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Modifiable Early Childhood Risk Factors for Obesity at Age Four Years

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Abstract

Background: Childhood obesity is associated with an increased risk of adult obesity and related chronic disease. Our aim was to identify modifiable exposures that are independently associated with obesity in the preschool age group.

Methods: A prospective cohort study of 5734 children in New Zealand with anthropometric measurements was completed at age 4.5 years. The modifiable exposures of interest, measured at age 9 months and 2 years, were: food security during infancy; and, at age 2 years, screen time; sleep duration; and takeaway food and soft drink intake. The risk of obesity independently associated with each exposure was determined using Binomial and Poisson regression and described using adjusted risk ratios (RRs) and 95% confidence intervals (CIs), after controlling for confounding variables including gender, ethnicity, birth weight, and mother's age. The probability of obesity given cumulative exposures to the four risk factors and the population attributable fraction (PAF) were estimated.

Results: Lower food security during infancy (<mean study sample score; RR = 1.32; 95% CI : 1.06–1.64) and, at age 2 years, more screen time (>1 hour/day; RR = 1.22; 95% CI : 1.01–1.48), shorter sleep duration (≤11.5 hours/day; RR = 1.30; 95% CI : 1.05–1.61), and weekly to daily consumption of takeaway/soft drink (RR = 1.25, 95% CI : 1.00–1.57) were independently associated with an increased risk of obesity at age 4.5 years. The cumulative PAF for childhood obesity was 42.9%, under an ideal scenario where all risk factors were eliminated.

Conclusion: Exposure to modifiable factors by age 2 years is associated with obesity at age 4.5 years. Interventions to prevent childhood obesity need to be effective during infancy.

Keywords: early childhood; modifiable risk factors; obesity

Introduction

Early childhood obesity is prevalent worldwide with an estimated 41 million children under 5 years old being overweight or obese in 2016.[1] Early childhood obesity has an adverse impact during this critical developmental phase and is associated with an increased risk of subsequent health issues, including diabetes, hypertension, dyslipidemia, cardiovascular diseases, depression, and obesity during adulthood.[2–7] The majority of

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children with obesity at age 3 years also have obesity as adolescents.[8] Among adolescents with obesity, the largest annual increments in BMI occur from ages 2 to 6 years.[8]

Therefore, it is essential to identify risk factors for childhood obesity as early as possible in life to develop effective preventative interventions at this critical stage. Early risk factors for childhood obesity have been identified in contemporary child cohort studies.[5,9–12] Of these, genetic factors, maternal socioeconomic position, prepregnancy parental BMI, gestational weight gain, gestational age, birth weight, and weight gain patterns from infancy have all been shown to have independent associations with the odds of being obese in later childhood.[9,10,13,14] There is an ongoing debate on what constitutes a modifiable/nonmodifiable factor. Behavioral factors are usually considered as modifiable, whereas environmental factors such as food insecurity, lack of green spaces in the neighborhood, obesogenic environment, lower education status for parents, and other risk factors are sometimes seen as nonmodifiable.[15] However, some of these nonmodifiable factors could be modifiable with introducing appropriate policies.[16]

Among these pre-, peri-, and postnatal factors, some are modifiable through health promotion and policy changes, and they thus provide potential opportunities to intervene before young children develop unhealthy weight trajectories. Early modifiable risk factors include physical activity,[11,17] including time spent playing outdoors,[15] diet quality and quantity, dietary behaviors,[18] screen time,[19] sleep duration[20,21] and quality,[22] and household routines around bed time.[23,24] However, the majority of studies that have identified factors independently associated with early childhood obesity have not considered their effect in the context of other relevant exposures nor their accumulated impact.[19,25–27] At best, these studies controlled for the association between the effect of one factor on childhood obesity by including some other factors in their final model.[20,27]

In this study, we first aimed to examine a range of potentially modifiable risk factors associated with early childhood obesity simultaneously, thus considering their independent relationship with early childhood obesity. Second, we investigated the cumulative impact of multiple factors on the risk of early childhood obesity.

Methods

Study Population

We completed this study in New Zealand (NZ), a country with the second highest prevalence of childhood overweight and obesity among 41 of the Organization for Economic Co-operation and Development (OECD) and European Union countries in 2018, with 39.5% of children aged 5 to 15 years having overweight or obesity.[28,29] The data used for this study were obtained from Growing Up in New Zealand (GUiNZ) (www.growingup.co.nz), a prospective cohort study into which were enrolled 6822 pregnant women, with the 6853 children born to these women during 2009–2010 creating the child cohort.[30]

Study eligibility for GUiNZ was defined by maternal residence, while pregnant, within a geographical region of NZ defined by the three contiguous District Health Board regions of Auckland and Counties-Manukau and Waikato and with an estimated delivery date between April 2009 and March 2010. This region was chosen for its socioeconomic and ethnic diversity.[30] The characteristics of the cohort at birth generally aligned with the national birth cohort in NZ from 2007 to 2010.[31] Exceptions to this were that a smaller proportion of children in the study cohort than the national birth cohort had low birth weight (4.9% vs. 6.1%) or preterm gestation (6.4% vs. 7.4%), and the pregnant women enrolled into the cohort study were more ethnically diverse. Ethical approval was granted by the NZ Ministry of Health Northern Y Regional Ethics Committee (NTY/08106/055). All participating women provided written informed consent. The study methodology is detailed in previous publications.[30,31]

Data Collection

Data on exposures of interest and potential confounders were collected from the prenatal period until the cohort children were 2 years old. Computer-assisted personal interviews (CAPIs) were completed with each child's main caregiver, usually their mother, at enrollment (most commonly during the last trimester of pregnancy) and then when their cohort child was 9 months and 2 years old. Computer-assisted telephone interviews (CATIs) were completed with each child's main caregiver when the cohort child was aged 6 weeks, 35 weeks and 15, 23, and 45 months.[30] Anthropometric measures, used to determine BMI, were collected at the CAPI that occurred when the cohort children were 4.5 years old.

Exposure Variables Measured at 2 Years

Modifiable exposure variables included in this study were food security, screen time, sleep duration, fast food intake, and soft drink intake.

The infant food security index was previously developed using data from GUiNZ.[32] The index is created using variables describing: exclusive breastfeeding to age 3 months and, at age 9 months, consumption of sentinel foods (*e.g.,* grains, legumes and nuts, flesh foods, eggs, fruits, and vegetables); consumption of energy-dense nutrient-poor foods, and maternal coping methods around food related to material hardship.[32] The food security index score ranged from 0 to 49.29, with a higher score indicating higher food security. Table 1 displays this score as quartiles to look at the distribution among children with and without obesity. For multivariate analyses, a binary food security variable was created based on a score below the mean score of 26 vs. 26 or greater. This cutoff point was created to divide the cohort to two food security categories.

Table 1 shows the average hours of TV viewing per day, the hours of using devices (ipads, computers, *etc.*) per day, and the total screen time (hours per day) combining TV

Table 1. Characteristics of Cohort Children with Anthropometric Data Available to Define Obesity at Age 4.5 Years

Exposures and potential confounders at 2 years/prenatal/9 months	*n* (col%)	Obesity status at 4.5 years				
		Nonobese		Obese		
		n	Row%	*n*	Row%	*p*[a]
All children	5598	5118	91.4	480	8.6	
Ethnicity[b] (at 4.5 years)						
European	2855 (51.8)	2704	94.7	151	5.3	<0.0001
Māori	737 (13.4)	640	86.8	97	13.2	
Pacific	711 (12.9)	554	77.9	157	22.1	
Asian	653 (11.9)	625	95.7	28	4.3	
MELAA/other	555 (10.1)	517	9.4	38	6.9	
Sex						
Female	2718 (48.5)	2462	90.6	256	9.4	0.03
Male	2880 (51.5)	2656	92.1	224	7.8	
Child's birth weight (g)						
<2500	265 (4.8)	297	95.5	14	4.5	<0.0001
2500 to <4000	4327 (77.9)	4052	92.0	350	8.0	
≥4000	963 (17.3)	847	86.8	129	13.2	
NZ deprivation index[c]						
Low deprivation (deciles 1 to 3)	1544 (28.5)	1465	94.9	79	5.1	<0.0001
Medium (deciles 4–7)	2040 (37.6)	1924	94.9	116	5.7	
High deprivation (deciles 8–10)	1844 (34.0)	1582	85.8	262	14.2	
Rurality[c]						
Rural	477 (8.8)	452	94.8	25	5.2	0.005
Urban	4953 (91.2)	4521	91.3	432	8.7	
Recipient of household income benefit at prenatal, 9 month, or 2 year interviews						
None	1189 (21.8)	1142	95.6	52	4.4	<0.0001
Once	1139 (20.9)	1076	93.6	74	6.4	
Twice	784 (14.4)	719	89.6	82	10.4	
Three times	892 (16.4)	813	89.6	94	10.4	
Four times	531 (9.8)	477	88.8	60	11.2	
Five times	906 (16.6)	803	87.6	114	12.4	
Mother's age in years when pregnant						
≤25	938 (17.5)	819	87.3	119	12.7	<0.0001
25–35	3081 (56.3)	2852	92.6	229	7.4	
≥35	1449 (26.5)	1335	92.1	114	7.9	
Mothers' education						
No secondary school education	334 (6.0)	289	86.5	45	4.7	<0.0001
Secondary school/NCEA1–4[d]	1236 (22.3)	1084	87.7	152	12.3	
Diploma/trade	1681 (30.3)	1509	89.8	172	10.2	
Bachelor's degree	1357 (24.5)	1300	95.8	57	4.2	
Higher education	932 (16.8)	888	95.3	44	4.7	

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Table 1. Characteristics of Cohort Children with Anthropometric Data Available to Define Obesity at Age 4.5 Years *continued*

Exposures and potential confounders at 2 years/prenatal/9 months	*n* (col%)	Obesity status at 4.5 years				
		Nonobese		Obese		
		n	Row%	*n*	Row%	*p*[a]
Early education care						
Yes	1976 (39.5)	1829	92.6	147	7.4	0.03
No	3016 (60.4)	2735	90.7	281	9.3	
Food security index at age 9 months[e]						
4.0–22.5	1258 (24.5)	1090	86.6	168	13.3	<0.0001
22.6–25.8	1310 (25.6)	1196	91.3	114	8.7	
25.8–29.2	1259 (24.6)	1184	94.0	75	6.0	
29.2–49.3	1298 (25.3)	1237	95.3	61	4.7	
TV viewing at age 2 years (hours/day)						
None	1235 (22.9)	1158	93.8	77	6.2	<0.001
≤1	2435 (45.2)	2262	92.9	173	7.1	
1–2	992 (18.4)	889	89.6	103	10.4	
>2	723 (13.4)	622	86.0	101	14.0	
Using devices with screens (ipad, computers, *etc.*) at age 2 years (hours/day)						
None	4508 (82.7)	4140	91.8	368	8.2	0.39
≤1	854 (15.7)	769	90.0	85	10.0	
1–2	64 (1.2)	58	90.6	<10	9.4	
>2	27 (0.5)	24	88.9	<10	11.1	
Total screen time (electronics +TV viewing) at age 2 years (hours/day)						
None	1156 (21.2)	1081	93.5	75	6.5	<0.0001
≤1	2316 (42.4)	2157	93.1	159	6.9	
1–2	1076 (19.7)	968	90.0	108	10.0	
>2	908 (16.6)	788	86.8	120	13.2	
Total sleep duration[f] at age 2 years (hours/day)						
≤11.5	606 (11.6)	509	84.0	97	16.0	<0.0001
11.5 to <12.5	1863 (34.0)	1710	91.8	153	8.2	
12.5 to <13.5	1615 (29.5)	1497	92.7	118	7.3	
≥13.5	1397 (25.5)	1300	93.1	97	6.9	
Night time sleep duration at age 2 years (hours/day)						
≤9.5	905 (16.5)	769	85.0	136	15.0	<0.0001
9.5–10.5	1392 (25.4)	1270	91.2	122	8.8	
>10.5 to 11.5	1824 (33.3)	1709	93.7	115	6.3	
>11.5 to 14	1357 (24.8)	1265	93.2	92	6.8	
Nap time at age 2 years (hours/day)						
≤1.5	2057 (37.7)	1876	91.1	181	8.8	0.002
1.5–2.0	2597 (47.5)	2406	92.6	191	7.4	
>2.0	808 (14.8)	717	88.9	91	11.3	

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Table 1. Characteristics of Cohort Children with Anthropometric Data Available to Define Obesity at Age 4.5 Years *continued*

Exposures and potential confounders at 2 years/prenatal/9 months	n (col%)	Obesity status at 4.5 years				
		Nonobese		Obese		
		n	Row%	n	Row%	p[a]
Soft drink consumption frequency at age 2 years						
None	3412 (62.3)	3206	94.0	206	6.0	<0.0001
≥1/month	737 (13.4)	670	90.9	67	9.1	
≥1/week	955 (17.4)	819	85.8	136	14.2	
≥1/day	376 (6.9)	320	85.1	56	14.9	
Takeaway food consumption frequency at age 2 years						
None	1383 (25.2)	1313	94.9	70	5.1	<0.0001
≥1/month	2411 (44.0)	2243	93.0	168	7.0	
≥1/week	1603 (29.2)	1394	87.0	209	13.0	
≥1/day	83 (1.5)	65	78.3	18	21.7	
Takeaway and soft drink consumption frequency at age 2 years (binary variable)						
None	3274 (59.8)	3088	94.3	186	5.7	<0.0001
Monthly/weekly or daily	2204 (40.2)	1925	87.3	279	12.7	
BMI (mean SD)	5598 (100)	16.32 ± 1.26		21.4 ± 2.73		<0.0001

[a]*p*-Value from Chi-square test—between group differences.

[b]Multiple responses were able to be provided.

[c]The NZDep2006 is a well-validated small area measure of relative deprivation derived from 2006 national census data.[62]

[d]One child lived in an area not defined as urban or rural.

[e]Total sleep duration = night time sleep duration+day time sleep/naps duration.

[f]Derived from variables describing infant food consumption, breastfeeding, and maternal food-related coping methods during infancy.[28] Food insecurity defined as a food security index score less than 26.

NCEA, National Certificate of Educational Achievement; NZ, New Zealand.

viewing and time on devices. These are shown at levels: "None," "less than 1 hour," "1 to 2 hours," and "greater than 2 hours." Thus the average screen time per day was created by a calculation that included 5 week days and two weekend days. For the first two tables, we used quartiles of screen time to examine the distribution of the children's screen time in relation to the outcome of interest. For the final multivariate analyses we dichotomized this variable as "1 hour or less" or "more than an hour" based on NZ Ministry of Health and WHO recommendations of no more than an hour of screen time after 2 years old.[33,34]

Twenty-four hour sleep duration was calculated by adding night-time and day-time sleep duration using information collected from the following two questions: "On average how much time does your child spend asleep at night in total?," and "On average, how much time does your child spend asleep during the day?." Night-time sleep and total sleep are shown in 1 hour grouping across four levels; nap time was broken into 30-min groupings across three levels. For the final multivariate analyses the two highest categories of total sleep were collapsed as their relationship with obesity was similar.

A semiquantitative food frequency questionnaire with 62 food items was used to collect data on frequency and portions of food items eaten in the previous 4 weeks. From this questionnaire, frequency of takeaway food and soft drink/fizzy drink intake was determined. Takeaway food and soft drink/fizzy drink intake were both categorized into four levels; none, 1–3/month, 1–5/week, and ≥1 daily. An aggregated variable was then created to assess the combined effect of takeaway food and soft drink intake at age 2 years on obesity status at 4.5 years. This exposure was described using a two level combined variable of takeaway food/soft drink intake of none or ≤1/month and ≥1/week or daily. The creation of these variable categorizations was both data driven (based on the sample distribution) and aimed at applicable threshold for policy recommendations (including zero/monthly consumption for this age as one category).

Measurements

Weight and height were measured by trained interviewers when the cohort children were 4.5 years old, using a standardized protocol that included the removal of shoes or hats, jackets or jumpers and the taking of duplicate measurements. International Obesity Task Force (IOTF) cutoff points were used to define obesity at age 54 months.[35–37] To develop these reference data, an international survey of six nationally representative growth studies was used with data from children in Brazil, Great Britain, Hong Kong, The Netherlands, Singapore, and the United States.[37]

Potential Confounding Variables

The potentially confounding variables that were measured were: child's sex, age in months, ethnicity, birth weight, mother's age at pregnancy, maternal education status, early childhood education attendance (ECE), and socioeconomic position. There were two measures of socioeconomic position used. First, the NZDep2006 Index of Deprivation was determined from household geographical location at the 2 year interview. The NZDep2006 is a validated small area measure of relative deprivation derived from 2006 national census data on nine household socioeconomic characteristics. Second, a household and maternal income benefit measure for each individual cohort member was derived from five questions asked in GUiNZ at age 9 months and 2 and 4.5 years on welfare with the specific receipt of either an unemployment benefit and/or sickness benefit. This benefit system provides payments at regular intervals. The score ranged from zero to a maximum score of 5.

Variables describing the mothers' education, pregnancy age, and residential rurality were measured at the prenatal CAPI.[38] At the 45-month CATI, mothers were asked to describe all (total response) and the main (self-prioritized) ethnic groups the child was identified with. Ethnicity was then categorized into five groups (European, Māori, Pacific, Asian, and finally Middle Eastern, Latin American, African, New Zealander, and Other). This classification is consistent with the Statistics NZ level 1 classification of ethnicity, except that "Middle Eastern, Latin American, and African" and "New Zealander" were combined with "Other."[39]

ECE at age 2 years was asked from parents and was described using a binary variable "Yes"/"No."

Statistical Analyses

The analytic sample was those cohort children who had anthropometric measurements performed at the 4.5-year data collection wave. This included 5734 (84%) of the 6853 cohort children.

Statistical analyses were performed in SAS (version 9.4, Cary, NC). Bivariate associations between obesity and each of the independent/confounding variables were described using chi-square tests. Two step binomial regressions were completed. First, the association between each exposure and obesity was assessed separately, adjusting for confounding variables. Then, the simultaneous relative risk of all exposures and obesity was estimated using log-binomial models through the maximum likelihood estimation. Poisson regression was used to estimate the relative risk for multivariate models and was used to address the convergence issue that occurs with log-binary models containing several independent variables. Relative Risks (RRs) and 95% confidence intervals (CIs) were calculated for each variable comparing the risk of obese vs. nonobese status at each level of the four exposure variables. Next, the probability of obesity at age 4.5 years, given the presence of each of the four exposure variables: food security, sleep duration, screen time, and takeaway food/soft drink consumption, was estimated. We calculated the probability of obesity given cumulative exposures to the four risk factors, using Proc Glimmix. Finally, a population attributable fraction (PAF) was calculated from estimated proportions of children exposed to each of one to four exposures and the corresponding relative risks compared with the unexposed group.[40,41] PAF is an epidemiological measure that describes the fraction of the population with a particular condition that is attributable to a specific risk factor.[40] PAF calculations were carried out using STATA (version 16) and the packages "punaf."[42] PAF calculations were based on an "ideal" scenario, whereby risk factors were set to zero at their ideal level, that is, ≤1 hour/day screen time, >11.5 hours/day sleep duration, no consumption of soft drinks or takeaway, and an infant food security index of ≥26.

Models were run with full response for both exposures and independent or confounding variables. Observations with missing records, including no responses or "do not know" and "do not remember" responses, were excluded from the analyses. This limited our total sample to 5734 children. We further excluded 74 children for being from a multiple pregnancy but were not the first born child, and another 62 children for having an age of >59.5 months when anthropometric measurements were conducted. The final analytic model included 5998 children.

Results

According to IOTF age- and sex-specific cutoff points for children from 2 to 18 years, obesity was present in 8.6% ($n = 480/5598$) of the children (Table 1). The sample included 2880 (51.4%) boys and 2718 (48.6%) girls with the prevalence of obesity being 1.6% higher in girls ($p = 0.03$).

Obesity prevalence varied with self-prioritized ethnicity, being highest in children who were identified by their mother as being of Pacific ethnicity (19.7%, $n = 224$), then Māori (11.2%, $n = 158$), then other ethnicities (7.5%, $n = 88$), then European (6.5%, $n = 251$), and lowest in Asian (4.9%, $n = 42$) (Table 1).

Obesity was more frequent in girls vs. boys and children with higher birth weight. Obesity occurred more frequently in children living in more deprived neighborhoods, in urban vs. rural settings, and those whose families received

more income-tested benefits. Obesity occurred more frequently in children born to younger women or to women whose educational status was lower and in children who did not attend early childhood education (Table 1).

With respect to the modifiable exposure factors, obesity was more frequent in children who were less food secure and who had more screen time or less sleep or more frequent servings of takeaway food and soft drink/fizzy drinks. Obesity was present in 13.4% of children with food security in the lowest quartile, 13.0% of children with a total screen time of >2 hours per day, 15.3% of children who slept ≤11.5 hours per day, and 13.3% of children who had takeaway food or soft drink/fizzy drinks weekly to daily (Table 1).

In analyses that adjusted for potential confounders, children who had an infant food security index score ≤26 had 1.35 times the risk of obesity at 4.5 years, compared to those who were more food secure (Table 2). A borderline association was found between screen time and obesity with an increasing trend in obesity seen with increasing screen time (Table 2). Children, at age 2 years, who were sleeping ≤11.5 hours/day had a 1.37 times increased risk of obesity at age 4.5 years compared to those who slept 13.5 hours/day or longer. Children, at age 2 years, who were consuming either takeaway food or soft drinks weekly to daily had a borderline increased risk of obesity compared with children who never had takeaway food or soft drinks (Table 2).

In combined modeling, with all exposures and confounding factors included, a food security score <26 during infancy, >1 hour/day screen time, ≤11.5 hours/day sleep duration at age 2 years, and weekly to daily consumption of takeaway/soft drink were each independently associated with an increased risk of childhood obesity at age 4.5 years (Table 3).

Table 2. Relationship between Presence of Each Modifiable Risk Factor before or at Age 2 Years and Risk of Obesity at Age 4.5 Years

			Models for each exposure adjusted for potential confounders[a]	
Parameter	**Level**	***n* (%)**	**Relative risk of obesity at age 4.5 years (95% CI)**	**p**
Food security index[b]	<26	2553 (49.8)	1.35 (1.08–1.69)	0.006
	≥26 (ref)	2572 (50.2)	1.00	
Screen time (hours/day)	None (ref)	1180 (21.15)	1.00	0.05
	≤1 hour/day	2358 (42.27)	0.98 (0.75–1.30)	
	1–2 hours/day	1104 (19.79)	1.27 (0.96–1.69)	
	>2 hours/day	937 (16.80)	1.31 (0.98–1.76)	
Sleep duration (hours/day)	<11.0	606 (11.6)	1.37 (1.03–1.82)	0.03
	11.0 to <12.5	1863 (34.0)	0.92 (0.71–1.18)	
	12.5 to <13.5	1615 (29.5)	0.98 (0.77–1.29)	
	≥13.5 (ref)	1397 (25.5)	1.00	
Takeaway food consumption frequency	None (ref)	1383 (25.2)	1.00	0.05
	≥1/month	2411 (44.0)	1.14 (0.85–1.51)	
	≥1/week	1686 (30.8)	1.39 (1.03–1.87)	
Soft drink consumption frequency	None (ref)	3412 (62.3)	1.00	0.19
	≥1/month	737 (13.4)	1.25 (0.94–1.65)	
	≥1/week	955 (17.4)	1.25 (0.99–1.59)	
	≥1/day	376 (6.9)	1.29 (0.94–1.77)	
Takeaway and soft drink consumption frequency	None/monthly (ref)	3274 (59.8)	1.00	0.05
	Weekly/daily	2204 (40.2)	1.25 (1.00–1.56)	

[a]All models are adjusted for mothers' age and education, child's sex, age, ethnicity and birth weight, rurality status, ECE, income tested benefit recipient, and NZ deprivation index.

[b]The higher the score the more food secure was the child.

CI, confidence interval; ECE, early childhood education attendance.

Table 3. Relationship between Presence of All the Modifiable Risk Factors Together and Childhood Obesity

Parameter	Level	*n* (%)	Relative risk of obesity at age 4.5 years (95% CI)			*p*
			Relative risk	Lower 95% CI	Upper 95% CI	
Intercept						
Child's age in months		5598 (100)	1.07	1.02	1.12	0.01
Child's self-prioritized ethnicity at age 4.5 years	European	2855 (51.8)	1.00	—	—	<0.001
	Māori	737 (13.4)	1.45	1.06	1.98	
	Pacific	711 (12.9)	2.21	1.64	2.99	
	Asian	635 (11.8)	0.75	0.49	1.15	
	MELAA*/NZer/Other	555 (10.1)	1.40	0.97	2.02	
Child's sex	Male	2880 (51.5)	1.00	—	—	0.01
	Female	2718 (48.5)	1.26	1.05	1.52	
Birth weight (g)	<2500	265 (4.8)	0.47	0.23	0.96	0.0001
	2500–3500	4327 (77.9)	1.00	—	—	
	≥4000	963 (17.3)	1.40	1.13	1.73	
NZ deprivation index	Low (deciles 1 to 3)	1544 (28.5)	1.00	—	—	0.001
	Medium (deciles 4–7)	2040 (37.6)	0.89	0.66	1.19	
	High (deciles 8–10)	1844 (34.0)	1.38	1.02	1.86	
Rurality	Urban	477 (8.8)	0.85	0.56	1.30	0.43
	Rural	4953 (91.2)	1.00	—	—	
Income tested benefit receipt	None	1189 (21.8)	1.00	—	—	0.57
	Once	1139 (20.9)	1.33	0.92	1.92	
	Twice	784 (14.4)	1.36	0.93	1.97	
	Three times	892 (16.4)	1.31	0.90	1.91	
	Four times	531 (9.8)	1.23	0.82	1.84	
	Five times	906 (16.6)	1.21	0.84	1.75	
Mother's age in years when pregnant	≤25	938 (17.1)	0.83	0.66	1.04	0.29
	25–35	3081 (56.4)	0.84	0.63	1.12	
	>35	1449 (26.5)	1.00	—	—	
Mother's educational status	No secondary school education	334 (6.0)	1.15	0.72	1.85	0.08
	Secondary school/NCEA	1236 (22.3)	1.28	0.88	1.88	
	Diploma/trade	1681 (30.3)	1.19	0.82	1.71	
	Bachelor degree	1357 (24.5)	0.81	0.54	1.22	
	Higher education	932 (16.8)	1.00	—	—	
Food security index during infancy	≥26 (food secure)	2472 (63.6)	1.00	—	—	0.01
	<26	1984 (36.4)	1.32	1.06	1.64	
Screen time at age 2 years	None to ≤1 hour/day	3538 (61.7)				0.04
	>1 hour/day	2196 (38.3)	1.22	1.01	1.48	

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Table 3. Relationship between Presence of All the Modifiable Risk Factors Together and Childhood Obesity *continued*

Parameter	Level	*n* (%)	Relative risk of obesity at age 4.5 years (95% CI)			*p*
			Relative risk	Lower 95% CI	Upper 95% CI	
Sleep duration at age 2 years	≤11.5 hours/day	1399 (25.5)	1.30	1.05	1.61	0.003
	11.6 to <12.5 hours/day	1070 (19.5)	0.83	0.63	1.09	
	>12.5 hours/day	3012 (55.0)	1.00	—	—	
Takeaway and soft drink intake	None/monthly	3274 (21.3)	1.00	—	—	0.05
	Weekly to daily	2204 (34.1)	1.25	1.00	1.57	

MELAA, Middle Eastern, Latin American, African; NCEA, National Certificate of Educational Achievement.

As shown in Figure 1, the cumulative prevalence of obesity, given exposure to one through to all four of the modifiable exposures, showed a dose–response relationship. The risk of obesity was increased with exposure to any one of the risk factors (RR = 1.55; 95% CI = 1.09–2.21, Table 4) and continued to increase with exposure to each additional risk factor. The prevalence of obesity associated with the number of exposures increased from 4.4% for children with no exposures to 20.7% for children with all four exposures (Table 4). The PAF of obesity for each level of exposure of risk factors is presented in Table 4. If associations are causal then the PAF for obesity, where in an ideal scenario all four exposures were able to be eliminated, was 42.9% (Table 4).

Discussion

This study investigated the relationship of modifiable risk factors present during the first 2 years of life with the risk of obesity at age 4.5 years. Three of the four modifiable factors were independently associated with an increased risk of obesity at age 4.5 years: being less food secure during infancy; ≤11.5 hours/day sleep at age 2 years; and weekly to daily consumption of takeaway foods/soft drinks at age 2 years. The risk of obesity at age 4.5 years increased as the number of risk factor exposures increased. Among children with no modifiable risk factors present, the prevalence of obesity was 4.4% vs. 20.7% when all four risk factors were present. Our findings

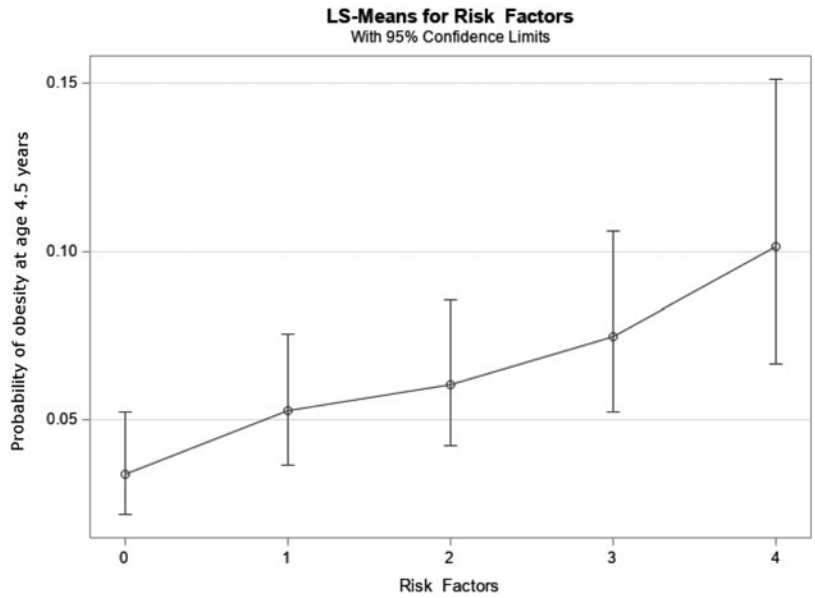

Figure 1. Probability of obesity at age 4.5 years by exposure up to age 2 years to the number of modifiable risk factors associated with obesity.

Table 4. Relative Risk and Population Attributable Risk of Obesity in Children at Age 4.5 Years by Exposure to Number of Modifiable Risk Factors before or at Age 2 Years

Number of risk factors[a] being exposed to	Obesity		Total	Adjusted relative risk (95% CI)	PAF	*p*
	Yes *n* (%)	No *n* (%)				
0	63 (4.4)	1381 (95.6)	1444	1.00	0	<0.001
1	101 (6.4)	1485 (93.6)	1586	1.65 (1.13–2.40)	7.7%	
2	134 (9.6)	1268 (90.4)	1402	1.81 (1.23–2.64)	12.5%	
3	126 (14.1)	769 (85.9)	895	2.12 (1.41–3.18)	14.6%	
4	56 (20.7)	215 (79.3)	271	2.93 (1.88–4.86)	8.0%	
Total	480 (8.6)	5118 (91.4)	5598		42.9%	

[a]Risk factors: >1 hour/day screen time, ≤11.5 hours/day sleep duration, weekly to daily consumption of soft drinks or takeaway food, and infant food security index score <26.

PAF, calculated by comparing the current number of risk factors to the "ideal" scenario of 0 risk factors.

PAF, population attributable fraction.

highlight the importance of considering the impact of exposure to risk factors for obesity in early childhood not just in isolation but together and cumulatively.

The study findings are in line with those from the Longitudinal Study of Australian children that assessed patterns of health behaviors predicting obesity[11] and which found increased odds of obesity at age 6 to 7 years among children with a sedentary lifestyle, truncated sleep, and unhealthy diets.[11] A longitudinal study in Belgium, which enrolled 3- to 6-year-old children, found a relationship between >1 hour/day of TV watching on weekdays at baseline and BMI z-score at 18 and 30 months follow-up.[43] This latter study also found a cross-sectional association between >65 mL/day soft drink consumption and childhood obesity at two of the study phases. A British cohort study that followed up 8234 children from before birth to age 7 years found that watching TV >8 hours/week and sleeping <10.5 hours/day were behavioral factors that predicted obesity at age 7 years.[10]

We considered exposures as early as infancy with outcomes measured at age 4.5 years. In this respect, this study is unique relative to other studies that have investigated risk factors from infancy to age 2 years for early childhood obesity. We found that the adjusted relative risk of obesity was 59% higher (RR = 1.59; 95% CI = 1.12–2.59) in those children exposed to any one of the four modifiable risk factors compared to no exposure, with a cumulative PAF of 43.3% for childhood obesity with exposure to all four vs. none of these modifiable risk factors (Table 4). This high cumulative PAF indicates potentially avoidable cases of obesity and provides evidence to support the value of multidimensional obesity prevention programs that address several modifiable risk factors present during early childhood and that address the ongoing need to sustain prevention over time. Our findings are supported by those from a cross-sectional study of 1614 Spanish children aged 5–18 years, which investigated the cumulative effect of behavioral risk factor exposure on childhood obesity.[44]

A cohort study conducted in Quebec found associations between different trajectories of childhood overweight (6–12 years) and some modifiable risk factors for obesity during early childhood (5 months to 5 years).[45] Night-time sleep duration and maternal overprotection were both associated with an early onset obesity trajectory.[45] Family food insufficiency when the child was 1.5 years old was associated with a later onset overweight trajectory at 6–12 years of age.[45] This economic context for families, which limits their ability to choose more expensive, less energy dense food is an important modifiable early childhood exposure that should be addressed to prevent obesity.[46]

Primary intervention studies that have targeted some of the modifiable risk factors identified have reported mixed findings.[47–50] Most reported studies focused on parenting practices around food behaviors and intake and physical activity with some also including screen time. Positive responses have been reported in terms of changes in feeding practices[49] and modest decreases in BMI z-scores (−0.26, 95% CI = −0.50 to −0.01) observed from a preschool-based healthy nutrition and physical activity program.[50]A NZ home-based multidisciplinary intervention program recruited 802 pregnant women and randomized them to four arms to receive education on (1) sleep, (2) food, activity, and breastfeeding, (3) both, (4) None-control group and followed their babies up to 3.5 and 5 years of age.[51] This study found that the two arms that received the sleep intervention had an almost 50% lower risk of obesity at age 5 years compared to the other two arms (relative risk = 0.49, 95% CI = 0.28–0.84). In our study, there was a curvilinear association between sleep duration of the toddler and childhood obesity at age 4.5 years as the lowest relative risk of obesity was present for the sleeping category of 11.0–12.5 hours/day (Table 2), in

line with the NZ Ministry of Health recommendations for sleep duration of children at this age (11–14 hours/day)[52] and the US National Sleep Foundation recommendations.[53] A US-based study (the INSIGHT study) provided education materials to parents of newborns on sleep, infant feeding, and active social play and found significantly lower weight gain in the intervention compared with the control group at age 1 year.[54] Longer term follow-up data are needed to better understand if such interventions have sustained effectiveness.

Strengths of the GUiNZ cohort are its high retention rate, 92% at age 5 years, as well as the ethnic and socioeconomic diversity of the cohort. Anthropometric measurements were made by trained research assistants using a standardized protocol, thus reducing error associated with using measurements obtained during clinical care visits and recall bias from parentally reported measurements.[55–58] Independent variables were collected both pre- and postnatally, thus reducing recall bias, and were collected in the context of a cohort study not focused specifically on obesity, hence reducing the potential for acquiescence bias.[59]

Weaknesses of this study include the use of parental report of sleep duration, the absence of quantitative measures of dietary intake and of physical activity, and the challenges in both determining screen time exposure and having measures of screen time that remain contemporarily relevant.[60–62]

It is also necessary to consider the importance of underlying factors that contribute to childhood obesity, that are not readily modifiable, some of which were not included in this study. These include the obesogenic environment,[63] household lifestyle,[64] cultural factors,[63,65] and genetic factors.[66,67] In addition to these, some other factors such as gestational weight gain, child's social factors such as trauma, missing factors, and so on that were not included in this study could be controlled for in further studies.

Results of this study, however, must be interpreted with caution as some of the estimates are borderline significant (*e.g.*, soft drink and takeaway) with relative risks so close to 1. This study addressed, to some extent, the paucity of data on the influence of modifiable risk factors in the first 2 years of life on childhood obesity at age 4.5 years. The findings from this study can assist policy makers in developing population-based obesity intervention programs designed to be effective during infancy and the preschool years.

Conclusion

The first 2 years of life are critically important for the establishment of healthy weight gain trajectories for subsequent life. We examined four key risk factors for obesity: food insecurity, higher screen time, shorter sleep duration, and takeaway/soft drink intake, and found that they contributed independently and cumulatively to the risk of childhood obesity at age 4.5 years. These findings indicate that interventions need to be designed with an understanding of the cumulative effect of modifiable risk factor exposure and the complexity of the environmental context within which obesity develops. Interventions need to occur early, be multidimensional, and occur in a social and political environment within which healthy lifestyles and dietary patterns are encouraged.

Authors' Contributions

Z.M. completed the data analysis, drafted and revised the article, and prepared the final article draft. D.S., R.P., L.H., S.D., and C.C.G. contributed to the design of the study, the data analysis and interpretation, and the revision of article drafts. P.A.C., T.O., and M.W. contributed to the main study grant application, provided comments on the interpretation of data, and contributed to the article writing. All authors approved the final version of the article.

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