	0.209	1.51	0.87–2.60	0.143	1.05	0.58–1.90	0.878
District 12	1.43	0.95–2.14	0.084	1.51	0.87–2.63	0.146	1.64	0.87–3.10	0.126

Reference categories: ¹Boys, ²Swiss, ³District 2, ⁴High taxable income, ⁵Married * Reference category for migration background: Southern and Eastern European background ** Reference category: Swiss Figures adjusted for all other listed variables **Bold** indicates significant results.

showed the greatest gain in BMI percentiles. In girls, we found no differences between the nationality groups, but the school type significantly influenced excess weight gain.

Discussion

Main findings

The aim of this study was to examine trajectories in children's weight status and to investigate sociodemographic and environmental factors associated with overweight/obesity at school entry, as well as with excess weight gain over school years. The results suggest that children's weight status was relatively stable over the eight school years considered. Among those who were obese in kindergarten, only 7.3% changed to the normal weight category, highlighting that weight status at school entry predicts weight status during childhood and adolescence. The study showed a strong association between migration background and overweight/obesity at school entry (kindergarten): compared with Swiss children, children with a migration background in southern and eastern Europe, in northern and western Europe, and outside Europe had higher odds of being overweight/obese.

Although a vast majority (>80%) of the children had a stable weight status over their school career, the mean BMI percentile changed over time. This indicator increased

from kindergarten to grade 8 (+12.8 BMI percentiles) and so did the prevalence of overweight/obesity (from 17.6 to 26.0%). The increase was associated with male sex, migration background (southern and eastern Europe or outside Europe), school type and the city district of residence, but not with environmental data such as proportions of green areas, traffic and buildings.

Comparison with other studies

The results of general weight status stability and tracking over school years are consistent with other research [20–22]. Comparing the prevalence of overweight/obesity with other high-income countries with high levels of migration the results are similar [23, 24].

Sex differences

Regarding sex the results are inconsistent. Wheaton et al. reported, in line with our results, a higher prevalence of overweight/obesity in boys [22], but others did not find an increased risk for excess weight gain in boys than in girls [20, 21]. However, these studies did not follow individuals until adolescence. A cross-sectional study including other urban and rural regions of Switzerland [14] also showed a higher prevalence of overweight/obesity for girls than boys in kindergarten and a catch up in excess BMI in boys, finally resulting in higher prevalence in boys at the end of the school career. In our study, the boys gained on average 1.9 BMI percentiles more per year than girls after full

Table 4: Results of a linear regression model for differences in BMI percentile over school time, based on sociodemographic variables, total and by sex.

	All children n = 6089			Boys n = 3117			Girls n = 2972		
	Coef.	95% CI	p-value	Coef.	95% CI	p-value	Coef.	95% CI	p-value
Sex ¹									
Girls	-1.90	-3.00 – -0.80	0.001	–	–	–	–	–	–
Migration background ²									
Northern and Western Europe (incl. Germany)	-1.85	-4.65–0.96	0.197	-1.60	-5.61–2.40	0.432	-2.09	-6.03–1.85	0.298
Southern and Eastern Europe	1.67	0.29–3.04	0.017	2.30	0.33–4.28	0.023	1.00	-0.91–2.91	0.306
Outside Europe	1.98	0.10–3.86	0.040	1.63	-1.02–4.27	0.228	2.41	-0.27–5.09	0.078
Taxable income ⁴									
Low	0.38	-0.83–1.59	0.533	0.39	-1.36–2.14	0.662	0.29	-1.38–1.96	0.734
Father's marital status ⁵									
Unmarried	-2.43	-5.05–0.18	0.069	-1.53	-5.32–2.26	0.430	-3.15	-6.77–0.46	0.087
Divorced/separated/ widowed	-1.34	-3.38–0.71	0.200	-2.16	-5.15–0.83	0.156	-0.47	-3.26–2.32	0.739
School type ⁶									
Intermediate level	4.92	2.14–7.69	0.001	2.02	-2.05–6.10	0.330	7.56	3.77–11.35	<0.001
Lower level	8.40	5.37–11.43	<0.001	4.03	-0.40–8.45	0.075	12.98	8.82–17.13	<0.001
Unknown	3.71	1.61–5.81	0.001	4.43	1.32–7.54	0.005	2.66	-0.18–5.50	0.066
District of residence ³									
District 1	1.54	-5.80–8.87	0.681	4.10	-7.12–15.33	0.474	-0.67	-10.29–8.95	0.891
District 2	5.37	2.55–8.18	<0.001	5.13	1.04–9.23	0.014	5.78	1.91–9.65	0.003
District 3	5.55	3.01–8.10	<0.001	4.93	1.22–8.63	0.009	6.04	2.56–9.52	0.001
District 4	7.59	4.56–10.63	<0.001	7.56	3.25–11.87	0.001	7.62	3.34–11.89	<0.001
District 5	1.56	-2.15–5.26	0.411	2.77	-2.39–7.92	0.293	-0.17	-5.55–5.21	0.950
District 7	1.92	-0.84–4.69	0.173	0.05	-3.99–4.09	0.981	3.58	-0.19–7.36	0.063
District 8	1.23	-2.35–4.82	0.500	1.51	-3.47–6.49	0.552	0.90	-4.31–6.11	0.734
District 9	6.38	3.85–8.90	<0.001	7.12	3.42–10.82	<0.001	5.61	2.16–9.05	0.001
District 10	1.78	-0.92–4.48	0.196	2.74	-1.23–6.70	0.176	0.93	-2.73–4.60	0.617
District 11	7.30	4.90–9.70	<0.001	7.91	4.44–11.39	<0.001	6.65	3.35–9.95	<0.001
District 12	6.34	3.75–8.92	<0.001	6.97	3.25–10.70	<0.001	5.86	2.29–9.44	0.001

Reference categories: ¹Boys, ²Swiss, ³District 6, ⁴High taxable income, ⁵Married, ⁶Upper level Adjusted for time (in years) between the first and the last available BMI-value and for age and BMI-percentile at the first available measurement **Bold** indicates significant results

adjustment. It can be speculated whether girls pay more attention to their body image and make more efforts to combat weight gain [25]. Sex differences further increased with increasing age. In Switzerland in 2012, adult overweight/obesity prevalence was 50.5% in men and 32.0% in women [26].

Differences in migration background

Differences in the prevalence of overweight/obesity and in excess BMI gain depend on the migration background. Cross-sectional European studies showed a north-south gradient in childhood obesity [27, 28], with a lower prevalence in northern than in southern European countries. Our findings corroborated such a north-south gradient. The explanations for higher rates in children with a migration background in southern or eastern Europe compared with those with western or northern European background could be explained by variations in health behaviour, education, socioeconomic position and cultural values [29].

Differences in socioeconomic status

Several studies found an inverse relationship between income and/or education and obesity risk [30, 31]. However, socioeconomic status is complex and comprises various dimensions, including income, education and occupation. In this study, only family income was available, and this dimension was not associated with variations in excess weight gain. Faeh et al. [31] pointed out that education, in comparison with income and occupational class, was the strongest predictor of overweight/obesity in adults, especially in women. As shown in table 4, lower school type was strongly associated with excess weight gain in girls, suggesting that this gradient is rooted at a young age. Moreover, our results show that children from more socially deprived city districts had higher risks of being or becoming overweight/obese compared with those living in more attractive and wealthy districts. In line with this result, Guessous et al. [32] showed that individual BMI is associated with the mean BMI in the neighbourhood. These BMI clusters were spatially dependent and influenced by neighbourhood-level income [32, 33]. In addition, Moser et al. [34] showed that life expectancy is strongly associated with the social standing of neighbourhoods in Switzerland.

Public health implications

The fact that overweight/obesity were already largely prevalent in kindergarten suggests that interventions aimed at preventing overweight/obesity must impact before school entry. This is supported by others, who showed that gestation [35, 36] and early childhood [37] are critical periods. Educating (future) parents may affect their children's development of food- and activity-related behaviours [38]. Migrants from southern and eastern Europe are an important target group for interventions, but difficult to reach with general prevention programs [39]. To meet this challenge, interventions need to be targeted and culturally adapted. Furthermore, appropriate language and intercultural education of public health professionals are important. Structural public health measures probably impact on the entire population, including families with migration background. Institutional organisations (e.g., public day nurseries, leisure centres, schools) must provide a healthy

environment, promoting a healthy behaviour in everyday life, such as physical activity, and fruit and vegetable consumption. At the school level, there should be a focus on boys with a southern and eastern European background and girls in a lower-level school type. Furthermore, city planners and politicians ought to be aware of (childhood) obesity in order to adapt built, social, political and legislative environments accordingly. Longitudinal data from routine medical examinations at school are crucial for monitoring childhood obesity and for the identification of potential determinants and specific target groups as well as of ideal life course periods for interventions. It is, therefore, worthwhile to invest in and improve these time- and cost-effective examinations.

Strength and limitations

The major strength of this study is the large and quite complete study sample from an economically highly developed country. Data were assessed up to four times over eight school years so that individual changes in measured BMI could be tracked. Besides BMI, a wide range of potential determinants of various routine data sources could be considered.

The study has several limitations. First, the completeness of data varied over the study period. Children who changed to baccalaureate school after grade 6 could not be followed until grade 8. Also, children attending private schools could not be included. However, these groups can be considered at "low-risk" for excess BMI gain and therefore not relevant for targeted public health interventions. Expectedly, 10% of pupils refused the medical examination at school and were attended to by their family doctor. In addition, children who moved into or away from Zurich could not be followed up over all school grades. Second, in longitudinal analyses considering the entire school grade range, children finally attaining a higher education level were underrepresented, because those who go to a baccalaureate school missed the final examination. This is likely to lead to an overestimation of overweight/obesity and possibly to a misestimation of determinants. A study in Swiss conscripts showed that 26% of unskilled workers were overweight versus 13% of students that attended baccalaureate school, and 12% of unskilled workers were obese against 2% of students [40].

Third, the database does not include information on the occupational and educational level of parents precluding a more detailed and complete examination of the role of socioeconomic status. Moreover, we used broad definitions for socioeconomic and migration background precluding to analyse associations between these two characteristics. In addition, we can't make any hypotheses why Switzerland is one of the countries with the lowest overall prevalence of overweight in childhood and adolescence. Switzerland has a large variability of ethnicities which do not allow to explain the differences in other countries by individual or genetic factors.

Conclusion

Overweight/obesity at school entry is associated with migration background and tracks strongly through childhood and adolescence. Boys with migration background in Southern and Eastern Europe and girls following lower-

level school trajectories are mostly at risk for excess weight gain over school years. Since almost one-fifth of the children in this study were overweight or obese already in kindergarten, routine gathering of relevant data of children and of their parents prior to school entry should be focused on.

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Appendix 1

Supplementary tables

Table S1: Demographic characteristics of the children who participated at least in kindergarten and in grade 8 (n = 3542).

	Kindergarten		Grade 1		Grade 4		Grade 8	
Nationality Swiss	1759 (49.7%)				2128 (77.6%)		2925 (82.7%)	
Missing (n)	0				150		10	
Migration background								
None			1391 (39.3%)					
Southern and eastern Europe			1540 (43.5%)					
Northern and western Europe (incl. Germany)			95 (2.7%)					
Outside Europe			512 (14.5%)					
Missing (n)			4					
Secondary school type								
Upper level							538 (13.2%)*	
Intermediate level							2104 (51.6%)	
Lower level							1379 (33.8%)	
Unknown							59 (1.4%)	
Place of residence								
District 1	18 (0.5%)		10 (0.4%)		14 (0.5%)		18 (0.5%)	
District 2	251 (7.1%)		152 (5.5%)		187 (6.8%)		251 (7.1%)	
District 3	440 (12.4%)		325 (11.8%)		362 (13.2%)		440 (12.4%)	
District 4	259 (7.3%)		226 (8.2%)		193 (7.0%)		259 (7.3%)	
District 5	113 (3.2%)		86 (3.1%)		87 (3.2%)		113 (3.2%)	
District 6	246 (7.0%)		198 (7.2%)		179 (6.5%)		246 (7.0%)	
District 7	202 (5.7%)		126 (4.6%)		147 (5.4%)		202 (5.7%)	
District 8	101 (2.9%)		71 (2.6%)		83 (3.0%)		101 (2.9%)	
District 9	480 (13.6%)		313 (11.4%)		364 (13.3%)		480 (13.6%)	
District 10	269 (7.6%)		223 (8.1%)		208 (7.6%)		269 (7.6%)	
District 11	665 (18.8%)		576 (21.0%)		528 (19.2%)		665 (18.8%)	
District 12	496 (14.0%)		439 (16.0%)		393 (14.3%)		496 (14.0%)	
Missing (n)	12		1875		160		50	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
No.	1835 (51.8%)	1707 (48.2%)	1425 (51.9%)	1321 (48.1%)	1413 (51.5%)	1332 (48.5%)	1835 (51.8%)	1707 (48.2%)
Age (years)	5.9	5.9	7.2	7.1	10.1	10.1	14.2	14.1
Height (cm)	117.4	116.2	125.1	123.7	141.5	140.8	167.1	161.5
Weight (kg)	22.3	21.5	26.2	25.5	36.8	36.4	59.8	56.5
BMI percentiles	53.8	50.7	59.7	55.7	63.8	58.4	66.2	64.0

* children participated in kindergarten, but not in grade 8

Table S2: Demographic characteristics of all children included in the study (n = 7145).

	Kindergarten		Grade 1		Grade 4		Grade 8	
Nationality Swiss	3598 (56.0%)		-		4798 (76.9%)		3673 (80.2%)	
Missing (n)	721				909		2567	
Migration background								
None			3282 (45.9%)					
Southern and eastern Europe			2525 (35.3%)					
Northern and western Europe (incl. Germany)			313 (4.4%)					
Outside Europe			1024 (14.3%)					
Missing (n)			1					
Secondary school type								
Upper level							641 (9.0%)	
Intermediate level							2686 (37.6%)	
Lower level							1793 (25.1%)	
Unknown							2025 (28.3%)	
Place of residence								
District 1	40 (0.6%)		19 (0.6%)		36 (0.6%)		28 (0.6%)	
District 2	480 (7.5%)		311 (9.8%)		467 (7.9%)		367 (8.1%)	
District 3	862 (13.5%)		407 (12.8%)		764 (13.0%)		578 (12.8%)	
District 4	433 (6.8%)		202 (6.3%)		300 (5.1%)		272 (6.0%)	
District 5	210 (3.3%)		132 (4.1%)		148 (2.5%)		102 (2.3%)	
District 6	428 (6.7%)		235 (7.4%)		469 (8.0%)		312 (6.9%)	
District 7	426 (6.7%)		240 (7.5%)		444 (7.5%)		233 (5.2%)	
District 8	177 (2.8%)		56 (1.8%)		157 (2.7%)		92 (2.0%)	
District 9	833 (13.0%)		303 (9.5%)		753 (12.8%)		610 (13.5%)	
District 10	549 (8.6%)		270 (8.5%)		512 (8.7%)		363 (8.0%)	
District 11	1157 (18.1%)		646 (20.3%)		1108 (18.8%)		930 (20.6%)	
District 12	803 (12.6%)		365 (11.5%)		736 (12.5%)		634 (14.0%)	
Missing (n)	747		3959		1251		2624	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
No.	3,082 (51.3%)	2,926 (48.7%)	2,908 (51.3%)	2,765 (48.7%)	2,604 (50.5%)	2,554 (49.5%)	2,252 (51.3%)	2,138 (48.7%)
Age (years)	5.9	5.9	7.2	7.1	10.1	10.1	14.2	14.2
Height (cm)	117.2	116.1	125.0	123.8	141.6	141.0	167.3	161.5
Weight (kg)	22.1	21.4	26.0	25.3	36.5	36.0	59.9	56.5
BMI percentiles	53.2	49.6	58.2	54.1	63.4	55.7	66.1	63.9