Received: 27 July 2019 | Revised: 25 September 2019 | Accepted: 21 October 2019
DOI: 10.1111/ijpo.12603

ORIGINAL RESEARCH

Pediatric OBESITY WILEY

Sex differences in the associations of physical activity and macronutrient intake with child body composition: A cross-sectional study of 3- to 7-year-olds in Samoa

Avery A. Thompson[1] | Rachel L. Duckham[2,3] | Mayur M. Desai[1] | Courtney C. Choy[4] | Lauren B. Sherar[5] | Take Naseri[6] | Christina Soti-Ulberg[6] | Muagatutia S. Reupena[7] | Abigail I. Wetzel[4] | Nicola L. Hawley[1]

[1]Department of Chronic Disease Epidemiology, Yale School of Public Health, New Haven, Connecticut

[2]Institute for Physical Activity and Nutrition, Deakin University, Geelong, Victoria, Australia

[3]Australian Institute for Musculoskeletal Science (AIMSS), The University of Melbourne and Western Health, St Albans, Victoria, Australia

[4]Department of Epidemiology, Brown University School of Public Health, Providence, Rhode Island

[5]Center for Global Health and Human Development, School of Sport and Exercise Sciences, Loughborough University, Loughborough, UK

[6]Ministry of Health, Apia, Samoa

[7]Lutia I Puava Ae Mapu I Fagalele, Apia, Samoa

Correspondence
Nicola L. Hawley, Department of Chronic Disease Epidemiology, Yale School of Public Health, 60 College Street, New Haven, CT 06520.
Email: nicola.hawley@yale.edu

Funding information
National Heart, Lung, and Blood Institute, Grant/Award Number: R01 HL093093; Yale University Downs International Health Student Travel Fellowship

Summary

Background: Overweight/obesity is prevalent among children in the Pacific Islands, but its aetiology is poorly understood. Few studies have considered body composition in addition to body mass index–based measures.

Objectives: To describe body composition among Samoan children and determine sex-specific associations among dietary intake, physical activity, and body composition.

Methods: Body composition (percent body fat [%BF], lean mass, and trunk-to-peripheral fat ratio) of n = 83 Samoan children (3-7 y) was assessed using dual-energy X-ray absorptiometry. Children completed 7 days of objective physical activity monitoring. Mothers reported child nutritional intake using a 115-item food frequency questionnaire. Stepwise generalized linear regression was used to determine independent associations of nutritional intake and physical activity with body composition.

Results: Samoan children had higher average %BF than reported among other ethnic groups but lower trunk-to-peripheral fat ratios. In sex-stratified analyses, quartile of carbohydrate intake was negatively associated with %BF (β = −2.02 SE = 0.58; $P < .001$) in girls only. Among boys, physical activity (quartile of accelerometer counts per minute) was negatively associated with %BF (β = −1.66 SE = 0.55; $P < .01$).

Conclusions: Sex differences in the associations among nutritional intake, physical activity, and body composition may be important to consider as interventions are developed to address overweight/obesity among Samoan children.

KEYWORDS
body composition, nutritional intake, obesity, physical activity, Samoa

1 | INTRODUCTION

The global prevalence of paediatric overweight and obesity has steadily increased over the last several decades; this is especially noticeable in low- and middle-income countries.[1] The Western Pacific Region has experienced a particularly sharp rise, and in some Pacific Island nations, prevalence of overweight and obesity among children and adolescents is close to 50%.[1] Despite their increased risk, very little is known about the aetiology of obesity among Pacific Island children.

As overweight and obesity are widely regarded as issues of energy imbalance, both etiological studies and interventions to prevent or treat childhood overweight and obesity have focused on energy intake and/or expenditure.[2-6] Results regarding dietary intake vary widely.[2-5] For example, Nguyen et al, in a sample of white and Native American 4- to 7-year-olds in the United States, found a positive association between fat mass and dietary fat intake in boys, but not with protein or carbohydrate intake. Similar associations were not observed in girls.[2] In contrast, studies of children in Europe (British 1- to 4-year-olds and Italian 7- to 11-year-olds) found no association between macronutrient intake and body composition.[3,4] Data on the effect of physical activity on body composition are more robust, with studies indicating a preventive effect of physical activity on childhood obesity. Lazaar et al, for example, have shown in French children aged 6 to 10 years that physical activity can strongly protect against overweight and obesity, specifically in girls.[5] To our knowledge, data from Pacific Island nations are limited to one recent cross-sectional study among 2- to 4-year-old Samoan children that identified no associations among dietary intake, physical activity, and overweight/obesity, although it should be noted that questionnaire measures of physical activity were used rather than objective measurement.[6]

Compounding the lack of current data on obesity aetiology is the fact that assessment of overweight/obesity is particularly complex among Pacific Islander children. The established methods for identifying children with overweight/obesity rely on body mass index (BMI)–for-age z-scores derived from reference populations in which Pacific Islanders (as well as other minority ethnic groups) are not included.[7-9] This approach relies on the widely held assumption that body fat increases with BMI, putting children with higher BMI at a greater risk of developing cardiometabolic and other noncommunicable diseases in adulthood. When measured using dual-energy X-ray absorptiometry (DXA), however, Polynesian and other Pacific Islander adults have been shown to have greater lean mass and more bone mineral content per kilogram of body weight than individuals of other racial/ethnic backgrounds, indicating that BMI may be misleading for these populations.[10,11]

Very few studies have used gold standard measures, such as DXA, to assess body composition among Pacific Island children. In a study of children and adolescents (ages 5-14 y) in New Zealand, girls of Pacific Islander ethnicity were found to have a similar body fat percentage, but an average BMI 5.9 kg/m^2 higher, than Europeans ($P < .0001$).[12] In contrast, BMI was not found to differ by body fat percentage among boys of European, Maori, or Pacific Island descent.[12] These findings call for further understanding of body composition among Pacific Island children and highlight potential sex differences in childhood body composition that may be important to consider when monitoring overweight and obesity and designing preventative interventions for this ethnic group.

This study addresses current knowledge gaps about body composition among Samoan children and the role that nutrition and physical activity may play in the aetiology of excess body fatness. The objectives were to (a) describe key measures of body composition in Samoan boys and girls aged 3 to 7 years as measured by DXA, the current gold standard for body composition, and (b) determine sex-specific associations among dietary intake, objectively measured physical activity and body composition.

2 | MATERIALS AND METHODS

2.1 | Setting

Samoa is a Pacific Island nation located equidistant between Hawaii and New Zealand. The 2016 per capita gross domestic product was $3761.90 USD, placing Samoa in the World Bank's lower-middle income group.[13] Over 75% of the population lives on the main island of Upolu, which is divided into three census regions representing an urban to rural spectrum: Apia Urban Area (AUA), North-west Upolu (NWU), and Rest of Upolu (ROU).[14]

2.2 | Study design and population

This analysis includes data collected from n = 83 children who were a randomly selected, sex- and regionally representative subset of n = 424 participants in the second wave of an ongoing longitudinal study, *Ola Tuputupua'e* ("Growing Up"), which aims to understand growth, development, and nutrition among Samoan children.[6] This subsample was selected to undergo objective monitoring of physical activity and DXA body composition assessment as part of a pilot study to understand the feasibility of incorporating these measures into future waves of cohort data collection.

The *Ola Tuputupua'e* study was initiated in 2015 when 319 mothers and their 2- to 4-year-old children were recruited by convenience sampling in their villages of residence (wave 1). The survey was not nationally representative but was designed to equally represent each of the three census regions of Upolu, since one of the study objectives was to describe child health according to urbanization. The sampling approach and the age group selected were chosen for consistency with a prior National Nutrition Survey (the only prior study of child nutritional status in Samoa), which was conducted in 1999.[6] In 2017 (wave 2), 424 mother-child pairs participated (240 returning participants and 184 newly recruited participants). Those of Samoan ethnicity were eligible (defined as the child having four Samoan grandparents), and biological mothers were required to be 18 years of age or older. Pregnancy was an exclusion criterion in both 2015 and in the recruitment of new participants in 2017. If the mother of a child recruited in 2015 was pregnant during the second data collection wave in 2017, she was included in the sample, but no anthropometric measures were taken. Exclusion criteria for children at both time points included chronic conditions and developmental disorders known to impact growth, dietary intake, or physical activity. Children newly recruited into the study in 2017 were between 4 and 6 years old on the day of enrolment to match the age of the 2015 participants.

All study protocols were reviewed and approved by the Yale University Human Investigations Committee Institutional Review Board (IRB) (HIC #2000020519) and the Samoan Ministry of Health Research Committee. Parents gave written informed consent for their child's participation. Children under 7 years of age provided verbal assent, while 7-year-olds provided their written assent per Yale IRB protocols.

2.3 | Questionnaires

Trained Samoan enumerators administered a comprehensive Child Health Questionnaire, which collected information on family sociodemographic characteristics and child dietary intake. Decimal age of the child was calculated based on maternal report of the child's birth date in decimal years (date of assessment − date of birth). Demographic characteristics included family composition and material lifestyle score (MLS), which was used to estimate household socio-economic status.[15] MLS was calculated by summing ownership of 19 household items such as a refrigerator, television, and washing machine. A 115-item food frequency questionnaire (FFQ), validated for use in adult Samoan populations and adapted for paediatric populations, was also administered to each mother.[6,16,17] All mothers indicated that they were primarily responsible for the dietary intake of the child and that they were familiar with the child's dietary intake over the 30-day FFQ reference period. Mothers indicated the frequency with which her child consumed each food in the last 30 days, choosing one of seven answers ranging from never/less than once per month to more than six times per day. Daily nutrient intake and total energy intake (TEI) were calculated by multiplying each food's frequency by the nutrient content of a standard, fixed portion size. Nutrient information was primarily obtained from the United States Department of Agriculture's (USDA) Food Composition Database, supplemented with the Food and Agriculture Organization's Pacific Islands Food Composition Tables where Pacific-specific foods were not listed in the USDA database.[18,19] Macronutrient intake was adjusted for average TEI using the residual method,[20] and quartiles of intake were used in analyses.

2.4 | Physical activity measurement

To measure physical activity, children wore a triaxial wGT3X-BT accelerometer on their nondominant wrist for 6 to 7 days (ActiGraph Corporation, FL, USA). Actigraphs were attached with a hospital band to prevent removal. Data were collected at 30-Hz resolution, integrated into 15 seconds epochs using ActiLife software (version 6.13.1), and processed using KineSoft software (version 3.3.80, Loughborough, UK). Nonwear was defined as 60 minutes of consecutive zero counts, allowing for 2-minute interruptions. We used the period between 7:00 AM and 9:00 PM, derived from the average wake and sleep times reported by mothers, to define daytime wear for the purpose of these analyses. The first day of wear was removed from analyses both because of varied start times for the assessment and to remove any initial reactivity to wearing the devices.[21] Children with at least 5 days of wear time were included in the analyses. Counts per minute (CPM) were calculated based on total vector magnitude counts per day divided by total wear time. Quartiles of activity intensity, based on CPM, were used in analyses.

2.5 | Body composition and anthropometric measurements

Anthropometric measurements of mothers and children were taken in light island clothing. Height was measured to the nearest 0.1 cm with a portable stadiometer (Pfister Imports, NY, USA) and weight to the nearest 0.1 kg with a digital scale (Tanita Corporation of America, IL, USA). Duplicate measures of height and weight were averaged and used to calculate BMI. Based on World Health Organization (WHO) definitions, children under 5 were categorized as having overweight or obesity if their BMI was greater than two or three standard deviations above the median for their age and sex, respectively.[7] Children aged 5 or above were categorized as having overweight or obesity if their BMI-for-age was one or two standard deviations above the median, respectively.[8] International Obesity Task Force (IOTF) classifications are shown for comparison in Table 1.[9]

Child body composition was assessed using DXA (Lunar iDXA, GE Healthcare, WI, USA). Participants were scanned in the paediatric mode (Encore Version 17), by two trained DXA operators, wearing standard clothing (t-shirt and shorts), and daily quality control scans of a manufacturer-supplied phantom spine were performed to ensure scan reliability. Body composition outcomes obtained from the full body less head scan included fat mass, lean mass, and total mass (grams). While there are different approaches to the assessment of body composition among recently published studies, we excluded the head for the purpose of our analyses because of the possible error in measuring brain soft tissue caused by the surrounding skull.[22] Regional percent body fat (%BF) and lean mass (%LM) were therefore calculated by dividing fat mass and lean mass, respectively, by total mass (less head). The trunk-to-peripheral fat ratio (TPFR) was calculated by dividing trunk fat by the sum of arm and leg fat to describe relative fat distribution, with a higher TPFR indicating greater fat storage in the trunk relative to the periphery.[23]

2.6 | Statistical analyses

First, to assess the representativeness of the subset of n = 83 children for whom we had physical activity and DXA data, we compared their sociodemographic characteristics, BMI, and nutritional intake with the remaining n = 341 children in the cohort. Independent-samples *t* tests were performed for continuous variables and chi-square tests of independence for categorical variables. We then used the same bivariate tests to compare sociodemographic characteristics, nutritional intake, physical activity, and body composition outcomes between boys (n = 40) and girls (n = 43) in our study sample, adjusting for child age using general linear models (ANCOVA) as appropriate. Associations between body composition outcomes (%BF, %LM, and TPFR) and sociodemographic characteristics were also explored using general linear models adjusted for child age. Statistical significance was set at $P < .05$. Finally, we used generalized linear regression modelling to determine how nutrition and physical activity were associated with measures of body composition. Sex-specific analyses were performed to determine if associations differed for boys and girls. Multivariable models were created in a stepwise fashion; sociodemographic characteristics that were significant at the $P < .10$ level in bivariate analyses were included in initial models with nutritional intake before physical activity was added to explore any attenuating effect that physical

TABLE 1 Sample characteristics by child sex

Characteristic	Boys (n = 40)	Girls (n = 43)	*P*
Maternal age (y), mean ± SD	35.4 ± 9.1	34.3 ± 8.5	.59
Maternal BMI, mean ± SD (excluding pregnant women)	35.8 ± 6.1	35.8 ± 8.2	.96
Child age (y), mean ± SD	5.3 ± 0.8	5.4 ± 1.0	.59
Child age groups (%)			
3.0-3.99 y	2.5	11.6	.08
4.0-4.99 y	37.5	16.3	
5.0-5.99 y	37.5	39.5	
6.0-6.99 y	22.5	32.6	
Census region (%)			.97
Apia Urban Area	37.5	39.5	
North-west Upolu	32.5	30.2	
Rest of Upolu	30.0	30.3	
Material lifestyle score, mean ± SD (range 0-19)	6.8 ± 4.1	6.9 ± 3.8	.86
School attendance, (%)	60.0	65.1	.77
Child's weight (kg), EMM ± SE[a]	21.2 ± 0.6	19.8 ± 0.6	.09
Child's height (cm), EMM ± SE[a]	111.5 ± 1.1	111.1 ± 1.1	.80
Child's BMI (kg/m^2), EMM ± SE[a]	16.3 ± 0.3	15.8 ± 0.3	.23
Child's weight status (WHO), (%)			.05
Normal weight	55.0	79.1	
Overweight	27.5	16.3	
Obese	17.5	4.6	
Child's weight status (IOTF), (%)			.34
Normal weight	72.5	83.7	
Overweight	22.5	11.6	
Obese	5.0	4.7	
Child's TEI (calories), EMM ± SE[a]	3977 ± 1195	4256 ± 1993	.86
Child's TEI-adjusted nutritional intake, EMM ± SE (g)[a]			
Protein	143 ± 4	139 ± 4	.49
Carbohydrates	513 ± 9	536 ± 9	.08
Fat	152 ± 4	155 ± 4	.62
Child's accelerometer counts per minute (CPM), EMM ± SE[a]			
Weekday	2926 ± 93	2829 ± 93	.52
Weekend	2934 ± 103	2713 ± 102	.13
Total	2919 ± 95	2789 ± 94	.34
DXA measures, EMM ± SE[a,b]			
%Body fat	24.8 ± 0.7	28.3 ± 0.6	**<.001****
%Lean mass	72.7 ± 0.7	69.2 ± 0.6	**<.001****
Trunk-to-peripheral fat ratio (TPFR)[c]	0.62 ± 0.01	0.66 ± 0.01	**.02***

Note: Bolding indicates statistically significant *P* values
**P* < .05, ***P* < 0.01.
Abbreviations: BMI, body mass index; IOTF: International Obesity Task Force; SD, standard deviation; TEI, total energy intake; WHO, World Health Organization.
[a]Means reported for these variables are estimated marginal means (EMM) from general linear models (ANCOVA) controlling for child age.
[b]DXA measures presented are based on total body, less head measures. For comparison with other studies that include the head in estimates of body composition, please see the following estimated marginal means ± SE: %body fat: boys 24.05 ± 3.32; girls 27.04 ± 3.85; %lean mass: boys 72.43 ± 3.24; girls 69.59 ± 3.73; Pearson correlations between estimates including and excluding the head exceeded 0.99.
[c]A higher TPFR indicates greater fat storage in the trunk relative to the periphery.

activity may have on the relationship between nutrition and body composition. Child age was included in all models. All analyses were performed in SAS version 9.4.

3 | RESULTS

No significant sociodemographic, BMI, or nutritional intake differences were found between the participants who completed the additional physical activity and DXA measures (n = 83) and the participants who did not (n = 341) (data not shown). Approximately one-third of participants (32.5% of the DXA subsample [Table 1] and 34.7% of the non-DXA subsample) were found to have overweight or obesity according to WHO cutpoints.

Boys and girls had similar BMI measurements (Table 1), although there was a marginally significant difference between boys and girls in terms of weight status. Fewer than half as many girls as boys were categorized as having overweight or obesity based on WHO z-scores (21% of girls compared with 45% of boys, *P* = .05). However, compared with boys, girls had significantly higher %BF (28.3% compared with 24.8%, *P* < .001) and lower %LM (69.2% compared with 72.7%, *P* < .001). Girls were also found to have a significantly higher TPFR than boys (0.66 compared with 0.62, *P* = .02). Nutritional intake, physical activity, and family sociodemographic characteristics did not differ between boys and girls.

In bivariate analyses, MLS was found to be significantly positively associated with %BF (*P* = .03) and negatively associated with %LM (*P* = .03) in boys. In girls, maternal age and child age were significantly negatively associated with TPFR (*P* = .01 for both) (data not shown). Mean %BF, %LM, and TPFR did not differ by quartile of TEI, quartile of TEI-adjusted fat intake, or protein intake in either boys or girls (Table 2). Quartile of TEI-adjusted carbohydrate intake was associated with %BF and %LM in girls, but not in boys. As quartile of carbohydrate consumption increased, girls' %BF decreased and %LM increased, with the greatest differences in body composition occurring between the first and second quartiles of carbohydrate consumption. Quartile of average daily physical activity was significantly associated with %BF, TPFR, and %LM in boys but not in girls. As physical activity increased, %BF and TPFR decreased while %LM increased. Similar trends were seen in %BF and %LM among girls, although the associations are not significant.

Based on the observed sex differences in body composition according to nutritional intake (Table 2), we tested for interactions between quartile of TEI-adjusted carbohydrate intake and sex. Multivariate regression with %BF as the outcome indicated a significant interaction between carbohydrate intake and sex (*P* = .04), where %BF decreased with increasing carbohydrate intake in girls, but there was no association in boys.

Multivariable models were created in order to further explore the impact of carbohydrate intake on body composition while controlling for other potential contributing factors such as child age, maternal age, and MLS and to determine whether associations would be attenuated with the addition of physical activity to the model. Among girls,

TABLE 2 Body composition outcomes by sex, nutritional intake, and physical activity estimated marginal (mean ± SE)

	Boys %BF	Girls %BF	Boys %LM	Girls %LM	Boys TPFR[a]	Girls TPFR[a]
Quartile of TEI						
1	24.3 ± 1.4	27.3 ± 1.3	73.2 ± 1.4	70.2 ± 1.3	0.64 ± 0.02	0.63 ± 0.03
2	24.3 ± 1.7	29.0 ± 1.2	73.0 ± 1.7	68.5 ± 1.2	0.62 ± 0.03	0.66 ± 0.03
3	25.5 ± 1.3	27.3 ± 1.5	71.8 ± 1.3	70.2 ± 1.5	0.60 ± 0.02	0.68 ± 0.03
4	24.8 ± 1.2	28.7 ± 1.6	72.8 ± 1.2	68.6 ± 1.6	0.61 ± 0.02	0.67 ± 0.03
P	.92	.70	.89	.70	.68	.72
Quartile of carbohydrate intake[b]						
1	24.6 ± 1.2	31.9 ± 1.3	72.9 ± 1.2	65.6 ± 1.3	0.59 ± 0.02	0.69 ± 0.03
2	25.0 ± 1.2	27.9 ± 1.4	72.4 ± 1.2	69.5 ± 1.4	0.66 ± 0.02	0.68 ± 0.03
3	25.9 ± 1.6	27.7 ± 1.1	71.6 ± 1.5	69.8 ± 1.1	0.61 ± 0.02	0.63 ± 0.03
4	23.8 ± 1.5	25.9 ± 1.1	73.5 ± 1.4	71.6 ± 1.1	0.59 ± 0.02	0.66 ± 0.03
P	.80	.01*	.830	.01*	.08	.48
Quartile of protein intake[b]						
1	24.0 ± 1.6	27.3 ± 1.1	73.1 ± 1.6	70.1 ± 1.1	0.60 ± 0.03	0.64 ± 0.03
2	26.9 ± 1.2	30.5 ± 1.4	70.6 ± 1.2	67.1 ± 1.4	0.63 ± 0.02	0.67 ± 0.03
3	23.3 ± 1.2	25.7 ± 1.3	74.0 ± 1.2	71.8 ± 1.3	0.62 ± 0.02	0.65 ± 0.03
4	24.4 ± 1.2	29.8 ± 1.4	73.1 ± 1.2	67.6 ± 1.4	0.60 ± 0.02	0.71 ± 0.03
P	.18	.05	.22	.05	.60	.31
Quartile of total fat intake[b]						
1	24.8 ± 1.3	27.5 ± 1.4	72.5 ± 1.3	70.0 ± 1.4	0.61 ± 0.02	0.66 ± 0.03
2	25.7 ± 1.4	29.0 ± 1.3	71.8 ± 1.4	68.5 ± 1.3	0.61 ± 0.03	0.66 ± 0.03
3	25.3 ± 1.2	27.5 ± 1.5	72.2 ± 1.2	69.9 ± 1.5	0.63 ± 0.02	0.64 ± 0.03
4	23.3 ± 1.4	28.2 ± 1.4	74.1 ± 1.3	69.2 ± 1.4	0.60 ± 0.02	0.68 ± 0.03
P	.65	.84	.65	.86	.77	.85
Quartile of physical activity (CPM)						
1	28.1 ± 1.3	29.6 ± 1.4	69.4 ± 1.3	67.9 ± 1.4	0.68 ± 0.02	0.69 ± 0.03
2	25.3 ± 1.1	28.5 ± 1.5	72.0 ± 1.1	68.9 ± 1.5	0.62 ± 0.02	0.63 ± 0.03
3	24.3 ± 1.3	28.3 ± 1.5	73.1 ± 1.2	69.2 ± 1.4	0.60 ± 0.02	0.64 ± 0.03
4	22.4 ± 1.1	26.2 ± 1.6	75.0 ± 1.1	71.2 ± 1.6	0.59 ± 0.02	0.67 ± 0.03
P	.02*	.49	.02*	.47	.05	.46

Note: Values are estimated marginal means ± SE based on general linear models (ANCOVA) controlling for child age $*P < 0.05$, $**P < 0.01$.
Abbreviations: BF, body fat; CPM, accelerometer counts per minute; LM, lean mass; TEI, total energy intake; TPFR, trunk-to-peripheral fat ratio.
[a]A higher TPFR indicates greater fat storage in the trunk relative to the periphery.
[b]All quartiles of macronutrient intake were adjusted for total energy intake (TEI).

the negative association between quartile of TEI-adjusted carbohydrate intake and %BF and the positive association with %LM persisted after controlling for child age ($P < .001$) (Table 3, model 1). Consistent with the bivariate analysis, MLS was a significant predictor of %BF and %LM in boys, but TEI-adjusted carbohydrate intake was not (Table 3, model 1). When physical activity was added to the model, it was a significant predictor of all three body composition outcomes in boys (negatively associated with %BF [$P < .001$], positively associated with %LM [$P < .001$], and negatively associated with TPFR [$P < .05$]) but not in girls (Table 3, model 2). The addition of the physical activity term to the model did not substantially change the parameter estimates for quartile of TEI-adjusted carbohydrate intake in girls.

4 | DISCUSSION

This study sought to investigate body composition as measured by DXA in young Samoan children, a population that has not yet been well studied. Body composition and its association with nutritional intake and physical activity differed significantly between boys and girls. Girls had greater %BF, lower %LM, and higher TPFR than boys. Girls' body composition was more sensitive to changes in quartile of carbohydrate intake than boys', and neither sex's %BF, %LM, or TPFR was linearly affected by quartile of TEI-adjusted protein or dietary fat intake. Boys' body composition was affected by physical activity quartile when tested alone and in multivariable models. Girls' body composition was only associated with physical activity quartile after controlling for child age. Physical activity did not change the influence of nutritional intake on child body composition.

There have been no other studies of Pacific Islander children in this age range, but body composition in this sample of Samoan children differs substantially from what has been reported in other population groups. Compared with Pacific children of the same age living in Auckland, New Zealand (47% of whom were Samoan), our sample were shorter and lighter.[24] Percent body fat among the Samoan sample, however, was high, reaching 28% in girls and 25% in boys ($P < .01$).

TABLE 3 Stepwise linear regressions models examining correlates of body composition among boys and girls

	%Body fat				%Lean mass				Trunk-to-peripheral fat ratio (TPFR)[a]			
	Model 1[b]		Model 2[c]		Model 1[b]		Model 2[c]		Model 1[b]		Model 2[c]	
	β (SE)	P	β (SE)	P	β (SE)	P	β (SE)	P	β (SE)	P	β (SE)	P
Boys												
Child age (y)	0.41 (0.75)	.589	0.81 (0.71)	.262	−0.56 (0.73)	.451	−0.94 (0.70)	.187	0.02 (0.01)	.220	0.02 (0.01)	.090
Material lifestyle score	0.38 (0.16)	.026*	0.29 (0.15)	.061	−0.36 (0.16)	.028*	−0.28 (0.15)	.064				
Quartile of carbohydrate intake	−0.58 (0.60)	.339	−0.61 (0.57)	.292	0.54 (0.59)	.367	0.56 (0.56)	.326	−0.01 (0.01)	.501	−0.01 (0.01)	.432
Quartile of physical activity (CPM)			−1.66 (0.55)	.005**			1.61 (0.55)	.006**			−0.03 (0.01)	.022*
Girls												
Child age (y)	−0.66 (0.62)	.293	−0.33 (0.72)	.652	0.53 (0.61)	.389	0.19 (0.71)	.789	−0.02 (0.02)	.127	−0.03 (0.02)	.064
Maternal age (y)									−0.003 (0.002)	.070	−0.003 (0.002)	.124
Quartile of carbohydrate intake	−1.84 (0.55)	.002**	−2.02 (0.58)	.001**	1.84 (0.55)	.002**	2.02 (0.57)	.001**	−0.02 (0.01)	.244	−0.02 (0.01)	.260
Quartile of physical activity (CPM)			−1.14 (0.58)	.056			1.15 (0.57)	.051			−0.01 (0.01)	.454

Note: $*P < 0.05$, $**P < 0.01$.

[a]A higher TPFR indicates greater fat storage in the trunk relative to the periphery.

[b]Model 1 included quartile of carbohydrate intake and material lifestyle score (%BF and %LM in boys) or maternal age (TPFR in girls). All models included child age in order to control for developmental differences across 3- to 7-year-olds.

[c]Model 2 included quartile of physical activity (counts per minute [CPM]) in addition to all terms in model 1.

While there is no comparable data among other Pacific Island children this age, this compares to 21% to 22% in girls and 17% to 19% in boys ($P < .01$) in previous studies of young children in Sweden and India.[25,26] TPFR tended, however, to be lower in the Samoan sample than in other populations. Average TPFR in Samoan girls and boys was 0.66 and 0.62, respectively, compared with an average TPFR in girls and boys of 0.83 and 0.85 in a study of 129 Chinese 5-year-olds (who are the only ethnicity, to our knowledge, to have published data on this measure in young children).[23] Our TPFR values did not appreciably change with increasing age, so differences in the age composition of our sample compared with the Chinese study likely do not explain the differences observed.

A relatively low TPFR indicates that Samoan children tend to store proportionally more fat in the periphery versus the trunk compared with other populations. This may be protective as trunk adiposity is associated with cardiometabolic risk factors such as high blood pressure and high fasting glucose later in life.[27] Indeed, this distribution of body fat is one of the hypothesized mechanisms by which the recently identified obesity-inducing *CREBRF* variant p.Arg457Gln, common among Samoans, confers a reduction in diabetes risk.[28] However, Samoans' relatively high %BF may put them at risk for these same poor cardiometabolic outcomes.[29] More research is therefore needed to better understand cardiometabolic risk factors and disease development in Pacific Islanders.

Our study findings make an important contribution to the discussion about the applicability of BMI-based overweight/obesity cutpoints for Pacific Island children. While more than half as many girls as boys were classified as having overweight or obesity based on WHO cutpoints, (21% compared with 45%), %BF was significantly higher in girls than in boys. Having an incomplete understanding of Samoan body composition and consequently misclassifying children's weight status based on their BMI z-score could have adverse effects on both ends of the weight spectrum. Healthy children could be subjected to weight control and calorie restriction programmes, negatively impacting their growth, and children at risk of obesity and cardiometabolic disease could be left behind, unable to benefit from early intervention.

While macronutrient intake did not significantly differ between boys and girls in this sample, the association between nutritional intake and body composition outcomes was sex-specific, with quartile of TEI-adjusted carbohydrate intake being a significant correlate of body composition in girls but not in boys. Specifically, increased carbohydrate intake in girls appeared to be associated with a lower %BF and higher %LM. This finding contradicts several studies that suggest an association between a high carbohydrate diet and subsequent development of obesity and cardiometabolic disease.[30,31] One potential explanation for this finding may be the source of carbohydrate intake among these children; approximately 60% of this sample's daily calories came from carbohydrates (data not shown), a little over half of which (approximately 55%) came from traditional starchy root crops (taro, breadfruit, bananas, and potatoes) with a relatively lower glycaemic index than processed foods (there were no differences in the proportion of carbohydrates consumed from traditional sources by child sex). As Samoa continues to undergo the nutrition transition and individuals become more exposed to imported and processed foods, including highly refined sources of carbohydrates such as white rice, bread, and noodles,[16] these relationships may change.

Physical activity was associated with body composition outcomes in the expected direction (decreased body fat and increased lean mass) in both boys and girls, although the association only reached statistical significance in boys. This finding replicates several prior studies that indicate that higher intensity of physical activity has beneficial effects for reduction of body fat,[32] development of muscle and bone,[33,34] and cardiovascular health in children.[35] Finally, although not the focus of this analysis, it should be noted that in boys only, MLS, our measure of socio-economic position, was associated with both %BF and lean mass before controlling for physical activity. While in high-income settings, low socio-economic position is generally associated with greater risk of childhood obesity,[36,37] in low- or middle-income nations the opposite is often true,[38] as indicated here; although these associations vary widely by ethnicity.

This study was not without limitations. First, small sample size and consequently low power to detect statistical (and clinical) significance is the greatest limitation of this cross-sectional study, although we believe that the general paucity of body composition data in young children warrants the description and analysis presented. Because this was a pilot study, the n = 83 participants included simply represent the sample that we were feasibly able to include given limited time and resources. We recognize that between the ages of 3 and 7 years is a period of extremely rapid growth and change in body proportions and that combining all children for this analysis was not ideal. We hope, however, that these findings, although preliminary, will encourage others to consider this underrepresented ethnic group in further studies. Second, the method of convenience sampling used, which intentionally sought to balance the regional distribution of the sample rather than making the survey nationally representative, may also limit the study's generalizability and we recognize that comparisons between our sample and those of other ethnic groups must be interpreted with caution given possible sampling bias. Additionally, some issues in the measurement of physical activity suggest a need for additional research and analyses in this area. While most children wore the accelerometers for the full 7 days, some had less than 14 hours of wear time in the 7 AM to 9 PM window. It is possible that low activity behaviours such as napping or sitting very still while watching television may have been registered as nonwear and been excluded in our data analysis approach, potentially overestimating intensity of physical activity. Finally, while the physical activity measures were objective, calculation of macronutrient intake from the FFQ, which was validated in adult Samoans but not in children, is subject to maternal recall bias based on her involvement in the preparation of food for her child and/or social desirability bias.[39]

Despite these limitations, our findings highlight the importance of continuing to explore body composition, nutritional intake, and physical activity among Samoan children, preferably in a longitudinal design that would allow for an association to chronic disease outcomes later in life. The high percentage of body fat observed among these young children places them at substantial risk for later cardiometabolic disease, and the results from this and future longitudinal studies should be used to inform early preventative intervention. Since boys and girls differ significantly in their body composition, physical activity appears to play a greater role in determining body composition in boys compared with girls, and dietary intake appears to be more influential in girls; future interventions may need to consider a sex-specific approach.

ACKNOWLEDGEMENTS

The authors would like to thank the Samoan Ministry of Health and Ministry of Women, Community, and Development as well as the Samoan and US research assistants, and the mothers and children who participated in this study. A.A.T. was supported by a Downs International Health Student Travel Fellowship from the Yale School of Public Health. C.C. was supported by a US Fulbright Research Fellowship. The DXA scanner used in this study was purchased using National Institutes of Health grant funding (2 R01 HL093093; PI: Stephen McGarvey).

AUTHOR CONTRIBUTIONS

A.A.T., N.L.H., C.C., R.L.D., and M.M.D. conceived the study design. A.A.T., C.C., A.I.W., R.L.D., T.N., and MSR contributed to data collection while A.A.T., R.L.D., M.M.D., L.B.S., and N.L.H. were responsible for data analysis. A.A.T. wrote the initial manuscript draft under the supervision of M.M.D. and N.L.H. All authors were involved in editing the paper and had final approval of the submitted and published versions.

ORCID

Nicola L. Hawley https://orcid.org/0000-0002-2601-3454

REFERENCES

1. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384:766-781.
2. Nguyen VT, Larson DE, Johnson RK, Goran MI. Fat intake and adiposity in children of lean and obese parents. *Am J Clin Nutr*. 1996;63:507-513.
3. Atkin LM, Davides PSW. Diet composition and body composition in preschool children. *Am J Clin Nutr*. 2000;72:15-21.
4. Maffeis C, Provera S, Filippi L, et al. Distribution of food intake as a risk factor for childhood obesity. *Int J Obes Relat Metab Disord*. 2000;24:75-80.
5. Lazaar N, Aucouturier J, Ratel S, Rance M, Meyer M, Duché P. Effect of physical activity intervention on body composition in young children: influence of body mass index status and gender. *Acta Paediatr*. 2007;96:1315-1320.
6. Choy CC, Desai MM, Park JJ, et al. Child, maternal and household-level correlates of nutritional status: a cross-sectional study among young Samoan children. *Public Health Nutr*. 2017;20:1235-1247.
7. WHO Child Growth Standards: *Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development*. Geneva: World Health Organization, 2006. http://www.who.int/childgrowth/standards/en/
8. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children

and adolescents. *Bull World Health Organ*. 2007;85:660-667. http://www.who.int/growthref/growthref_who_bull/en/index.html.
9. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320:1240-1245. http://bmj.bmjjournals.com/cgi/reprint/320/7244/1240.
10. Rush EC, Freitas I, Plank LD. Body size, body composition and fat distribution: comparative analysis of European, Maori, Pacific Island and Asian Indian adults. *Br J Nutr*. 2009;102:632-641.
11. Reid IR, Cullen S, Schooler BA, Livingston NE, Evans MC. Calcitropic hormone levels in Polynesians: evidence against their role in interracial differences in bone mass. *J Clin Endocrinol Metab*. 1990;70:1452-1456.
12. Rush EC, Puniani K, Valencia ME, Davies PSW, Plank LD. Estimation of body fatness from body mass index and bioelectrical impedance: comparison of New Zealand European, Maori and Pacific Island children. *Eur J Clin Nutr*. 2003;57:1394-1401.
13. Trading Economies. Samoa GDP per capita PPP. https://tradingeconomics.com/samoa/gdp-per-capita-ppp
14. Samoan Bureau of Statistics. 2016 Census Brief No. 1. Apia, Samoa: 2017. http://www.sbs.gov.ws/index.php/new-document-library?view=download&fileId=2174
15. Ezeamama AE, Viali S, Tuitele J, McGarvey ST. The influence of socioeconomic factors on cardiovascular disease risk factors in the context of economic development in the Samoan archipelago. *Soc Sci Med*. 2006;63:2533-2545.
16. Wang D, Hawley NL, Thompson AA, et al. Dietary patterns are associated with metabolic outcomes among adult Samoans in a cross-sectional study. *J Nutr*. 2017;147:628-635.
17. DiBello JR, McGarvey ST, Kraft P, et al. Dietary patterns are associated with metabolic syndrome in adult Samoans. *J Nutr*. 2009;139:1933-1943.
18. United States Department of Agriculture. USDA food composition databases. https://ndb.nal.usda.gov/ndb/search/list
19. Dignan C, Burlingame B, Kumar S, et al. *The Pacific Islands Food Composition Tables*. Rome: FAO; 2004.
20. Willet WC, Howe GR, Kushi LH. Adjustment for total energy intake in epidemiological studies. *Am J Clin Nutr*. 1997;65:1220S-1228S.
21. Dössegger A, Ruch N, Jimmy G, et al. Reactivity to accelerometer measurement of children and adolescents. *Med Sci Sports Exerc*. 2014;46:1140-1146.
22. Roubenoff R, Kehyais JJ, Dawson-Hughes B, et al. Use of dual energy x-ray absorptiometry in body composition studies: not yet a "gold standard". *Am J Clin Nutr*. 1993;58:589-591.
23. Guo B, Wu Q, Gong J, et al. Gender difference in body fat for healthy Chinese children and adolescents. *Child Obes*. 2016;12:144-154.
24. Rush E, Obolonkin V, Savila F. Growth centiles of Pacific children living in Auckland, New Zealand. *Ann Hum Biol*. 2013;40:1464-5033.
25. Karlsson AK, Kullberg J, Stokland E, et al. Measurements of total and regional body composition in preschool children: a comparison of MRI, DXA, and anthropometric data. *Obesity*. 2013;21:1018-1024.
26. Khadgawat R, Marwaha RK, Tandon N, et al. Percentage body fat in apparently healthy school children from northern India. *Indian Pediatr*. 2013;50:859-866.
27. Hu G, Bouchard C, Bray GA, et al. Trunk versus extremity adiposity and cardiometabolic risk factors in white and African American adults. *Diabetes Care*. 2011;34:1415-1418.
28. Minster RL, Hawley NL, Su CT, et al. A thrifty variant in CREBRF strongly influences body mass index in Samoans. *Nat Genet*. 2016;48:1049-1054.
29. Shea JL, King MTC, Yi Y, Gulliver W, Sun G. Body fat percentage is associated with cardiometabolic dysregulation in BMI-defined normal weight subjects. *Nutr Metab Cardiovasc Dis*. 2012;22:741-747.
30. Ma Y, Olendzki B, Chiriboga D, et al. Association between dietary carbohydrates and body weight. *Am J Epidemiol*. 2005;161:359-367.
31. Beulens JWJ, de Bruijne LM, Stolk RP, et al. High dietary glycemic load and glycemic index increase risk of cardiovascular disease among middle-aged women. *J Am Coll Cardiol*. 2007;50:14-21.
32. Strong WB, Malina RM, Blimkie CJR, et al. Evidence based physical activity for school-age youth. *J Pediatr*. 2005;146:732-737.
33. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Dorado C, Calbet J. Muscular development and physical activity as major determinants of femoral bone mass acquisition during growth. *Br J Sports Med*. 2004;39:611-616.
34. Fritz J, Duckham RL, Rantalainen T, Rosengren BE, Karlsson MK, Daly RM. Influence of a school-based physical activity intervention on cortical bone mass distribution: a 7-year intervention study. *Calcified Tissue Int*. 2016;99:443-453.
35. Leary SD, Ness AR, Smith GD, et al. Physical activity and blood pressure in children: findings from a population-based study. *Hypertension*. 2008;51:92-98.
36. Centers for Disease Control. 2014. Childhood obesity facts: childhood obesity among pre-schoolers is more prevalent among those from lower-income families. https://www.cdc.gov/obesity/data/childhood.html#obesity-among-preschoolers. Accessed July 7, 2019.
37. Fradkin C, Wallander JL, Elliot MN, Tortolero S, Cuccaro P, Schuster MA. Associations between socioeconomic status and obesity in diverse, young adolescents: variation across race/ethnicity and gender. *Health Psychol*. 2015;34:1-9.
38. Wang Y. Cross-national comparison of childhood obesity: the epidemic and the relationship between obesity and socioeconomic status. *Int J Epidemiol*. 2001;30(5):1129-1136.
39. Pérez-Rodrigo C, Escauriaza BA, Bartrina JA, Allúe IP. Dietary assessment in children and adolescents: issues and recommendations. *Nutr Hosp*. 2015;31:S76-S83.

How to cite this article: Thompson AA, Duckham RL, Desai MM, et al. Sex differences in the associations of physical activity and macronutrient intake with child body composition: A cross-sectional study of 3- to 7-year-olds in Samoa. *Pediatric Obesity*. 2020;15:e12603. https://doi.org/10.1111/ijpo.12603