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Original research

Drivers of adolescent adiposity: Evidence from the Australian LOOK study

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ABSTRACT

Objectives: To contribute to our understanding of the drivers of body composition during adolescence we sought to employ valid and reliable measures to investigate cross-sectional and longitudinal relationships between percentage body fat (%BF) and physical activity (PA), moderate and vigorous PA (MVPA), sedentary time (ST), total energy, sugar and fat intake.

Design: Longitudinal cohort study.

Methods: We measured 556 (289 male) participants at age 12.4 (SD 0.4) years, and 269 (123 males) at 16.3 (SD 0.4) years, for %BF (dual energy X-ray absorptiometry); habitual PA, MVPA, ST (accelerometry); and dietary intake ('multi-pass' weekday and weekend 24-h recall). Accounting for likely under-reporting of energy intake (Goldberg cut-off), general linear mixed modelling was used to generate relationships with %BF.

Results: Cross-sectional analyses indicated that 10 min more MVPA per day was associated with 0.6 lower %BF (95%CI 0.4–0.9, $p < 0.001$), and 10 min less ST/day with 0.07 lower %BF (95%CI 0.00–0.15, $p < 0.001$), independently of PA. In contrast, %BF was unrelated to total energy ($p = 0.4$), sugar intake ($p = 0.2$) or fat intake ($p = 0.9$). Longitudinal analysis showed that if PA was increased by 3% (10,000 counts/day) over the 4 years, then %BF was reduced by 0.08 (95%CI 0.05–0.12, $p = 0.06$).

Conclusions: The independent relationships of %BF with PA and ST, but absence of relationships with energy, sugar or fat intake, suggest that general community campaigns in a developed country directed at reducing adolescent obesity through modifications to energy intake and output would benefit from a more concerted focus on the latter.

Practical implications

General community obesity reduction campaigns might be better placed to focus mainly on an enhancement of physical activity rather than a restriction of food and beverage.

A reduction in sitting time, even without any change in physical activity, is likely to reduce an adolescent's percent body fat.

That no relationship emerged between adiposity and sugar and fat intake is quite separate to any consideration of their consumption on health

Our evidence suggests PA to be the main driver of adolescent body composition, but does not preclude individual variation.

1. Introduction

While community-based campaigns and interventions involving both dietary intake and physical activity (PA) have been suggested as having the most favourable effect in reducing obesity in youth, effects have been inconsistent and moderate at best.[1] It has been proposed that a more effective approach might be to place the major emphasis on PA, rather than on restriction of energy intake,[2] a premise supported by a recent finding that adolescents with greater fat mass had a lower energy intake, irrespective of their PA level,[3] but sufficient evidence for any such assertion is generally lacking.[4]

A better understanding of the relative contributions of energy intake and output in healthy free-living children and adolescents is likely to lead to more effective community programs targeting obesity. In order to compare independent effects of each variable, valid and reliable measurements of PA, dietary intake and adiposity are required within the one cohort study. Moreover, a frequently ignored misleading factor in the interpretation of many longitudi-

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nal studies (and ensuing literature reviews), is the use of body mass index (BMI, kg ht^{-2}) as a proxy for percent body fat (%BF). Increased BMI in both boys and girls between ages 10 and 12 years,[5–7] and in boys between 12 and 16 years[8] is likely to coincide with decreased, not increased %BF.

There is a paucity of cross-sectional population studies involving valid and reliable procedures for determination of %BF, PA, sedentary time (ST), and dietary intake within the one adolescent cohort. One study involving PA and dietary measures in 10–18 year-olds[9] used bioelectric impedance to estimate fat mass. They reported moderate and vigorous activity (MVPA) to be higher in leaner children; and while no relationships emerged between adiposity and energy intake, interpretation is hindered in that under-reporting was not accounted for, and PA and ST were measured by self-report. Similar evidence of relationships between fat mass and PA has been reported during early adolescence (grade 7), again without detection of any relationships with ST or with their measure of diet quality.[10]

We sought to contribute to the understanding of the determinants of adiposity during adolescence by measuring our cohort of males and females at average age 12 and 16 years with well-accepted measures for all of the dietary, PA and ST variables and comparing their relationships with %BF within a general linear mixed model.

2. Methods

This study was part of the multidisciplinary Lifestyle of our Kids (LOOK) project.[11] All procedures in this study were approved by the Australian Capital Territory Health Human Research Ethics Committee (ETH.5.13.103). Written parental consent was obtained for all measures, along with participant consent at follow-up, and participants were well-advised that they could withdraw from the study at any time. Our cohort participated in two main measurement periods, at grade 6 (age 12.4 year, SD 0.4), and grade 10 (16.3 year, SD 0.4). Repeated measures on individuals were used to calculate longitudinal relationships, and all data at both age groups were used to calculate cross-sectional relationships.

The grade 6 children were attending government-funded primary (elementary) schools situated in outer suburbs of the city of population approximately 330,000, where Australian Bureau of Statistics data indicated average household income to be slightly higher than the Australian average. A condition of inclusion in the study was that children were in good health and able to participate freely in vigorous PA. Approximately 90% of the participants had both parents of European descent; 8% had one or both parents of Asian descent; 1% were of Indigenous Australian or Polynesian descent, and we had no data on the ethnicity of 1% of the adolescents.

Body composition was measured as previously described[12] in a hospital setting using dual energy X-ray absorptiometry, DXA (Hologic Discovery QDR Series, Hologic Inc., Bedford, MA, USA (DXA HD)). All scans were performed with participants wearing light clothing and total body scans were analyzed using QDR Hologic Software Version 12.4.7 to generate total lean tissue mass and fat mass, from which %BF was calculated. Height was measured by a portable stadiometer to the nearest 0.001 m and body weight by portable electronic scales to the nearest 0.05 kg.

Accelerometers (Actigraph GTIM, Pensacola, FL, USA), positioned on a belt around the waist in line with the right knee, were worn for 7 days and analyzed using Meterplus software (Santech, San Diego, USA). MVPA was defined as counts greater than 2296 per minute based on recommendations,[13] using an epoch length of 60 s; ST defined as counts <100 per min. The first day of accelerometer data was discarded to minimize any potential reactivity. Days of accelerometer data were only included if there were 10 or more hours of activity; an hour being considered invalid if there were more than 30 zero counts in a row (30 min of non-wear time).

Total energy and macronutrient energy intakes were assessed by a team trained and supervised by a nutritionist with experience in nutritional surveys. Dietary intake was collected using the "multi-pass" 24-h recall method,[14] involving data collection on a school day and a non-school day, based on the methodology adopted in the 2007 Australian National Children's Nutrition and PA Survey.[15] To assist in the reporting, a standard protocol was used to conduct the 24-h recall phone interviews, with consistent prompts and questions to ensure parents and the children or adolescents reported specific details of the food and drinks consumed. During the interviews, participants referred to provided photographs of common foods and beverages, along with portion sizes to assist in reporting. Initial training sessions were conducted to ensure a uniform approach in interviews, and to minimize coding errors. Data analysis was performed with the aid of the FoodWorks Professional™ software system (version 2007, Xyris, Brisbane Queensland).

To reduce the likelihood of misreporting of food intake, and in particular adiposity-related underreporting, we adopted the following strategies. As an incentive to provide accurate dietary reporting, parents and children were reminded throughout the study of the importance of accurate dietary records to interpret blood tests and assess general health as part of the larger LOOK study. Secondly, we adopted the Goldberg method[16] of identifying implausible dietary energy intake recalls by comparing them with basal metabolic rate estimated from height and weight. Cut-off values considered most suitable were those adapted for adolescents according to sex and age.[17] For males, the cutoff for under-reporting was <1.10 and over-reporting >2.97; and for females the respective values were <0.99 and >2.72. Participants identified in these categories of under- and over-reporting were not included in our statistical analysis.

The data were analyzed with a general linear mixed model using the R package lme4. A random intercept for both Subjects and School was initially included in accordance with the multilevel nature of the data. All models were estimated using Restricted Maximum Likelihood. Visual inspection of 34 residual plots did not reveal any deviations from homoscedasticity or normality. P-values were obtained using Type II Wald F tests with Kenward-Roger degrees of freedom as implemented in the R package. Results are reported as mean estimates and 95% confidence intervals. Our model to explain the response (dependent) variable %BF included Year, Sex, and the explanatory (independent) variable of interest, along with their interactions. Longitudinal relationships were derived from repeated values in the same subject in different years, with cross-sectional relationships making use of all data and adjusting for repeated measurements in any individual. Models were constructed both without, and with adjustments for covariates; the former permitting investigation of the fundamental questions as to whether an adolescent with higher %BF was likely to engage in higher or lower PA, MVPA, or ST, and whether they consumed more or less energy, sugar and fat intake. The models incorporating adjustments were used to explore the independence of each variable's association with %BF.

3. Results

In all, there were 556 participants (289 males) measured in grade 6 and 269 (123 males) measured in grade 10. For %BF and PA measures were obtained in 556 participants (289 males) in grade 6, and 269 (123 males) in grade 10. For the dietary variables we mea-

Table 1
Participant characteristics, accelerometer and dietary recall measures, including those of under and over-reporters, expressed as means and standard deviations.

	School grade 6 (age = 12.4 ± 0.4 year)		School grade 10 (age = 16.3 ± 0.4 year)	
	Males	Females	Males	Females
Height, cm	154.3 ± 7.7	154.4 ± 6.8	176 ± 7.1	165 ± 6.3
Weight, kg	46.7 ± 9.8	47.2 ± 10.3	70.1 ± 12.8	63.7 ± 10.7
Percent body fat (%BF)	24.3 ± 7.2	28.6 ± 6.3	17.8 ± 7.1	31.5 ± 6.1
Physical activity (PA), cts.10^{-3}	419 ± 150	369 ± 125	403 ± 171	321 ± 112
MVPA, min day^{-1}	48 ± 23	35 ± 18	27 ± 14	21 ± 11
ST, min day^{-1}	386 ± 69	403 ± 68	452 ± 83.5	478 ± 74
Total energy intake, kJ day^{-1}	8755 ± 2848	8226 ± 2659	8959 ± 3204	6707 ± 2161
Total sugar intake, g day^{-1}	124 ± 57.8	117 ± 50	109 ± 51.9	79 ± 46
Total fat intake, g day^{-1}	77 ± 35	73 ± 31	64 ± 34	59 ± 25

For %BF and PA measures N = 556 (289 males) in grade 6, and N = 269 (123 males) in grade 10; for the dietary measures in grade 6 was N = 269 (134 males) in grade 6, and N = 103 (53 males) in grade 10. Participant details include those later excluded for over- and under-reporting.

Table 2
Relationships of %BF with accelerometer and dietary recall variables.

	F ratio	β ± se	p-Value
PA, counts × 10^{-4}	21.3	−8.2 ± 1.8	<0.001
MVPA, min day^{-1}	23.3	−0.06 ± 0.013	<0.001
Sed Time, min day^{-1}	12.4	0.01 ± 0.003	<0.01
Total energy intake, kJ day^{-1}	2.57	Not relevant	0.4 NS
Total sugar Intake, g day^{-1}	1.85	Not relevant	0.2 NS
Total fat Intake, g day^{-1}	0.06	Not relevant	0.9 NS
Total fat Intake, g day^{-1} (year 10 only)	4.8	0.065 ± 0.03	<0.05

sured 269 participants (134 males) in grade 6 and 103 (53 males) in grade 10.

The anthropometric characteristics of all the participants, including those omitted from statistical analyses, together with the means and standard deviations of the dietary recall and accelerometer measured variables in each year are presented in tabular form in Table 1. There were no significant gender interactions in the relationships between %BF and accelerometer or dietary variables so male and female data are pooled. Twenty-two males and 21 females were removed from our statistical analyses in Grade 6 after applying the Goldberg cut-off method of detecting under-reporting of energy intake; and 17 males and 29 females were removed in Grade 10. Also removed from our dietary analyses were one female and 3 males suspected of over-reporting by the Goldberg method in grade 6 and none in grade 10.

Table 2 summarizes the between-adolescent relationships of our variables with %BF in terms of F ratios, effect sizes, probabilities; and Fig. 1 depicts the significant relationships between %BF and MVPA and ST. With practical implications expanded in the Discussion, we can summarize our findings as follows. The relationships between %BF and each of PA, MVPA (both positive), and ST (negative) were all significant ($p < 0.001$). On the other hand, there was no evidence of any significant relationships between %BF and energy intake, or sugar intake ($p = 0.4$ and 0.2 respectively); and although there was no significant relationship between %BF and fat intake overall, it was significant in the 16 year-olds ($p < 0.05$). When we ran the same models adjusting for total energy, in effect investigating fat and sugar as a fraction of total energy intake, again there was no evidence of any relationship, with the significant relationship between %BF and fat intake at age 16 not being sustained.

In constructing the longitudinal (within-adolescent) relationships, we used repeated data for the DXA, %BF and PA measures from 269 adolescents (123 males) and for the dietary measures 103 adolescents (53 males). With longitudinal data limited in comparison with those cross-sectional, the trend towards a longitudinal relationship between %BF and PA supported the cross-sectional findings. On average, if an adolescent increased their PA by 10,000 counts per day between age 12 and 16, then their %BF was lowered by 0.08 (95%CI 0.05–0.12, $p = 0.07$); but no corresponding trends emerged to suggest that change in %BF might be associated with changes in MVPA, ST, energy, fat or sugar intake (all $p > 0.1$).

To provide more evidence as to the independence of each relationship, we constructed models involving adjustment for each covariate. The relationships of %BF with PA, MVPA, and ST were sustained, with estimated effects of the same order of magnitude as those presented in Table 2. ST was a significant explanatory variable for %BF, independently of PA. An adolescent engaging in 10 min per day less ST, without any change in PA, is likely to have on average a 0.07 lower %BF (95%CI = 0.004–0.15). For the dietary data, after adjusting for PA (counts), there were no changes in the (non-significant) relationships between %BF and energy intake or sugar intake, and the previously significant relationship between %BF and fat intake in the 16 year-olds was not sustained ($p = 0.1$).

Finally, we conducted post-hoc analyses, on the premise that the contrasting relationships of the PA and dietary variables with %BF may have resulted from a difference in statistical power brought about by different numbers of measurements, or the number of days over which data were collected. Consequently, we re-calculated the relationships between %BF and PA, ST, and MVPA, restricting these to the same number of participants (269 in 2009 and 103 in 2013), and the same number of days of observation (two days) as for the dietary assessments. The outcomes were essentially the same as those reported above, with only minor modifications to the confidence intervals.

4. Discussion

To our knowledge, this is the first longitudinal study of adolescence where each of PA, MVPA, ST have been measured by accelerometers, the total energy, sugar and fat intake by weekend and weekday multi-pass methodology, and %BF measured by DXA. Here we report that PA, MVPA and ST were significant contributors to the variation in %BF during adolescence, contrasting with an absence of any similar evidence for total energy or sugar intake, with only weak evidence of an association with fat intake in the 16 year-olds.

Outcomes of this study are of practical as well as statistical significance, and here we provide pertinent examples. With essentially the same statistical outcomes in models with and without adjustment for covariates, our data indicate that an adolescent (male or female) who engages in an extra 10 min of MVPA per day, will have, on average, a 0.6 lower %BF (95%CI 0.4-0.9, $p < 0.001$). In contrast, adolescents with higher %BF did not have higher total dietary energy intake or sugar intake. Our data also allowed us to compare a 16 year-old female of average weight, average MVPA (20 min/day), and average ST (480 min/day) with a 16 year-old female whose meets the internationally recommended level of

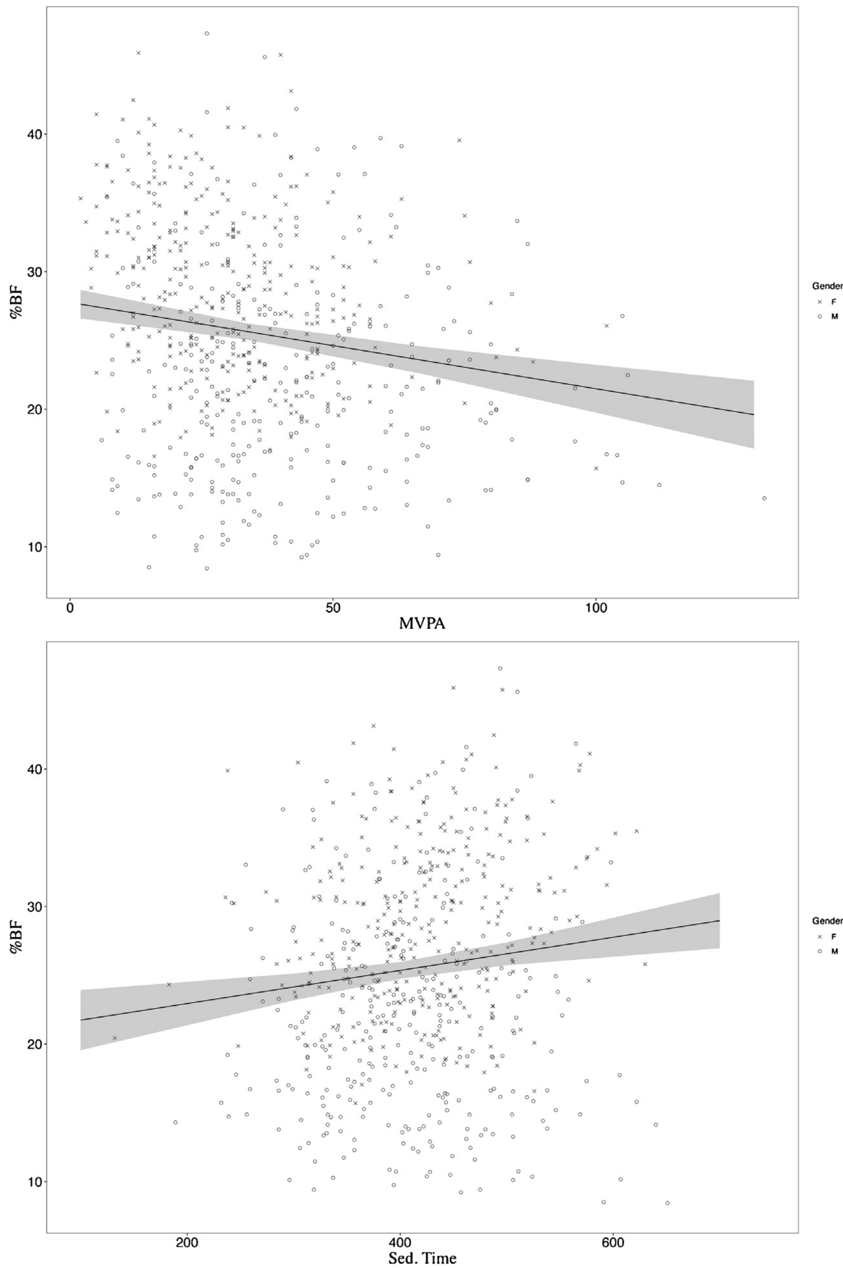

Fig. 1. The statistically significant relationships of %BF with MVPA (min/day) and sedentary time (min/day), incorporating grades 6 and 10 data, the shaded area showing the 95% confidence intervals.

60 min/day MVPA along with a 60 min less daily ST (420 min/day). The %BF of the former would be, on average, 31% and the latter 28%, representing a difference of 1.8 kg of body fat.

It is unlikely that differences in the sensitivities of the assessment procedures, the numbers of subjects or days of observation investigated had any significant bearing on the contrasting relationships between %BF and the PA and dietary outcomes. Firstly, our dietary multi-pass methodology is considered thorough, and suspected under-reporters were systematically removed. Secondly, in restricting analyses of accelerometer data to the same number of days and same number of participants as for the dietary data, the relationships between %BF and each of the variables were essentially unchanged.

While incorporation of each of our objective measures, dietary assessment, and statistical modelling appears to be novel in a longitudinal study of adolescents, one report in adults approximated our design and methodology.[18] Interestingly, the two studies had similar findings in that leaner adults were more physically active, but did not have lower energy intakes. Our findings are also consistent with reports of positive relationships between PA and adiposity in youth,[19–22] supporting the premise that in youth, energy balance is better achieved within a physically active lifestyle.[23] In addition, our data suggest that as well as being more active, leaner adolescents are less sedentary, ST being independently and positively related to %BF. Our finding is at variation with a previous report in 13 and 15 year-olds,[24] although, as alluded to above, the latter study's use of BMI as the indicator of adiposity may have influenced their findings. It is of interest to compare the independent effects of ST and PA on variation of %BF in our cohort. For example, in general terms, and bearing in mind the limitations imposed upon inferences derived from the relationships in our model, 5 min of MVPA (about 24% of mean daily PA in our 16 year-olds) would be needed to offset the higher %BF brought about by 60 min ST (about 13% of mean daily ST).

In contrast with previous reports in the literature of significant associations of adolescent adiposity with PA, evidence of relationships between adiposity and dietary intake is sparse and inconsistent. Some studies have failed to detect relationships between adiposity in adolescents or children with energy intake [9,25] or energy intake quality;[10] and a negative relationship was reported in one study[3] even after steps were taken to remove potential under-reporters. Of particular current interest, with some countries introducing taxes on highly concentrated sugar beverages, is that our typical Australian adolescents of higher %BF did not consume more sugar than their leaner counterparts; consistent with previous reports.[26,27] However, these findings appear at odds with the reports that sugar consumption has risen in countries along with the incidence of obesity,[28] although use of this correlation has been challenged recently in that sugar consumption has decreased in Australia while overweight and obesity levels have risen.[29]

Strengths of our work are the use of DXA, accelerometry, weekday and weekend multi-pass 24 h dietary recalls, systematic exclusion of likely under-reporters, and measures of each of %BF, PA, MVPA, ST, energy intake, fat and sugar intake within the one cohort. On the other hand, despite our attempts to employ the most valid and reliable measures of physical activity and dietary intake, the methods have their limitations. For example, accelerometers do not record all types of PA, and variation occurs in individual wear time; and the multi-pass dietary recall, despite all the precautions, is still subject to inaccurate reporting. Other limitations of the study include the time required for the multi-pass dietary assessments, which precluded dietary assessments of all of our cohort; and that this cohort consisted of predominantly white Australian youth of middle-range socio-economic status, which means our conclusions may not be generalizable to other populations.

5. Conclusion

In our free-living healthy adolescents living within an affluent society, the strong relationships between %BF and both PA and ST, together with the absence of independent associations between %BF and dietary energy, fat or sugar, support the premise suggested previously,[2,3] that campaigns directed at reducing the prevalence of adolescent obesity are more likely to be effective when PA and ST form the major foci of attention.

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The authors also declare they have no competing interests and that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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