Lifestyle and body composition in adolescents in the South Pacific

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A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy in Community Health,
The University of Auckland,
2012

ABSTRACT

Obesity prevalence among Pacific Island adolescents is high and is a major health concern. In view of this, obesity interventions targeted at this group are urgently required. However, evidence of suitable intervention strategies for this population is lacking. In addition, it is not clear how well measures of obesity that can be used in the field setting quantify fatness in South Pacific youth.

To address these gaps of knowledge in the literature, this thesis aimed to examine the association between lifestyle risk factors of obesity and body composition variables in this population (Obesity Prevention In Communities (OPIC) study). To assist this objective, a second aim of this thesis was to examine the relationship between fatness estimated by field methods (anthropometric and bioimpedance analysis (BIA) variables) and measured by an accepted reference method in South Pacific youth (validation study).

In the validation study, 432 adolescents (Pacific Island, Maori, Asian and European) were purposively selected from high schools in Auckland. Anthropometric variables were measured, impedance variables were measured on an 8-electrode BIA (BIA_8) device (Tanita BC-418; Tanita, Tokyo, Japan) and body composition variables were measured by dual-energy X-ray absorptiometry (DXA). In the OPIC study, data were collected from >17,000 students from 4 countries (New Zealand (NZ), Australia, Fiji and Tonga) and 8 ethnic groups (NZ Pacific Island, NZ Maori, NZ Asian, NZ European, Indigenous Fijian, Fijian Indian and Tongan), which comprised information on demographic, lifestyle and body composition variables.

Results from the validation study showed that, compared to Europeans, for the same body mass index (BMI), Asian Indians had more percent body fat (%BF), while Maori and Pacific Islanders had less %BF. In boys, readily measured variables, waist circumference/height and conicity index, had notable effects on the %BF ethnic differences. Other factors that contributed to these differences in boys and girls were variation in muscularity, bone mass, fat distribution and relative leg length. BIA_8 estimated DXA-measured total fat mass (TFM), %BF and fat-free mass with significant bias. BIA-based prediction equations developed in the sample performed better than reliance on the manufacturer's equations and these equations depended upon ethnicity. For the same waist circumference (WC), compared to Europeans and Maori, Asians had more percent abdominal fat (%AbFM) and Pacific Islanders had less %AbFM. Adjustment for trunk impedance (Z_{Tr}) removed or

reduced these %AbFM differences. In fact, at a given WC, ethnic differences in Z_{Tr} mirrored variation in %AbFM across ethnic groups.

OPIC analyses revealed that Pacific Islanders had markedly higher fatness levels than other groups, including when %BF, TFM and %AbFM were used as fatness measures. Among all ethnic groups combined, TV watching was positively related to fatness in a dose-dependent manner. Overall effects showed strong, dose-dependent associations between fatness and soft drink consumption (positive relationship), breakfast consumption (inverse relationship) and after-school physical activity (inverse relationship). Differences in lifestyle obesity risk factors were associated with percentage differences in body composition variables that were greatest for TFM, followed by %BF and then BMI.

This thesis supports the view that TV watching, soft drink consumption, breakfast consumption and physical inactivity contribute to increased obesity prevalence among Pacific Island youth. Body composition (DXA-measured fatness) notably varies at a given body size. Consistent with this, and an original finding, is that lifestyle factors are most strongly related to TFM and %BF, suggesting that obesity interventions and studies that use only BMI to quantify fatness may underestimate the "true" effect of lifestyle on adiposity.

ACKNOWLEDGEMENTS

I sincerely thank Professor Robert Scragg, my main supervisor, for his continuous support, guidance and encouragement. I gratefully acknowledge the ongoing advice and assistance from Associate Professor Lindsay Plank, my co-supervisor. I thank Dr Teuila Percival, my advisor, for her support.

Thank you to Dr David Schaaf, for his support earlier on. I thank Analosa Ulugia-Veukiso for supporting me while she was Pacific Manager (Emerging Researchers).

I acknowledge the OPIC teams in New Zealand, Australia, Fiji and Tonga for collecting and managing the data, as well as providing support. Thank you to Professor Boyd Swinburn, for allowing me to use the OPIC data and for guiding me.

I am grateful for the funding support the Health Research Council of New Zealand and the New Zealand Ministry of Health have provided. I acknowledge the funding support from the Wellcome Trust (United Kingdom), who supported the Tongan and Fijian arms of the OPIC study, and the National Health and Medical Research Council of Australia, who supported the Australian arm of the OPIC study.

Thank you to the participating schools. I gratefully acknowledge the students who participated in the studies; this thesis would not be possible without them.

Finally, I would like to thank my mother, Theresa Sluyter, for her continuous support and encouragement.

CONTRIBUTIONS OF CANDIDATE AND SUPERVISORS

For the validation study, the candidate contributed to the design, recruited all participants and collected all data (transported participants to the Department of Surgery, University of Auckland, and carried out measurements there). For the OPIC study, the candidate collected data at all of the classes in the New Zealand high schools for two years. The candidate analysed all data for both studies and wrote the entire thesis.

Professor Robert Scragg (main supervisor) contributed to the design of both studies, acquired ethical approval for the studies, provided support with the recruitment in the validation study (met with senior staff at participating schools), helped with the data collection for the OPIC study, gave advice for the statistical analyses and provided critical feedback for each chapter.

Associate Professor Lindsay Plank (co-supervisor) contributed to the design of the validation study and gave overall advice for this study. He provided advice for the statistical analyses and critically reviewed the entire thesis.

LIST OF ABBREVIATIONS

%AbFM ..... Percent abdominal fat
%BF ..... Percent body fat
%TF ..... Percent trunk fat
4-CM ..... Four-compartment model
AbFM ..... Abdominal fat mass
AHHS ..... Auckland High School Heart Survey
AIC ..... Akaike's Information Criterion
ANCOVA ..... Analysis of covariance
ANOVA ..... Analysis of variance
ASMM ..... Appendicular skeletal muscle mass
BIA ..... Bioimpedance analysis
BIA_8 ..... Tanita BC-418 Body Composition Analyzer
BMI ..... Body mass index
BMC ..... Bone mineral content
BMD ..... Bone mineral density
ClFM ..... Central fat mass
CI ..... Conicity index or confidence interval (indicated in text)
CNS02 ..... 2002 National Children's Nutrition Survey
Cp ..... Mallow's Cp Statistic
CT ..... Computed tomography
CV ..... Coefficient of variation
DHHS ..... Diabetes, Heart and Health Survey
DMHD ..... Dunedin Multidisciplinary Health and Development
DXA ..... Dual-energy X-ray absorptiometry
FFM ..... Fat-free mass
FFQ ..... Food frequency questionnaire
FLAME study ..... Family Lifestyle, Activity, Movement and Eating study
FM ..... Fat mass
HBLPY ..... Health Behaviour and Lifestyle of Pacific Youth
HFCS ..... High-fructose corn syrup
IOTF ..... International Obesity Task Force

LbFM ..... Limb fat mass
MRI ..... Magnetic resonance imaging
NNS97 ..... 1997 National Nutrition Survey
NZ ..... New Zealand
NZEO ..... New Zealand European/Other
OPIC ..... Obesity Prevention In Communities
OR ..... Odds ratio
PDA ..... Personal digital assistant
PIF:PAC ..... Pacific Island Families: Child and Parental Physical Activity and Body Size
RMR ..... Resting metabolic rate
ROI ..... Region of interest
SBC ..... Schwarz-Bayesian criterion
SD ..... Standard deviation
SE ..... Standard error
SEE ..... Standard error of estimate
SEIFA ..... Socio-economic Indexes for Areas
SES ..... Socio-economic status
SSB ..... Sugar-sweetened beverage
TAAT ..... Total abdominal adipose tissue
TFM ..... Total fat mass
ThFM ..... Thigh fat mass
TV ..... Television
US ..... United States
VAT ..... Visceral adipose tissue
VFA ..... Visceral fat area
VIF ..... Variance inflation factor
WC ..... Waist circumference
WHTR ..... Waist:height ratio
Z ..... Impedance
Z_{Tr} ..... Trunk impedance

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CHAPTER 1: INTRODUCTION

This thesis aims to provide important information that will help to identify appropriate areas for obesity intervention in Pacific Island youth. In this thesis, *Pacific Island* refers to people from Polynesia (excluding Maori). However, data analysis will be performed among *South Pacific* youth – that is, youth from Australia, New Zealand and Pacific Island countries, which comprises Pacific Island people and non-Pacific people (including European, Maori and Asian). This chapter will discuss the rationale for doing this (Section 1.1) and then describe, in Section 1.2, how this will be done in the following chapters.

1.1 Rationale of thesis

Obesity is a well-known important public health issue. For instance, international research shows that childhood overweight and obesity are associated longitudinally with an increased risk of mortality (1) and a variety of health problems (2). New Zealand data indicate that overweight and obesity are partly responsible for mortality (3) and morbidity (4) as well.

Obesity interventions targeted at youth are important as they potentially prevent obesity in adulthood in addition to addressing obesity among adolescents. This is because obesity in adolescence tends to persist into adulthood (5, 6) and adolescence is a critical period in which lifelong behaviours are established.

Data from the Pacific Obesity Prevention In Communities (OPIC) study show that Pacific Island youth have a high body mass index (BMI) and this is notably higher than other ethnic groups (7). These patterns are true for waist circumference (WC) girth measures as well (7), which is important, given the adverse health risks associated with central obesity (8, 9). Other data show that Pacific Islanders have higher obesity prevalence, when compared internationally to other ethnic groups in Westernised countries (10).

In view of all of this, obesity interventions targeted at Pacific Island youth are urgently needed. However, as will be shown in this thesis, evidence to inform suitable areas for intervention is lacking. This thesis provides evidence to inform such decisions. The next section (Section 1.2) will describe how this is done.

1.2 Structure of thesis

Table 1.1 shows the structure of this thesis. In order to understand what accounts for variation in obesity prevalence among Pacific Island youth, it is first necessary to examine obesity epidemiological evidence in South Pacific populations. This will be done in Chapter 2.

Another important factor to take into account is measurement of obesity. There has been concern raised over how fatness is quantified across different ethnic groups (11), including Pacific Island populations (12). Therefore, it is important to determine from the literature whether previous studies are able to determine how well fatness is measured in South Pacific youth. This will be done in Chapter 3. As Chapter 3 will show, past research is not able to deduce the appropriateness of fatness measures to adolescents living in the South Pacific and thus there is a need to collect data and use this to: 1) examine the ability of anthropometric variables to quantify fatness in South Pacific youth and, 2) develop bioimpedance analysis (BIA)-based measures of fatness in this population. These two aims will be achieved by carrying out a validation study. The methodology of the validation study is described in Chapter 5 and results are shown in Chapter 6.

Lifestyle variables are likely to contribute to the high obesity prevalence among Pacific Island youth. As a result, it is important to know whether past research is able to quantify the contribution of lifestyle variables to the high fatness levels in this population. This will be done in Chapter 4. This chapter will demonstrate that there is limited research on this topic. Consequently, additional research that addresses this problem is required to address this gap of knowledge in the literature. This new research is analysis of the baseline dataset of the OPIC study (7). The OPIC study was a community-based obesity prevention study carried out in New Zealand, Fiji, Tonga and Australia (13). However, only the baseline cross-sectional data are analysed in this thesis. Chapter 7 will describe the methodology of the OPIC study and Chapter 8 will describe results. This analysis will use results from the validation study (Chapter 6) to provide more accurate estimates of fatness among OPIC study participants.

The final chapter of the thesis, Chapter 9, will discuss the results of the validation and OPIC studies. Here, the contribution of new knowledge that each study makes to the literature will be discussed, together with recommendations for the health sector and future research.

Table 1.1. Structure of the thesis

Chapter	**Aim of chapter**
Chapter 2: Obesity epidemiology	Examine temporal trends and ethnic differences in fatness levels in South Pacific populations
Chapter 3: Measures of fatness	Review previous studies that have examined: 1) The ability of waist circumference and trunk impedance to predict abdominal obesity, 2) The relationship between BMI and percent body fat, and 3) The relationship between BIA and body composition. Evaluate how well the results of these studies apply to South Pacific youth
Chapter 4: Lifestyle predictors of fatness	Review previous studies that have examined whether lifestyle variables are causally related to fatness in children and adolescents. Determine how well the results of these studies apply to South Pacific youth
Chapter 5: Methodology of validation study	Describe the methodology of the validation study
Chapter 6: Validation study results	Describe the results of the validation study
Chapter 7: Methodology of OPIC study	Describe the methodology of the OPIC study
Chapter 8: OPIC study results	Describe the results of the OPIC study
Chapter 9: Discussion	Compare findings of the OPIC and validation studies with those of previous studies and discuss how they can be applied

CHAPTER 2: OBESITY EPIDEMIOLOGY

This chapter will first examine temporal trends in fatness in South Pacific populations (Section 2.1). Ethnic differences in fatness between Pacific and non-Pacific groups will next be described (Section 2.2), followed by a discussion of potential reasons for these (Section 2.3). This chapter will conclude by suggesting what research is required to explain disparities in adiposity level between these ethnic groups.

Literature relevant to this chapter was searched up to April 2012 on the following databases: *Medline In-process & Other non-indexed Citations and Medline, Scopus, PubMed* and *Google Scholar*. Combinations of keywords were used to identify relevant articles: *body mass index*, *obesity*, *overweight*, *temporal trend*, *ethnic*, *race*, *Pacific*, *Australia*, *New Zealand* and *obesity epidemiology*. In addition, several articles were located through citations in other articles.

2.1 Temporal trends in fatness in South Pacific populations

Temporal increases in fatness for South Pacific populations have been reported in Australia, New Zealand and Pacific Island countries since the 1980's. These increases can only be due to changes in lifestyle and the environment.

Australian studies

A comparison of nationally representative Australian samples showed that, among Australian adults, the prevalence of obesity increased from 1980 to 1999/2000 by 2.5 times (14). This is consistent with the marked increase in overweight and obesity observed among 264, 905 Australian children and adolescents aged 2-18 years (from 41 studies) from 1985 to the end of the 1990s (15).

New Zealand studies

An analysis of nationally representative samples of adult New Zealanders has shown that, between 1977 and 2003, obesity prevalence has rapidly increased (16). Similarly, a study of 11-12 year-old children in Hawkes Bay found that BMI markedly increased (9.2% relative increase) from 1989 to 2000 (17). Over approximately the same time period, BMI levels of New Zealanders increased, with an increasing trend toward central obesity (18). This is important because central fatness is a more important predictor of morbidity and cardiovascular risk factors than total fatness alone (8, 9). Further, a direct comparison of two studies showed that BMI and WC notably increased (e.g., 90th

BMI percentile increased by 3.7 kg/m^2 and 90th WC percentile increased by 19 cm) among Auckland high school students over approximately 7 years (1997/1998 – 2005) (19).

Pacific Island studies

Some studies have examined temporal trends in obesity prevalence or fatness levels in Pacific Island countries (20-22). Between 1966 and 1996, mean BMI of adult Cook Islanders significantly increased (e.g., among men, BMI increased by 4.8 kg/m^2) (22). Another adult study showed that the prevalence of obesity in Samoa dramatically increased from 1978 to 1991 by up to 297% among all age groups combined (20). Over a 5-year period, BMI of Samoan adults increased more rapidly than 10-year changes in BMI of US black and white adults (21).

2.2 Differences in fatness between Pacific Island and non-Pacific groups

Ethnic differences in fatness between Pacific Island and non-Pacific groups provide further support for lifestyle differences contributing to obesity in the South Pacific. Comparisons of fatness between Pacific and non-Pacific groups have been carried out in Australia, New Zealand or Pacific Island countries. Results are summarised in Table 2.1.

Australian studies

The only study to have compared Pacific Island and non-Pacific groups in Australia was a study of Australian children, in which obesity was more prevalent among Pacific Islanders than other ethnic groups (23). However, these comparisons must be interpreted with caution because only a small number of Pacific Islanders were studied (87 boys, 96 girls) (23).

New Zealand studies

Adult studies

Previous surveys carried out in New Zealand adults have found large ethnic differences in BMI levels and overweight/obesity prevalence (24-26). The 1997 National Nutrition Survey (NNS97) found that, compared to Europeans, Maori and Pacific Islanders aged 15 years and over had a higher overweight and obesity prevalence, BMI and skinfold thicknesses (25). More recently, the Diabetes Heart and Health Survey (DHHS) (26) also found that Pacific Island adults had a higher obesity prevalence and BMI levels than European adults. Similarly, the 2006/7 NZ Health Survey reported that Maori and Pacific Island adults had higher BMI levels and obesity prevalence than European adults (24).

Studies of children and adolescents

Previous studies of children and adolescents have compared fatness between Pacific Island and non-Pacific groups (17, 24, 27-31). The Auckland High School Heart survey (AHHS) showed that Pacific Island youth had a higher BMI than non-Pacific youth (31). Further, this study (31) showed that percent body fat (%BF) was higher among Pacific Island than among European adolescents, although %BF was estimated from a BIA prediction equation developed in mainly primary school- and intermediate school-aged children (32) (a background to BIA is provided in Section 3.2.2). Similarly, a survey of Auckland children aged 5-10.9 years showed that 49.3% of Pacific Islanders had a %BF of over 30%, which was markedly larger than the proportion of 30.3% for European children (29). Of note, though, the %BF estimates were derived from a BIA prediction equation that had not been cross-validated (33). Another regional study of Hawkes Bay children aged 11-12 years found that compared with European children, BMI was greater and overweight or obesity prevalence was a higher among Maori and Pacific Island children (17). The 2002 National Children's Nutrition Survey (CNS02) showed that 26% of Pacific boys and 31% of Pacific girls were obese, which was markedly higher than for other ethnic groups (27). Another analysis of the CNS02 showed that Pacific Island children were eleven times more likely to be extremely obese than European/Other children (28). A different analysis of the CNS02 found that Pacific Islanders had more %BF (estimated from a BIA prediction equation) than Europeans in boys but not in girls (30). A more recent study, the 2006/7 NZ Health Survey, reported that Maori and Pacific Island children aged 2-14 years had higher BMI levels and obesity prevalence than Europeans (24). The Youth 2007 survey, which comprised a nationally representative New Zealand sample of adolescents, showed that Pacific Island youth had a markedly higher obesity prevalence than non-Pacific youth, and a higher mean BMI and WC, than European and Asian adolescents (34).

Pacific Island studies

There are some data on obesity prevalence among Pacific Island children living outside of New Zealand and Australia. A study of preschool children living in Hawaii found that weight-for-height percentile among Samoans was higher than among other ethnic groups, although the number of children in each ethnic group was not large (ranging from 33 to 196) (35). A larger survey of children and adolescents living in Tonga (n=895) carried out in 2002 and 2003 found that the prevalence of overweight and obesity was approximately 20% (36), which was notably lower than overweight and obesity prevalence reported for Pacific Island children and adolescents living in New Zealand (17, 27, 29). A study found that Samoan children living in American Samoa and Hawaii – especially the latter – had a higher BMI than Samoan children living in Samoa (37). Another study

found that Hawaiians had higher BMI than non-Hawaiians; and at some, but not all ages, Hawaiians also had higher skinfold thickness (38). However, Hawaiian children and adolescents had distinctly higher BMI and skinfold thickness (matched for age), when compared to a US reference population (38).

2.3 Explanations for high fatness levels in Pacific Island populations

There are a number of determinants of obesity (11, 39) and factors that account for ethnic differences in obesity prevalence (40). Factors that are either commonly studied or appear to be correlated with Pacific Island ethnicity, and thus are potential reasons for why Pacific Island populations have high BMI levels, include differences in socio-economic status (SES), rate of maturation and growth, and socio-cultural factors. These are discussed below.

1) Socioeconomic status

Because Pacific Islanders have a lower SES than non-Pacific groups (41), it is possible that SES may potentially account for increased obesity prevalence among Pacific Islanders. In support of this, international research shows that SES influences ethnic differences in obesity prevalence (42, 43). A nationally representative sample of US youth showed that ethnic differences in odds of overweight were largest among those with low SES (42). In another nationally representative US sample of children and adolescents aged 6-19 years, BMI differences between gender/race subgroups were dependent upon income status (43).

The contribution of SES to ethnic variation in weight status has been examined by New Zealand data. The Youth 2007 survey showed that Maori and Pacific Islanders, particularly the latter, had higher BMI, WC and rates of overweight and obesity than other ethnic groups, and these ethnic differences were largest among those living in the most deprived areas (34). Other New Zealand studies demonstrate that Maori or Pacific Islanders have higher BMI (44) or odds of obesity (26) than Europeans, even after accounting for SES. Altogether, these findings suggest that SES does not fully explain differences in fatness between Pacific and non-Pacific ethnic groups (26, 34, 44). Of note, a limitation of this New Zealand research is that direct measures of body fat were not obtained in these studies (26, 34, 44).

2) Maturation and growth

Another plausible explanation is differences in rate of maturation because previous studies suggest that, compared to European children, Pacific children enter puberty or mature earlier (30, 45-47).

International research has shown that pubertal status contributes to ethnic differences in fatness (48, 49). In a nationally representative US sample, ethnic differences in overweight and obesity were eliminated after adjustment for sexual maturation (48). However, this effect may have been confounded by dietary intake, as the study used only a single 24-hour recall to adjust for energy intake (48). Among 2799 black and white children aged 9-10 years, racial differences in BMI and skinfold thickness were removed after adjustment for maturation stage (49). It is important to note, however, that this study did not adjust for important confounders (including dietary intake and physical activity) (49).

These studies (48, 49) show that rate of maturation and growth have the potential to contribute to increased obesity prevalence among Pacific Island youth. However, these factors do not appear to be major contributors because adult studies indicate that Pacific Island groups have higher BMI levels than non-Pacific groups. Furthermore, these factors do not seem to be plausible explanations for the increase in body size observed among South Pacific youth over time.

3) Socio-cultural factors

Another plausible determinant is socio-cultural factors. Socio-cultural factors inherent to Pacific Island groups have been recognised as important influences of individual behaviours that include eating, physical activity and sedentary behaviours (50). However, it is not clear exactly what socio-cultural factors are important in determining obesity in Pacific youth (50). Qualitative research is required to determine the particular socio-cultural factors that are important (50, 51).

One type of socio-cultural factor that has been commonly researched in Pacific Island groups is body image or weight perception. Because a large body size appears to be more acceptable to Pacific groups than other ethnic groups (23, 26, 52-54), it is possible that weight perception may be a factor in determining higher obesity prevalence among Pacific Islanders. However, the increase in body size among South Pacific youth depicted above suggests that weight perceptions are not driving the temporal trends in obesity, and consequently are not major reasons for the higher body size observed among Pacific populations. This is supported by evidence suggesting that Pacific groups are adopting preferences for smaller body sizes (54, 55).

4) Genetics

It has been proposed that Polynesian settlement many years ago entailed long ocean voyages, in which sailors would have experienced low temperatures and food supply shortage. Being overweight

would have provided a survival advantage because this would have given greater energy reserve stores (adipose tissue) and more insulation for the sailors (21). In addition, a large muscular physique, characteristic of Polynesians, would have helped to maintain body temperature (56). A genotype that predisposes such individuals to rapid weight gain would have therefore facilitated survival and consequently become prevalent in the gene pool (21, 57). This supports the view that genetic factors may make Pacific groups more susceptible to weight gain.

Other evidence supporting a role of genetics is the finding of the presence of genetic polymorphisms in Pacific populations which have been shown to be associated with obesity (57). Further, genetic predisposition to obesity (single-nucleotide polymorphisms known to be associated with BMI) has been shown to moderate the longitudinal association of sugar-sweetened beverage consumption with BMI (58).

While all of the above supports a role of genetics in accounting for increased obesity prevalence in Pacific populations, the large increases in obesity prevalence in these groups have occurred over a short period of time (Section 2.1), suggesting that factors other than genetics *drove* the rising obesity prevalence. In addition, it is not known what specific role genetic factors play in obesity aetiology in South Pacific youth.

Conclusion

In conclusion, obesity prevalence and BMI levels in South Pacific populations have increased rapidly in a short time-frame. Studies of children and adults consistently show that body size is notably larger or obesity prevalence is distinctly higher among Pacific Islanders than among non-Pacific groups.

Plausible explanations for the increased fatness levels among Pacific Island populations include low SES and high rate of maturation and growth. However, these do not seem to be major determinants. Body image does not appear to be an important explanation either, and other socio-cultural factors need to be identified through more research. Further, socio-cultural factors do not appear to be driving higher obesity prevalences among Pacific populations because it does not seem plausible that they account for large differences in BMI observed between Pacific Islanders living in different countries (37). Another explanation is genetic factors, but the large increases in obesity prevalence observed over a short time-frame suggest that other factors have driven the increased fatness levels.

Environmental factors are likely to be responsible for the abovementioned temporal trends and ethnic variations because the temporal trends have occurred over a short period of time. Consistent with this hypothesis, Pacific Island groups living in the same environment have similar fatness levels (26, 31); but, in comparison, Pacific groups living in different environments notably differ in fatness. It is difficult to identify exactly what environmental factors account for high fatness levels in Pacific populations. This has been complicated by the fact that several previous studies that have examined differences in fatness levels between Pacific and non-Pacific groups have not statistically modelled the influence of environmental variables on these ethnic differences in fatness and only a few used direct measures of body fat. An understanding of what accounts for high fatness levels among Pacific Island youth could identify areas suitable for interventions.

Successful interventions should focus on environmental factors that are modifiable. Environmental factors that are most amenable to change in adolescence, where lifelong behaviours are being formed, are lifestyle factors. It is not only for this reason that lifestyle variables appear to be suitable targets for interventions; there has been some suggestion that they may be responsible for the temporal trends in obesity prevalence. Obesity prevalence in Australia and New Zealand has plateaued over the last decade and it has been suggested that lifestyle changes may be a potential reason for this (15, 16, 24). Therefore, this thesis will examine the association of lifestyle variables with fatness among South Pacific youth. Before this is done, though, it is necessary to consider how well BMI measures fatness in South Pacific youth because BMI has been criticised for overestimating fatness in Pacific populations (12). This will be done in Chapter 3.

Table 2.1. Studies that compared differences in fatness between Pacific Island and other ethnic groups

First author	Subjects	Findings	Limitations
Australian studies			
O'Dea (23)	7889 Australian children aged 6-18 y	Pacific Islanders had a higher obesity prevalence (6-11 y: 18.8% for males, 15.6% for females; 12-18 y: 23.6% for males, 23.4% for females) than other ethnic groups (6-11 y: ≤10.0% for males, ≤13.3% for females; 12-18 y: ≤21.9% for males, ≤17.2% for females)	1) Small number of Pacific Islanders (87 boys, 96 girls) 2) Used only height & weight to measure fatness
NZ studies			
NZ Ministry of Health (24)	4,921 children aged 0-14 y & 12,488 adults aged 15 y & over	For both children (2-14 y) & adults, mean BMI & the prevalence of obesity was higher in Maori (children: BMI=19.4; adults: BMI=29.8) & Pacific Islanders (children: BMI=21.1; adults: BMI=33.2) than in Europeans (children: BMI=18.3; adults: BMI=26.8)	Used only height, weight & WC to measure fatness
Russell (25)	4420 adolescents & adults aged 15 y & over. 273 Pacific subjects	Overweight & obesity prevalence, BMI & skinfold thickness higher in Pacific (BMI=31.1 in males & 32.2 in females) & Maori (BMI=28.7 in males & females) than in European (BMI=25.6 in males & 25.5 in females) adults	1) Subjects were mainly adults 2) Small number of Pacific subjects 3) Used only anthropometry to estimate fatness
Sundborn (26)	Representative sample of Aucklanders aged 35-74 y: 1011 Pacific & 1745 European	BMI & prevalence of obesity higher in Pacific Islanders (BMI=up to 34.4 in men & up to 36.3 in women) than in Europeans (BMI=27.6 in men & 27.3 in women)	1) Subjects were adults 2) Used only height, weight &WC to measure fatness
Turnbull (17)	871 NZ children aged 11-12 y from Hawkes Bay	Compared with Europeans, a higher percentage of Maori & Pacific Islanders were overweight or obese. BMI higher in Maori (20.8) & Pacific Islanders (21.3) than in Europeans (19.2)	1) Not representative of Pacific children living in NZ 2) Subjects were mainly primary school- & intermediate school-aged children 3) Used only height & weight to measure fatness
Tyrrell (29)	2273 Auckland children aged 5-10.9 y	Higher proportion of Pacific children had a %BF>30% (49.3% for Pacific, 30.3% for European) & BMI>95th percentile (24.1% for Pacific, 8.6% for European) than European	1) Young age of participants 2) %BF derived from a BIA prediction equation that was not cross-validated

		children	
NZ Ministry of Health (27)	3275 Maori, Pacific, NZEO 5-14 y children aged 5-14 y (same study as (28) & (30))	Obesity prevalence, BMI levels & skinfold thickness was higher in Pacific than in non-Pacific children (obesity prevalence=26.1% in Pacific males, 31% in Pacific females, 4.7% in NZEO males & 6% in NZEO females)	1) Subjects were mainly primary school- & intermediate school-aged children 2) Used only anthropometry to estimate fatness
Goulding (28)	3049 NZ children aged 5-14 y (same study as (27) & (30))	Pacific children were 11 times more likely to be extremely obese than NZEO children	1) Subjects were mainly primary school- & intermediate school-aged children 2) Used only a categorical variable based on height & weight to measure fatness
Rush (30)	643 Auckland children aged 5-14 y (same study as (27) & (28))	Pacific Islanders had more %BF (estimated from a BIA prediction equation) than Europeans in boys (23.5% in Pacific, 20.4% in European) but not in girls	1) Small numbers in ethnic groups 2) Appears that age was not adjusted for
Schaaf (31)	2487 adolescents from Auckland high schools	Pacific adolescents had a higher BMI than non-Pacific adolescents (4.5 units more than Europeans) & 3.2% more %BF than Europeans	%BF was derived from a BIA prediction equation developed in mainly primary school- & intermediate school-aged children
Utter (34)	Nationally representative sample of NZ adolescents (n=8796)	Maori & Pacific Islanders had higher BMI, WC & rates of overweight & obesity than Europeans, Asians & other ethnic groups (obesity prevalence=27.1% for Pacific, 16.1% for Maori & ≤7.3% for other ethnic groups). These ethnic differences were largest among those living in the most deprived areas	Used only height, weight & WC to measure fatness
Pacific Island studies			
Bindon (37)	786 Samoan children aged 5.5-11.5 y	Samoan children living in American Samoa & Hawaii had a higher BMI than Samoan children living in Samoa	Used only height & weight to measure fatness
Derrickson (35)	616 preschool children living in Hawaii	Weight-for-height percentile among Samoans (74.7) was higher than among other ethnic groups (≤58.5)	1) Small number of Samoans (n=61) 2) Used only height & weight to measure fatness
Chai (38)	1437 Hawaiian & non-Hawaiian children & adolescents aged 6-17 y	1) At nearly all ages, Hawaiians had higher BMI than non-Hawaiians. Hawaiians also had more skinfold thickness at some but not all ages	Used only anthropometry to estimate fatness

		2) Hawaiians had distinctly higher BMI & skinfold thickness compared to a US reference population	

NZEO=New Zealand European/Other; %BF=Percent body fat; BIA=bioimpedance; WC=Waist circumference.

CHAPTER 3: MEASURES OF FATNESS

3.1 Introduction

As mentioned in Chapter 2, it is important to consider how well BMI measures fatness in South Pacific youth. This will be examined in this chapter (Section 3.2.1). Another method for quantifying fatness, besides BMI, is BIA. This may potentially be a better method for quantifying fatness because, unlike BMI, it distinguishes lean mass from fat mass (FM). However, it is necessary to consider the ability of BIA to predict fatness in South Pacific youth. Accordingly, this will be done in Section 3.2.2.

Central fatness is a more important predictor of morbidity and cardiovascular risk factors than total fatness alone (8), and abdominal adipose tissue is a recognised predictor of disease risk (59). As reference methods to measure abdominal fatness, such as DXA, are not suitable for field use, it is important to consider whether surrogate measures can be used to accurately estimate abdominal obesity. This will be examined in Section 3.2.3 (*Waist circumference*).

Although the study population in this thesis is adolescents, studies of adults are nevertheless examined in this chapter, in addition to studies of children and adolescents. This is because there is a limited number of the latter.

Literature relevant to this chapter was searched on the following databases up to April 2012 (no limit placed on the year of publication): *Medline In-process & Other non-indexed Citations and Medline, Scopus, PubMed* and *Google Scholar*. Combinations of keywords were used to identify relevant articles: *four-compartment model*, *densitometry*, *hydrostatic weighing*, *plethysmography*, *isotope dilution*, *dual-energy X-ray absorptiometry*, *waist*, *abdominal fat*, *trunk fat*, *trunk impedance*, *body mass index*, *body fat*, *muscle*, *muscularity*, *bone*, *fat distribution*, *body shape*, *leg length*, *bioimpedance*, *bioelectrical impedance*, *BC-418*, *ethnic*, *race*, *Pacific*, *Australia* and *New Zealand*. Furthermore, several articles were located through citations in other articles.

3.2 Measures to estimate adiposity

3.2.1 Body mass index

As mentioned in Chapter 2, BMI has been criticised for overestimating fatness in Pacific populations (12). Similarly, international research has observed that the relationship between BMI and body fat depends on ethnicity or race (11). Thus, BMI may not be an equivalent measure of fatness across ethnic groups participating in the OPIC study. This section will review previous studies that have examined whether the relationship between BMI and %BF is ethnicity-dependent. In addition, it will explore factors that may account for ethnic differences in the relationship between BMI and %BF.

Influence of ethnicity on the relationship between BMI and fatness

International studies (non-Pacific)

Because of the substantial research on this topic, international studies have been limited to those of children and adolescents. Table 3.1 shows that six international studies of children and adolescents have examined ethnic differences in the relationship between BMI and %BF as derived from DXA, densitometry, BIA or skinfold thickness prediction. All studies reported ethnic differences in fatness at a given body size (60-65). As is evident from Table 3.1, there is a lack of information about what accounts for these ethnic differences. These studies did not assess what factors contribute to the %BF ethnic differences (60-65). Other limitations of these previous studies are described in Table 3.1.

Only a few studies compared BMI-%BF relationships between Asians and Caucasians (63-65). However, in these studies, participants were young (7-12 years) (63), age range was limited (spanned 2 years) (64, 65), girls were not studied (findings among boys were not provided) (64), and a prediction equation was used to estimate %BF (rather than using accepted reference methods such as DXA) (64, 65).

Pacific Island studies

Only two studies which compared participants living in Pacific Island countries with those in other countries were identified (55, 66). Both studies (55, 66) found that, for the same BMI, Pacific Islanders had less %BF than Caucasian Australians (Table 3.2). However, these studies were limited by the fact that they were carried out in adults, %BF was derived from a BIA prediction equation, and the factors that may account for ethnic differences in the relationship between BMI and %BF were not assessed. Estimating %BF from a BIA prediction equation is a limitation because BIA is

not a gold standard measurement for an individual (67); it is preferable to measure %BF with an accepted reference method such as DXA to obtain greater certainty (precision) of %BF values.

New Zealand studies

Adults

Six previous adult studies carried out in New Zealand have reported ethnic differences in fatness at a given BMI (Table 3.3). In these studies, compared to Europeans, for the same BMI, Pacific Islanders had less %BF (68-72) or FM (73), while Asian Indians had more %BF (69-72). One study measured %BF from isotope dilution (68), while all other studies used DXA (69-73).

However, these studies are not without limitations (Table 3.3). Absolute fat mass, which is not normalised for size, was used as a fatness measure instead of %BF (73). Males (68, 72) and females (70) were not studied together (only findings about one gender was provided), and what accounted for ethnic differences in the relationship between BMI and %BF was not examined (68, 70-73).

Children and adolescents

Three previous studies of children and adolescents carried out in New Zealand have reported ethnic differences in %BF at a given BMI (Table 3.4). For the same BMI, Pacific Island and Maori girls had less %BF than European girls (32). A similar difference was not reported between Pacific Island, Maori and European boys (Table 3.4), possibly because of the limited BMI and %BF range for the European boys participating in that study (32). Another limitation in this study is that participants were mainly primary school- and intermediate school-aged children (32); ethnic differences reported in young children may underestimate those present in adolescents (74). A large (n>2000) study of Auckland children found that for the same BMI, Asian Indians had more %BF than Europeans (29). However, that study used a prediction equation to estimate %BF (29). Another study reported that, compared to Europeans, Pacific Islanders had less %BF, while South and East Asians had more %BF (75). Drawbacks of that study are that it did not study boys and %BF was estimated from a BIA prediction equation (75). A limitation common to all studies is that factors that accounted for ethnic differences in the relationship between BMI and %BF were not assessed (29, 32, 75).

Factors that account for ethnic differences in the relationship between BMI and fatness

Muscularity, bone mass, fat distribution and relative leg length

There are various factors that may contribute to ethnic differences in %BF at a given BMI. There are ethnic differences in skeletal muscle mass between Pacific Islanders, Asian Indians and Europeans (69, 70), and this has partly accounted for ethnic differences in %BF at a fixed BMI (69). Frame size also contributes to %BF differences at a given BMI (76, 77). Fat distribution variables differ between ethnic groups and these have partly accounted for differences in %BF between ethnic groups at the same BMI (69). Differences in relative sitting height partly explain %BF differences between ethnic groups at fixed BMI (76). However, a limitation of these studies is that they have been carried out in adults.

Body shape

A factor that may potentially contribute to ethnic differences in %BF at a given BMI is WC-based measures (body shape). This is plausible because, in children and adolescents, WC-based measures predict trunk fat mass (78). Consequently, because BMI is influenced by limb mass, the use of WC may provide information on the degree of body fatness independently of BMI. In support of this, a study of children and adolescents aged 7-17 years found that, for the same BMI, gender, race and maturation stage, %BF increased with waist:hip ratio (60). While this girth measure added 3% to the explained variance of that model and showed that waist:hip ratio predicts %BF independently of BMI, its effect on ethnic differences in %BF at a given BMI was not reported (60).

Conclusion

BMI is a practical and widely used method for measuring body fat. However, previous studies suggest that the relationship between BMI and %BF varies with ethnicity. This implies that it is difficult to compare body fat between ethnic groups using BMI alone.

Studies have found that muscularity, bone mass/frame size, fat distribution and relative sitting height/leg length influence the effect of ethnicity on BMI-%BF relationships; however, these have been carried out in adults. WC-based measures have the potential to contribute as well, but previous studies have not assessed this possibility in youth.

Whether ethnic differences in %BF at a given BMI exist between Asian, Pacific Island, Maori and Caucasian children and adolescents has been examined in previous research. However, the number of

studies is few (32, 64, 65, 75). Three studies used prediction equations to estimate %BF, rather than measuring %BF with accepted reference methods such as DXA (64, 65, 75). One study which used an accepted reference method (isotope dilution), studied mainly primary school- and intermediate school-aged children, and had a limited BMI and %BF range for the European male participants (32). Two of these had a narrow age range and did not study Maori or Pacific Islanders (64, 65). Another limitation is that both boys (75) and girls (64) were not studied. Therefore, it is not clear whether the relationship between BMI and %BF varies with ethnicity in Pacific Island, Maori, Asian Indian and European boys and girls.

To address the gaps of knowledge in the literature mentioned above, this thesis aimed to: 1) compare %BF at a given BMI between Pacific Island, Maori, Asian Indian and European adolescent boys and girls and, 2) examine whether body shape and other factors contribute to ethnic differences in this relationship.

Table 3.1. International studies of *children and adolescents* that examined ethnic differences in the relationship between BMI and fatness

First author	Subjects	Measurements & definitions	Variables in fatness prediction model	Findings	Limitations
Daniels (60)	192 black & white children (100 boys, 92 girls). Mean age: 12 y for boys & 11 y for girls	Body fat by DXA	BMI, gender, race, maturational stage, waist:hip ratio	For the same BMI, gender, race, maturational stage & waist:hip ratio, whites had 1.5% more %BF than blacks	1) Mean age is young 2) Only assessed the effect of waist:hip ratio on ethnic differences in %BF
Ellis (61)	297 US boys (145 white, 78 black, 74 Hispanic) aged 3-18 y	Body fat by DXA		Compared to whites & blacks, for the same body size, Hispanics had more body fat	1) Did not study girls 2) Did not adjust for BMI 3) Did not assess what factors accounted for ethnic differences
Ellis (62)	313 US girls (141 white, 104 black, 68 Hispanic)	Body fat by DXA	Weight, height	Compared to whites, for the same body size, Hispanics had more fat mass & %BF	1) Did not study boys 2) Did not adjust for BMI 3) Did not assess what factors accounted for ethnic differences
Deurenberg (63)	150 children (75 boys, 75 girls), aged 7-12 y, from Singapore, Beijing & Wageningen (Holland)	Body fat by densitometry in Beijing & Wageningen, & by DXA in Singapore	BMI, sex, age	For the same BMI, sex & age, compared to Dutch children, Singaporean children had 4.3% more %BF	1) Young age of participants 2) Did not assess what factors accounted for ethnic differences
Mehta (64)	139 white & South Asian boys aged 14-16 y	Body fat by BIA	BMI	At a fixed BMI, South Asian boys had 4.5% %BF than white boys	1) Limited age range 2) Did not study girls 3) Used a BIA prediction equation to estimate %BF 4) Did not assess what factors accounted for ethnic differences
Deurenberg (65)	89 Dutch & 101 Singaporean adolescents aged 16-18 y	Body fat by skinfold prediction equations	BMI, age	At a given BMI & age, Singaporean adolescents had more %BF than Dutch adolescents. This %BF ethnic difference ranged from 4.1-9.1% for boys & 5.2-7.2% for girls, depending on the %BF prediction equation used	1) Limited age range 2) Used a BIA prediction equation to estimate %BF 3) Did not assess what factors accounted for ethnic differences

DXA=Dual-energy X-ray absorptiometry; %BF=Percent body fat; BIA=Bioimpedance analysis.

Table 3.2. Pacific Island studies that examined ethnic differences in the relationship between BMI and fatness

First author	Subjects	Measurements & definitions	Variables in fatness prediction model	Findings	Limitations
Craig (55)	543 Tongans & 393 Caucasian Australians	%BF by BIA	Mean %BF was compared between ethnic groups in BMI groups	In each sex, Australians had more %BF than Tongans in each of the following BMI groups: 1) 20-<25 kg/m^2, 2) 25-<30 kg/m^2, 3) 30-<35 kg/m^2, 4) ≥35 kg/m^2	1) Used a BIA prediction equation to estimate %BF 2) Did not assess what factors accounted for ethnic differences
Swinburn (66)	128 Cook Islanders & 493 Caucasian Australians	%BF by BIA	BMI	For the same BMI, Cook Islanders had more %BF than Caucasian Australians	1) Used a BIA prediction equation to estimate %BF 2) Did not assess what factors accounted for ethnic differences

%BF=Percent body fat; BIA=Bioimpedance analysis.

Table 3.3. New Zealand studies of *adults* that examined ethnic differences in the relationship between BMI and fatness

First author	Subjects	Measures	Variables in fatness prediction model	Findings	Limitations
Rush (68)	42 white & 40 Polynesian women aged 18-27 y	Body fat by isotope dilution	BMI	For the same BMI, Polynesians had 3.6% less %BF than NZ Europeans	1) Did not study males 2) Did not assess what factors accounted for ethnic differences
Swinburn (73)	189 Maori, 185 Samoans, 241 Europeans aged 20-70 y	Body fat by DXA	BMI	At a given BMI, Polynesians had less FM than Europeans. This effect was exaggerated at higher BMI values	1) Measure of fatness was fat mass, rather than %BF 2) Did not assess what factors accounted for ethnic differences
Rush (70)	114 men (64 European, 31 Pacific, 19 Asian Indian) aged 17-30 y	Body fat by DXA	BMI	For the same BMI, compared to Europeans, Pacific Islanders had 3.8% less %BF & Asian Indians had 7.6% more %BF	1) Did not study females 2) Did not assess what factors accounted for ethnic differences
Rush (72)	Women aged 18-60 y: 201 SA black, 94 SA European, 173 NZ European, 76 NZ Maori, 84 NZ Pacific, 93 NZ Asian Indian	Body fat by DXA	BMI	At a BMI of 30 in NZ Europeans, the BMI of: 1) Maori & Pacific Islanders that would predict the same %BF was lower. Such differences in the BMI-%BF relationship were exaggerated at higher BMI values 2) Asian Indians that would predict the same %BF was 26.4	1) Did not study males 2) Did not assess what factors accounted for ethnic differences
Rush (69)	933 European, Maori, Pacific & Asian Indian adults aged 17-80 y	Body fat by DXA	BMI, age	1) In men, compared to Europeans & Maori, at a fixed BMI, Pacific Islanders had less %BF & Asian Indians had more %BF 2) In women, compared to Europeans, at a fixed BMI, Maori & Pacific Islanders had less %BF & Asian Indians had more %BF	1) Did not assess the impact of body shape & central/limb FM on ethnic differences 2) Changes to coefficients of the ethnic differences were reported in a limited number of cases
Wen (71)	European, Maori, Pacific Island, Asian Indian & Chinese adults aged 30-39 y	Body fat by DXA	BMI	1) In men, compared to Europeans & Maori, for the same BMI, Pacific Islanders had 2.9% less %BF, Asian Indians had 11.7% more %BF & Chinese had 3.9% more %BF 2) In women, compared to Europeans & Maori, for the same BMI, Pacific Islanders had less %BF (depending on the BMI), Asian Indians had 8.1% more %BF, Chinese had 2.8% more %BF	Did not assess what factors accounted for ethnic differences

DXA=Dual-energy X-ray absorptiometry; %BF=Percent body fat; FM=Fat mass; SA=South African; NZ=New Zealand.

Table 3.4. New Zealand studies of *children and adolescents* that examined ethnic differences in the relationship between BMI and fatness

First author	Subjects	Measurements & definitions	Variables in fatness prediction model	Findings	Limitations
Rush (32)	172 Pacific Island, Maori & European children aged 5-14 y	Body fat by isotope dilution	Only BMI & ethnicity in models	1) For the same BMI, Pacific & Maori girls had 3.7% less %BF than European girls 2) For the same BMI, %BF did not differ between Pacific, Maori & European boys	1) Young age of participants 2) Did not examine factors that account for ethnic differences in the relationship between BMI & %BF 3) BMI & %BF of European boys were limited in range
Tyrrell (29)	2273 Auckland children aged 5-10.9 y	Body fat by BIA	BMI	Compared to Europeans, for the same BMI, Asian Indians had more %BF	1) Used a BIA prediction equation to estimate %BF 2) Did not assess what factors accounted for ethnic differences
Duncan (75)	1676 girls aged 5-16 y from Pacific Island, Maori, European, South Asian & East Asian ethnic groups	Body fat by BIA	BMI, age	Compared to Europeans, for the same BMI, South Asians had 4.5% more %BF, East Asians had 1.4% more %BF, Maori had 0.7% less %BF (though not statistically significant) & Pacific Islanders had 1.8% less %BF	1) Did not study boys 2) Used a BIA prediction equation to estimate %BF 3) Did not assess what factors accounted for ethnic differences

%BF=Percent body fat; BIA=Bioimpedance analysis.

3.2.2 Bioimpedance analysis

As mentioned previously, a limitation of BMI is that it does not differentiate fat mass from lean mass. In addition, as mentioned in the previous section, past research suggests that the relationship between BMI and %BF varies with ethnicity. Thus, there is a need to develop simple methods that more accurately measure fatness in South Pacific youth.

BIA is a simple approach to measurement of fatness; it allows body fat to be measured quickly and easily, BIA instruments are portable, and the technique is non-invasive and suitable for field use. Measurement involves passing an electrical current through the body. This current flows through the electrically conducting compartment of the body, namely the water space. Thus, the impedance to this current flow provides a measure of total body water. Total body water comprises a significant and relatively fixed fraction of the lean tissue or FFM of the body. Therefore, BIA can also provide a measure of FFM (which can be used to derive body fat by knowing body weight) and differentiates this from FM. The relationship between BIA measures of impedance and FFM is dependent on physical (height and weight) and demographic (age, gender and ethnicity) factors (67). Thus, prediction of FFM relies on the use of equations based on not only BIA measurement, but also measurement of physical and demographic factors. The BIA equations for estimating fatness tend to be specific for the population in which they were developed and, therefore, need to be validated in the populations in which they are to be applied. Consequently, this section will examine studies that developed BIA prediction equations in South Pacific children and adolescents and determine whether these equations apply to youth participating in the OPIC study.

The BIA measurement obtained is dependent upon posture: measurement in the standing position will give a different impedance value from that when one lies down (79). Measurement is also affected by placement of electrodes: for instance, if electrodes are placed more distally, impedance will increase as current has to flow a greater distance. The OPIC study used an 8-electrode bioimpedance analysis (BIA_8) device (BC-418; Tanita, Tokyo, Japan) to estimate body composition. This instrument measures impedance in the standing position, whereas most BIA devices carry out measurement with the individual lying supine (67). Further, the electrodes BIA_8 uses make contact with the skin at the anterior surface of the hand (palm and fingers) and the plantar surface of the feet (heel and toes); in comparison, the electrodes of most other BIA instruments make contact with the skin at the wrist and ankle (67). BIA_8 measures whole-body impedance from a current that passes through the left leg, trunk and left arm (foot-to-leg pathway; (80)); this differs from "foot-to-foot" BIA devices, which utilise a current that passes through both legs only (33). Because BIA_8 is

different to other BIA devices with respect to position during measurement (standing or lying), placement of electrodes and/or electrical pathway utilised (foot-to-foot or foot-to-leg), impedance obtained from other BIA devices cannot be treated as equivalent to that measured by BIA_8, indicating that BIA_8 needs to be specifically validated for study populations. Therefore, it is important to know whether BIA_8 accurately predicts fatness in South Pacific youth. To achieve this objective, previous studies that have assessed the predictive accuracy of BIA_8 in samples will be reviewed.

Studies that developed BIA prediction equations in Pacific Islanders, Maori and Asians

As shown in the summary provided by the study of Nielson *et al* (67), several BIA models have been developed in white samples. In comparison, few models have been developed in Pacific Island, Maori and Asians samples (67). Therefore, studies that have developed BIA models in these three ethnic groups will be discussed below.

Pacific Islanders and Maori

Few studies have examined the relationship between BIA and body composition in Pacific Island or Maori children and adolescents (32, 33). In 82 New Zealand children aged 4.9-10.9 years, a FFM prediction equation based on height^2/impedance, weight, height and gender, with an R^2 of 0.97, was developed (33). However, there were only 16 Maori and 13 Pacific Island participants, the prediction equation was not cross-validated and the participants were primary school-aged (33).

The other study, of New Zealand children aged 5-14 years, used a double cross-validation technique to develop a FFM prediction equation (boys and girls combined) based on height^2/impedance and weight, with an R^2 of 0.96 and standard error of estimate (SEE) of 2.44 kg (coefficient of variation (CV)=8.0%) (32). However, the study sample comprised mainly primary school- and intermediate school-aged children – younger than the age group studied in this thesis.

Asians

Few studies have developed prediction equations for Asians (67). A limitation of these studies are that the samples have consisted of only Chinese, Japanese or Korean subjects (81-84) and did not include people from other parts of Asia. One study did not specify the ethnic make-up of their Asian subjects, which adds some uncertainty to the applicability of its BIA equations (85). In addition, the BIA prediction equations developed in that study (85) necessitated measurement of skinfold thickness, which is not easy to measure in the field setting.

Only one study has examined the relationship between BIA and body composition in Asian children living in New Zealand (86). In this study, Duncan and colleagues (86) developed a prediction equation for Chinese and Indian boys and girls aged 5-14 years, and obtained a FFM model with height^2/resistance and weight as a predictors and with an R^2 of 0.98 and SEE of 1.49 (CV=5.4%). However, because the subjects were mainly primary school- and intermediate school-aged children, it is difficult to extrapolate these findings to older youth.

Studies that assessed the ability of BIA_8 to predict body composition

Table 3.5 shows studies that have examined the ability of BIA_8 to predict body composition. All studies have found that BIA_8 provided biased estimates of body composition (Table 3.5). That is, BIA_8 underestimated FM (87-89) or %BF (87, 88, 90), while in other studies BIA_8 tended overestimate %BF in leaner subjects (91, 92) but underestimate in fatter subjects (91).

However, the limitations of these studies need to be taken into consideration. Most studies consisted of adults (87-91). Three studies (88-90) comprised only obese subjects; these studies do not provide information on the ability of BIA_8 to predict body composition in those who are non-obese. Further, not one study comprised Pacific Island, Maori or Asian subjects (87-92).

Conclusion

Only two studies have developed BIA prediction equations in Pacific Island and Maori children/adolescents (32, 33). In one study, participants belonging to these ethnic groups were few in number (33) and the BIA prediction model was not cross-validated; and in both studies, the subjects were young children (32, 33). Therefore, there is uncertainty in the ability of the BIA prediction equations developed in these studies (32, 33) to accurately predict fatness in Pacific Island and Maori adolescents.

There are a limited number of studies that have developed BIA prediction equations in Asians. Limitations of the studies include the fact that the prediction models were not developed in young subjects (<14 years of age) and that the majority of these studies have not included Asian Indian subjects. Therefore, it is not known how well these equations predict fatness in Asians participating in the OPIC study.

Because BIA_8 is used in the OPIC study to estimate fatness, it is important to know how well it predicts body composition. Previous studies have found that estimates of body composition from the BIA_8 manufacturer's equations do not agree with measures of body composition derived from reference methods. However, owing to the abovementioned limitations of these studies, it is not clear whether these results would be observed in South Pacific youth. Thus, this thesis aimed to: 1) determine the predictive accuracy of the BIA_8 estimates in European, Maori, Pacific Island and Asian adolescents and, 2) develop BIA prediction equations that apply to this population.

Table 3.5. Studies that examined the ability of BIA_8 to predict body composition

First author	Subjects	Measurements	Findings	Limitations
Völgyi (87)	168 Finnish adults aged 37-81 y	Body composition by DXA	BIA_8 underestimated FM & % BF	1) Old age of subjects 2) No Pacific, Maori or Asian subjects 3) Did not develop prediction model in sample
Neovius (88) (baseline analysis of sample in (90))	136 white obese women aged 27-60 y	Body composition by DXA	BIA_8 underestimated FM by 3.6 kg & %BF by 5.0%	1) Old age & obese status of subjects 2) No Pacific, Maori or Asian subjects 3) Did not develop prediction model in sample
Neovius (90) (same study as (88))	Longitudinal study of 106 white obese women (aged 27-60 y at baseline) followed up for 6 months	Body composition by DXA	BIA_8 underestimated % BF cross-sectionally (by 5.0% at baseline & 4.4% at follow-up) & longitudinally (by 0.6%)	1) Old age & obese status of subjects 2) No Pacific, Maori or Asian subjects 3) Did not develop prediction model in sample
Pietrobelli (91)	40 subjects (20 male, 20 female) aged 6-64 y	Body composition by DXA	BIA_8 tended to overestimate %BF in leaner subjects & underestimate in fatter subjects	1) Sample comprised adults 2) No Pacific, Maori or Asian subjects
Prins (92)	133 Gambian children & adolescents aged 5-17 y	Body composition by isotope dilution	BIA_8 overestimated % BF toward the lower end of %BF	1) Body composition measurement reference method was isotope dilution 2) No Pacific, Maori or Asian subjects
Haroun (89)	77 white obese children & adults aged 5-22 y	Body composition by 3-compartment model	1) BIA_8 underestimated FM by 3.5 kg in males & 3.6 kg in females 2) FFM model developed in sample consisted of only height^2/impedance as a predictor. FFM model was cross-validated in 17 subjects	1) Subjects were obese & consisted of adults 2) No Pacific, Maori or Asian subjects 3) Sample that the equation was developed in was small & sample that it was cross-validation in was even smaller

DXA=Dual-energy X-ray absorptiometry; BIA_8=Bioimpedance device (BC-418; Tanita, Tokyo, Japan); FM=Fat mass; FFM=Fat-free mass; %BF=Percent body fat.

3.2.3 Waist circumference

This section will review studies that examined the ability of WC to predict abdominal fatness. A limitation of the literature is that previous studies have examined the association between WC and *absolute* abdominal or trunk fat mass (78, 93). This does not normalise for body size. It does not take into account that fat mass increases with height, so that taller people may have more abdominal fat mass. Further, it does not account for the fact that a person with a large frame would have more organ and abdominal muscle mass and therefore would require more abdominal fat to support the larger frame size. This could mean that for the same abdominal fat mass, disease risk could be overestimated among those with a larger frame size.

Another approach is to derive a regional percent fat measurement by expressing fat mass in the abdomen or trunk as a percentage of weight in those regions. This regional percent fat measurement will correlate less with height and growth by adjusting for weight in the region, which increases with height (94), and may potentially be a better correlate of health risk. Therefore, this section will review studies that have examined the ability of WC to predict regional percent fat in the abdomen or trunk.

As will be discussed, WC is not a direct measure of fatness and there is some evidence that directly measuring abdominal fatness by BIA can potentially improve estimation of abdominal adiposity. This section will review this evidence.

Prediction of percent trunk fat

Adult studies

International adult studies have been included in the review because of the limited research on this topic. There were five adult studies identified that have examined the relationship between WC and percent trunk fat (percentage of trunk weight that is fat; %TF), which are described in Table 3.6. All studies found that WC predicts %TF (Table 3.6).

Given these were adult studies, it is not clear whether these findings would be observed in adolescents. Other limitations of some of these studies are relatively small sample size (95), subjects with a limited WC range (95) and only univariate relationships were examined (96, 97). Some studies did not comprise males (96) or females (97), indicating that they provided findings about only one gender. Another drawback is that not one study cross-validated its %TF equations by

calculating equations in part of their study sample and then checking their validity in the remainder of the sample (95-99) (Table 3.6).

Studies of children and adolescents

Three studies of children and adolescents that have assessed WC-%TF associations were identified and are described in Table 3.7. As illustrated (Table 3.7), all studies found that WC predicts %TF.

However, limitations of these studies (Table 3.7) need to be considered. The %TF models in each study were not cross-validated (100-102). Most studies examined only univariate relationships; that is, they did not assess what factors predict %TF independently of WC (100-102). Other limitations include the fact that the study sample included adults (102), a small sample size (n=74) (102) and the WC range of the participants was limited (101).

Trunk or abdominal impedance

A limitation of using WC to estimate abdominal obesity is that it does not differentiate fat mass from lean mass. This is evident in research that shows that there are racial differences in adipose tissue area at a given WC (103). Further, WC does not fully explain variability in total abdominal adipose tissue (104).

BIA is a technique that distinguishes fat mass from lean mass and is widely used to measure whole-body composition. In recent years, BIA has been used to estimate abdominal visceral fat area (VFA). One study that has examined the ability of abdominal BIA to predict abdominal VFA was a study of 59 subjects (105). This study reported good correlation between WC and CT-measured VFA (r=0.77) (105). In contrast, a significantly higher correlation was found between abdominal BIA and VFA (r=0.88) (105). Thus, abdominal BIA predicted VFA better than WC (105).

Further evidence that BIA can be useful in estimating abdominal VFA was a larger study of 73 adults aged 20-57 years (106). This study found that the correlation between abdominal VFA (measured by computed tomography (CT)) and anthropometry-based equations (using sagittal abdominal diameter, waist:hip ratio, gender, age and weight) was 0.906, and when impedance was added to the model, the correlation increased by up to 0.014, depending on the posture of the subjects, the distance between electrodes and current frequency (106).

A larger study examined the ability of a BIA device to measure visceral adipose tissue (VAT) and total abdominal adipose tissue (TAAT) measured by magnetic resonance imaging (MRI) in 120 adults (107). Visceral fatness estimated from this device correlated with MRI-measured VAT (0.65 for men, 0.64 for women) and TAAT (0.94 for men, 0.92 for women) (107). These correlations, though, were no better than correlations between WC and either VAT or TAAT measured by MRI. At first, this suggests that BIA may not improve the ability to predict visceral and total abdominal fatness over WC (107). However, it needs to be considered that estimates of abdominal adipose tissue from the manufacturer's equations, rather than impedance alone, were compared with the MRI measurements (107).

These studies suggest that measurement of impedance in the abdomen predicts abdominal fat (105-107) and may improve estimation of this over WC-based methods (105, 106). Limitations of all these studies are that they studied adults, and diverse ethnic groups were not studied. Because the relationship between WC and abdominal fatness varies with ethnicity (103), impedance may have provided even better estimation of abdominal adipose tissue better had multiple ethnic groups been studied. Further, an important aspect of these studies is that the BIA devices used in them require the subject to lie supine and for electrodes to be positioned carefully and directly on the skin of the abdomen, indicating that it is not always practical for impedance measurements to be carried out.

Conclusion

Previous studies suggest that WC has the potential to accurately predict %TF and therefore possibility percent abdominal fatness. However, these studies are limited by the fact that the %TF models were not cross-validated. In addition, the majority of these studies did not examine whether factors predict %TF independently of WC.

Percent abdominal fat (percentage of abdominal weight that is fat; %AbFM) measured by DXA is expected to be a better measure of abdominal adiposity than %TF because, unlike the latter, it is not derived from measurement of the chest, which contains bone pixels from the ribs that may affect the accuracy of the separation of fat mass from lean mass by the DXA scanner. However, the relationship between anthropometric variables and %AbFM has not been previously assessed.

WC is not a direct measure of abdominal obesity and there is some research that suggests the use of a BIA measure can improve the ability to quantify abdominal fatness. However, previous studies have

not examined this in adolescents and in multi-ethnic samples, and BIA methods used in such studies are not practical.

To overcome the abovementioned gaps of knowledge in the literature, this thesis aimed to: 1) examine the relationship between WC and %AbFM, 2) assess the ability of anthropometry-based %AbFM prediction equations to accurately estimate %AbFM and, 3) use a practical method to obtain a more direct measure of abdominal fatness – trunk impedance from an 8-electrode hand-to-foot BIA device (BIA_8) – and examine its utility in %AbFM prediction in adolescents from diverse ethnic groups.

Table 3.6. Studies of *adults* that examined the relationship between waist circumference and percent trunk fat

First author	Subjects	Measurements & definitions	Variables in %TF prediction model	Findings	Limitations
Demura (98)	107 adults (77 men, 30 women) aged 21-82 y	%TF by DXA	WC, hip circumference, skinfold thicknesses	%TF prediction equation based on WC, hip circumference & skinfold thicknesses had an R^2 of 0.74 & SEE of 4.9%	1) Equations were not cross-validated 2) Did not report on the ability of WC *per se* to predict %TF
Kagawa (95)	45 Japanese & 42 Australian Caucasian males aged 18-40 y	%TF by DXA	WC, ethnicity	1) Spearman's correlation coefficients for associations between WC & %TF=0.62 (Japanese males) & 0.77 (Australian Caucasian males) 2) For the same WC, Japanese males had more %TF. R^2=0.51	1) Relatively small sample size 2) Equations were not cross-validated 3) Limited WC range of subjects
Chen (99)	1122 Hong Kong Chinese women aged 41-63 y	%TF by DXA	WC, with or without age	WC predicted %TF with an R^2 of 0.506 (univariate relationship). R^2 increased to 0.512 when age was added to this %TF prediction model	1) Did not study males 2) Equations were not cross-validated
Jiang (96)	850 Chinese females aged 20-40 y	%TF by DXA	Only WC was a predictor	Correlations between WC & %TF: 1) r=0.60 among those aged 20-24 y 2) r=0.35 among those aged 25-29 y 3) r=0.71 among those aged 30-34 y 4) r=0.64 among those aged 35-39 y	1) Did not study males 2) Equations were not cross-validated 3) Examined only univariate relationships
Xiao (97)	1090 males aged 20-40 y	%TF by DXA	Only WC was a predictor	Correlations between WC & %TF: 1) r=0.74 among those aged 20-24 y 2) r=0.72 among those aged 25-29 y 3) r=0.70 among those aged 30-34 y 4) r=0.73 among those aged 35-39 y	1) Did not study females 2) Equations were not cross-validated 3) Examined only univariate relationships

%TF=Percent trunk fat; WC=Waist circumference; SEE=Standard error of estimate.

Table 3.7. Studies of *children and adolescents* that examined the relationship between waist circumference and percent trunk fat

First author	Subjects	Measurements & definitions	Variables in %TF prediction model	Findings	Limitations
Yamborisut (100)	509 Thai children & adolescents (238 boys, 271 girls) aged 10-18 y	%TF by DXA	Only WC was a predictor	WC (measured at the umbilicus) alone explained 60% & 73% of the variability in %TF in boys & girls, respectively	1) Cross-sectional study 2) Equations were not cross-validated 3) Examined only univariate relationships
Wang (101)	2493 Chinese children & adolescents aged 6-18 y (1472 aged 6-11 y, 1021 aged 12-18 y)	%TF by DXA	Only WC was a predictor	Among 12-18 year-olds, the correlation between WC & %TF in Chinese: 1) boys: r=0.51, 2) girls: r=0.69	1) Cross-sectional study 2) Equations were not cross-validated 3) Examined only univariate relationships 4) Limited WC range of participants
Wang (102)	74 children & adults (28 males, 46 females) aged 7-83 y	%TF by DXA	Only WC was a predictor	The R^2 of the prediction of %TF by WC varied from 0.33 to 0.42 in males & 0.67 to 0.68 in females, depending on the site WC was measured at	1) Cross-sectional study 2) Small sample size 3) Subjects comprised adults 4) Equations were not cross-validated 5) Examined only univariate relationships

%TF=Percent trunk fat; DXA=Dual-energy X-ray absorptiometry; WC=Waist circumference.

CHAPTER 4: LIFESTYLE PREDICTORS OF FATNESS

4.1 Introduction

As discussed in Chapter 2, lifestyle variables may account for high obesity prevalence among Pacific Island youth and, accordingly, may be suitable targets for obesity interventions. Therefore, an aim of this chapter is to review research on the possible contribution of lifestyle factors to fatness levels in South Pacific youth.

There are several lifestyle factors that have been studied in the aetiology of obesity (108). Computer use, snacking and fruit and vegetable consumption have been considered as possible determinants of fatness (108). However, there is no evidence that snacking predicts BMI in Pacific Island children and both computer use and fruit and vegetable consumption do not predict BMI in this population (44).

Other lifestyle variables – TV watching, sugary drink consumption and breakfast consumption – on the other hand, appear to have the potential to contribute to fatness levels among South Pacific youth. This is because their effects on fatness are commonly studied (109-111) and they predict fatness in Pacific Island children (44). Physical activity may be another important lifestyle variable (112) and exercise level is significantly associated with fatness in Pacific Island children (113). Therefore, these lifestyle variables will be discussed in this chapter.

TV watching will be discussed in Section 4.2, sugary drink consumption in Section 4.3, breakfast consumption in Section 4.4 and physical activity in Section 4.5. First, the association of each of these lifestyle variables with fatness – as shown by previous studies – will be discussed (Sections 4.2.1, 4.3.1, 4.4.1 and 4.5.1). Second, mechanisms by which each lifestyle variable may cause changes in body composition will be explored, through findings of previous studies, to determine whether it is biologically plausible for the variable to be implicated as a determinant of body composition (Sections 4.2.2, 4.3.2, 4.4.2 and 4.5.2).

It is essential to know, though, whether findings of lifestyle-fatness relationships examined by previous studies apply to South Pacific youth. This will be determined by critically appraising these

previous studies (Sections 4.2.3, 4.3.3, 4.4.3 and 4.5.3). The Bradford-Hill criteria (114) were used to examine whether findings of previous studies suggested that causal relationships existed. Thus, in the following sections of this chapter, the literature will be critically appraised by describing findings in terms of these criteria. For example, associations will be described as "having large effect sizes" or "strong", "dose-dependent", "biologically plausible," "consistent with other findings" or "findings obtained from an intervention study." This will allow one to see the strength of the evidence for causality supported from previous studies.

Literature relevant to this chapter was searched up to April 2012 on the following databases (no limit placed on the year of publication): *Medline In-process & Other non-indexed Citations and Medline, Scopus, PubMed* and *Google Scholar*. Combinations of keywords were used to identify relevant articles: *body mass index*, *waist*, *skinfold*, *body fat*, *obesity*, *overweight*, *television*, *TV*, *beverage*, *sugary drink*, *soft drink*, *fruit drink*, *breakfast*, *cereal*, *activity*, *exercise*, *ethnic*, *race*, *Pacific*, *Australia* and *New Zealand*. An example of a literature search carried out is shown in Appendix 1. In addition, several articles were located through citations in other articles.

4.2 Television watching

4.2.1 Association with fatness

For TV watching to be considered as a potential cause of fatness, it is necessary to consider evidence from studies that have assessed the association of TV viewing with body composition. This section will examine this. Studies from Australia (summarised in Table 4.1), Pacific Island countries (Table 4.2) and New Zealand (Table 4.3) have been considered separately from other countries because of their greater relevance to the samples analysed in this thesis. The studies from all countries in the world that have examined the association between TV watching and fatness are summarised collectively in Table 4.4.

Australian studies

Three Australian studies were identified (115-117) (described in Table 4.1 and summarised in Table 4.4). A cross-sectional, Australian study found that TV viewing was positively associated with the odds of overweight/obesity in boys and negatively associated in girls, although the effect sizes were small (115). Another cross-sectional study of Australian children, who were aged 5-13 years, reported that hours of TV per week was positively associated with the odds of overweight/obesity (116). A cohort study of children from Perth found that TV viewing at 6 years was positively associated with the odds of overweight including obesity at 8 years (117).

Pacific Island studies

Only one Pacific Island (cross-sectional) study, the Health Behaviour and Lifestyle of Pacific Youth (HBLPY) study, which was carried out in adolescents living in Tonga, was found (113) (Table 4.2). Results of this study showed that, compared to those who watched TV/videos for 1 hour/day, those who watched more TV/videos each day had a higher odds of overweight/obesity, although this effect was not significant (113).

New Zealand studies

Six studies from New Zealand were identified (31, 44, 118-123) One of these – the Family Lifestyle, Activity, Movement and Eating (FLAME) study – was a cohort study that did not find a significant TV watching-fatness association (123). However, the sample size was small (n=202 in longitudinal analysis) (123). In contrast, the other five studies found that TV viewing was positively related to fatness (31, 44, 118-122) (Tables 4.3 and 4.4). The CNS02 found that, in a dose-dependent manner, TV viewing was positively associated with the odds of obesity (118) and positively correlated with

BMI (44). The AHHS found that, in a dose-dependent manner, TV viewing was positively associated with BMI and %BF (31). The Dunedin Multidisciplinary Health and Development Study (DMHD Study) found that, longitudinally, TV watching in childhood and adolescence was associated with overweight in adulthood (119). Analysis of the same dataset showed that time spent watching TV was positively associated with BMI, although the effect size was small (120). A study of Pacific Island children aged 6 years found that watching TV everyday was associated with increased body fat z-scores (121). The Auckland Birthweight Collaborative (ABC) study reported that TV viewing was positively related to %BF in European children aged 7 years (122).

Non-South Pacific studies

Studies from countries outside of the South Pacific are reviewed in this section.

Cross-sectional

A total of 53 comparisons from 53 cross-sectional studies were identified (Table 4.4). Many studies (n=13) reported no significant association between TV viewing and fatness (124-136). In contrast, nearly twice as many studies (n=25) found that TV watching was positively related to fatness (42, 137-160). Out of these (42, 137-160), studies that contained nationally representative samples reported strong, dose-dependent relationships (137, 142, 146). Several studies showed mixed results – that is, positive associations were observed in a fraction of the total sample (43, 161-174).

Case-control

Three out of three case-control studies reported positive associations between TV watching and odds of obesity (175-177) (Table 4.4). One of these studies reported a dose-dependent relationship (176).

Cohort

Cohort studies (n=14), which provide stronger evidence for a causal effect than cross-sectional studies, showed that TV viewing was positively associated with fatness (134, 138, 141, 142, 150, 155, 160, 167, 178-183) (Table 4.4). In contrast, fewer cohort studies (n=10) did not show a significant relationship (133, 135, 145, 152, 154, 184-188). Of note, the studies that did not find significant association had several study limitations: small sample size (133, 135, 152, 154, 184, 185, 188), short follow-up period (133, 145, 186-188), used only height and weight to measure fatness (133, 135, 154, 187), used only weight status based on BMI to measure fatness (145), and only non-obese subjects were studied (185, 188).

Intervention

Intervention studies provide the strongest evidence for a causal association between two variables. As shown in Table 4.4, two intervention studies did not find a significant effect of decreased TV viewing on fatness (189, 190). In one of these studies, however, the participants were young (2.6-5.5 years) and the level of TV watching was low, which would have limited the ability of the intervention to reduce BMI (189). The other intervention study that reported no significant association comprised 61 African American girls aged 8-10 years and showed that a decrease in TV watching was not accompanied by a significant decrease in BMI and waist circumference (190). That study was limited, though, by the fact that the sample size was small, participants were young and boys were not studied (190). In contrast to these two studies (189, 190), all other intervention studies found that a decrease in TV watching was associated with a decrease in fatness (191-197).

Meta-analyses

A meta-analysis (year of publication=2004) of 30 studies found that 96% of them reported a positive association between TV watching and fatness (198).

Conclusion

In conclusion, international cross-sectional and cohort studies show that TV watching is positively associated with fatness, as does a meta-analysis (198). Most intervention studies show that reducing TV viewing decreases fatness and there is evidence of dose-dependent associations. Further, not one study reported a negative TV watching-fatness relationship (Table 4.4). While this suggests that TV viewing may cause obesity, it is necessary to consider whether this is biologically plausible. This will be examined next.

4.2.2 Mechanisms of effect on fatness

Mechanisms by which TV watching contributes to obesity are discussed below in order to determine the strength of the evidence supporting each one.

1) Decreasing resting metabolic rate (RMR)

It has been hypothesised that TV watching may lead to weight gain by decreasing resting metabolic rate (RMR). Only a few studies have examined this hypothesis (199-202). One of these, a small (n=31) study of obese and normal-weight children aged 8-12 years, found that metabolic rate during TV viewing was much lower than during rest (199). Another one, a small (n=17) study of girls

(mean age of 10.4 years), however, found that RMR was similar during resting, reading or watching TV (200). Similarly, a small (n=8) study of adolescents reported that TV watching was not associated with reduced metabolic rate (202). A larger (n=90) study of girls aged 7-12 years found no association between TV watching and RMR (201). Therefore, there is not strong evidence to suggest that TV watching contributes to obesity by reducing RMR.

2) Reducing physical activity

Another hypothesis is that TV watching displaces physical activity and thereby increases fatness. Indeed, it makes sense that TV watching may reduce the amount of time spent doing physical activity. Studies that examined the association of TV watching with physical activity in children and adolescents are discussed below.

New Zealand studies

One New Zealand study was carried out in Pacific Island, Maori, Asian and European high school students living in Auckland, and reported that increased TV exposure was cross-sectionally associated with a decreased likelihood of being active after school (203). Another New Zealand study, which was longitudinal, found that TV viewing was inversely related to physical activity in adolescents, though the study sample comprised mostly NZ Europeans (119).

Non-South Pacific studies

Several international, cross-sectional studies showed that TV watching was inversely associated with physical activity (127, 140, 143, 168, 177, 186, 204, 205), a few of which reported large effect sizes (143, 168, 205). In contrast, international cohort (186, 206) and intervention (192, 193) studies do not support the 'displacement hypothesis'; but these longitudinal studies were not nationally representative and they are only few in number (186, 192, 193, 206).

Meta-analyses

A meta-analysis (year of publication=2004) found that TV watching was inversely related to physical activity, with an effect size of –0.129 (fully corrected sample-weighted mean effect size) (198). Although this effect size is small, this may be partly due to the difficulty in measuring physical activity accurately.

The 'displacement hypothesis' does not fully account for TV watching-fatness associations. For instance, TV viewing is significantly related to body composition even after adjustment for physical

activity (207) and TV watching has a stronger relationship with obesity than physical activity (120, 140, 159). This suggests that there is another mechanism, at least, to account for the association between TV watching and fatness.

3) Decreasing nutritious dietary intake

Another mediating factor is the consumption of unhealthy foods: snack foods may be consumed during TV viewing (208) or TV food advertising may encourage unhealthy food choices. In support of the latter, two studies found that the advertising content on New Zealand TV was not conducive to nutritious dietary intake in children (209, 210). Similarly, about half of the advertising content on Australian TV during children's viewing hours was for high-fat or high-sugar foods (211). Further, a randomised, controlled trial found that short exposures to TV food commercials can influence food preferences (212).

Studies that examined the association of TV watching with dietary intake in children and adolescents are discussed below.

New Zealand studies

Analysis of the CNS02 showed that children who watched 2 or more hours of TV per day were more than twice as likely to drink soft drinks 5 times/week (118). Further, TV viewing was inversely associated with frequency of consumption of fruits and vegetables, and positively associated with frequency of consumption of fruit drinks, biscuits, potato crisps, hamburgers, French fries and fried chicken (118).

Non-South Pacific studies

Most international, cross-sectional studies show that TV watching is associated with the consumption of unhealthy foods (177), increased energy intake (140, 161) or low fruit and vegetable intake (168). A few cohort studies have been carried out (134, 181, 213, 214), and most found that TV watching was inversely associated with fruit and vegetable intake (213) or positively associated with the consumption of snack foods (181, 214).

4) Reducing the amount of sleep

Because short sleep duration is associated with weight gain (123, 215), TV viewing may lead to weight gain by crowding out sleep. This would particularly be possible if TV watching tended to occur late in the evenings. However, as demonstrated in a systematic review, the causal relationship

between sleep deprivation and obesity needs to be established by carrying out more studies that measure sleep objectively, have repeated assessments of both sleep and weight, and use experimental designs that manipulate sleep (215).

Conclusion

In conclusion, some biologically plausible mechanisms have been proposed to explain how TV watching can affect body composition. Evidence does not support the hypothesis that TV viewing affects fatness by reducing RMR and more research is required to establish whether sleep reduction is a mediator. Other mechanisms – a reduction in physical activity and leading to a less nutritious dietary intake – have strong support from the research evidence.

This evidence supports the hypothesis that TV viewing is causally related to obesity. However, it is necessary to know whether TV viewing causes obesity in adolescents participating in the OPIC study. To determine this, the next section will examine the limitations of studies that assessed TV watching-fatness relationships in South Pacific populations.

4.2.3 Limitations of previous studies

Studies of South Pacific populations that examined the association of TV watching with fatness have limitations. These limitations are summarised in Tables 4.1 (Australian studies), 4.2 (Pacific Island studies) and 4.3 (New Zealand studies), and are discussed below.

1) Sample size

While most studies that examined TV watching-fatness relationships of South Pacific groups had large (n>1000) sample sizes (31, 44, 116-118, 120), two had small sample sizes (n=102 (121) and n=202 (123); Table 4.3). This small sample size is particularly a limitation given that the study measured TV watching subjectively (121), (TV questionnaires are more appropriate for large samples). Further, one Australian study and the HBLPY study did not have large sample sizes (n=602 and n=443, respectively), yet measured TV viewing with a self-reported questionnaire (113, 115).

2) Sample selection

The participants in the Pacific Island Families: Child and Parental Physical Activity and Body Size (PIF:PAC) study were only Pacific children who were born at Middlemore Hospital in South

Auckland and who had at least one parent who was a permanent resident of New Zealand (121), and therefore are not representative of all Pacific children living in New Zealand. In the ABC study, participants were only recruited from the Waitemata Health or Auckland Healthcare regions and the sample for this study is not representative of children living outside these regions (122). The DMHD Study and FLAME study recruited only children who were born in Dunedin and still resided in Otago at 3 years of age (119, 120, 123). Thus, the DMHD Study sample was not representative of children and adolescents living outside of Otago.

One of the Australian studies recruited participants from 10 schools in the Perth metropolitan area (115). Another Australian study comprised a sample from Perth (117). The sample of the other Australian study was derived from only primary schools in Victoria (116). Therefore, the samples in these Australian studies are not representative of children living outside of Perth (115, 117) or Victoria (116).

3) Response rate

The CNS02 had a response rate of 69% (44, 118) (74% for Pacific participants (44)), while the AHHS had an overall response rate of 66% (31). Similarly, a notable fraction (34%) of subjects invited to participate in the PIF:PAC study declined to participate (121). Thus, the response rates of these New Zealand studies are not ideal. Further, the response rate in the FLAME study was 59% and the retention rate for its longitudinal analysis was 83%; this indicates that more than half of those who were invited to take part in the study did not participate in both the baseline and follow-up measurements (123). In addition, two of the Australian studies did not report their response rates (115, 117), which adds uncertainty to the representativeness of their samples, and the response rate (62%) of the HBLPY study was not large (113).

4) Subject characteristics

The ABC study consisted of only European participants (122), the DMHD Study and FLAME study comprised mostly NZ Europeans (119, 120, 123), while the CNS02 combined Europeans with other ethnic groups, such as Asians (44, 118). Another limitation is that the participants in the ABC study were 7 years old (122), the subjects in the FLAME study were 3 years at baseline and 7 years at follow-up (123), the CNS02 (44, 118) participants were 5-14 years of age and the subjects in the PIF:PAC study were 6 years old (121). Further, all Australian studies had subjects aged under 14 years (115-117). This limits the applicability of these studies (44, 115-118, 121) to adolescents.

5) Adjustment for confounders

The CNS02 is subject to possible residual confounding by SES because it used only a proxy measure of SES in analyses (2001 New Zealand Deprivation Index (NZDep01)) (44, 118). Also subject to potential confounding is the AHHS (31), the PIF:PAC study (121) and the ABC study (122), which did not adjust for dietary intake.

6) Body composition measures

All Australian studies used only height and weight to measure fatness (115-117). Similarly, the DMHD Study (119, 120) and CNS02 (44, 118) used only BMI as a fatness measure, and the fatness measure in one of the HBLPY study and CNS02 analyses was weight status based on BMI (113, 118). The AHHS (31) used waist:hip ratio, BMI and %BF, but the latter was derived from a BIA prediction equation developed in mainly primary school- and intermediate school-aged children (32).

7) TV watching variables

A limitation of the DMHD Study is that its measure of TV viewing did not include weekend TV watching (120).

8) Year of study

The AHHS was carried out between 1997 and 1998 (31), now over a decade old. At approximately the same point in time, data were collected for two of the Australian studies (116, 117). Even older is the DMHD Study, which started data collection in the 1970s (119, 120). Because the environment or environmental conditions under which these studies were carried out is different to that of today, it is difficult to extrapolate those study findings (effect sizes) (31, 116, 117, 119, 120) to the OPIC study. For instance, if there are more obesogenic factors other than TV watching in today's environment, TV watching may have a weaker effect on fatness. As another example, if the number of non-TV indoor activities (e.g., computer use) changes over time, the degree to which TV watching displaces physical activity may change, and therefore its association with fatness may change.

Conclusion

Studies show that TV watching is positively associated with fatness and there are biologically plausible mechanisms that account for this. Further, dose-dependent TV watching-fatness relationships have been reported. These provide a reason to believe that TV watching may be causally related to obesity. Despite this, it is difficult to extrapolate the findings of these international studies to South Pacific youth. In comparison, studies carried out in South Pacific groups apply

better to adolescents participating in the OPIC study. However, not many of these studies have been carried out and the studies that did had important limitations. Most were carried out in children and most used only BMI as a fatness measure. One study had a small sample size, yet measured TV watching subjectively (121). A few studies were carried out a long time ago, which makes it is difficult to extrapolate their findings to the present. In addition, there is scarce published data on the association of TV watching with body composition in Pacific Island countries. Therefore, because of the small number of studies carried out in South Pacific populations and the abovementioned limitations of these, it is unclear whether TV watching contributes to increased fatness levels in South Pacific youth. To address this gap of knowledge in the literature, this thesis aimed to examine the association of TV watching with fatness among adolescents living in New Zealand, Australia and in the Pacific Islands.

Table 4.1. Australian studies that examined the association of TV watching with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
CROSS-SECTIONAL					
Burke (115)	281 boys & 321 girls aged 10.4-13.8 y recruited from 10 schools in the Perth metropolitan area	Validated self-reported questionnaires were used to record time spent viewing TV, videos, computer use & other sedentary behaviours. Overweight & obesity were defined by IOTF BMI cut-offs	Age, SES, clustering by school. A 2nd set of analyses adjusted for other lifestyle variables that were statistically significant individually. (Sex-specific analyses)	TV viewing (hours/week) was positively associated with odds of overweight/obesity in boys (OR=1.03; 95% CI: 1.01-1.06) & negatively associated in girls (OR=0.98; 95% CI: 0.96-0.99)	1) Sample size was not large 2) Sample was not nationally representative 3) Did not report its response rate 4) Young age of subjects 5) Used only weight status based on BMI to measure fatness
Burke (117) (also cohort)	Cross-sectional analysis of 1430 boys & girls (mean age=8 y) from Perth	Hours spent TV viewing per day	Sex	BMI was positively associated with hours/day of TV watching (0.185 kg/m^2 increase at 8 y for each hours/day increase in TV watching at 8 y)	1) Young age of participants 2) Sample was not nationally representative 3) Did not report its response rate 4) Used only BMI to measure fatness 5) Study was carried out >10 years ago
Wake (116)	2862 Australian children aged 5-13 y from 24 primary schools in Victoria. Response rate=75%	Hours of TV viewing on average school & non-school day reported by parents via a questionnaire. Overweight & obesity were defined by IOTF BMI cut-offs	Sex, age, activity, food intake, family size, maternal BMI, maternal education	1) Hours of TV per week was positively associated with odds of overweight/obesity (overweight & obesity combined into a category) 2) Hours of TV per week was positively associated with BMI z-score, except in 11-13 year-olds	1) Young age of participants 2) Sample was not nationally representative 3) Used only BMI z-score & weight status (based on BMI) to measure fatness 4) Study was carried out >10 years ago
COHORT					
Burke (117) (also cross-sectional)	Longitudinal analysis of 741 boys & 689	Hours/day of TV watching. Overweight defined by	Sex, physical activity, maternal obesity, smoking, education	Hours per day of TV watching at 6 y was positively associated with odds of overweight	1) Short follow-up period 2) Sample was not nationally representative

	girls from Perth (mean age=6 y at initial assessment of TV watching) followed for 2 years	IOTF BMI cut-offs		including obesity at 8 y	3) Did not report a response rate 4) Young age of participants 5) Used only weight status based on BMI to measure fatness 6) Study was carried out >10 years ago

SES=Socioeconomic status; IOTF=International Obesity Task Force; TV=Television; OR=Odds ratio; CI=Confidence interval.

Table 4.2. Pacific Island studies that examined the association of TV watching with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Smith (113)	Nationally representative sample of 443 adolescents from Tonga aged 11-16 y. Cross-sectional study. Response rate=62%	TV & video watching assessed by a questionnaire	Gender, age, island group, parent's job, fruits, soft drinks, sweets/chocolates, fresh vegetables, taro, tinned fish, tinned mutton/corned beef, exercise frequency/duration	Daily TV/video use (hours/day) was positively correlated with odds of overweight/obesity: compared to 1 hour/day of watching, OR for 1-3 hours/day=1.82 (95% CI: 0.85-3.93) & OR for 4 hours/day=1.45 (95% CI: 0.74-2.85)	1) Relatively small sample size 2) Not a large response rate 3) Used only weight status based on BMI to measure fatness

OR=Odds ratio.

Table 4.3. New Zealand studies that examined the association of TV watching with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
CROSS-SECTIONAL					
Utter (44) (same study as (118))	Nationally representative sample of 3275 children (Maori, Pacific, NZEO) aged 5-14 y from the CNS02. Response rate=69%	TV watching assessed by questions that asked about the frequency & duration of TV use over the previous week. SES estimated by NZDep	Model 1: Sex, age, ethnicity, SES Model 2: Model 1 + fruit & vegetable consumption, computer use, bring school food from home, buying school food from dairy/takeaways, buying school food from the school tuck shop/canteen, ate-home breakfast consumption, fruit & soft drink consumption, physical activity	Daily TV use (hours/day) was positively correlated with BMI (adjusting for sex, age, ethnicity, SES) (P=0.020), even after further adjustment for lifestyle variables (though this effect was marginally significant: P=0.07)	1) Young age of participants 2) Combined Europeans with other ethnic groups, such as Asians 3) Relationships subject to possible confounding by SES 4) Used only BMI as a fatness measure
Utter (118) (same study as (44))	Nationally representative sample of 3275 children (Maori, Pacific, NZEO) aged 5-14 y from the CNS02. Response rate=69%	TV viewing examined by a 7-day recall (days of TV asked separately). SES estimated by NZDep	Sex, age, ethnicity, SES	TV watching (hours/day) was positively associated with odds of overweight (5-10 y only) & obese (5-10 y & 11-14 y)	1) Young age of participants 2) Combined Europeans with other ethnic groups, such as Asians 3) Only adjusted for demographic variables. Relationships subject to possible confounding by SES 4) Used only weight status based on BMI to measure fatness
Oliver (121)	102 Pacific children aged 6 years	Mothers reported whether their child watched TV almost every day or not & provided an estimate of	Physical activity, maternal waist circumference	Watching TV everyday was associated with increased body fat z-scores	1) Small sample size 2) Sample was not representative of all Pacific children living in NZ 3) A notable fraction (34%) of subjects declined an invitation to

		weekly hours of screen time (watching TV & videos, using computer games). %BF by BIA			participate 4) Young age of participants 5) Did not adjust for dietary intake
Schaaf (31)	2487 Auckland boys & girls (Pacific, Maori, Asian, European) aged 14-21 y. Response rate=66%	Self-reported hours each day, on average, that TV was watched in the last 4 weeks. %BF by BIA	Sex, age, ethnicity, smoking, alcohol consumption, sun exposure, physical activity	1) BMI was 0.68 kg/m^2 higher among those watched TV for ≥29 hours/week, compared to those who watched for ≤14 hours/week 2) No association between TV watching & waist:hip ratio 3) Dose-dependent relationship between TV watching & %BF. Compared to those who watched for ≤14 hours/week, %BF was 0.96% higher among those who watched for between 14 & 29 hours/week, & 1.65% higher among those who watched for ≥29 hours/week	1) Did not adjust for dietary intake 2) Did not use WC or WHTR as fatness measures 3) %BF was estimated from a prediction equation developed in a young sample of children 4) Did not consider interactions between variables in analyses 5) Study was carried out >10 years ago
Hancox (120) (same study as (119))	1037 children (mostly NZ European ethnicity) assessed at age 3 y & 976 of these measured again at age 15 y	Parental estimates of TV viewing on weekdays between 5 & 11 y. Self-reported estimates of usual weekday & weekend TV watching at age 13 & 15 y	Parental BMI, SES	1) Time spent watching TV was positively associated with BMI. Effect sizes were small & associations were stronger in girls than in boys 2) At age 15 y, after adjustment for sex, SES, parental BMI & BMI at age 5 y, each hour of weeknight TV viewing was significantly associated with a 0.30 kg/m^2 increase in BMI	1) Sample was not representative of children & adolescents living outside of Otago 2) Comprised mostly NZ European 3) Used only BMI as a fatness measure 4) Measure of TV watching did not include weekend TV viewing 5) Study was carried out a long time ago
Blair (122)	871 European children aged 7 y	Details of data collection of TV watching were not described. %BF by BIA	Gender, maternal BMI, maternal age at birth of child, sedentary activity	Compared to those who watched TV for <1 hour/day, those who watched 1-3 hours/day had 2.5% (95% CI=0.7 to 4.2%) more %BF & those who watched >3 hours/day had 5.2% (95% CI=1.2 to 9.1%) more %BF	1) Sample was not representative of children living outside of the Waitemata Health or Auckland Healthcare regions 2) Young age of participants 3) Comprised only European

					children 4) Did not adjust for dietary intake 5) Maternal height & weight were self-reported
Carter (123) (also cohort)	244 mainly white children from Dunedin followed up from 3 to 7 y of age. Response rate=59%	Mothers reported TV hours/day viewed by their child	Age, sex, maternal education & BMI, income, ethnicity, birth weight, smoking during pregnancy, physical activity, fruit-vegetable intake, non-core food intake, sleep	No association between TV watching (hours per day) & BMI with or without adjustment for confounders (P>0.05)	1) Young age of participants 2) Small sample size 3) Sample was not nationally representative 4) Not a large response rate
COHORT					
Hancox (119) (same study as (120))	1037 children (mostly NZ European ethnicity) assessed at age 3 y & 980 of these measured again at age 26 y	Parental estimates of hours of TV viewing on weekdays between 5 & 11 y. Self-reported estimates of usual weekday & weekend TV watching at ages 13, 15 & 21 y	Childhood SES, BMI at 5 y, parental BMI, parental smoking, physical activity at 15 y	TV viewing in childhood & adolescence was associated with overweight in adulthood	1) Sample was not representative of children & adolescents living outside of Otago 2) Comprised mostly NZ European 3) Used only BMI as a fatness measure 4) Did not measure weekend TV watching between ages 5 & 11 y 5) Study was carried out a long time ago
Carter (123) (also cross-sectional)	202 mainly white children from Dunedin followed up from 3 to 7 y of age. Response rate=59%, retention rate=83%	Mothers reported TV hours/day viewed by their child. Fat mass was measured by DXA	BMI at age 3 y, sex, maternal education & BMI, income, ethnicity, birth weight, smoking during pregnancy, physical activity, fruit-vegetable intake, non-core food intake, sleep	No association between TV watching (hours per day) & BMI (P>0.05)	1) Young age of participants 2) Small sample size 3) Sample was not nationally representative 4) As response rate=59% & retention rate=83%, the number of subjects analysed in the cohort is <50% of the number of eligible participants

NZEO=New Zealand European/Other; FFQ=Food frequency questionnaire; SES=Socioeconomic status; NZDep=New Zealand Deprivation Index; %BF=Percent body fat; BIA=Bioimpedance analysis; TV=Television; OR=Odds ratio; CI=Confidence interval; DXA=Dual-energy X-ray absorptiometry.

Table 4.4. Summary of studies that examined the association of TV watching with fatness[1]

Type of study	Direction of relationship				Total
	Positive	**None**	**Negative**	**Mixed[2]**	
Australian	2 (116, 117)	0	0	1 (115)	3
Pacific Island	0	1 (113)	0	0	1
New Zealand	5 (31, 44, 118-122)	1 (123)	0	0	6
Non-South Pacific cross-sectional	25 (42, 137-160)	13 (124-136)	0	15 (43, 161-174)	53
Non-South Pacific case-control	3 (175-177)	0	0	0	3
Non-South Pacific cohort	14 (134, 138, 141, 142, 150, 155, 160, 167, 178-183)	10 (133, 135, 145, 152, 154, 184-188)	0	0	24
Non-South Pacific intervention	7 (191-197)	2 (189, 190)	0	0	9
Total[3]	48	25	0	16	86

[1]Values in cells=Number of studies (reference). In some cases, number of references>number of studies because some references are from the same study.
[2]Positive relationship observed in a fraction of the total sample.
[3]Some cells in this row are not equal to total number of studies shown in additive cells as some publications (133, 135, 138, 141, 142, 150, 155, 160, 175-177) are in more than 1 additive cell and some publications across additive cells ((153) and (183), (163) and (184), (126) and (179), (166) and (145)) are from the same study.

4.3 Sugary drink consumption

4.3.1 Association with fatness

This section will assess the association of soft drink and fruit drink consumption with fatness. As these beverages differ in ingredients, their effect on satiety may potentially be different (216). In addition, some beverages may be consumed with energy-dense foods more than others (217), and others may displace milk from the diet more than others (218). Therefore, the type of beverage may influence the effect on body composition. For this reason, individual types of drinks will be considered separately.

Due to their greater relevance to the samples analysed in this thesis, studies from Australia (Table 4.5), Pacific Island countries (Table 4.6) and New Zealand (Table 4.7) have been examined separately from other countries. These studies, as well as those from studies outside of the South Pacific, are summarised in Tables 4.8 (soft drink consumption-fatness association) and 4.9 (fruit drink/cordial consumption-fatness association).

1) Soft drinks

A total of 46 comparisons from 44 studies around the world were identified (Table 4.8).

Australian studies

One Australian study was identified (219) (Table 4.5). That study found that daily carbohydrate intake derived from soft drink/cordial intake at age 8 years was associated with excess weight gain 5 years later (219).

Pacific Island studies

Only one Pacific Island study, the HBLPY study, was identified (113) (Table 4.6). This study reported a positive relationship between soft drink consumption and odds of overweight/obesity, although this effect was not statistically significant (113).

New Zealand studies

A few studies have examined the association of sugary drink consumption with adiposity in New Zealand (Table 4.7). The CNS02 showed that frequency of consumption of fruit/soft drinks was positively associated with BMI in a dose-dependent manner, although this effect was not significant after further adjustment for lifestyle variables (44). In another New Zealand study, compared to

children who did not have any weekly servings of sugary drinks, the odds of being overfat was higher among children who had 3-4 servings/week (OR=2.26) and even higher among those who had 5 or more servings/week (OR=2.37) (220). Similarly, an analysis of the OPIC data showed that among New Zealand adolescents who were not trying to change weight, soft drink consumption was positively associated with BMI in a dose-dependent manner (221).

Non-South Pacific studies

Studies from countries outside of the South Pacific are reviewed in this section.

Cross-sectional

A total of 17 cross-sectional studies that have examined the relationship between soft drink consumption and fatness were identified. Five studies showed that soft drink consumption was positively related to fatness (124, 222-225). An equal number of studies, in contrast, reported no significant association between soft drink consumption and body composition (43, 217, 226-228). Other studies examined the combined association of soft drinks and other drinks with adiposity and found a positive relationship (225, 229-233), while fewer reported no significant association (133, 234). Importantly, not one study reported a negative relationship.

Case-control

As shown in Table 4.8, only one case-control study examined the association of soft drink consumption with fatness (177). That study reported that obese children did not differ with non-obese children in daily frequency of soft drink consumption (177). However, it had several limitations: the sample size was small (n=53), participants were self-selected, confounders were not adjusted for, it used a categorical variable based on BMI to measure fatness and it did not control for beverage serving size (177).

Cohort

Table 4.8 summarises the findings of cohort studies that examined the longitudinal relationship of soft drink consumption with fatness. Four cohort studies did not show a significant relationship between soft drink consumption and fatness (235-238), while four found a positive association (214, 219, 239, 240). Other studies examined the combined association of soft drinks and other drinks with adiposity and found a positive relationship (233, 241-246), while fewer found no significant association (133, 235, 236, 247). Not one study reported a negative relationship.

Intervention

Intervention studies have consistently found a positive association between soft drink consumption and fatness; that is, a reduction in soft drink consumption reduces fatness (248-251) (Table 4.8). Not one intervention that reduced soft drink consumption increased fatness (Table 4.8).

2) Fruit drinks/cordial

Studies that have examined relationships between non-diet fruit drink/cordial consumption and fatness are summarised in Table 4.9 and are discussed below.

Australian studies

Only one Australian study (219) (Table 4.5) examined the association of cordial intake with excess weight gain and has been discussed in the *Soft drinks* section above. Further, that study reported no association between carbohydrate consumed from fruit juice/fruit drinks and BMI status, though did not assess the association of fruit drinks *per se* with weight status (219).

New Zealand studies

The CNS02 assessed the combined association of fruit and soft drink consumption with BMI (44) and the study by Duncan *et al* (220) assessed the association of sugary drink consumption with fatness. These studies have been discussed above.

Non-South Pacific studies

Three international, cross-sectional studies that have examined the combined association of fruit drinks and other drinks with adiposity found a positive relationship (229, 230, 233). Similarly, five cohort studies have examined the combined association of fruit drinks and other drinks with adiposity and found a positive relationship (233, 241-244). Not one study (cross-sectional or cohort) reported an inverse association (Table 4.9).

3) Meta-analyses

A meta-analysis (year of publication=2008) found that the relationship between sugar-sweetened beverage (SSB) consumption and BMI was close to zero (252). However, this meta-analysis had analytical errors and a re-analysis of it found a significant, positive, overall effect size (253). Another meta-analysis (year of publication=2007) found that soft drink consumption was consistently and positively associated with fatness (254). Of note, the "true" sizes of the associations from all previous studies (published and unpublished) may be weaker than those observed in these meta-

analyses as there is a possibility of publication bias against studies that did not report statistically significant results (252, 255).

Conclusion

In conclusion, most published previous studies that assessed the association of sugary drink consumption with fatness have found a positive relationship. Cross-sectional, cohort and intervention studies have reported positive associations and dose-dependent relationships have been reported. While this implies that the consumption of SSBs may be causally related to weight gain, it is necessary to examine whether this association is biologically plausible. This will be assessed in the next section.

4.3.2 Mechanisms of effect on fatness

There are plausible mechanisms by which SSBs can lead to weight gain. These are discussed below.

1) Low satiety of liquid carbohydrates

One mechanism that has been suggested is the low satiety of liquid carbohydrates and the consequent incomplete compensation of energy in subsequent meals. That is, some calories from beverages act as "extra" calories.

This mechanism relies on the "extra" calories from sugary drinks being sufficient to increase fatness. In New Zealand, each 250 mL of regular soft drinks contains about 452 kJ of energy, while fruit juice and fruit drinks contain a little less (256). The CNS02 showed that a large fraction of New Zealand children consumed at least 2 soft or fruit drinks per day (44). If each drink is 250 mL, then this means that a large proportion of children consumed at least 900 kJ per day from these drinks. This is a notable fraction of the recommended total daily energy intake for children, and hence regular and fruit drink consumption may be an important contributor to weight gain. This effect may be augmented in groups that consume large food serving sizes, such as Pacific Islanders (257).

If sugary drinks contained "extra calories", energy intake among those who drink more SSBs would be higher. Evidence to support this and hence this mechanism comes from a study of US adolescents, in which energy intake was higher among those who had a higher consumption of soft drinks (258). Energy intake was 620 kcal (2596 KJ) greater among adolescents who ≥26 oz/day (737 g/day),

compared to those who did not consume soft drinks (258). The size of this additional energy is large and if not compensated for by additional physical activity, can lead to weight gain.

Evidence for this mechanism also relies on findings from experimental studies that assessed the influence of sugary drinks on satiety and incomplete compensation of energy in subsequent meals. An adult study found that satiety or energy intake did not depend on whether food was consumed as a liquid or solid (259). In contrast, another adult study found that drinks containing only sucrose had a lower satiety effect than a drink with mixed nutrients, although it did not assess whether subsequent food intake was greater following consumption of the drink containing only sucrose (216). Similarly, a study of young adults showed that foods consumed over 4 weeks as liquids – soda – had a lower satiety effect than solid foods – jelly beans (260). Of note, though, the beverages contained high fructose corn syrup, whereas the jelly beans were high in sucrose; these differences may have influenced the results (260). Further support for this mechanism is evident in another study, which reported that adults who consumed sucrose-containing beverages did not completely compensate for the energy received from these drinks by reducing energy intake from their own foods by an equal amount, and they gained weight (261).

The hypothesis that the "extra calories" in sugary drinks leads to weight gain is challenged by findings which show that diet and regular soda had similar effects on BMI (108, 244). In other words, this explanation does not account for positive associations between diet soft drinks and fatness. Therefore, this may not be the only mechanism by which sugary drink consumption predicts weight gain.

2) High-fructose corn syrup

Another mechanism arises from the fructose content in sugary drinks. Hepatic metabolism of fructose favours de novo lipogenesis (262). Fructose is metabolised differently than glucose and does not stimulate insulin secretion or the production of leptin (262). Because insulin and leptin regulate food intake and body weight, intake of fructose may promote weight gain (262).

Owing to its fructose content, it has been hypothesised that high-fructose corn syrup (HFCS), a sweetener in soft drinks in the US, may lead to weight gain. Further evidence to support this comes from research showing that the increased use of HFCS in the US mirrors the rapid increase in obesity rates (262). HFCS was introduced in the food supply just before 1970 and its use increased rapidly over time (262). As noted by Bray *et al* (262), the increase in HFCS consumption just preceded the

rapid increase in obesity prevalence that occurred among US adults (263). However, it is difficult to determine whether this mechanism may be responsible for rising obesity rates in non-US countries, owing to the lack of data about HFCS consumption in these countries.

3) Decreasing milk consumption

Another mechanism is decreasing milk consumption. Milk is a source of calcium. As shown in a review article, there is emerging evidence that calcium may regulate body fat (264). Animal, observational and population studies, and clinical trials show that dietary calcium and dairy foods have an antiobesity effect (264). For instance, a longitudinal study of children found that calcium intake was inversely associated with BMI (265).

It has been suggested that soft drink intake displaces milk consumption in the diet. Analysis of nationally representative US samples of children and adolescents found that, over a period of nearly 25 years, sweetened beverage consumption increased, while milk consumption decreased (266). A separate, cross-sectional analysis of one of these samples found that, among adolescents, after adjustment for age, sex, race and energy, soft drink consumption was positively associated with the odds of consuming less than 8 oz/day of milk (258). A representative sample of Spanish children aged 6-7 years found that consumption of SSBs was associated with a lower consumption of milk and calcium (225).

Stronger evidence that sugary drink-milk consumption relationships account for changes in body composition can be obtained from intervention studies. One 16-week intervention study of 93 children aged 8-10 years replaced soft drinks with milk and found that lean mass increased more in the intervention group, while %BF or BMI did not change (251). The authors suggested that this may have occurred through milk promoting anabolism (251). Due to the small sample size and short intervention period (251), larger and longer intervention studies are required to provide stronger evidence for a causal relationship.

Meta-analyses

One meta-analysis of children and adult studies found that soft drink consumption was consistently associated with increased energy intake (254). The effect size reported for the children studies was 0.03 (254). Of note, a limitation of that meta-analysis is that studies of children were combined with studies of adolescents (254). This is important because since younger children compensate for energy

better than older children (267, 268), over-consumption of SSBs may lead to increased energy intake in adolescents but not in young children. Therefore, the effect size of 0.03 may not be representative of the studies that examined only adolescents.

Conclusion

In conclusion, there are plausible mechanisms by which sugary drink consumption may influence body composition. This supports the view that a causal relationship between SSB consumption and fatness may exist. It is necessary to know, though, whether this causal association applies to adolescents participating in the OPIC study. To determine this, the next section will assess the limitations of South Pacific studies that examined the association between sugary drink consumption and fatness.

4.3.3 Limitations of previous studies

Previous studies examining the association between sugary drink consumption and fatness in South Pacific populations have limitations. These limitations are summarised in Tables 4.5 (Australian studies), 4.6 (Pacific Island studies) and 4.7 (New Zealand studies), and are discussed below.

1) Sample size

While the New Zealand studies did not have low sample sizes (44, 220, 221), the Australian study had a small sample size (n=281) (219). Similarly, the sample size of the HBLPY study was relatively small (113).

2) Sample selection

The CNS02 had a nationally representative sample (44). However, the participants in the study by Duncan *et al* (220) were recruited from primary schools in the Auckland region and are therefore not nationally representative. Similarly, the Australian study sampled from only children who were born in West Sydney (219) and is thus not nationally representative.

3) Response rate

Another limitation is response rate. The study of Utter *et al* (221) and the CNS02 (44) had response rates of 54% and 69%, respectively, which are not ideal response rates. The HBLPY study did not have a large response rate as well (62%) (113). Further, the Australian study had a low response rate: 1,346 children fulfilled the study selection criteria, yet only 281 children participated (219, 269). In

addition, a response rate was not reported in the study of Duncan *et al* (220), which adds uncertainty to the representativeness of its sample.

4) Subject characteristics

Apart from one study (221), all studies that examined the association of SSBs with fatness comprised subjects whose ages are younger than our study participants (44, 219, 220). This is important because adolescents have poorer energy compensation than young children – they eat more in the same or subsequent meals (267, 270). Therefore, adolescents may be more susceptible to weight gain from SSB consumption, compared to young children. Hence, more research is needed in adolescents.

5) Adjustment for confounders

New Zealand studies did not adjust for TV viewing (220, 221), physical activity (221) and dietary intake (221). In addition, New Zealand studies that used only proxy measures of SES in analyses (NZDep01 (44) or school decile ratings (220)) may be subject to residual confounding by SES (44, 220). Also subject to confounding is the Australian study, which did not adjust for any confounders (219).

Another limitation of previous studies is that they are unable to determine whether sugary drink consumption causes fatness because their findings may be influenced by the possibility that overweight adolescents are limiting their intake of sugary drinks as a way of controlling their weight. Apart from one study (221), previous studies have not accounted for weight-control attempts in their analyses (Tables 4.5-4.7).

6) Body composition measures

Most studies used only BMI (44, 221), or overweight/obesity defined by BMI groups (a dichotomous variable based on BMI) (113, 219). Only one study measured whole-body fat mass (220). This study only examined excess fat (*categorical* variable) as the outcome variable (220), but did not consider the association with *continuous* fatness variables. In addition, that study (220) predicted body fat in Asians using a BIA prediction equation not developed in Asians (32).

7) Types of beverages

A meta-analysis found that the effect sizes depended upon the type of beverage (254). As discussed in Section 4.3.1, because ingredients differ between beverages and different beverages may have variable effects on fatness, it is important to consider their individual effects rather than their

combined effect on body composition. However, an analysis of the CNS02 examined the combined association with fatness of soft drinks and fruit drinks (44), rather than assessing their individual associations. Another New Zealand study did not define sugary drinks (220), which makes it difficult to apply the study findings to other samples. In addition, the Australian study combined soft drink intake with cordial intake and combined fruit juice intake with fruit drink intake (219). Another drawback relating to beverage type is that the HBLPY study did not measure fruit drink/cordial consumption (113).

8) Beverage serving size (measurement error)

The HBLPY study and CNS02 used *frequency of consumption per day* to estimate beverage consumption (44, 113), while the study of Duncan *et al* (220) used *servings per week*. These measures of consumption do not account for variation in serving size and thus do not accurately measure volume of beverage consumed each day. The fact that Pacific Islanders consume larger food servings sizes than those from other ethnic groups (257) suggests that it is difficult to use the effect sizes estimated in those New Zealand studies (44, 220) to accurately estimate sugary drink-fatness associations across Pacific and non-Pacific populations.

Conclusion

Previous studies have found positive relationships between sugary drink consumption and fatness, and there are biologically plausible mechanisms that account for this. This suggests that the consumption of SSBs may cause weight gain.

However, studies of sugary drink consumption-fatness associations that have been carried out in Australian, New Zealand and Pacific Island populations are lacking. In addition, these studies had important limitations. The Australian study had a small sample size (219), nearly all studies comprised children aged under 14 years, some studies did not account for variation in beverage serving size, and nearly all studies relied on just height and weight to measure body composition. Further, there is a lack of published data on the effect of SSB consumption on body composition in Pacific Island countries. Therefore, it is not known whether sugary drink consumption is associated with fatness among South Pacific adolescents. This thesis aimed to examine this.

Table 4.5. Australian studies that examined the association of sugary drink consumption with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Tam (219)	281 children (136 boys), who were born at Nepean Hospital in Western Sydney, followed up 5 y later (mean age=7.7±0.6 y at baseline & 13.0±0.2 y at follow-up)	3-day food record. Overweight & obesity defined by IOTF BMI criteria	None	1) Soft drink/cordial intake (carbohydrate obtained from per day) at age 8 years was associated with excess weight gain 5 years later 2) No association between carbohydrate consumed from fruit juice/fruit drinks & BMI status	1) Small sample size 2) Sample was not nationally representative 3) Modest response rate 4) Young age of participants 5) Used only BMI categories as a fatness measure 6) Assessed the combined association of fruit drinks & fruit juice with weight status, rather than separating their associations

IOTF=International Obesity Task Force.

Table 4.6. Pacific Island studies that examined the association of sugary drink consumption with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Smith (113)	Nationally representative sample of 403 adolescents from Tonga aged 11-16 y. Cross-sectional study. Response rate=62%	Soft drink consumption assessed by a questionnaire	Gender, age, island group, parent's job, fruits, soft drinks, sweets/chocolates, fresh vegetables, taro, tinned fish, tinned mutton/corned beef, exercise frequency/duration	Soft drink consumption (number of drinks per day) was positively correlated with odds of overweight/obesity: compared to <1 drink per day, OR for ≥1 drink per day=1.30 (95% CI: 0.57-2.97)	1) Relatively small sample size 2) Not a large response rate 3) Used only weight status based on BMI to measure fatness 4) Did not adjust for dieting or portion size 5) Did not measure fruit drink/cordial consumption

OR=Odds ratio.

Table 4.7. New Zealand studies that examined the association of sugary drink consumption with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Utter (221)	3079 adolescents (Pacific, Maori, Asian, European), 1202 of which were not trying to change weight (OPIC study). Response rate=54%	Soft drink consumption assessed by a questionnaire	Sex, age, ethnicity. Analyses by weight-control attempts	Among those who were not trying to lose weight, soft drink consumption (cans per day) was positively associated with BMI	1) Did not adjust for potential confounders such as physical activity, TV watching & breakfast consumption 2) Used only BMI as a fatness measure 3) No information on fruit drink/cordial consumption-fatness association provided
Utter (44)	Nationally representative sample of 3275 children (Maori, Pacific, NZEO) aged 5-14 y from the CNS02. Response rate=69%	Fruit drink/soft drink consumption was assessed by a FFQ. Fruit drink/soft drinks were defined as fruit drinks made from powder, concentrate or cordial & 3 different types of carbonated soft drinks	Model 1: Sex, age, ethnicity, SES Model 2: Model 1 + fruit & vegetable consumption, computer use, bring school food from home, buying school food from dairy/takeaways, buying school food from the school tuck shop/canteen, ate-home breakfast consumption, physical activity	Frequency of consumption of fruit/soft drinks was positively associated with BMI in a dose-dependent manner (model 1). This effect was not significant after further adjustment for lifestyle variables (model 2)	1) Young age of participants 2) Combined Europeans with other ethnic groups, such as Asians 3) Relationships subject to possible confounding by SES 4) Used only BMI as a fatness measure 5) Assessed the combined association of fruit drinks & soft drinks with BMI, rather than their individual associations 6) Did not control for weight-loss attempts 7) Did not control for beverage serving size
Duncan (220)	1229 (603M, 626F) children (European, Pacific, Maori, Asian) aged 5-11y randomly selected from 27 primary schools in Auckland	SES estimated by school decile ratings. Parental-reported sugary drink consumption in last full week via a questionnaire. %BF by BIA. Overfat	Sex, age, ethnicity, SES, physical activity, active transport, sports participation, bought lunch, fast food, breakfast consumption, weekday sleep, weekend sleep	Compared to the odds of overfat among children who did not have any weekly servings of sugary drinks, the odds of overfat was higher among children who had 3-4 servings/week (OR=2.26) & even higher	1) Young age of participants 2) Sample was not nationally representative 3) Did not report its response rate 4) Used only a categorical variable based on %BF as a fatness measure 5) Did not adjust for TV watching & weight-loss attempts. Subject to

		was defined as >25% %BF (boys) & >30% %BF (girls)		among those who had 5+ servings/week (OR=2.37)	possible confounding by SES 6) Predicted body fat in Asians using a BIA prediction equation not developed in Asians 7) Small number of Asian boys (n=99) & girls (n=97) 8) Did not define sugary drinks 9) Did not control for beverage serving size

FFQ=Food frequency questionnaire; NZEO=New Zealand European/Other; SES=Socioeconomic status; TV=Television; %BF=Percent body fat; BIA=Bioimpedance analysis; OR=Odds ratio; CNS02=2002 National Children's Nutrition Survey.

Table 4.8. Summary of studies that examined the association of non-diet soft drink consumption with fatness[1]

Type of study	Direction of relationship				Total
	Positive	**None**	**Negative**	**Mixed[2]**	
SOFT DRINKS					
Pacific Island	0	1 (113)	0	0	1
New Zealand	1 (221)	0	0	0	1
Non-South Pacific cross-sectional	5 (124, 222-225)	5 (43, 217, 226-228)	0	0	10
Non-South Pacific case-control	0	1 (177)	0	0	1
Non-South Pacific cohort	4 (214, 219, 239, 240)	4 (235-238)	0	0	8
Non-South Pacific intervention	4 (248-251)	0	0	0	4
Total	14	11	0	0	25
SOFT DRINKS + OTHER DRINKS					
Australian	1 (219)	0	0	0	1
New Zealand	1 (220)	1 (44)	0	0	2
Non-South Pacific cross-sectional	4 (229-231, 233)	2 (133, 234)	0	1 (232)	7
Non-South Pacific cohort	6 (233, 241-245)	4 (133, 235, 236, 247)	0	1 (246)	11
Total[3]	11	6	0	2	19

[1]Values in cells=Number of studies (reference). In some cases, number of references>number of studies because some references are from the same study.
[2]Positive relationship observed in a fraction of the total sample.
[3]Some cells in this row are not equal to total number of studies shown in additive cells as some publications (133, 233) are in more than 1 additive cell.

Table 4.9. Summary of studies that examined the association of non-diet fruit drink/cordial consumption with fatness

Type of study	**Direction of relationship**				**Total**
	Positive	**None**	**Negative**	**Mixed**	
FRUIT DRINKS/CORDIAL					
Non-South Pacific cross-sectional	0	3 (43, 217, 227)	0	0	3
Non-South Pacific cohort	0	2 (238, 240)	0	0	2
Total	0	5	0	0	5
FRUIT DRINKS/CORDIAL + OTHER DRINKS					
Australian	0	0	0	1 (219)	1
New Zealand	1 (220)	1 (44)	0	1	3
Non-South Pacific cross-sectional	4 (229-231, 233)	0	0	0	4
Non-South Pacific cohort	6 (233, 241-245)	5 (133, 235-237, 247)	0	1 (246)	12
Total	11	6	0	3	20

4.4 Breakfast consumption

4.4.1 Association with fatness

This section will examine the findings of previous studies that assessed the association of breakfast consumption with fatness. In past research, two categories of breakfast have been studied. The first is "cereal." If the breakfast food is not described in the study as "cereal", then it is defined in this section as "breakfast", which is the second category. Because of evidence suggesting that "breakfast" and "cereal" have differential relationships with fatness (271), their associations will be considered separately.

1) Breakfast consumption

Studies from Australia (Table 4.10), Pacific Island countries (Table 4.11) and New Zealand (Table 4.12) are described separately from other countries, owing to their greater relevance to this thesis. Studies from all over the world are summarised in Table 4.13.

Australian studies

Only one Australian study was identified (272) (Table 4.10). That study (272), of Australians aged 18 years, found that males who had a continental (included toast and cereal) or cooked breakfast on both days had a lower BMI (22.3 versus 23.1 kg/m^2, $P<0.05$) and waist:hip ratio (0.79 versus 0.81, $P<0.05$) than males who had no breakfast.

Pacific Island studies

The only Pacific Island study was one carried out in Fijian adolescents girls (273) (Table 4.11). In that study (273), breakfast omission was positively related to odds of overweight and obesity.

New Zealand studies

All of the New Zealand studies found an inverse association between breakfast consumption and fatness (Table 4.12). In the CNS02, at-home breakfast consumption was strongly and inversely related to BMI in a dose-dependent manner (44, 218). Duncan *et al* (220) found that children who had breakfast 3-4 days/week had a higher odds of overfat (OR=2.24) than children who had it 5+ days/week. An analysis of the Pacific OPIC study showed that, after adjustment for sex, age and ethnicity, among those who were not trying to change weight, breakfast consumption was inversely related to BMI in a dose-dependent manner (221).

Non-South Pacific studies

Studies from outside the South Pacific are reviewed in this section.

Cross-sectional

As shown in Table 4.13, only five international, cross-sectional studies found no significant relationship between breakfast consumption and fatness (43, 274-277) and not one study found a positive relationship. Some reported mixed results; these studies reported an inverse breakfast consumption-fatness association in one or more groups but not in another or others (278-281). All other international, cross-sectional studies (n=18) found that breakfast consumption was inversely related to fatness (282-299). Some studies that found a significant, inverse relationship had large and nationally representative samples (279, 284, 294, 299). These studies reported weak to moderately strong associations.

Cohort

One cohort study found no significant relationship between breakfast consumption and fatness (Table 4.13); however, the sample size was relatively small, nearly half of the subjects did not complete follow-up measurements and only BMI was used as a fatness measure (135). All other cohort studies found that breakfast consumption was inversely associated with fatness (246, 300-304).

Intervention

Only one intervention study examined the effect of breakfast (cereal) consumption on fatness and is discussed in the "Cereal consumption" section below.

2) Cereal consumption

Studies which examined the association of cereal consumption with body composition are summarised in Table 4.13 and discussed below.

Australian, Pacific Island and New Zealand studies

Not one Australian, Pacific Island or New Zealand study examined the association of cereal consumption with fatness.

Non-South Pacific studies

Cross-sectional

As illustrated in Table 4.13, only one cross-sectional study found no significant relationship between cereal consumption and fatness (305) and not one found a positive relationship. More cross-sectional studies found that cereal consumption was inversely related to fatness (277, 306-308), and some of the effect sizes reported in these studies were large (306-308).

Cohort

One cohort study that examined the association of cereal consumption with fatness was identified (271) (Table 4.13). This was a US cohort study of 2379 African American and white girls aged 9-10 years, who were followed up for 10 years, and it found that cereal consumption, but not breakfast consumption, was inversely related to fatness (271). That is, there was no relationship between breakfast consumption and weight status (BMI-for-age z-score or risk of overweight), but cereal consumption (number of days) was strongly associated with lower BMI in a dose-dependent manner.

Intervention

As shown in Table 4.13, one intervention study was carried out, which found an inverse association between cereal consumption and weight status (309). That is, an intervention, which included the consumption of two servings/day of ready-to-eat-cereal, was associated with a decrease in BMI and %BF among children (309).

Conclusion

In conclusion, many cross-sectional studies and several longitudinal studies have found inverse relationships between breakfast consumption and fatness, and not one study has observed a positive correlation. Dose-dependent associations have been reported and one intervention study showed that increasing cereal consumption had a beneficial effect on weight status. While this implies that breakfast consumption may be causally related to weight gain, it is necessary to examine whether this association is biologically plausible. This will be examined in the next section.

4.4.2 Mechanisms of effect on fatness

There are mechanisms by which low breakfast consumption may be causally related to fatness. These are discussed below.

1) Decreasing satiety

One mechanism is decreasing satiety. Breakfast consumption increases satiety and therefore has the potential to reduce energy intake later in the day (278, 304, 310). Cereal consumption increases fibre intake, which may improve glucose and insulin parameters and increase satiety (311). This mechanism, though, is not supported by cross-sectional (312, 313) and longitudinal (300) studies which indicate that daily energy intake is greater among adolescents who eat breakfast. This may be because these findings may be influenced by under-reporting of energy intake among high-BMI subjects (300, 312, 313).

2) Decreasing calcium intake

Another mechanism is decreasing calcium intake from milk. As shown in Section 4.4.3, calcium may lower the level of fatness. Therefore, an increase in calcium intake may result in a favourable effect on body composition. Some evidence that calcium intake may mediate the beneficial effect of breakfast consumption on weight status comes from international (271, 312) and New Zealand (314) research that show that breakfast consumption is positively related to calcium intake. Further evidence comes from a cohort study that measured cereal consumption, calcium intake and BMI simultaneously (271). In this study of US girls followed up for 10 years, cereal consumption predicted lower BMI (271). This association may have been mediated through calcium intake because calcium intake increased at the same time (271).

3) Decrease the ability to engage in regular physical activity

A third mechanism is that food consumed at breakfast may give one a better ability to perform physical activity (315). Two studies found that breakfast consumption was positively related to physical activity (316, 317). Further, a US longitudinal study showed that the combination of physical activity, parental education and energy intake contributed to a breakfast consumption-BMI relationship (303). However, these associations (303, 316, 317) may exist as a result of breakfast consumption being a marker of a healthy lifestyle.

4) Increasing consumption of foods outside of home and energy-dense foods

A fourth mechanism is that low breakfast consumption increases the consumption of foods outside of home, which are more likely to be energy-dense. Analysis of the CNS02 showed that children who did not have breakfast at home were more likely to usually eat breakfast on the way to school, buy school food from school and buy school food from the dairy (218). Another analysis of the CNS02

showed that the relationship between breakfast consumption and BMI was attenuated after correction for buying school food from the dairy/takeaway shops, buying school food from the tuck shop/canteen and bringing school food from home, although other variables – fruit and vegetable consumption, daily television use, daily computer use, fruit drink and soft drink consumption, and physical activity – were adjusted for at the same time (44). Foods prepared away from home may be less nutritious (318) and lead to weight gain (319), and foods sold in schools are obesogenic (320, 321). Therefore, breakfast consumption may reduce the consumption of foods outside of home that promote weight gain.

Conclusion

In conclusion, there are potential mechanisms that may account for breakfast consumption-fatness relationships. This supports the possibility that breakfast consumption may be causally related to fatness. An important thing to consider, however, is whether this causal association applies to adolescents participating in the OPIC study. To determine this, the next section will examine the limitations of previous studies that assessed the association of breakfast consumption with fatness in South Pacific populations.

4.4.3 Limitations of previous studies

There are limitations of previous studies that have examined the relationship between breakfast consumption and fatness in South Pacific populations. These are summarised in Tables 4.10 (Australian studies), 4.11 (Pacific Island studies) and 4.12 (New Zealand studies), and are discussed below.

1) Sample size

The New Zealand studies had large sample sizes (n>1200) (44, 218, 220, 221). However, the Pacific Island (n=517) (273) and Australian (n=508) (272) studies had relatively small sample sizes.

2) Sample selection

The sample in the study by Duncan *et al* (220) was obtained from Auckland primary schools and is therefore not nationally representative. In the Pacific Island study, the participants were only sampled from a region on the main Fijian island of Viti Levu and did not include boys (273). Also not nationally representative is the Australian study sample, which was recruited from Perth schools (272).

3) Response rate

The CNS02 had a response rate of 69% (44, 218). The Australian study was limited by the fact that only 32% of the study cohort were analysed (272). These response rates are not ideal. Further, the study of Duncan *et al* (220) did not report its response rate, which adds uncertainty to the representativeness of its sample.

4) Subject characteristics

Participants in most New Zealand studies were no older than 14 years (44, 218, 220). Further, the CNS02 did not separate Europeans from other ethnic groups in analyses (44, 218).

5) Adjustment for confounders

The Australian study did not adjust for any potential confounders (272) and the study of Utter *et al* (221) only adjusted for demographic variables. The Pacific Island study did not control for physical activity and dietary intake (273). Analyses of other studies are possibly subject to confounding by SES (as only proxy measures of SES were used in analyses) (44, 218, 220) and sugary drink consumption (218).

Another limitation is that, with the exception of the study by Utter *et al* (221), all South Pacific studies did not control for weight-loss attempts or dieting (44, 218, 220, 272, 273). This is important because an inverse association between breakfast consumption and BMI may exist because overweight adolescents are reducing their consumption of breakfast as a means of trying to lose weight (282, 322).

6) Body composition measures

The CNS02 (44, 218) and the study of Utter *et al* (221) used only BMI as a fatness measure. Similarly, the Pacific Island family used only weight status based on BMI to measure fatness (273). Another study used only BMI and waist:hip ratio as the outcome variable (272).

Only one study used %BF, which was estimated from a BIA prediction equation (220). It examined excess fat (*categorical* variable) as the outcome variable (220), but did not consider the association with *continuous* fatness variables. In addition, that study (220) predicted body fat in Asians using a BIA prediction equation not developed in Asians (32).

7) Breakfast definitions

The Pacific Island study (273) and the study of Duncan *et al* (220) did not differentiate between breakfast consumed at home and outside of home. This is important because the nutritional content of foods prepared away from home may be less nutritious (318) and the relationship between breakfast consumption and BMI depends on how breakfast is defined (281).

Conclusion

As shown by previous studies, breakfast consumption is inversely related to fatness and there are biologically plausible mechanisms that may account for this. Therefore, there is evidence to suggest that reduced breakfast consumption may be causally associated with obesity.

Studies carried out in South Pacific groups are few in number. These studies had several limitations, including the fact that most of them comprised subjects no older than 14 years and nearly all relied on just height and weight to measure fatness. Therefore, it is not known whether breakfast consumption is associated with fatness among youth participating in the OPIC study. This thesis aimed to investigate this.

Table 4.10. Australian studies that examined the association of breakfast consumption with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Milligan (272)	508 male & female Australians aged 18 y from a cohort study. Subjects were recruited from Perth schools & 32% of cohort were analysed	Breakfast consumption determined from two-day diet records. Continental breakfast included items such as toast & cereal	None	Males who had a continental or cooked breakfast on both days had a lower BMI (22.3 vs 23.1 kg/m^2, $P<0.05$) & waist:hip ratio (0.79 vs 0.81, $P<0.05$) than males who had no breakfast at least once. These differences were not observed among females	1) Relatively small sample size 2) Only 32% of the study cohort were analysed 3) Sample was not nationally representative 4) Did not adjust for confounders 5) Only used BMI & waist:hip ratio to measure fatness

Table 4.11. Pacific Island studies that examined the association of breakfast consumption with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Thompson-McCormick (273)	517 Fijian adolescent girls aged 15-20 y. Cross-sectional study. Response rate=71%	Breakfast skipping assessed by a question. Overweight was defined by BMI≥85th percentile and obesity by BMI≥95th percentile	Age, peri-urban school location, low relative material wealth, perceived feasibility of & desire for upward social mobility, perceived Western/global cultural knowledge & competencies	Breakfast skipping was positively associated with odds of overweight (OR=1.15, P<0.01) & obesity (OR=1.18, P<0.01). After further adjustment for eating disorders, these effects were no longer significant	1) Relatively small sample size 2) Sample was not nationally representative. Sample did not include boys 3) Used only weight status based on BMI to measure fatness 4) Did not adjust for dieting, physical activity & dietary intake 5) Did not differentiate between breakfast consumed at home and outside of home

OR=Odds ratio.

Table 4.12. New Zealand studies that examined the association of breakfast consumption with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Utter (221)	3079 adolescents (Pacific, Maori, Asian, European), 1202 of which were not trying to change weight (OPIC study). Response rate=54%	Breakfast consumption assessed with the question, "In the last 5 school days, on how many days did you have something to eat for breakfast before school started?"	Sex, age, ethnicity. Analyses by weight-control attempts	Among those who were not trying to change weight, breakfast consumption was inversely related to BMI in a dose-dependent manner	1) Did not adjust for potential confounders such as physical activity & sugary drink consumption 2) Used only BMI as a fatness measure
Utter (44) (same study as (218))	Nationally representative sample of 3275 children (Maori, Pacific, NZEO) aged 5-14 y from the CNS02. Response rate=69%	Breakfast defined as something eaten at home before school	Sex, age, ethnicity, SES, fruit & vegetables, TV use, computer use, bringing school food from home, bring school food from the dairy/takeaway shops, bring school food from the school tuck shop/canteen, fruit & soft drinks, physical activity	At-home breakfast consumption was negatively correlated with BMI	1) Young age of participants 2) Used only BMI as a fatness measure 3) Combined Europeans with other ethnic groups, such as Asians 4) Relationships subject to possible confounding by SES 5) Did not control for weight-loss attempts
Utter (218) (same study as (44))	Nationally representative sample of 3042 children (Maori, Pacific, NZEO) aged 5-14 y from the CNS02. Response rate=69%	Breakfast assessed with the question, "Over the past week, did you eat or drink something before you left home for school in the morning?"	Sex, age, ethnicity, SES, physical activity	BMI was lower in children who usually had at-home breakfast (18.7 kg/m^2), than in children who sometimes (21.5 kg/m^2) or did not have it (22.1 kg/m^2)	1) Young age of participants 2) Used only BMI as a fatness measure 3) Did not adjust for potential confounders such as sugary drink consumption 4) Combined Europeans with other ethnic groups, such as Asians 5) Relationships subject to possible confounding by SES 6) Did not control for weight-loss attempts
Duncan	1229 (603M,	SES estimated by	Sex, age, ethnicity, SES,	Children who had	1) Young age of participants

(220)	626F) children (European, Pacific, Maori, Asian) aged 5-11y randomly selected from 27 primary schools in Auckland	school deciles. Parental-reported breakfast consumption in last full week via a questionnaire. %BF by BIA. Overfat was defined as >25% %BF (boys) & >30% %BF (girls)	physical activity, active transport, sports participation, bought lunch, fast food, sugary drinks, weekday sleep, weekend sleep	breakfast 3-4 days/week had a higher odds of overfat (OR=2.24) than children who had it 5+ days/week	2) Sample was not nationally representative 3) Did not report its response rate 4) Did not adjust for weight-loss attempts. Subject to possible confounding by SES 5) Used only a categorical variable based on %BF as a fatness measure 6) Small number of Asian boys (n=99) & girls (n=97) 7) Predicted body fat in Asians using a BIA prediction not developed in Asians 8) Did not differentiate between breakfast consumed at home and outside of home

NZEO=New Zealand European/Other; SES=Socioeconomic status; TV=Television; %BF=Percent body fat; BIA=Bioimpedance analysis; OR=Odds ratio; CNS02=2002 National Children's Nutrition Survey.

Table 4.13. Summary of studies that examined the association of breakfast or cereal consumption with fatness[1]

Type of study	Direction of relationship				Total
	Positive	**None**	**Inverse**	**Mixed[2]**	
BREAKFAST CONSUMPTION					
Australian	0	0	1 (272)	0	1
Pacific Island	0	0	1 (273)	0	1
New Zealand	0	0	3 (44, 218, 220, 221)	0	3
Non-South Pacific cross-sectional	0	5 (43, 274-277)	18 (282-299)	4 (278-281)	27
Non-South Pacific cohort	0	1 (135)	15 (246, 300-304)	0	16
Total	0	6	38	4	48
CEREAL CONSUMPTION					
Non-South Pacific cross-sectional	0	1 (305)	4 (277, 306-308)	2 (313, 323)	7
Non-South Pacific cohort	0	0	1 (271)	0	1
Non-South Pacific intervention	0	0	1 (309)	0	1
Total	0	1	6	2	9

[1]Values in cells=Number of studies (reference). In some cases, number of references>number of studies because some references are from the same study: (246) and (301).
[2]Negative relationship observed in a fraction of the total sample.

4.5 Physical activity

4.5.1 Association with fatness

In this section, the findings of previous studies that assessed the association of physical activity with fatness will be examined. Because of the substantial research on this topic, only studies of children and adolescents are included.

Studies from Australia (summarised in Table 4.14), Pacific Island countries (Table 4.15) and New Zealand (Table 4.16) have been considered separately from other countries because of their greater relevance to the samples analysed in this thesis. The studies from all countries in the world that have examined the association between physical activity and fatness are summarised collectively in Table 4.17.

Methods to measure energy expenditure – calorimetry and doubly-labelled water – do not measure the *motion per se* associated with physical activity; rather, they measure the *result* of physical activity (324). Nevertheless, they are objective markers of physical activity (324). Therefore, studies that have used these techniques to examine associations between physical activity and fatness in free-living conditions have been included in this literature review.

Australian studies

Fourteen Australian studies were identified (115, 117, 325-336) (described in Table 4.14 and summarised in Table 4.17).

Cross-sectional

Twelve Australian studies comprised cross-sectional analyses (115, 117, 325-328, 330-333, 335, 336) (Table 4.14). Two of these studies did not observe a significant association between physical activity and fatness (115, 335). Limitations of these studies include the fact that they had relatively small sample sizes (n=281 boys and 321 girls (115); and n=518 (335)) and relied on only weight status based on BMI to measure fatness (115, 335). One of the twelve studies was small (n=106) and reported a "mixed" finding: no relationship was evident among girls but a notable, inverse association was observed in boys (328). The remaining nine Australian studies reported that physical activity was inversely related to fatness (117, 325-327, 330-333, 336). Of these nine studies, physical activity was mostly measured objectively: five by pedometry (325, 327, 331-333), one by accelerometry (326) and one by a criterion method (doubly labelled water) (330). The inverse

association in one of these studies was strong and dose-dependent (117); while in other studies, the size of the relationship was notable (325, 327, 330) (Table 4.14).

Cohort

Two Australian studies comprised longitudinal, observational analyses (326, 329) (Table 4.14). One of these studies reported no association between hours of planned exercise and BMI z-score; however, the sample size was small (n=41), planned exercise was assessed subjectively (parent-reported), participants were young (6-9 years), the sample was non-randomly selected and the follow-up period (12 months) was short (329). In contrast, the other Australian study measured physical activity objectively (with accelerometry) and reported an inverse association between physical activity and fatness (326).

Intervention

As for international intervention studies, Australian intervention studies in which it was difficult to quantify the contribution of physical activity *per se* to changes in fatness or in which physical activity did not change were excluded from this review. One Australian intervention study was identified (334) (Table 4.14). This was a school-based intervention study of primary school-aged children in South Australia which found that skinfold thickness reduced after the introduction of a physical activity programme (334).

Pacific Island studies

Only one Pacific Island study, the HBLPY study, was identified (113) (Table 4.15). This study reported an inverse association between exercise frequency/duration and odds of overweight/obesity (113).

New Zealand studies

Seven studies from New Zealand were identified (44, 122, 123, 220, 337-341) (Table 4.16).

Cross-sectional

Six New Zealand studies comprised cross-sectional analyses (44, 122, 123, 220, 337-340) (Table 4.16). The CNS02 showed that physical activity was inversely associated with BMI, although this effect was no longer significant after further adjustment for lifestyle variables (44). In a small (n=244) sample of children, physical activity was not significantly related to BMI (123). A study of Maori, Pacific Island and European children reported a “mixed” result (significant association in

only a fraction of the total sample): physical activity was inversely correlated with %BF in boys but not girls, but the sample size was small (n=79) (340). The remaining three studies (five publications) found that physical activity was inversely associated with fatness (122, 220, 337-339). Two of these three studies measured physical activity objectively – by pedometry (220, 338, 339) or accelerometry (122) and one of these showed evidence of a dose-dependent association (338). In studies that did find an inverse relationship, the sizes of the associations were quite notable (122, 220, 338, 339) (Table 4.16).

Cohort

One cohort study – the FLAME study – was identified (123) (Table 4.16). This study was small (n=202) and did not find a significant physical activity-fatness association. (123).

Intervention

One intervention study was identified (341) (Table 4.16). In this study, an intervention to increase extra-curricular levels of activity in children aged 5-12 years increased physical activity levels (measured by accelerometry and by a questionnaire) and reduced BMI z-score by –0.12 over 1 year (341).

Non-South Pacific studies

Studies from countries outside of the South Pacific are reviewed in this section.

Cross-sectional

Because of the substantial research on this topic, the literature review for cross-sectional studies was limited to those that measured physical activity objectively. As shown in a recent review article, cross-sectional studies that measured physical activity objectively (heart-rate monitoring, pedometry or accelerometry) consistently show that physical activity is inversely associated with fatness (342). Of note, a large study (n=5,500) found that physical activity measured by accelerometry had a strong, inverse dose-response association with DXA-measured fatness (343).

Case-control

One case-control study was identified (177) (Table 4.17). Compared to non-obese children, obese children were less physically active (as determined by self-report of physical activity frequency and maternal rating of level of physical activity) (155, 177).

Cohort

A total of 38 cohort studies were identified (118-120, 130, 135, 136, 144, 155, 163, 164, 167-170, 172, 173, 238, 239, 280, 320-338) (Table 4.17). Twelve studies did not find a longitudinal association between physical activity and fatness (133, 152, 155, 160, 179, 183, 344-349). Some studies showed mixed results – that is, inverse associations were reported in a fraction of the total sample (167, 247, 350-353). Most (n=20) cohort studies found that physical activity was inversely related to body composition variables (119, 120, 144, 163, 167, 169, 170, 172, 173, 238, 280, 325, 327-334). Out of these 20 studies, one study found a strong and dose-dependent relationship after following up girls over nearly a decade (354); while a large (n=4,150) study found a strong, inverse association between accelerometry-measured physical activity and DXA-measured fat mass (355). Similarly, the inverse associations reported in other studies were strong (178, 187, 356, 357) and dose-dependent (356). Of note, not one study reported a positive association.

Intervention

There are a number of international intervention studies that have modified physical activity (358); but many have included modifications to aspects of lifestyle in addition to physical activity (e.g., diet). This makes it hard to determine whether changes in fatness are due to physical activity or not. Therefore, studies in which it was difficult to quantify the contribution of physical activity *per se* to changes in fatness were not included in this review. In addition, as physical activity must change in order to assess its effect on fatness, studies that did not observe a change in physical activity level over the intervention or follow-up period were excluded from this review.

Twenty three intervention studies were examined in this review (190, 359-381) (Table 4.17). Only a few of these (n=4) reported that an increase in the level of physical activity did not change fatness level (359-363). Limitations of these studies include a small sample size (n=81) (363) and that only height and weight were used to measure fatness (359, 363). One study reported a "mixed" result: an exercise intervention was inversely associated with BMI in girls but not in boys (381). In contrast, the majority of the studies (n=18) found that increasing physical activity level resulted in a reduction in fatness (175, 346-362). Not one intervention study reported that increasing physical activity resulted in an increase in fatness.

Meta-analyses

One meta-analysis (year of publication=2000) showed that there was a small to moderate, inverse association (mean effect size: r=-0.16) between activity and fatness in children and adolescents

(382). A meta-analysis (year of publication=2009) of school-based physical activity interventions reported that they did not improve BMI (383). However, this meta-analysis did not consider the effect of the interventions on TFM or %BF and the samples comprised mainly primary-school aged children (383). A recent (year of publication=2011) meta-analysis of cohort prospective studies found no significant overall association between physical activity and fatness; however, only 6 studies were reviewed (384) and a number of cohort studies that found an inverse association were missing from the analyses of that study (Table 4.17). Another meta-analysis (year of publication=2002) of exercise treatment programs found that exercise reduced %BF (mean reduction=0.70%) and BMI (mean reduction=0.76 kg/m^2) (385). A more recent meta-analysis (year of publication=2006) of randomised trials for treating overweight in children and adolescents with exercise found that exercise lowered %BF (pooled standardised mean difference=-0.4) (386).

Conclusion

As shown in a recent review article, studies consistently show that physical activity has an expected, inverse relationship with fatness (112). This is reflected in the current analysis of the literature, which showed that the majority of international cross-sectional and cohort studies found that physical activity is inversely associated with fatness (Table 4.17). Similarly, most South Pacific studies have found that physical activity level is inversely related to fatness. In the international and South Pacific literature, strong effect sizes and dose-dependent associations have been observed, and intervention studies consistently show that increasing physical activity results in a reduction in fatness level. Importantly, not one study reported a positive association. These findings are reflected in the fact that three meta-analyses (382, 385, 386) – two of which were of exercise intervention studies (385, 386) – showed that physical activity is inversely associated with fatness. Therefore, the literature gives evidence for an inverse, causal relationship between physical activity and fatness.

4.5.2 Mechanisms of effect on fatness

It is well-recognised that physical activity utilises energy, thereby reducing weight (387). For instance, energy expenditure prediction equations based on accelerometer-measured counts have been developed (388). In addition, physical activity promotes fat oxidation during and post-exercise, resulting in a reduction in fat storage (387, 389, 390).

4.5.3 Limitations of previous studies

There are limitations of previous studies that have examined the relationship between physical activity and fatness in South Pacific populations. These are summarised in Tables 4.14 (Australian studies), 4.15 (Pacific Island studies) and 4.16 (New Zealand studies), and are discussed below.

1) Sample size

One Australian study (115) and the HBLPY study (113) did not have large sample sizes (n=602 and n=443, respectively), yet measured physical activity with a self-reported questionnaire. Two New Zealand studies had small sample sizes (n=79 (340) and n=202 (123)), as did some Australian studies (n=106 (328), n=47 (330) and n=22 (331)). Other studies did not have large sample sizes too (n=297 (332), n=518 (335) and n=563 (327)).

2) Sample selection

In the ABC study, participants were only recruited from the Waitemata Health or Auckland Healthcare regions and the sample for this study is not representative of children living outside these regions (122). The participants in the study by Duncan *et al* (220, 338, 339) were recruited from primary schools in the Auckland region and are therefore not nationally representative. Also not nationally representative is subjects in the FLAME study, who were recruited from a birth cohort in Dunedin (123). In the intervention study by Taylor *et al* (341), the participants were not randomly selected.

One of the Australian studies recruited participants from 10 schools in the Perth metropolitan area (115), another recruited subjects from 4 Brisbane state primary schools (331), another from schools in Brisbane (335), while another recruited participants from schools in Western Australia (333). The samples of other Australian studies comprised participants from Perth (117) or Melbourne (326, 336). Therefore, the samples in these Australian studies are not representative of children living outside of Perth (115, 117), Melbourne (326, 336), Brisbane (331, 335) or Western Australia (333). The sample of one study is of limited representativeness, as the participants were recruited from a non-state/private high school in Southeast Queensland (332). Another study used a convenience sample from an urban city in an east coast Australian state (327), while another recruited subjects via advertising (329). In another study, the participants were recruited from schools in Brisbane and Sydney, and through staff at the Queensland University of Technology (328). Similarly, the subjects in another study were a convenience sample of children from a school in Brisbane or recruited through staff at a university (330). Another drawback of the Australian literature is that, in one study,

a notable percentage of participants did not comply with the protocol relating to the measurement of physical activity via pedometry and were subsequently excluded from analyses (333).

3) Response rate

Low response rates were observed in one Australian survey (41%) (325) and in another Australian study (44% in 2001 survey) (336). In one Australian study, 3507 families were invited to participate; however, data on 518 (15%) children were analysed (335). The CNS02 had a response rate of 69% (44), which is not ideal. The FLAME study reported a response rate of 59% and retention rate of 83% for its longitudinal analysis; this indicates that a notable fraction (>50%) of those who were invited to take part in the study did not participate in both the baseline and follow-up measurements (123). There are New Zealand (220, 338, 339) and Australian (115, 117, 332) studies that did not report their response rates, which adds uncertainty to the representativeness of their samples. Further, the response rate (62%) of the HBLPY study was not large (113).

4) Subject characteristics

The ABC study consisted of only European participants (122), while the study of Taylor *et al* (341) and the FLAME study (123) comprised primarily Caucasian subjects. The CNS02 combined Europeans with other ethnic groups, such as Asians (44). Most New Zealand studies comprised participants that were no older than 14 years, the majority of which were primary school-aged children (44, 122, 123, 220, 338, 339, 341). All Australian studies, except for one (325), comprised participants who were aged under 14 years (115, 117, 326-331, 335, 336). In comparison, only a small number of studies comprised samples of youth aged over 14 years (113, 325, 332, 333, 337). Furthermore, one Australian study did not provide any findings on males, as all of its participants were female (332).

5) Adjustment for confounders

Several studies did not adjust for any confounders (325, 327, 328, 330-333, 336, 338-340), which is a limitation of these studies. Other studies may be subject to residual confounding as they sampled from schools across high and low SES areas, yet used proxy measures of SES (NZDep01 (44), school decile ratings (220, 338, 339) and maternal education (326)) to adjust for SES in statistical models. A limitation of the study by Taylor *et al* (341) is that, although its intervention was primarily physical activity-based, the incorporation of simple dietary advice into the intervention programme complicates the ability to quantify the effect of physical activity *per se* on fatness.

Another limitation of previous studies is that they are unable to determine whether physical activity causes a reduction in fatness because their findings may be influenced by the possibility that overweight adolescents are exercising more as a way of controlling their weight. Previous studies have not accounted for weight-control attempts in their analyses (Tables 4.14-4.16).

6) Body composition measures

The CNS02 (44) used only BMI as a fatness measure, while the study by Taylor *et al* (341) used only BMI z-score and WC. The fatness measure used in the HBLPY study (113), the study by Teevale *et al* (337) and some Australian studies (325, 326, 335, 336) was weight status based on BMI. Other Australian studies used only height and weight to measure fatness (115, 117, 327, 331, 332), while one used only BMI- and WC-based measures of fatness (333). Only a few studies quantified whole-body fat mass (220, 328, 338-340). One of these studies used categorised body composition variables (including %BF) in analyses, rather than analysing these as continuous variables (220, 338, 339). In addition, that study (220, 338, 339) predicted body fat in Asians using a BIA prediction equation not developed in Asians (32).

7) Physical activity measurement

Although the ABC study measured physical activity objectively via accelerometry, the information on physical activity was collected over only one 24-hour period (122). This is a short-time frame and suggests that the physical activity measurement may not be a good measure of "typical" activity patterns. In a different study, physical activity at school was not measured (335).

A limitation of one Australian study that compared data from two different surveys (one carried out in 1985 and the other in 2001) is that physical activity was measured differently in each survey: physical activity habits in *week preceding* data collection in one survey and *usual* physical activity habits in the other survey (336). In addition, data from the two surveys were collected at different times of the year: the 2001 survey was carried out 8 weeks later in the year than the 1985 survey (336). Due to seasonal variation in physical activity patterns, this makes it is difficult to quantify the temporal change in "typical" frequency of physical activity level over the 16-year period.

Another limitation of previous South Pacific studies is that several studies simply measured *overall* physical activity in analyses – daily step counts (327, 331-333, 338, 339), counts per minute (123), time spent doing physical activity (122), hours of activity per week (115), physical activity level (derived from total and resting energy expenditure) (328, 330, 340) or overall activity level

(measured from questions) (44, 117). However, such measures do not provide information on when and where physical activity is occurring (e.g., during school lunchtime). Identifying which particular activity periods – for instance, after-school physical activity – are associated with fatness will help to identify appropriate physical activity interventions (352, 391).

Conclusion

Most international studies show that physical activity is inversely associated with fatness. Dose-dependent and strong associations have been observed, and the majority of intervention studies show that increasing physical activity reduces fatness. This gives evidence for a causal, inverse physical activity-fatness association. This is also the case for South Pacific studies, which relate more to this thesis. However, only a small number of these studies have been carried out, and there are a very limited number of Pacific Island studies in the literature (Table 4.15). The South Pacific studies that have been published had important limitations. Nearly all relied on only BMI to measure fatness, most were carried out in children and not one adjusted for weight-control attempts. Several studies did not measure when and where physical activity occurred in statistical analyses. Two studies did not have large sample sizes, yet measure physical activity subjectively (113, 115). Therefore, because of the small number of studies carried out in South Pacific populations and the abovementioned limitations of these, it is unclear whether low physical activity level contributes to increased fatness levels in South Pacific youth. To address this gap of knowledge in the literature, this thesis aimed to examine the association of physical activity variables with fatness among adolescents living in New Zealand, Australia and in the Pacific Islands.

Table 4.14. Australian studies that examined the association of physical activity with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
CROSS-SECTIONAL					
Burke (115)	281 boys & 321 girls aged 10.4-13.8 y recruited from 10 schools in the Perth metropolitan area	Self-reported questionnaire was used to record PA data for the week prior to data collection. SES based on area. Weight status was defined by IOTF criteria	Age, SES, clustering by school (Sex-specific analyses)	Moderate/vigorous activity (hours/week) was not significantly associated with odds of overweight/obesity in boys (OR=0.99; 95% CI: 0.98-1.01) & girls (OR=1.01; 95% CI: 0.99-1.02)	1) Sample size was not large 2) Sample was not nationally representative 3) Did not report its response rate 4) Young age of subjects 5) Used only weight status based on BMI to measure fatness 6) Residual confounding by SES may exist as SES range was wide & defined by area 7) Did not measure when & where PA occurred in analyses
Burke (117)	Cross-sectional analysis of 1,430 boys & girls (mean age=8 y) from Perth	Activity level assessed by questions & categorised as sedentary, slightly active or active	Sex	Dose-dependent, inverse PA-BMI association: compared to those who were sedentary, those who were slightly active had 0.732 kg/m^2 less BMI (P=0.001) & those who were active had 1.181 kg/m^2 less BMI (P<0.001)	1) Young age of participants 2) Sample was not nationally representative 3) Did not report its response rate 4) Used only BMI to measure fatness 5) Study was carried out >10 years ago 6) Only adjusted for sex 7) Did not measure when & where PA occurred in analyses
Olds (325)	2,200 children aged 9-16 y from all states in Australia. Response rate=41%	Pedometer-measured step counts over 7 days. Self-reported PA measured by 24-hour recall. Weight status was defined by IOTF criteria	None	Compared to normal-weight participants, obese participants reported 20 minutes/day less MVPA, took 1,609 fewer daily steps & had a lower PAL (1.55 versus 1.76 METs)	1) Low response rate 2) Used only weight-status based on BMI to measure fatness 3) Did not control for any confounders
Cleland (326) (also cohort)	188 children aged 5-6 years & 360 children aged 10-12 y from elementary	Time children spent outdoors was reported by parents via answering questions. Moderate & vigorous	Maternal education	1) Each additional hour outdoors on weekdays & weekend days during cooler months was associated with more moderate & vigorous PA	1) Small sample size 2) Sample was not nationally representative 3) Young age of participants 4) Used only weight-status based on BMI

	schools in Melbourne	PA assessed by accelerometry. Weight status was defined by IOTF criteria		2) During cooler months, ≥1 hour/day of time spent outdoors was associated with a lower prevalence ratio (0.54, 95% CI: 0.34 to 0.94) of overweight/obesity (P<0.05) in older girls	to measure fatness 5) Measure of time spent outdoors was not validated 6) Findings may be subject to selection bias, as half of the baseline sample did not participate in the follow-up 7) Relatively temperate weather in Melbourne limits generalisability of findings to countries with cooler or warmer climates
Vincent (327)	Children aged 6-12 y from Australia (278 boys, 285 girls), US & Sweden. Australians were from a large urban city in an east coast Australian state	Step counts measured by pedometry over 4 weekdays	None	Among Australian girls aged 8 y, BMI was negatively correlated with step counts (r=-0.331)	1) Convenience sample 2) Young age of participants 3) No weekend data were assessed 4) Used only BMI to measure fatness 5) Did not control for any confounders 6) Did not measure when & where PA occurred in analyses
Ball (328)	106 children (52M, 54F) aged 7.8±0.9 y. Recruited from schools in Sydney & Brisbane, & from QUT staff	PA level calculated from TEE (by DLW over 10 days) & REE by prediction equations. %BF measured by isotope dilution	None	PAL was inversely associated with fatness in boys (r=-0.50 for %BF, r=-0.46 for fat mass, r=-0.37 for BMI) but not girls	1) Small sample size 2) Convenience sample 3) Young age of participants 4) Did not control for any confounders 5) Did not measure when & where PA occurred in analyses
Abbott (330)	47 children aged 5-10.5 y. Recruited from a Brisbane state school & from QUT staff	PAL calculated from TEE (by DLW over 10 days) & REE (by prediction equations). %BF measured by isotope dilution	None	PAL was negatively correlated with BMI (r=-0.45) & %BF (r=-0.43)	1) Small sample size 2) Convenience sample 3) Young age of participants 4) Did not control for any confounders 5) Did not measure when & where PA occurred in analyses
Cuddihy (332)	297 females aged 13-15 y who attended a non-state/private high school in	Pedometer-measured daily steps	None	Mean steps/day was inversely associated with BMI (r=-0.251)	1) Relatively small sample size 2) Sample was not nationally representative 3) Did not report its response rate 4) Did not study males

	Southeast Queensland				5) Used only BMI as a fatness measure 6) Did not control for any confounders 7) Did not measure when & where PA occurred in analyses
Hands (333)	1,539 (787M, 752F) children & adolescents aged 7-16 y. Recruited from primary & secondary schools in Western Australia	Pedometer-measured daily steps. Weight status was defined by IOTF criteria	None	Daily steps were lower among those who: 1) were overweight/obese (P=0.06 for boys, P=0.003 for girls) 2) had high a high WC-for-age value (P=0.03 for boys, P=0.000 for girls)	1) Sample was not nationally representative 2) May be subject to selection bias as notable % (nearly one third) of participants did not comply with the pedometer protocol & were subsequently excluded from analyses 3) Used only BMI- & WC-based measures to quantify fatness 4 Did not control for any confounders 5) Did not measure when & where PA occurred in analyses
Salmon (336)	Children aged 9-13 y from a cross-sectional survey carried out in 1985 (n=557) & another carried out in 2001 (n=926). Recruited from government schools in Melbourne. Response rate=77.5% for 1985 survey, 44% for 2001 survey	Children answered a questionnaire about frequency of: 1) walking & cycling to & from school 2) participation in PE In 1985, children reported their previous week of PA; while, in 2001, children reported PA in their usual week in a school term. Weight status was defined by IOTF criteria	Analyses were performed by SES. No confounders adjusted for in models	From 1985 to 2001: 1) Frequency of walking to or from school decreased from 4.38 to 3.61 trips/week 2) Frequency of cycling to or from school decreased from 1.22 to 0.36 trips/week 3) Frequency of PE lessons decreased from 1.64 to 1.18 lessons/week At the same time, overweight/obesity increased from 11.7% in 1985 to 28.7% in 2001	1) Young age of participants 2) Sample was not nationally representative 3) Low response rate in 2001 survey 4) Did not control for confounders. May be subject to residual confounding by SES 5) As there is seasonal variation in PA patterns/PE lessons & data from the 2 surveys were collected at different times of the year, it is difficult to quantify temporal change in "typical" frequency of PA patterns/PE lessons 6) PA was measured differently between the 2 surveys: *previous* week of PA in 1985 & *usual* week of PA in 2001 7) Used only weight-status based on BMI to measure fatness
Spinks (335)	518 children aged 5-12 y randomly selected from Brisbane primary	PA recorded on a 7-day diary completed by parents. Overweight was defined	Gender, age group, school SES, non-compliance with	Those who did <60 minutes of moderate- to vigorous-intensity activities every day had a non-significantly higher odds of	1) Relatively small sample 2) Young age of participants 3) Sample was not nationally representative

	& preschools. 3,507 families invited to participate	by IOTF criteria	electronic media use recommendations, school clustering	overweight (OR=1.28; 95% CI=0.60 to 2.70)	4) Low participation rate: 518 participated, yet 3,507 families were invited to participate 5) Used only weight-status based on BMI to measure fatness 6) Diary did not capture PA done at school
Ziviani (331)	Cross-sectional analysis of 59 children (26M, 33F) aged 8-10 y. Recruited from 4 Brisbane state primary schools	Pedometer-measured daily steps	None	BMI was inversely associated with steps taken on weekdays (r=-0.28) & on the weekend (r=-0.32)	1) Small sample size 2) Young age of participants 3) Sample was not nationally representative 4) Used only BMI to measure fatness 5) Did not control for any confounders 6) Did not measure when & where PA occurred in analyses
COHORT					
Cleland (326) (also cross-sectional)	188 children aged 5-6 years & 360 children aged 10-12 y from elementary schools in Melbourne followed up after 3 years	Time children spent outdoors was reported by parents via answering questions. Moderate & vigorous PA assessed by accelerometry. Weight status was defined by IOTF criteria	Maternal education	1) More time spent outdoors predicted higher moderate & vigorous PA 2) During warmer months, time spent outdoors hours/day was associated with a lower relative risk of overweight/obesity (P<0.05) in younger girls	1) Small sample size 2) Sample was not nationally representative 3) Young age of participants 4) Measure of time spent outdoors was not validated 5) As half of the baseline sample did not participate in the follow-up, there may be selection bias 6) Relatively temperate weather in Melbourne limits generalisability of findings to countries with cooler or warmer climates
Bogaert (329)	41 children (21M, 20F) aged 6-9 y followed up after 12 months	Parent-reported hours of planned exercise. %BF by BIA	Confounding variables	No association between hours of planned exercise & BMI z-score or %BF	1) Small sample size 2) Young age of participants 3) Sample was not randomly selected (recruited through advertising) 4) Short follow-up period
INTER-VENTION					
Dwyer (334)	Children aged 10 y from South	1) Phase I (14 weeks, 7 primary schools,	None	1) Phase I: sum of 4 skinfolds decreased by 1.26 mm in fitness	1) Relatively small sample size 2) Young age of participants

	Australian primary schools	n=513): control group (1.5 hours of PE/week), skill group (same as control group, plus PA was increased to 1.25 hours/day), fitness group (same as skill group, plus goal was to raise heart rate). 2) Phase II: daily PA programmes in 5 primary schools (n=216)		group but did not change in other groups 2) Phase II: Over a 2-year period, sum of 4 skinfolds decreased (males: from 31.90 mm to 28.62 mm; females: from 40.24 mm to 36.23 mm)	3) Sample was not nationally representative 4) Although it measured physical work capacity, it did not measure PA level of each child 5) Did not control for confounders 6) There were no control schools for Phase II

IOTF criteria=BMI cut-offs adopted by the International Obesity Task Force (392); SES=Socioeconomic status; OR=Odds ratio; MVPA=Moderate-to-vigorous physical activity; PA=Physical activity; DLW=Doubly-labelled water; CI=Confidence interval; US=United States; TEE=Total energy expenditure; REE=Resting energy expenditure; %BF=Percent body fat; BIA=Bioimpedance analysis; QUT=Queensland University of Technology; WC=Waist circumference; PE=Physical education; METs=Metabolic equivalent of tasks.

Table 4.15. Pacific Island studies that examined the association of physical activity with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
Smith (113)	Nationally representative sample of 443 adolescents from Tonga aged 11-16 y. Cross-sectional study. Response rate=62%	Exercise frequency/duration assessed by a questionnaire – data was categorised: "sedentary" (≤30 min/week & ≤1 bout/week), "regular" (≥2-3 hours/week & 4-6 bouts/week) & "low" (falling between the other categories)	Gender, age, island group, parent's job, fruits, soft drinks, sweets/chocolates, fresh vegetables, taro, tinned fish, tinned mutton/corned beef, TV & video watching	Exercise frequency/duration was inversely associated with odds of overweight/obesity: compared to those who were "sedentary", OR for those who had a "low" level of exercise frequency/duration=0.55 (95% CI: 0.31-0.99)	1) Relatively small sample size 2) Not a large response rate 3) Used only weight status based on BMI to measure fatness

TV=Television; CI=Confidence interval; OR=Odds ratio.

Table 4.16. New Zealand studies that examined the association of physical activity with fatness

First author	Subjects	Measurements & definitions	Confounders adjusted for	Findings	Limitations
CROSS-SECTIONAL					
Teevale (337)	1,596 Pacific (Samoan, Cook Island, Tongan, "Other" Pacific) youth aged 12-17 y (OPIC study). Response rate=54%	PA during morning tea/recess, lunch & after school were each assessed with a question. Weight status was defined by IOTF BMI cut-offs	Sex, age, Pacific ethnicity	Obesity prevalence had an inverse association with school lunchtime PA (P=0.0062) & an inverse association with after-school PA that was borderline significant (P=0.06)	1) Used only weight status based on BMI to measure fatness 2) Did not adjust for weight-control attempts
Utter (44)	Nationally representative sample of 3,275 children (Maori, Pacific, NZEO) aged 5-14 y. Response rate=69%	PA was assessed by a questionnaire	Sex, age, ethnicity, SES, fruit & vegetables, TV use, computer use, bringing school food from home, bringing school food from the dairy/takeaway shops, bring school food from the school tuck shop/canteen, fruit & soft drinks, breakfast consumption	PA was negatively correlated with BMI (P=0.039), but not after adjustment for lifestyle variables (P=0.22)	1) Young age of participants 2) Used only BMI as a fatness measure 3) Combined Europeans with other ethnic groups, such as Asians 4) Relationships subject to possible residual confounding by SES 5) Did not control for weight-loss attempts 6) Did not measure when & where PA occurred in analyses
Blair (122)	871 European children aged 7 y	Accelerometers were worn the day before the interview to measure PA %BF measured by BIA	Gender, maternal BMI, maternal age at birth of child, TV watching	For every additional hour of sedentary activity, %BF increased by 0.8% (95% CI=0.2 to 1.4%)	1) Sample was not representative of children living outside of the Waitemata Health or Auckland Healthcare regions 2) Young age of participants 3) Comprised only European children 4) Did not adjust for dietary intake or weight-loss attempts 5) Maternal height & weight were self-reported 6) PA over only one 24-hour period was measured

					7) Did not measure when & where PA occurred in analyses
Duncan (220) (same study as (338) & (339))	1229 (603M, 626F) children (European, Pacific, Maori, Asian) aged 5-11 y randomly selected from 27 primary schools in Auckland	SES estimated by school deciles. Pedometer-measured step counts dichotimised into "active" & "inactive" groups. %BF estimated by BIA. Overfat = >25% %BF (boys) or >30% %BF (girls)	Sex, age, ethnicity, SES, breakfast consumption, active transport, sports participation, bought lunch, fast food, sugary drinks, weekday sleep, weekend sleep	Children who were "inactive" had a higher odds of overfat (OR=2.09; 95% CI: 1.36 to 3.20) than children who were "active"	1) Young age of participants 2) Sample was not nationally representative 3) Did not report its response rate 4) Did not adjust for weight-loss attempts. Subject to possible confounding by SES 5) Used only a categorical variable based on %BF as a fatness measure 6) Small number of Asians (n=99M, n=97F) 7) Predicted body fat in Asians using a BIA prediction equation not developed in Asians
Duncan (338) (same study as (220) & (339))	1115 (536M, 579F) children (European, Pacific, Maori, Asian) aged 5-12 y randomly selected from 27 primary schools in Auckland	SES estimated by school deciles. Pedometer-measured step counts. %BF estimated by BIA. Weight status was defined by IOTF BMI cut-offs	None	Weekend daily step counts were greater among those who had a: 1) normal weight (12,185), compared to overweight (11,139) & obese (10,872). This association was dose-dependent (P<0.005) 2) normal WC-for age (12,101), compared to high WC-for age (11,152) 3) low %BF (12,028 for <90^{th} %BF percentile, 10,693 for ≥90^{th} %BF percentile)	1) Young age of participants 2) Sample was not nationally representative 3) Did not report its response rate 4) Did not adjust for any confounders. Subject to possible confounding by SES 5) Used categorical variables, rather than continuous variables, as a fatness measures 6) Small number of Asians (n=99M, n=97F) 7) Predicted body fat in Asians using a BIA prediction equation not developed in Asians 8) Step counts did not quantify when & where PA occurred in analyses
Duncan (339) (same study as (220) & (338))	969 (515M, 454F) children (European, Pacific, Maori, Asian) aged 5-12 y randomly selected from 27 primary schools in Auckland	SES estimated by school deciles. Pedometer-measured step counts. Weight status was defined by IOTF BMI cut-offs	None	Overweight children had lower daily step counts (14,238 for boys, 12,555 for girls) than non-overweight children (16,106 boys, 14,176 for girls)	1) Young age of participants 2) Sample was not nationally representative 3) Did not report its response rate 4) Did not adjust for any confounders. Subject to possible confounding by SES 5) Used only a categorical variable based on %BF as a fatness measure 6) Small number of Asians (n=99M, n=97F) 7) Predicted body fat in Asians using a BIA prediction equation not developed in Asians 8) Step counts did not quantify when & where

					PA occurred in analyses
Rush (340)	79 children (27 Maori, 26 Pacific, 26 European) aged 5-14 y from Auckland schools & the community	PA level calculated from TEE (by doubly-labelled water over 10 days) & RMR (by indirect calorimetry). %BF measured by isotope dilution & BIA	None	PA level was inversely correlated with %BF in boys (r=-0.43, P=0.006) but not girls (r=-0.02, P=0.90)	1) Young age of participants 2) Small sample size 3) Sample was not nationally representative 4) Did not control for any confounders 5) Measurement of PA level by TEE & RMR did not quantify when & where PA occurred
Carter (123) (also cohort)	244 mainly white children from Dunedin followed up from 3 to 7 y of age. Response rate=59%	Accelerometry was used to measure mean counts per minute. Fat mass was measured by DXA	Age, sex, maternal education & BMI, income, ethnicity, birth weight, smoking during pregnancy, TV viewing, fruit-vegetable intake, non-core food intake, sleep	No association between mean counts per minute & BMI with or without adjustment for confounders (P>0.05)	1) Young age of participants 2) Small sample size 3) Sample was not nationally representative 4) Not a large response rate 5) Did not measure when & where PA occurred in analyses. Did not measure intensity of PA
COHORT					
Carter (123) (also cross-sectional)	202 mainly white children from Dunedin followed up from 3 to 7 y of age. Response rate=59%, retention rate=83%	Accelerometry was used to measure mean counts per minute. Fat mass was measured by DXA	BMI at age 3 y, sex, maternal education & BMI, income, ethnicity, birth weight, smoking during pregnancy, TV viewing, fruit-vegetable intake, non-core food intake, sleep	No association between mean counts per minute & BMI (β-coefficient=0.12, 95% CI=-0.11 to 0.34) or fat mass index (β-coefficient=-0.12, 95% CI=-0.39 to 0.15)	1) Young age of participants 2) Small sample size 3) Sample was not nationally representative 4) As response rate=59% & retention rate=83%, the number of subjects analysed in the cohort is <50% of the number of eligible participants 5) Did not measure when & where PA occurred in analyses. Did not measure intensity of PA
INTER-VENTION					
Taylor (341)	384 children (mainly Caucasian) aged 5-12 y followed up after 1 year. Intervention based in Otago	Intervention included: 1) widening of exposure to activity 2) encouragement of participation in activities during extra-curricular time at school, after school &	1) In analyses that examined differences in activity level: age, sex, baseline values, school. 2) In analyses that examined differences in body composition:	Compared to the control group at follow-up, the intervention group had: 1) higher activity level (counts & activity time) 2) lower BMI z-score (-0.12, 95% CI: -0.21 to –0.02)	1) Young age of participants 2) Mainly Caucasian children 3) Used only height, weight & WC to measure fatness 4) Control & intervention groups were not randomly selected 5) The incorporation of simple dietary advice into the intervention programme complicates

		during vacations 3) simple dietary advice. Accelerometry-measured counts. Activity time determined from a 7-day recall questionnaire	age, sex, baseline body composition value, school, TV, baseline PA	3) the same WC (difference=-0.1, 95% CI: -1.1 to 0.9)	the ability to quantify the effect of PA *per se* on fatness

NZEO=New Zealand European/Other; SES=Socioeconomic status; TV=Television; %BF=Percent body fat; BIA=Bioimpedance analysis; OR=Odds ratio; CI=Confidence interval; WC=Waist circumference; PA=Physical activity; IOTF BMI cut-offs=BMI cut-offs adopted by the International Obesity Task Force (392); TEE=Total energy expenditure; RMR=Resting metabolic rate; DXA=Dual-energy X-ray absorptiometry.

Table 4.17. Summary of studies that examined the association of physical activity with fatness[1]

Type of study	Direction of relationship				Total
	Positive	**None**	**Inverse**	**Mixed[2]**	
Australian	0	3 (115, 329, 335)	9 (117, 325, 327, 330-334, 336)	2 (326, 328)	14
Pacific Island	0	0	1 (113)	0	1
New Zealand	0	2 (44, 123)	4 (122, 220, 337-339, 341)	1 (340)	7
Non-South Pacific case-control	0	0	1 (177)	0	1
Non-South Pacific cohort	0	12 (133, 152, 155, 160, 179, 183, 344-349)	20 (119, 120, 144, 163, 167, 169, 170, 172, 173, 238, 280, 325, 327-334)	6 (167, 247, 350-353)	38
Non-South Pacific intervention	0	4 (359-363)	18 (188, 361-377)	1 (381)	23
Total	0	21	53	10	84

[1]Values in cells=Number of studies (reference). In some cases, number of references>number of studies because some references are from the same study: (220), (338) and (339); (360) and (361); (303) and (354). [2]Significant relationship observed in a fraction of the total sample.

CHAPTER 5: METHODOLOGY OF VALIDATION STUDY

5.1 Introduction

This chapter will describe the methodology of the validation study. First, the subjects will be described in Section 5.2. Next, Section 5.3 will describe the measurements. The final section, Section 5.4, will describe the statistical methods.

As mentioned in Chapter 1, results of the validation study will be applied to the OPIC study; so, the methodology of the validation study was chosen to reflect this. Other rationales for the methodology are explained in this chapter.

5.2 Subjects

The author recruited all participants, either through school assemblies or with the help of student health groups, from five Auckland high schools. All five schools were given similar socio-economic decile ratings by the Ministry of Education, indicating homogeneity of socio-economic status for the students in their catchment areas. Most were participating in the OPIC study. A non-random purposive sampling approach was carried out aimed at recruiting participants with a wide range of weight and height with participant numbers uniformly distributed across school year, ethnic group (European, Maori, Pacific Island and Asian) and gender. The only exclusion criteria were pregnancy and medication (such as growth hormone therapy) which could affect body composition. No participants indicated they were on diet treatment and none were excluded on the basis of their physical activity level. Ethnicity was self-defined by each participant as that single group with which he or she most strongly identified. This approach to ethnicity measurement was chosen because it was used in the OPIC study. Written consent was obtained from each participant. Ethical approval was obtained from the Northern X Regional Ethics Committee. A total sample size of at least 390 was required in order to detect (α=0.05, power=80%) a 2% increment in the squared multiple correlation coefficient (R^2) (393).

5.3 Measurements

The author transported all participants, in groups of up to four, to the Body Composition Laboratory in the Department of Surgery, University of Auckland, where all data were collected. All measurements were performed by a single investigator (John Sluyter). Height (±0.1 cm) was measured with a stadiometer. WC (±0.1 cm) was measured with a Novel products Figure-Finder® non-stretchable tape (Novel Products Inc., Rockton, IL) in the horizontal plane of the umbilicus (indicated with a finger by participants) at the end of normal expiration. One layer of thin clothing was accepted. Impedance (±1 Ω) and body weight (±0.1 kg) in light clothing (estimated to nearest 0.05 kg) were measured on a BC-418 bioimpedance (BIA) device (Tanita Corp., Tokyo, Japan) and net body weight (body weight less clothing weight) was used for the analyses. The BIA device provided measurements of impedance (±1 Ω) and estimates of %BF (±0.1 %), FM (±0.1 kg) and FFM (±0.1 kg). These measurements were carried out in sequential order and then repeated in the same order. The average of each pair of measurements was used for the analyses. BIA measurements were carried out at a frequency of 50kHz. BMI was calculated as net body weight (kg)/height $(m)^2$. These anthropometric and BIA measurements were taken in the same way as in the OPIC study; failure to do so would have weakened the applicability of the validation study results to the OPIC study. All measurements (including demographic data but excluding DXA data) were recorded on a paper questionnaire, which the author had designed.

The method BIA_8 uses to measure whole-body, left leg and left arm impedance, as indicated by the BIA_8 instruction manual (provided by the manufacturer) (80), is based on the method for segmental impedance measurement in the study of Organ *et al* (394). Organ *et al* (394) showed that the sum of the resistance values for upper limb, trunk and lower limb segments of one side of the body was equal to the total resistance for a current pathway comprising these three segments – from the wrist to the ankle of the same side of the body. Since BIA_8 measures whole-body impedance from a current that passes through the left leg, trunk and left arm, these three segments can be regarded as three resistors connected in series. Therefore, trunk impedance (Z_{Tr}) was calculated as whole-body impedance minus the sum of left arm impedance and left leg impedance. In support of this, Organ *et al* (394) found good correlations between trunk resistance values measured directly on the trunk and those measured indirectly from electrodes attached to the wrist and ankle.

There are several reference methods of body fat. The four-compartment model (4-CM) is the most accurate method, but is expensive, complex (involves multiple measurements) and time-consuming.

Hydrostatic weighing and water-displacement plethysmography are less expensive, less complex, less time-consuming, but are still not easy to use (require the subject to be immersed in water). Air-displacement plethysmography is easier to use, but the measuring equipment is not portable (and nor are the previously mentioned methods) and assumes, as for hydrostatic weighing, that the densities of FM and FFM are constant. Isotope dilution can accommodate different body types (e.g., unlike hydrostatic weighing, it is not difficult to measure disabled subjects) and its equipment is not bulky; however, it requires subject co-operation (neither food nor water is permitted during the period in which the isotope is equilibrating and a sample is taken from the subject at the end of this period), uses FFM hydration factors to estimate FFM, is invasive and requires specialised equipment for sample analysis. In contrast, DXA is non-invasive and acceptable to subjects, easily applied and less time-consuming (e.g., isotope dilution requires time for the isotope to equilibrate, while DXA typically takes about 20 minutes). Further, DXA can be used to measure mass and length of different regions of the body, is widely available and provides %BF estimates (when compared with the 4-CM) that are independent of several factors such as ethnicity (395, 396). Therefore, DXA was chosen as the reference method for body fat measurement in the present study.

DXA whole-body scans were carried out using a pencil-beam scanner (Model DPX+, software version 3.6y, extended analysis mode, GE-Lunar, Madison, WI). Scan images were analysed for total body FM, fat-free soft tissue mass and bone mineral content (BMC). DXA FFM was calculated as the sum of fat-free soft tissue mass and BMC. %BF was calculated from the DXA measurements as 100xFM/(FM + FFM).

Abdominal and thigh regions of interest (ROI) were defined following similar criteria to Ley *et al* (397). Abdominal fat mass (AbFM) was determined from a ROI positioned with the lower horizontal border touching the iliac crests, the upper border at the junction of the T12 and L1 vertebrae and the lateral margins including the waist outline. Thigh fat mass (ThFM) was determined from a ROI of identical height with the upper horizontal border immediately below the ischial tuberosities and the lateral margins including the outer thigh outline. Limb fat mass (LbFM) was defined as the total fat mass of the arms and legs, which were delineated by lines passing through the glenohumeral joints and by lines passing through the femoral necks, respectively (398). Central fat mass (ClFM) was calculated as total body fat mass minus limb fat mass. Fat distribution variables were derived by expressing AbFM, ThFM, ClFM and LbFM as a percentage of total fat mass. The ratios of AbFM to ThFM and ClFM to LbFM were calculated as additional fat distribution variables. %AbFM was calculated as 100xFM/(FM + fat-free soft tissue mass + BMC) in the abdominal region. Abdominal

FFM per cm height was calculated as FFM in the abdominal ROI box divided by height of the abdominal ROI box in cm; the latter was derived by measuring the height of the abdominal ROI box in pixels and converting it to cm based on a DXA scan of a standard ruler.

Appendicular skeletal muscle mass (ASMM) was derived from the DXA scans as total limb mass minus the sum of limb fat mass and wet bone mass, estimated as BMC divided by 0.55. In this model, mass of the skin and associated dermal tissues is assumed to be negligible relative to the skeletal muscle component (399).

Leg length was calculated as the sum of the lengths of the femur and tibia bones measured on the right side using the pixelled DXA image. Femur bone length was measured from the top of the greater trochanter to the middle patellar surface, and tibia bone length was measured from the superior intercondylar eminence to the inferior surface of the medial malleolus. Sitting height was measured as the vertical distance from the apex of the cranium to the top of the greater trochanter. Dimensions were measured in pixels and converted to cm based on a DXA scan of a standard ruler.

Waist:height ratio (WHTR) was calculated as WC (cm)/height (cm) and conicity index (CI) (400, 401) was calculated as:

$$\text{CI} = \text{Waist circumference (m)}/(0.109\sqrt{\text{weight (kg)}/\text{height (m)}})$$

Measurement of puberty was considered in order to account for maturational stage in statistical models (Sections 9.2.1.2 and 9.2.2.1). Physical examination by a trained clinician using Tanner staging is the preferred (gold standard) measure, but several obstacles preclude its use in field studies: difficulty in obtaining consent (by participants and others such as school staff), reliance on photographs obtained from white youth only (of limited representativeness), logistical difficulty (because of time constraints and privacy) and the requirement of an experienced and comfortable clinician (402, 403). Self-reported assessments are easier to implement, but these still may be regarded as unacceptable and their staging measures have been shown to be poorly correlated with those by physical examination (402, 403). In support of the latter, the AHHS showed that: 1) compared to males of European ethnicity, a lower proportion of those of Pacific ethnicity were at a high stage of maturation measured by self-reported assessment (yet the Pacific participants were older) and, 2) compared to females, a higher proportion of males (of the same age) were at a high maturation stage (self-rated) (31). These were unexpected findings that question the validity of self-

report measurement in Pacific youth (31). For these reasons, puberty was not measured in the current study.

5.4 Statistical methods

Data were analysed using SAS version 9.1 (SAS Institute, Cary, NC). All variables were examined for normality and transformation applied if needed. Statistical significance for all analyses of the validation study was set at $P<0.05$.

As there are differences in the relationship between BMI and %BF between Asian groups, including between Asian Indians and other Asian groups (71, 404), non-Indian Asians were removed from the analyses for Section 6.2 (*Body mass index and percent body fat*). For the results in Section 6.2, simple regression models in which %BF was regressed on BMI were used to identify outliers through use of residual analysis and influence diagnostics (Cook's D) (405). Between-group differences in subject characteristics were examined by one-way ANOVA followed by Tukey's multiple comparison procedure if a significant F test was obtained. Analysis of covariance (ANCOVA) was used to adjust body composition results for comparison across ethnic groups. Before carrying out the ANCOVA, similarity of regression slopes among the ethnic groups was verified by examining the significance of the interaction between the covariate(s) and the group variable. Multiple regression models were used to identify significant differences in %BF predicted from BMI for boys and girls of the four ethnic groups. Dummy variables were used to identify ethnicity where European was taken as the reference group and Maori was coded 0,1,0,0; Pacific 0,0,1,0; and Asian 0,0,0,1 for European, Maori, Pacific Island and Asian Indian ethnic groups, respectively. The difference in %BF between two ethnic groups is found by taking the difference between the regression coefficients for their dummy variables (with 0 being the coefficient for Europeans). Linearity with %BF and normality of the residuals of regression models were examined for each variable and transformation applied if necessary. To decide on the best transformation to adopt, fractional polynomial and log transformations were applied; for each transformation, scatter plots (to inspect linearity), Akaike's Information Criterion (AIC) (406) and the R^2 were examined. Linear scatter plots, low AIC and high R^2 values indicated optimum transformations. Equality of the regression slopes for boys and girls was tested for statistical significance by testing the addition of an interaction term consisting of the product of sex and the independent variable. Separate equations were developed for each sex if the slopes were found to differ. For the results in Section 6.2, to ensure that ratio variables in the regression models fully control for the denominator, the numerator

of each ratio was adjusted by subtracting the intercept of the regression of the numerator on the denominator, as suggested by Allison *et al* (407). Through this adjustment the intercept of the regression of the adjusted numerator on the denominator is zero. Potential interactions between BMI and age, and between ethnicity and both BMI and age were examined. Covariance analysis was used to examine ethnic differences in each model. Variance inflation factors were examined to check for collinearity among independent variables.

For the results in Section 6.3 (*Bioimpedance and body composition*), differences between ethnic groups for each sex were examined by pairwise comparisons using Tukey's test. Stepwise linear regression and 'all-possible subsets' regression procedures were used to develop prediction equations based on whole-body BIA (Section 6.3). The potential predictor variables that were used to develop the equations were weight, height (*H*), sitting height (*SH*), leg length (*LL*), age, impedance (*Z*), impedance index based on height (H^2/Z), sitting height (SH^2/Z) and leg length (LL^2/Z), sex (0=boys, 1=girls), ethnicity (coded as three dummy variables for Maori, Pacific and Asian with European as the reference category) and waist circumference. Potential interactions between ethnicity and the other variables and between age and height were examined. Mallow's Cp statistic (Cp) (408) and the Schwarz-Bayesian criterion (SBC) (409) were used as measures of the appropriate number of predictors. High adjusted R^2 values, small SEEs, Cp values close to the number of predictors in the model and minimum SBC indicated optimal models. These equations were examined for the significance of the regression coefficients. A variance inflation factor (VIF) was calculated to assess the stability of each estimated coefficient in the prediction equations. Large VIF values (>10) imply considerable inter-relationships (collinearity) among the independent variables and such equations tend to be sample-specific. Residual analysis was used to check the assumptions of linear regression analysis.

For the development of the whole-body BIA-based equations (Section 6.3), a double cross-validation was carried out, in which the total sample (stratified for sex) was randomly divided into two equal-sized groups (groups 1 and 2), an equation was developed in each group, and the other group was used to cross-validate each equation. Equality of the regression slopes for boys and girls was tested for statistical significance by testing the addition of an interaction term consisting of the product of sex and the independent variable. Separate equations were developed for each sex if the slopes were found to differ. If the equations were similar in the two groups with comparable cross-validation performance, a single equation was developed. Covariance analysis was used to compare the regression models in the two groups. Pure error, calculated as the square root of the mean of the

squared differences between the measured and predicted FFM, was used to examine the accuracy of the predictive equations on cross-validation. This error should be similar to the value of the SEE for the same equation for the group from which it was developed.

The performance of whole-body BIA equations (Section 6.3) was assessed based on the correlation between measured and predicted values (Pearson correlation coefficient), the concordance between these (concordance correlation coefficient (410)), their difference (bias, expressed as mean ± SD, tested against zero using paired *t*-tests), the limits of agreement (expressed as 2 SD above and below the bias) and the dependence of the bias on the mean of measured and predicted values (both assessed on Bland-Altman plots (411)), and the pure error.

For the results in Section 6.4 (*Waist circumference and trunk impedance*), differences between ethnic groups for each sex were examined by pairwise comparisons using Tukey's test. Repeatability of the WC measurements for each sex was examined by paired *t*-tests and calculating the coefficient of variation for each set of measurements. In order to determine whether a transformation needed to be applied to Z_{Tr} to attain linearity with abdominal FFM, the physiological relationship between Z_{Tr} and FFM in the trunk was determined using the principle of volume conduction. That is, it was assumed that the current BIA_8 utilises for whole-body impedance measurement passes only through FFM when in the trunk and so the impedance to its flow in the trunk (Z_{Tr}) can be determined by the expression

$$Z_{Tr} = p \cdot L/A_{FFM}$$

where p = a constant; L = length of trunk FFM, and A_{FFM} = cross-sectional area of trunk FFM. Therefore, $1/Z_{Tr}$ should be proportional to A_{FFM} and abdominal FFM. Linear regression was used to examine univariate relationships between anthropometric variables and %AbFM. Linearity with %AbFM and normality of the residuals of regression models were examined for each variable and transformation applied if necessary. To decide on the best transformation to adopt, fractional polynomial and log transformations were applied; for each one, scatter plots (to inspect linearity), AIC (406) and the R^2 were examined. Equality of the regression slopes for boys and girls was tested for statistical significance by testing the addition of an interaction term consisting of the product of sex and the independent variable. Separate equations were developed for each sex if the slopes were found to differ. Stepwise linear regression and 'all-possible subsets' regression procedures were used to develop the best %AbFM prediction equation based on each anthropometric variable. The potential predictors of these equations were the anthropometric variable (WC, WHTR, CI or BMI), weight, height, age, sex (0=boys, 1=girls) and ethnicity (coded as three dummy variables for Maori,

Pacific and Asian with European as the reference category). The variable, $1/Z_{Tr}$, was added as another potential predictor to develop a second set of equations based on anthropometric variables and trunk impedance. Covariance analysis was used to examine ethnic differences in the %AbFM models. Potential interactions between independent variables were examined. Cp (408) and SBC (409) values were used to identify optimal models, as described above. VIF values were examined to check for collinearity between independent variables. Residual analysis was used to check the assumptions of linear regression analysis. An equation was developed in two thirds of the total sample selected randomly (development sample) and the remaining third (validation sample) was used for cross-validation. Pure error was used to examine the accuracy of the prediction equation in the validation sample. The difference between measured and predicted values (bias) was tested against zero using paired *t*-tests. Bland-Altman plots (411) were used to assess the limits of agreement of the bias and the dependence of the bias on the mean of measured and predicted values.

CHAPTER 6: VALIDATION STUDY RESULTS

6.1 Introduction

This chapter will describe the results of the validation study. Section 6.2 will: 1) compare %BF for a given BMI between Pacific Island, Maori, Asian Indian and European adolescents and, 2) examine the effects of muscularity, bone mass and density, relative leg length, fat distribution and body shape on ethnic differences in the relationship between %BF and BMI. In the following section, Section 6.3, the predictive accuracy of BIA_8 estimates of body composition in European, Maori, Pacific Island and Asian adolescents will be assessed and BIA prediction equations that apply to this population will be developed. In the next section (Section 6.4), the ability of waist circumference and trunk impedance to predict abdominal fatness will be examined. Finally, in Section 6.5, the findings of this chapter will be summarised.

A total of 432 participants were measured in the validation study (Table 6.1). One Maori boy was not able to be accommodated within the DXA scanning area and a dual-scanning approach was attempted. Since this resulted in a large difference (>3 kg) between scale weight and DXA weight (sum of FM, fat-free soft tissue mass and BMC) he was excluded from further analysis. The ethnic composition of the resulting sample (n=431; 215 boys, 216 girls) was 91 European (37 boys), 91 Maori (45 boys), 129 Pacific Island (73 boys) and 120 Asian (61 boys) (Table 6.1). The Asian group comprised 90 Asian Indians (49 boys) and 30 "Other" Asians (12 boys) of heterogenous makeup (Table 6.1): 8 Vietnamese (4 boys), 5 Cambodians (3 boys), 4 Chinese (1 boy), 4 Filipinos (2 boys), 2 Laotians (1 boy), 2 Pakistani girls, 2 Afghan girls, 1 South Korean boy, 1 Thai girl and 1 Malaysian girl. Table 6.2 shows the age and physical characteristics of the participants.

Table 6.1. Total number of participants measured (n=432) by gender and ethnic group

	Boys	Girls	Total
Total sample	216	216	432
Pacific Island	73	56	129
Maori	45*	47	91
European	37	54	91
Asian Indian	49	41	90
"Other" Asian (excluding Asian Indian)	12	18	30

*One of the 45 Maori boys who participated was removed from all analyses, as described in Section 6.1.

Table 6.2. Age and physical characteristics of 431 participants (non-Indian Asians *included*)[d]

BOYS	European (n=37)	Maori (n=44)	Pacific (n=73)	Asian (n=61)
Age (y)	15.4±1.2	15.7±1.6	15.9±1.3	15.6±1.3
	(13.4-18.1)	(13.2-18.3)	(13.2-18.5)	(13.4-17.9)
Height (cm)	173.5±9.0	173.5±8.3	174.2±6.8	167.8±8.2[abc]
	(140.7-188.1)	(156.7-191.3)	(154.6-192.4)	(148.0-186.9)
Leg length (cm)	83.9±5.1	82.9±4.5	83.8±3.7	82.0±4.8
	(69.3-94.6)	(73.9-92.2)	(74.1-91.8)	(70.1-92.2)
Sitting height (cm)	83.1±4.4	83.9±4.0	83.7±3.6	79.5±4.2[abc]
	(67.2-92.2)	(74.9-95.0)	(72.0-90.2)	(68.2-86.4)
Leg length/height	0.489±0.014	0.483±0.011	0.487±0.011	0.494±0.014[bc]
	(0.457-0.524)	(0.458-0.505)	(0.462-0.510)	(0.468-0.527)
Weight (kg)	69.5±19.2	76.3±19.0	80.6±18.3[a]	60.8±17.5[bc]
	(41.8-110.4)	(43.6-126.2)	(44.2-141.2)	(32.4-116.6)
Body mass index (kg/m^2)	22.9±5.1	25.2±5.3	26.4±4.9[a]	21.4±5.1[bc]
	(16.7-35.3)	(17.8-36.5)	(18.0-41.8)	(13.9-34.5)
Fat-free mass (kg)	52.0±8.6	56.9±10.2	61.1±10.5[a]	45.8±8.8[abc]
	(29.5-68.7)	(37.6-81.9)	(34.8-83.9)	(26.1-72.6)
Fat mass (kg)	17.7±13.2	19.7±12.1	19.9±11.3	15.0±12.1
	(3.8-46.5)	(5.3-46.8)	(6.9-56.2)	(2.4-54.0)
Body fat (%)	23.0±11.1	23.8±10.1	23.3±8.7	22.3±12.1
	(7.1-43.2)	(9.6-48.1)	(11.5-48.9)	(6.6-52.4)
Appendicular skeletal muscle mass (kg)	21.7±4.0	24.4±4.7[a]	26.4±4.9[a]	19.3±4.1[bc]
	(12.0-28.9)	(16.6-35.6)	(14.6-38.0)	(10.3-31.3)
Bone mineral content (kg)	2.7±0.5	3.0±0.6	3.3±0.6[a]	2.4±0.5[bc]
	(1.6-3.6)	(1.8-4.5)	(1.6-4.6)	(1.1-3.6)
Bone mineral density (g/cm^2)	1.13±0.11	1.20±0.13[a]	1.23±0.13[a]	1.09±0.11[bc]
	(0.92-1.34)	(0.99-1.49)	(0.93-1.46)	(0.81-1.35)
%AbFM	23.9±12.7	25.7±12.5	23.4±9.7	24.1±13.8
	(6.1-49.2)	(8.7-53.9)	(10.3-47.6)	(6.8-55.6)
AbFFM (kg)/height (cm)	0.35±0.06	0.38±0.07	0.40±0.07[a]	0.31±0.06[abc]
	(0.24-0.51)	(0.26-0.56)	(0.27-0.68)	(0.19-0.54)
AbFM (% of total)	6.9±1.7	7.1±1.5	6.5±1.2	7.2±1.4[c]
	(3.7-11.7)	(4.7-10.8)	(4.5-10.3)	(4.2-10.3)
ThFM (% of total)	11.2±1.7	11.2±1.5	11.4±1.4	11.4±1.6
	(7.2-16.2)	(7.7-14.7)	(8.4-14.7)	(7.6-14.8)
ClFM (% of total)	51.4±4.9	51.3±4.1	48.2±4.3[ab]	51.4±4.5[c]
	(41.2-63.8)	(41.7-59.6)	(39.1-57.1)	(41.2-60.2)
LbFM (% of total)	48.6±4.9	48.7±4.1	51.8±4.2[ab]	48.6±4.5[c]
	(36.2-58.8)	(40.4-58.3)	(42.9-60.9)	(39.8-58.8)
AbFM/ThFM	0.64±0.20	0.65±0.20	0.58±0.14	0.65±0.19
	(0.29-1.17)	(0.35-1.15)	(0.35-0.99)	(0.30-1.13)
ClFM/LbFM	1.08±0.22	1.07±0.17	0.94±0.16[ab]	1.08±0.20[c]
	(0.70-1.76)	(0.72-1.47)	(0.64-1.33)	(0.70-1.51)
Waist circumference (cm)	82.4±13.7	84.5±14.3	84.5±12.2	77.1±14.2[bc]
	(63.7-114.5)	(64.7-118.9)	(66.4-128.6)	(56.9-119.0)
WHTR	0.474±0.071	0.487±0.078	0.484±0.063	0.459±0.076[bc]
	(0.371-0.648)	(0.387-0.709)	(0.381-0.699)	(0.355-0.682)
Conicity index	1.20±0.07	1.17±0.08	1.14±0.06[ab]	1.18±0.08[c]
	(1.05-1.38)	(1.04-1.44)	(1.03-1.35)	(1.04-1.41)
Trunk impedance (Ω)	28.4±4.4	27.3±4.1	24.6±4.0[ab]	32.0±5.2[abc]
	(19.0-39.5)	(19.5-35.5)	(16.5-38.5)	(23.0-44.5)

GIRLS	European (n=54)	Maori (n=47)	Pacific (n=56)	Asian (n=59)
Age (y)	15.5±1.4 (12.9-18.4)	15.9±1.4 (13.2-18.1)	15.8±1.4 (13.3-19.1)	16.0±1.5 (13.4-19.5)
Height (cm)	164.4±6.3 (147.7-176.3)	164.2±8.5 (137.7-179.5)	165.6±7.1 (150.7-186.3)	157.9±5.3[abc] (145.1-170.4)
Leg length (cm)	78.6±4.0 (69.2-87.5)	78.0±5.1 (63.4-89.8)	79.1±4.2 (71.0-90.4)	76.6±4.8[c] (62.9-91.6)
Sitting height (cm)	80.1±3.2 (73.0-87.3)	80.5±4.5 (66.2-87.4)	81.0±3.6 (73.0-90.2)	76.2±2.7[abc] (68.2-83.4)
Leg length/height	0.482±0.012 (0.457-0.507)	0.480±0.014 (0.452-0.529)	0.481±0.011 (0.454-0.501)	0.488±0.019[bc] (0.438-0.561)
Weight (kg)	62.8±15.6 (36.9-101.8)	70.2±18.7 (47.3-124.3)	72.2±14.4[a] (48.4-118.6)	52.4±10.6[abc] (36.3-90.0)
Body mass index (kg/m^2)	23.1±5.0 (15.2-34.4)	25.8±5.4[a] (18.3-41.6)	26.3±4.8[a] (18.5-42.2)	21.0±3.8[bc] (15.0-32.4)
Fat-free mass (kg)	40.1±5.2 (29.2-51.2)	42.9±7.3 (25.6-59.2)	45.6±6.0[a] (31.8-69.0)	34.7±4.4[abc] (27.5-46.7)
Fat mass (kg)	22.4±11.7 (4.9-50.0)	27.1±13.1 (12.7-66.6)	26.4±10.4 (9.1-54.7)	17.4±7.7[bc] (6.3-45.4)
Body fat (%)	33.8±9.7 (13.5-51.3)	37.1±8.5 (22.0-54.4)	35.5±7.5 (18.7-53.8)	32.1±8.2[b] (16.2-51.4)
Appendicular skeletal muscle mass (kg)	15.7±2.4 (11.0-21.4)	17.2±3.5[a] (9.8-26.4)	18.7±3.1[ab] (10.3-31.6)	13.7±2.0[abc] (9.3-19.1)
Bone mineral content (kg)	2.3±0.4 (1.5-2.9)	2.6±0.5[a] (1.5-4.0)	2.8±0.4[a] (1.9-3.8)	2.0±0.3[abc] (1.4-2.8)
Bone mineral density (g/cm^2)	1.12±0.09 (0.90-1.28)	1.17±0.09[a] (0.98-1.38)	1.20±0.09[a] (1.04-1.39)	1.07±0.08[abc] (0.89-1.25)
%AbFM	33.3±11.8 (9.5-54.8)	38.6±9.8[a] (18.9-59.2)	36.1±9.5 (17.1-56.6)	33.4±10.0[b] (12.6-55.7)
AbFFM (kg)/height (cm)	0.29±0.04 (0.22-0.42)	0.31±0.06[a] (0.23-0.48)	0.32±0.04[a] (0.25-0.45)	0.25±0.03[abc] (0.19-0.36)
AbFM (% of total)	6.8±1.5 (3.8-10.1)	7.6±1.1[a] (4.9-10.0)	7.3±1.4 (4.7-10.9)	7.2±1.3 (4.1-9.6)
ThFM (% of total)	12.2±1.6 (8.7-15.7)	11.3±1.2[a] (9.2-15.4)	11.9±1.5 (8.8-16.6)	12.7±1.6[bc] (9.6-16.9)
ClFM (% of total)	49.5±4.1 (39.9-57.5)	51.5±2.9[a] (45.8-57.5)	49.5±3.3[b] (43.1-56.6)	49.7±4.3 (38.9-61.0)
LbFM (% of total)	50.5±4.1 (42.5-60.1)	48.5±2.9[a] (42.5-54.2)	50.5±3.3[b] (43.4-56.9)	50.3±4.3 (39.0-61.1)
AbFM/ThFM	0.58±0.18 (0.30-1.09)	0.68±0.15[a] (0.37-1.09)	0.63±0.16 (0.35-0.99)	0.58±0.15[b] (0.25-0.99)
ClFM/LbFM	0.99±0.16 (0.66-1.35)	1.07±0.13 (0.85-1.35)	0.99±0.13[b] (0.76-1.30)	1.00±0.18 (0.64-1.57)
Waist circumference (cm)	79.7±13.2 (60.8-113.7)	84.4±14.9 (65.4-129.3)	85.9±12.4[a] (64.7-122.3)	73.8±9.3[bc] (58.9-103.8)
WHTR	0.484±0.074 (0.385-0.686)	0.515±0.084[a] (0.377-0.757)	0.517±0.072[a] (0.404-0.721)	0.467±0.055[bc] (0.377-0.623)
Conicity index	1.19±0.09 (1.03-1.40)	1.19±0.09 (0.98-1.41)	1.19±0.08 (1.02-1.45)	1.17±0.07 (1.05-1.31)
Trunk impedance (Ω)	34.5±5.2 (26.5-47.0)	33.6±4.8 (22.5-46.5)	32.0±5.4[a] (18.0-47.5)	38.6±5.9[abc] (28.5-51.0)

%AbFM=Percent abdominal fat (%); AbFFM (kg)/height (cm)=Abdominal fat-free mass (kg) per cm height; AbFM=Abdominal fat mass; ThFM=Thigh fat mass; ClFM=Central fat mass; LbFM=Limb fat mass; WHTR=Waist circumference (cm)/height (cm); [a,b,c]significantly different to European, Maori and Pacific, respectively, of same sex ($P<0.05$); [d]Mean ± standard deviation, range in parentheses.

6.2 Body mass index and percent body fat

As mentioned above, the purpose of this section was to examine ethnic differences in %BF at a given BMI and to assess what effect factors have on these differences.

Subject characteristics

Non-Indian Asians were removed from analyses for this section, as research indicates that the %BF-BMI relationship varies across Asian groups (Section 5.4). In addition, one Maori girl and one Asian Indian boy were outliers in the %BF-BMI relationship for their ethnicity/gender subgroup and were excluded because their Cook's D values markedly exceeded those for all other subjects, indicating appreciable influence on the regression model. Analyses were performed on 399 adolescents (202 boys, 197 girls), comprising 91 European, 90 Maori, 129 Pacific Island, and 89 Asian Indians.

Table 6.3 shows ethnic differences in body composition variables at a given age, height and weight; adjusted variables which show marked differences might be expected to influence ethnicity effects in the %BF-BMI relationship. ASMM and BMC were highest in Pacific Islanders and Maori and lowest in Asian Indians and Europeans. AbFM, after adjustment, did not differ between ethnic groups in girls while, in boys, Pacific Islanders had lower AbFM than the other three ethnic groups. Adjusted WC, WHTR and CI did not differ between ethnic groups in girls while, in boys, they were highest in Asian Indians and Europeans, and lowest in Pacific Islanders with Maori having intermediate values.

Relationships between percent body fat and BMI

The regression of %BF by DXA on BMI was examined for each ethnicity subgroup for boys and girls. For boys, curvilinear relationships between %BF and BMI for each ethnic group were linearised by logarithmically transforming BMI. For girls, curvilinear relationships between %BF and BMI for each ethnic group were linearised by regression of %BF on the reciprocal of BMI. These transformations were chosen as scatter plots showed that they yielded linear relationships and they were associated with the lowest AIC and highest R^2 values. Because of the different transformations required for boys and girls, equations were developed for each gender. Equations were developed for each sex also because the regression coefficients of the %BF-BMI relationships significantly differed between boys and girls.

For boys, BMI, age and ethnicity were significant predictors of %BF and the common slope regression equation was:

%BF = 101.52 $\log_{10}$(BMI) – 1.92 age – 84.59 – 2.81 Maori – 5.20 Pacific + 3.52 Asian

(SEE (standard error of estimate) = 5.16%, R^2 = 0.75)

where Maori, Pacific and Asian represent dummy variables (coded as described in *Statistical methods*). For a fixed BMI and age, Maori boys had 2.8% (95% confidence interval (CI): 0.5% to 5.1%) less %BF, Pacific Island boys had 5.2% (95% CI: 3.1% to 7.3%) less %BF and Asian Indian boys had 3.5% (95% CI: 1.3% to 5.8%) more %BF, compared to European boys (Figure 6.1).

For girls, BMI and ethnicity were significant, but not age, and the common slope regression equation was:

%BF = –976.52 (1/BMI) + 77.87 – 1.88 Maori – 4.13 Pacific + 3.55 Asian

(SEE = 4.00%, R^2 = 0.79).

For a fixed BMI, Maori girls had 1.9% (95% CI: 0.3% to 3.5%) less %BF, Pacific Island girls had 4.1% (95% CI: 2.6% to 5.7%) less %BF and Asian Indian girls had 3.6% (95% CI: 1.9% to 5.2%) more %BF, compared to European girls (Figure 6.1).

Based on the internationally accepted thresholds for obesity in adolescents, developed in mixed populations dominated by Europeans (392), the equivalent BMI thresholds that would apply to the Maori, Pacific Island and Asian Indian groups are shown in Table 6.4. These thresholds were calculated by first predicting %BF in Europeans at each sex- and age-specific BMI cut-off for obesity (392) using the models developed above. These models were then solved for BMI using these %BF values in order to give the BMI values for non-Europeans that would give the same %BF.

Factors affecting %BF-BMI relationships

The impact of measured variables on the relationships between BMI and %BF was examined to assess their effects on the ethnicity differences (Table 6.5). Correction for ASMM resulted in substantial reduction in %BF differences between the ethnic groups and increased the R^2 by 0.12 in boys and 0.06 in girls. Adjustment for BMC or BMD decreased ethnic differences in %BF to a lesser extent, and yielded smaller improvements in the R^2. Ethnic differences in the %BF-BMI relationships remained significant after adjustment for LL/height despite the fact that the latter was positively associated with %BF. In boys, WC, WHTR and CI markedly reduced ethnic differences in %BF, had significant positive regression coefficients, and increased the R^2 from 0.75 to 0.78, 0.80 and 0.81, respectively. Most notably, in boys, CI reduced the Maori and Pacific Island dummy variables by 1.9% and 3.4% respectively; and WHTR reduced the Asian Indian dummy variable by 1.3%. In girls, models containing LbFM and ASMM or LbFM, ASMM and CI both eliminated the

Maori and Pacific Island ethnic differences relative to Europeans but %BF for Asian Indians remained higher than Europeans. These findings suggest that skeletal muscle, bone mass and fat distribution significantly contribute to ethnic differences in the %BF-BMI relationship.

Table 6.3. Physical characteristics of 399 boys and girls adjusted for age, height and weight within each sex (non-Indian Asians *excluded*)[*]

BOYS	European (n=37)	Maori (n=44)	Pacific Island (n=73)	Asian Indian (n=48)	*P*-value[†]
ASMM (kg)	22.1±0.4	23.7±0.3[a]	24.9±0.3[ab]	21.7±0.3[bc]	<0.0001
Bone mineral content (kg)	2.74±0.05	2.93±0.05[a]	3.07±0.04[a]	2.68±0.05[bc]	<0.0001
Bone mineral density (g/cm^2)	1.15±0.01	1.19±0.01	1.20±0.01[a]	1.13±0.01[bc]	0.0003
Leg length (cm)	83.3±0.4	82.4±0.3	83.0±0.3	84.9±0.3[abc]	<0.0001
$\log_{10}$(abdominal FM (kg))	0.03±0.03	-0.01±0.02	-0.09±0.02[ab]	0.07±0.02[c]	<0.0001
Thigh FM (kg)	2.14±0.08	1.87±0.07	1.75±0.06[a]	2.26±0.08[bc]	<0.0001
$\log_{10}$(central FM (kg))	0.90±0.02	0.87±0.02	0.81±0.01[ab]	0.90±0.02[c]	0.0004
$\log_{10}$(Limb FM (kg))	0.87±0.02	0.84±0.02	0.84±0.02	0.89±0.02	0.25
Waist circumference (cm)	85.1±0.7	82.0±0.6[a]	78.9±0.5[ab]	84.9±0.6[bc]	<0.0001
WHTR	0.493±0.004	0.475±0.004[a]	0.457±0.003[ab]	0.490±0.004[bc]	<0.0001
Conicity index	1.21±0.01	1.16±0.01[a]	1.12±0.01[ab]	1.21±0.01[bc]	<0.0001

GIRLS	European (n=54)	Maori (n=46)	Pacific Island (n=56)	Asian Indian (n=41)	*P*-value[†]
ASMM (kg)	15.8±0.2	16.6±0.2[a]	17.6±0.2[ab]	15.9±0.2[c]	<0.0001
Bone mineral content (kg)	2.35±0.03	2.53±0.04[a]	2.63±0.03[a]	2.26±0.04[bc]	<0.0001
Bone mineral density (g/cm^2)	1.13±0.01	1.15±0.01	1.18±0.01[a]	1.10±0.01[bc]	<0.0001
Leg length (cm)	78.0±0.3	77.7±0.3	78.0±0.3	80.6±0.4[abc]	<0.0001
$\log_{10}$(abdominal FM (kg))	0.17±0.02	0.18±0.02	0.15±0.02	0.19±0.02	0.32
Thigh FM (kg)	2.83±0.05	2.61±0.06[a]	2.61±0.05[a]	2.96±0.07[bc]	0.0001
$\log_{10}$(central FM (kg))	1.03±0.01	1.03±0.01	1.00±0.01	1.02±0.01	0.35
$\log_{10}$(limb FM (kg))	1.03±0.01	1.01±0.01	1.01±0.01	1.05±0.01	0.15
Waist circumference (cm)	82.1±0.7	80.3±0.7	80.6±0.7	82.7±0.8	0.11
WHTR	0.501±0.004	0.491±0.004	0.494±0.004	0.503±0.005	0.22
Conicity index	1.20±0.01	1.17±0.01	1.17±0.01	1.21±0.01	0.038

ASMM=Appendicular skeletal muscle mass; FM=Fat mass; WHTR=Waist circumference (cm)/height (cm); [*]Mean ± Standard error; [†]ANCOVA; [a,b,c]significantly different to European, Maori and Pacific Island, respectively (P<0.05).

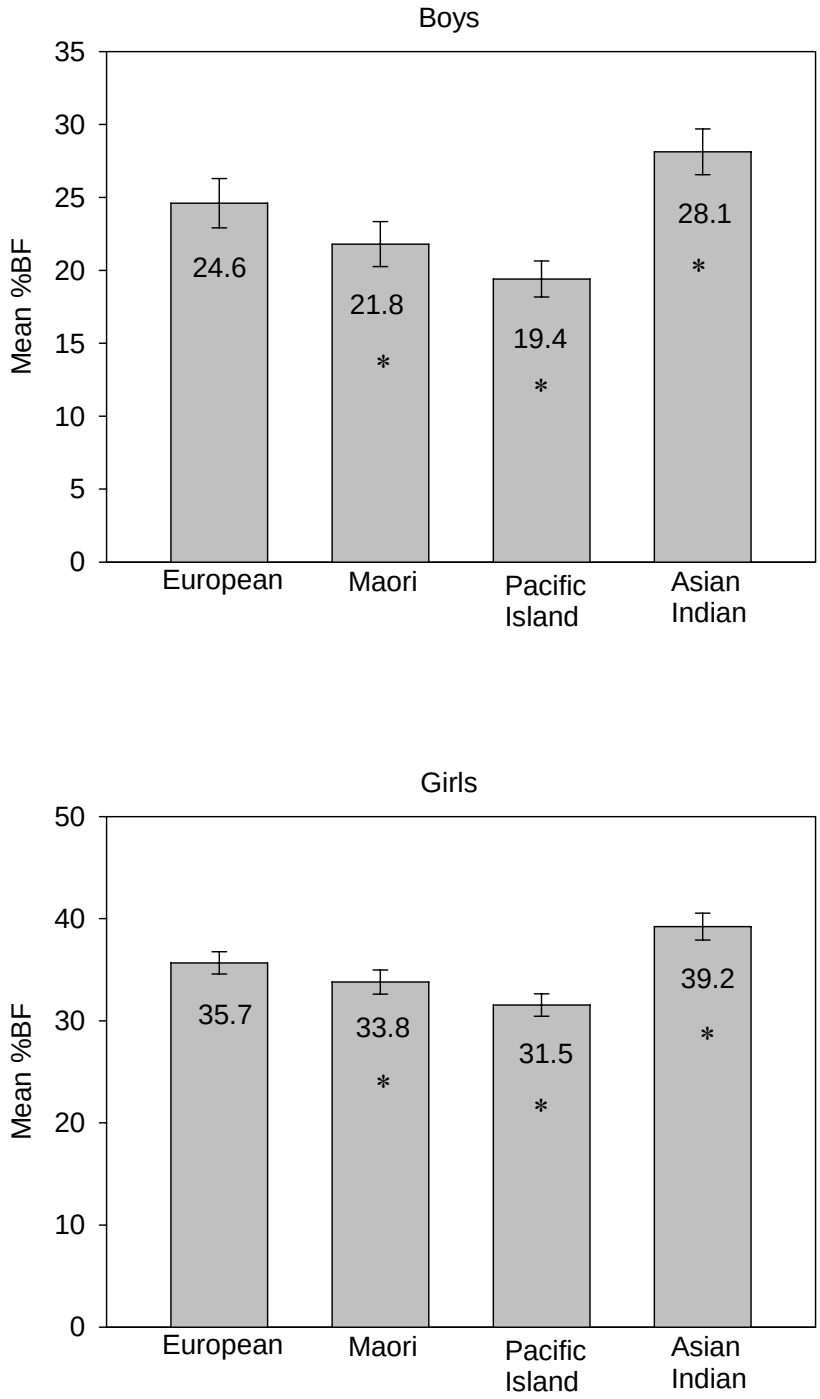


Figure 6.1. Percent body fat (%BF) levels across ethnic groups after statistical adjustment for body mass index (BMI) and age among boys (*upper panel*) and after statistical adjustment for BMI among girls (*lower panel*). Error bars represent 95% confidence intervals; *P<0.05 compared to Europeans.

Table 6.4. Body mass index (BMI) cut-offs for Maori, Pacific Island and Asian Indian adolescents equivalent to obesity thresholds developed in predominantly European populations and adopted by the International Obesity Task Force (IOTF)

	European			Maori	Pacific Island	Asian Indian
	Age	IOTF BMI threshold for obesity (kg/m^2)*	%BF†	Estimated BMI (kg/m^2) for same %BF in European †		
Boys	13	26.8	35.5	28.6	30.2	24.8
	14	27.6	34.9	29.4	31.1	25.5
	15	28.3	34.0	30.2	31.8	26.1
	16	28.9	33.0	30.8	32.5	26.7
	17	29.4	31.9	31.3	33.1	27.2
	18	30.0	30.9	32.0	33.8	27.7
Girls	13	27.8	42.7	29.3	31.5	25.2
	14	28.6	43.7	30.2	32.5	25.9
	15	29.1	44.3	30.8	33.2	26.3
	16	29.4	44.7	31.2	33.6	26.6
	17	29.7	45.0	31.5	34.0	26.8
	18	30.0	45.3	31.8	34.4	27.0

*From Cole *et al* (392); †Calculated using %BF prediction equations in text. IOTF threshold (and age for boys) predict %BF, which is used to predict equivalent BMI values.

Table 6.5. Effect of body composition variables on the ethnicity differences in the relationship between BMI and %BF

Model	Beta coefficient ± standard error			R^2	SEE (%)
	Maori	Pacific Island	Asian Indian		
BOYS					
Initial model (IM)	*-2.81±1.17*	*-5.20 ±1.08*	*3.52±1.15*	*0.753*	*5.16*
IM + ASMM	-1.53±0.83 †	-2.59±0.79	1.52±0.83 †	0.876	3.67
IM + BMC	-1.93±0.97	-3.40±0.91	2.00±0.97	0.831	4.28
IM + BMD	-1.78±1.02 †	-4.01±0.95	2.68±1.00	0.815	4.48
IM + LL/height	-2.25±1.14	-5.03±1.05	2.63±1.14	0.769	5.01
IM + $\log_{10}$(AbFM)	-1.24±0.70 †	-1.08±0.68 †	1.64±0.69	0.912	3.08
IM + ThFM	-0.37±0.74 †	-1.80±0.70	1.98±0.72	0.904	3.23
IM + $\log_{10}$(ClFM)	-1.13±0.72 †	-1.06±0.70 †	2.72±0.70	0.908	3.16
IM + $\log_{10}$(LbFM)	-1.44±0.69	-3.57±0.64	2.18±0.68	0.915	3.04
IM + WC	-1.44±1.13 †	-2.68±1.13	3.54±1.08	0.782	4.86
IM + WHTR	-1.82±1.05 †	-3.01±1.02	2.17±1.05	0.803	4.63
IM + CI	-0.94±1.07 †	-1.76±1.07 †	3.02±1.02	0.806	4.59
IM + $\log_{10}$(LbFM) + ASMM	-0.82±0.42 †	-2.07±0.40	1.05±0.42	0.969	1.85
IM + $\log_{10}$(LbFM) + ASMM + CI	-0.25±0.39 †	-1.02±0.39	1.04±0.38	0.975	1.66
GIRLS					
Initial model (IM)	*-1.88±0.82*	*-4.13±0.79*	*3.55±0.85*	*0.794*	*4.00*
IM + ASMM	-1.36±0.69	-2.45±0.68	2.53±0.71	0.859	3.33
IM + BMC	-1.47±0.81 †	-3.33±0.80	3.01±0.83	0.807	3.88
IM + BMD	-1.63±0.81	-3.59±0.79	3.32±0.83	0.804	3.91
IM + LL/height	-1.88±0.83	-4.13±0.80	3.59±0.89	0.794	4.01
IM + $\log_{10}$(AbFM)	-1.52±0.64	-2.56±0.64	1.70±0.68	0.875	3.13
IM + Thigh FM	-0.61±0.70 †	-2.76±0.68	2.62±0.72	0.856	3.35
IM + $\log_{10}$(ClFM)	-1.40±0.60	-2.07±0.59	2.70±0.62	0.893	2.89
IM + $\log_{10}$(LbFM)	-0.33±0.60 †	-2.43±0.58	2.23±0.61	0.895	2.87
IM + WC	-1.84±0.83	-4.10±0.80	3.54±0.85	0.794	4.01
IM + WHTR	-1.82±0.83	-4.03±0.80	3.36±0.86	0.795	4.00
IM + CI	-1.82±0.83	-4.07±0.80	3.49±0.85	0.795	4.01
IM + $\log_{10}$(LbFM) + ASMM	0.30±0.33 †	-0.55±0.33 †	1.08±0.34	0.969	1.55
IM + $\log_{10}$(LbFM) + ASMM + CI	0.43±0.32 †	-0.42±0.32 †	0.95±0.33	0.971	1.51

†Not significant; Initial model=%BF regressed on $\log_{10}$(BMI), age, ethnicity (boys) or (1/BMI), ethnicity (girls). SEE=Standard error of estimate; ASMM=Appendicular skeletal muscle mass (kg); BMC=Bone mineral content (kg); BMD=Bone mineral density (g/cm^2); LL/height=Leg length/DXA height; AbFM=Abdominal fat mass (kg); ThFM=Thigh FM (kg); ClFM=Central FM (kg); LbFM=Limb FM (kg); WC=Waist circumference (cm); WHTR=Waist circumference (cm)/height (cm); CI=Conicity index; Maori: coded as 0,1,0,0; Pacific Island: coded as 0,0,1,0; Asian Indian: coded as 0,0,0,1 for European, Maori, Pacific Island and Asian Indian ethnic groups, respectively.

6.3 Bioimpedance analysis and body composition

As mentioned in Section 6.1, the aims of this section were to: 1) examine the predictive accuracy of BIA_8 estimates of body composition in European, Maori, Pacific Island and Asian adolescents and, 2) develop BIA prediction equations that apply to this population. All 431 participants described in Table 6.2 were included in analyses for this aspect of the validation study.

The mean difference between scale weight and DXA weight was 0.00±0.59 (SD) kg (a histogram of the differences is provided in Appendix 4). The manufacturer's estimates and DXA measurements of FM, %BF and FFM were strongly correlated (r=0.97, 0.92 and 0.96, respectively). The concordance correlation coefficients for these respective comparisons were 0.93, 0.85 and 0.94. Bland-Altman analysis (Figure 6.2) showed that, on average, the manufacturer's predictions underestimated FM by 2.06±3.57 kg (P<0.0001) and tended to overestimate FM at low FM values and underestimate at high FM values. The differences between the manufacturer's estimates and the DXA measurements of FM (BIA_8 – DXA) were negatively correlated with the average of these two measures (r=–0.62, P<0.0001). On average, the manufacturer's predictions underestimated %BF by 2.84±4.70% (P<0.0001) and tended to overestimate %BF at low %BF values and underestimate at high %BF values (r=–0.59, P<0.0001, Figure 6.2). The manufacturer's predictions overestimated FFM by 2.61±3.46 kg (P<0.0001), on average. These patterns were seen in each sex/ethnicity subgroup.

Prediction equations based on BIA were developed, as described in Section 5.4. After data splitting, equations were developed for each sex because the regression coefficients of the best-fitting lines differed significantly between boys and girls. FFM prediction equations developed in groups 1 and 2 for each sex are shown in Table 6.6 and, for each sex, the same predictors entered into both equations. The predictors for boys were: H^2/Z, weight, height, age and ethnicity (0=European or Asian, 1=Maori or Pacific); and, for girls: H^2/Z, weight, height and ethnicity (0=non-Pacific, 1=Pacific). For boys, waist circumference was a significant predictor but had very high collinearity with weight. *Z*, LL^2/Z, SH^2/Z, *LL* and *SH* did not add significantly to the equation. For girls, *Z*, LL^2/Z, SH^2/Z, *LL*, *SH,* age, waist circumference and other ethnicity variables were not significant. The regression models developed in group 2 were used to predict FFM in group 1. In group 1, there was no significant difference between the predicted FFM and the measured FFM in boys (54.12±10.64 kg and 53.87±11.07 kg, respectively; P=0.41, limits of agreement for this difference: –5.94 and +6.44 kg) and girls (41.31±7.27 kg and 41.52±7.70 kg, respectively; P=0.34, limits of agreement for this difference: –4.34 and +4.76 kg). Similarly, the equations developed in group 1 were used to predict

FFM in group 2. In group 2, the predicted FFM did not differ significantly from the measured FFM in boys (54.47±11.35 kg versus 54.76±11.81 kg, respectively; P=0.33, limits of agreement for this difference: –6.42 and +5.84 kg) and girls (40.07±5.98 kg versus 39.84±6.26 kg, respectively; P=0.25, limits of agreement for this difference: –4.36 and +3.90 kg).

Table 6.6 summarises the cross-validation results and it is apparent that, for each sex, the R^2, SEE and pure error values are similar between the two groups. For each sex, regressions of predicted FFM on measured FFM developed for each group were almost identical with similar deviations from the line of identity (boys: slope=0.92 for group 1 and slope=0.93 for group 2; girls: slope=0.91 for group 1 and slope=0.89 for group 2). Therefore, single equations using all 215 boys and 216 girls were developed (Table 6.6). Regression analysis with FFM as the dependent variable and the predictors as the independent variables (H^2/Z, age, height, weight and Maori/Pacific ethnicity for boys; H^2/Z, height, weight and Pacific ethnicity for girls) in the two combined groups, using group as a dummy variable, showed no group effect in the relation (P=0.53 for boys and P=0.47 for girls). The equation for boys explained 93% of the variance in FFM and H^2/Z alone explained 86% of the variability. The equation for girls explained 91% of the variability in FFM and H^2/Z alone accounted for 87%. The concordance correlation coefficients for predicted versus measured FFM, FM and %BF were, respectively, 0.96, 0.96, 0.90 (boys) and 0.95, 0.98, 0.91 (girls). There was no difference between predicted and measured FFM for boys (limits of agreement: –6.11 to +6.11 kg) and girls (limits of agreement: –4.33 to +4.33 kg). Further, there was no difference between measured and predicted FFM in each sex/ethnicity subgroup. For both boys and girls, absolute differences between measured and predicted FFM were randomly distributed around the mean difference (Figure 6.3). Bland-Altman analyses assessing agreement for FM and %BF also showed good agreement between measured and predicted values. That is, there were no differences between measured and predicted values for FM (P=0.31 for boys and P=0.16 for girls, respectively) and %BF (P=0.59 for boys and P=0.24 for girls, respectively), and the differences between measured and predicted values were minimally or not correlated with the average of these among boys (r=–0.16 (P=0.02) and r=–0.13 (P=0.06) for FM and %BF, respectively) and girls (r=–0.14 (P=0.04) and r=–0.25 (P=0.0002) for FM and %BF, respectively).

Table 6.6. Fat-free mass prediction equations based on BIA

	Boys	Girls
Group 1	*n=108*	*n=108*
Measured FFM (kg)	53.87±11.07	41.52±7.70
FFM prediction equation	$0.608H^2/Z + 1.670A + 0.202H + 0.092W + 2.043E_b - 46.476$	$0.542H^2/Z + 0.190H + 0.090W + 1.507E_g - 16.966$
	R^2=0.92, SEE=3.14 kg, CV=5.8%	R^2=0.91, SEE=2.31 kg, CV=5.6%
Predicted FFM (kg)	53.87±10.63	41.52±7.36
Cross-validation using Group 2 participants		
FFM	54.12±10.64 kg, pure error=3.09 kg, CV=5.7%	41.31±7.27 kg, pure error=2.27 kg, CV=5.5%
Group 2	*n=107*	*n=108*
Measured FFM (kg)	54.76±11.81	39.84±6.26
FFM prediction equation	$0.594H^2/Z + 1.410A + 0.233H + 0.105W + 1.710E_b - 47.511$	$0.517H^2/Z + 0.174H + 0.102W + 1.554E_g - 14.435$
	R^2=0.93, SEE=3.11 kg, CV=5.7%	R^2=0.89, SEE=2.10 kg, CV=5.3%
Predicted FFM (kg)	54.76±11.42	39.84±5.91
Cross-validation using Group 1 participants		
FFM	54.47±11.35 kg, pure error=3.06 kg, CV=5.6%	40.07±5.98 kg, pure error=2.07 kg, CV=5.2%
Groups 1 & 2 combined	*n=215*	*n=216*
Measured FFM (kg)	54.31±11.43	40.68±7.05
FFM prediction equation	$0.607H^2/Z + 1.542A + 0.220H + 0.096W + 1.836E_b - 47.547$	$0.531H^2/Z + 0.182H + 0.096W + 1.562E_g - 15.782$
	R^2=0.93, SEE=3.09 kg, CV=5.7%	R^2=0.91, SEE=2.19 kg, CV=5.4%
Predicted FFM (kg)	54.31±11.01	40.68±6.71

FFM=Fat-free mass (kg); *H*=height (cm); *Z*=Impedance (Ω); *A*=Age (y); *W*=weight (kg); E_b: 0=European or Asian, 1=Maori or Pacific; E_g:0=non-Pacific, 1=Pacific; SEE=standard error of estimate; CV=coefficient of variation.

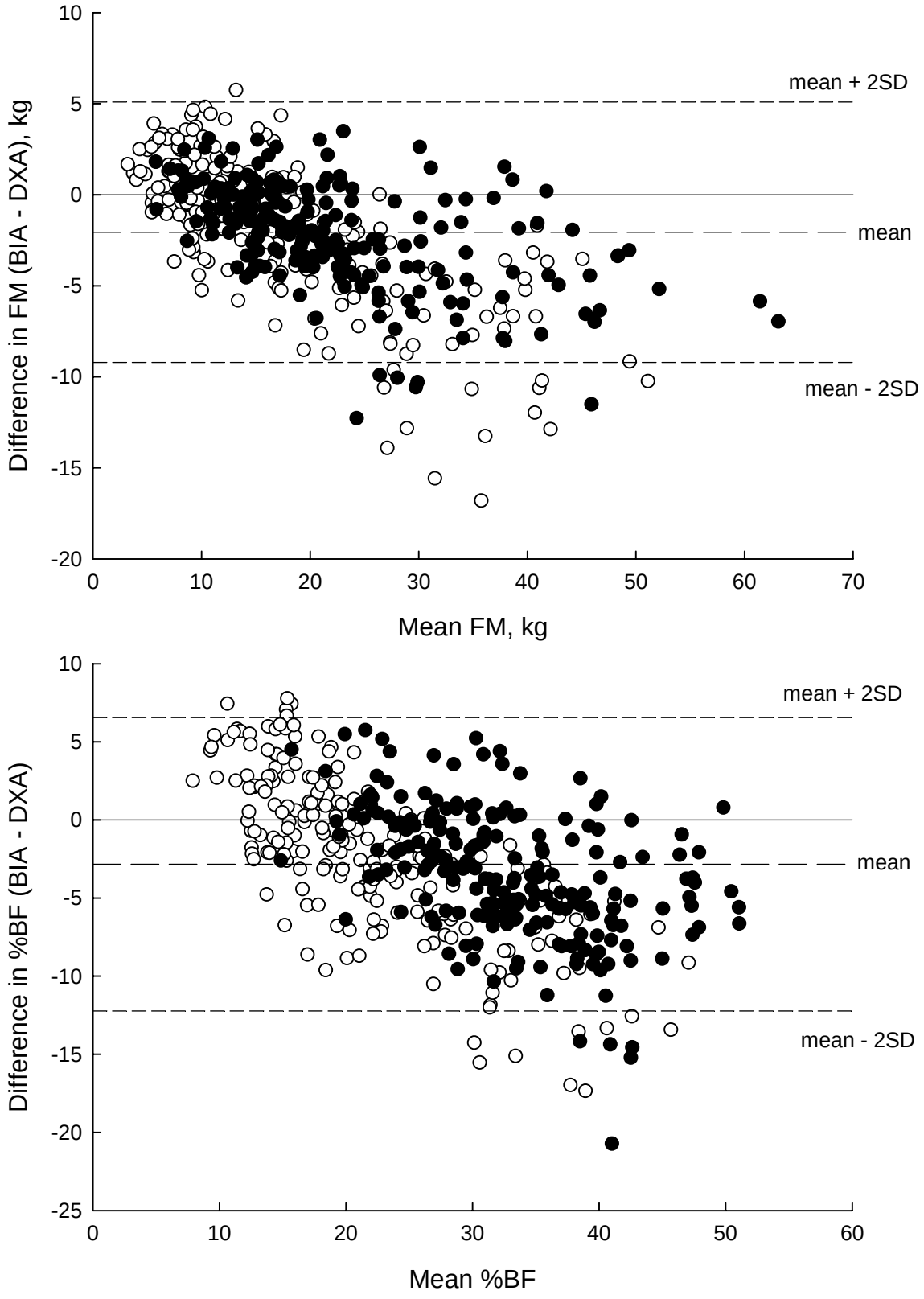


Figure 6.2. Differences in fat mass (FM, *upper panel*) and percent body fat (%BF, *lower panel*) measured by dual-energy X-ray absorptiometry (DXA) and estimated by bioimpedance analysis (BIA, Tanita BC-418) in 215 boys (open symbols) and 216 girls (closed symbols).

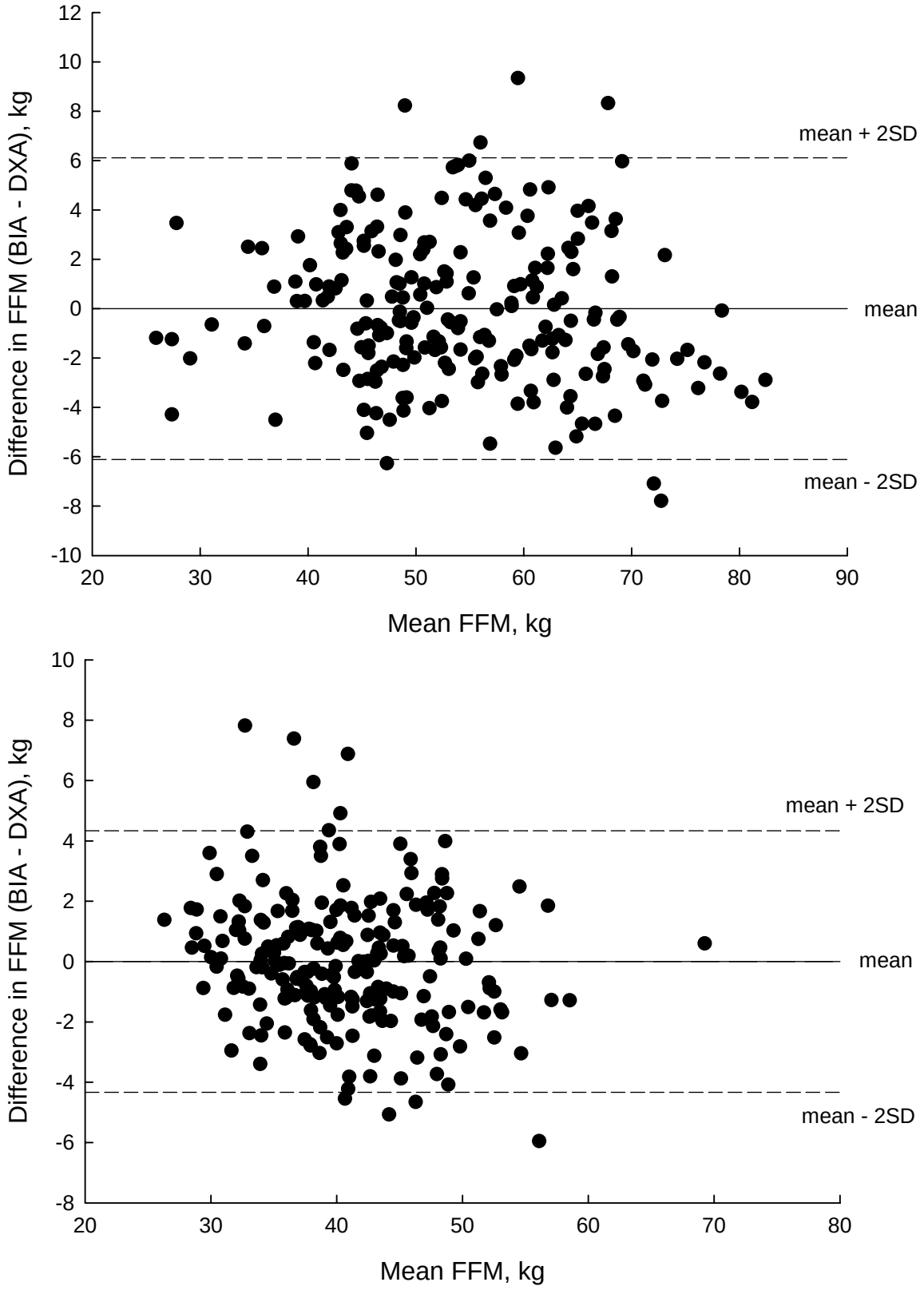


Figure 6.3. Differences in fat-free mass (FFM) measured by dual-energy X-ray absorptiometry (DXA) and estimated by bioimpedance analysis (BIA) using new equations developed in 215 boys (*upper panel*) and 216 girls (*lower panel*).

6.4 Waist circumference and trunk impedance

This section will examine the ability of waist circumference and trunk impedance to predict abdominal fatness. One Asian girl was an outlier in the %AbFM-WC relationship and was excluded. Analyses were performed on 430 adolescents.

Table 6.2 shows that the range of WC and %AbFM values of the participants were wide. In boys, trunk impedance was highest in Asians and lowest in Pacific Islanders; while in girls, trunk impedance was highest in Asians (Table 6.2).

The two sets of WC measurements for each individual had a coefficient of variation (CV) of 1.1% in boys and 1.6% in girls, and no mean difference (P=0.52 for boys, P=0.09 for girls). This indicates that the repeatability of the WC measurements in the validation study was good.

Relationships between %AbFM and anthropometric variables in the whole sample

The whole sample was stratified by ethnicity and sex, and regressions of %AbFM on WC, WHTR, CI and BMI (one anthropometric variable at a time) were examined for each ethnicity/sex subgroup. The WC, WHTR and BMI relationships were curvilinear and were linearised in boys by logarithmically transforming these anthropometric variables; while in girls, linearity was attained by applying a reciprocal transformation. These transformations were chosen as scatter plots showed that they yielded linear relationships and they were associated with the lowest AIC and highest R^2 values. Because of the different transformations needed for boys and girls, equations were developed for each gender. Equations were developed for each sex also because the regression coefficients of the %AbFM-WC and %AbFM-WHTR relationships significantly differed between boys and girls.

Table 6.7 shows, in each ethnicity/sex subgroup, the R^2 values for the regression of %AbFM on WC, WHTR, CI and BMI. The best predictor of %AbFM (based on highest R^2 value) was $\log_{10}$(WHTR) in boys and 1/BMI in girls. Out of all anthropometric variables, CI predicted %AbFM with the lowest R^2 (boys and girls). In girls, 1/WC, 1/WHTR and CI predicted %AbFM with a much lower R^2 in Asians, compared to non-Asians.

Anthropometry-based %AbFM prediction equations in the whole sample

Table 6.8 shows the best (identified by statistical criteria described in Section 5.4) %AbFM prediction equations based on anthropometric variables, developed in the whole sample. Age, height,

weight and ethnicity predicted %AbFM independently of other anthropometric variables. The predictors of the best equation overall were: for boys, $\log_{10}$(WHTR), age, Pacific ethnicity (0=non-Pacific, 1=Pacific) and Asian ethnicity (0=non-Asian, 1=Asian); and, for girls: 1/WC, 1/BMI, Pacific ethnicity (0=non-Pacific, 1=Pacific) and Asian ethnicity (0=non-Asian, 1=Asian). To examine the predictive accuracy of these two best "overall" equations, models with these predictors were developed in the development sample (n=142 for boys, n=143 for girls) and cross-validated in the validation sample (n=73 for boys, n=72 for girls), as described in Section 5.4. The predicted %AbFM in the validation group did not differ significantly from the measured %AbFM in this group (P=0.52 for boys, P=0.54 for girls). In each sex, the pure errors in the validation sample (5.14% for boys, 4.68% for girls) were similar to SEEs in the development groups (5.04% for boys, 5.31% for girls).

Relationship between abdominal FFM and trunk impedance in the whole sample

Figure 6.4 (upper panel) shows the relationship between abdominal FFM per cm height and trunk impedance in the whole sample (430 adolescents). This graph indicated that as trunk impedance increased, abdominal FFM per cm height decreased and approached a minimum value. As this suggested a reciprocal relationship, abdominal FFM per cm height was plotted against 1/trunk impedance and this resulted in a positive, linear association (lower panel of Figure 6.4).

Effect of trunk impedance on ethnicity difference in %AbFM-anthropometry relationships

Table 6.9 examines the effect of adjusting the models in Table 6.8 for trunk impedance on their %AbFM ethnicity differences. Correction for trunk impedance increased the Pacific (less negative) and reduced the Asian (less positive) ethnicity variables. The changes were markedly greater in boys than in girls. Among boys, the changes, in general, were slightly larger for the Pacific ethnicity variable, compared to the Asian ethnicity variable. In some cases, ethnic differences in %AbFM were eliminated.

Ethnic differences in Z_{Tr} adjusted for WC variables

To examine whether the ethnic variation in abdominal fatness at a given WC or WHTR could be measured with Z_{Tr}, differences in Z_{Tr} between ethnic groups at a fixed WC or WHTR were compared and are illustrated in Figure 6.5. Among girls, Asians had more Z_{Tr} than non-Asians at a given WC (P-value ranged from <0.0001 to 0.0022) or WHTR (P-value ranged from <0.0001 to 0.0002). Among boys, at the same WC, Pacific Islanders had 3 Ω less Z_{Tr} (P<0.0001) and Asians had 3 Ω more Z_{Tr} (P=0.0023), compared to Europeans. Similarly, when these analyses for boys were repeated

with WHTR as an independent variable instead of WC, compared to Europeans, Pacific Islanders had 4 Ω less Z_{Tr} (P<0.0001), while Asians had 3 Ω more Z_{Tr} (P=0.0002).

Anthropometry- and trunk BIA-based %AbFM prediction equations in the whole sample

Table 6.10 shows the best %AbFM prediction equations based on anthropometric variables and $1/Z_{Tr}$. These equations were identified by statistical criteria described in Section 5.4 and were developed in the whole sample. Age, height, weight and ethnicity predicted %AbFM independently of anthropometric and trunk BIA variables. The predictors of the best equation overall were: for boys, $\log_{10}$(WHTR), $\log_{10}$(BMI), Asian ethnicity (0=non-Asian, 1=Asian), age and $1/Z_{Tr}$; and, for girls: 1/WC, 1/BMI, Pacific ethnicity (0=non-Pacific, 1=Pacific), Asian ethnicity (0=non-Asian, 1=Asian) and $1/Z_{Tr}$. To assess the predictive accuracy of these two best "overall" models, equations with these predictors were developed in the development sample (n=142 for boys, n=143 for girls) and cross-validated in the validation sample (n=73 for boys, n=72 for girls), as previously mentioned (Section 5.4). The predicted %AbFM in the validation group did not differ significantly from the measured %AbFM in this group (P=0.87 for boys, P=0.39 for girls). In each sex, the pure error in the validation sample (4.88% for boys, 4.80% for girls) was similar to the SEE in the development group (4.58% for boys, 4.83% for girls).

Table 6.7. Variance (%) of percent abdominal fat (%AbFM) explained by anthropometry variables

	Anthropometry variable	European	Maori	Pacific Island	Asian
BOYS	$\log_{10}$(WC)	75.2	77.9	65.7	75.7
	$\log_{10}$(WHTR)	80.3	86.1	71.4	86.2
	CI	49.0	64.6	52.2	56.1
	$\log_{10}$(BMI)	76.5	77.9	58.1	72.1
GIRLS	1/WC	75.9	60.0	70.5	43.9
	1/WHTR	75.2	59.9	70.7	48.5
	CI	26.9	28.5	39.2	5.9*
	1/BMI	84.2	70.0	76.2	69.5

*Not significant; WC=Waist circumference (cm); WHTR=Waist circumference (cm)/height (cm); CI=Conicity index; BMI=Body mass index (kg/m^2).

Table 6.8. Prediction equations for percent abdominal fat (%AbFM), based on anthropometric variables

	Anthropometry variable	Prediction equation	R^2	SEE
BOYS	WC	175.68 $\log_{10}$(WC) – 1.90 Pacific + 3.38 Asian – 1.20 A – 0.39 H + 225.08	0.829	5.04
	WHTR	176.36 $\log_{10}$(WHTR) – 1.88 Pacific + 3.07 Asian – 1.06 A + 98.23	0.828	5.04
	CI	57.01 CI + 0.51 W – 1.12 A – 0.55 H – 2.10 Pacific + 2.70 Asian + 33.66	0.794	5.54
	BMI	121.73 $\log_{10}$(BMI) – 2.78 Maori – 7.35 Pacific + 3.47 Asian – 1.36 A – 0.16 H – 91.17	0.747	6.14
	All[†]	176.36 $\log_{10}$(WHTR) – 1.88 Pacific + 3.07 Asian – 1.06 A + 98.23	0.828	5.04
GIRLS	WC	–2406.14 (1/WC) – 2.90 Pacific + 2.39 Asian + 0.69 A – 0.45 H + 0.38 W + 103.68	0.728	5.59
	WHTR	–14.73 (1/WHTR) – 2.86 Pacific + 2.26 Asian + 0.70 A – 0.26 H + 0.38 W + 73.48	0.727	5.61
	CI	0.65 W – 2.81 Pacific + 2.37 Asian + 0.84 A – 0.55 H + 70.05	0.698	5.88
	BMI	–1168.92 (1/BMI) – 3.78 Pacific + 4.35 Asian + 86.15	0.765	5.16
	All[†]	–7.47 (1/WHTR) – 3.65 Pacific + 3.61 Asian + 0.49 A – 927.77 (1/BMI) + 83.51	0.777	5.05

SEE=Standard error of estimate (%); WC=Waist circumference (cm); WHTR=Waist circumference (cm)/height (cm); CI=Conicity index; A=Age (years); H=Height (cm); W=Weight (kg); BMI=Body mass index (kg/m^2); [†]All four anthropometric variables (WC, WHTR, CI and BMI) considered as potential predictors; Maori: coded as 0,1,0,0; Pacific: coded as 0,0,1,0; Asian: coded as 0,0,0,1 for European, Maori, Pacific Island and Asian ethnic groups, respectively.

Table 6.9. Impact of adding trunk impedance to statistical models of ethnic differences in percent abdominal fat (%AbFM)

	Model from Table 6.8	Change in beta coefficient[1] when $1/Z_{Tr}$ is added (initial beta coefficient[2])		
		Maori	Pacific	Asian
BOYS	$\log_{10}$(WC), Pacific, Asian, A, H	.	1.57 (-1.90)*	-1.21 (3.38)
	$\log_{10}$(WHTR), Pacific, Asian, A	.	1.43 (-1.88)*	-1.35 (3.07)
	CI, W, A, H, Pacific, Asian	.	0.59 (-2.10)*	-0.99 (2.70)*
	$\log_{10}$(BMI), Maori, Pacific, Asian, A, H	-0.06 (-2.78)	2.40 (-7.35)	-2.02 (3.47)*
GIRLS	1/WC, Pacific, Asian, A, H, W	.	0.39 (-2.90)	-0.37 (2.39)
	1/WHTR, Pacific, Asian, A, H, W	.	0.39 (-2.86)	-0.37 (2.26)*
	W, Pacific, Asian, A, H	.	0.38 (-2.81)	-0.36 (2.37)*
	1/BMI, Pacific, Asian	.	0.54 (-3.78)	-0.81 (4.35)
	1/WHTR, Pacific, Asian, A, 1/BMI	.	0.48 (-3.65)	-0.55 (3.61)

[1]Change in beta coefficient=Beta coefficient when 1/trunk impedance ($1/Z_{Tr}$) is in model minus beta coefficient without $1/Z_{Tr}$ in model; [2]Initial beta coefficient=Beta coefficient without $1/Z_{Tr}$ in model; *Beta coefficient of ethnicity variable became non-significant when $1/Z_{Tr}$ was added to model; WC=Waist circumference (cm); WHTR=Waist circumference (cm)/height (cm); CI=Conicity index; BMI=Body mass index (kg/m^2); A=Age (years); H=Height (cm); W=Weight (kg); Maori: coded as 0,1,0,0; Pacific: coded as 0,0,1,0; Asian: coded as 0,0,0,1 for European, Maori, Pacific Island and Asian ethnic groups, respectively.

Table 6.10. Prediction equations for percent abdominal fat (%AbFM), based on anthropometric and trunk BIA variables

BOYS	Anthropometry + trunk BIA variable	Prediction equation	R^2	SEE
	WC + $1/Z_{Tr}$	187.10 $\log_{10}$(WC) + 2.28 Asian – 1.14 A – 0.37 H – 238.08 – 363.17 ($1/Z_{Tr}$)	0.853	4.67
	WHTR + $1/Z_{Tr}$	163.98 $\log_{10}$(WHTR) + 2.46 Asian + 0.11 W – 1.17 A + 103.06 – 416.76 ($1/Z_{Tr}$)	0.855	4.64
	CI + $1/Z_{Tr}$	45.89 CI + 0.62 W – 1.13 A – 0.60 H + 2.15 Asian + 63.43 – 443.23 ($1/Z_{Tr}$)	0.818	5.20
	BMI + $1/Z_{Tr}$	146.33 $\log_{10}$(BMI) – 3.65 Maori – 5.70 Pacific – 1.21 A – 0.14 H – 103.52 – 751.48 ($1/Z_{Tr}$)	0.835	4.95
	All† + $1/Z_{Tr}$	120.90 $\log_{10}$(WHTR) + 55.90 $\log_{10}$(BMI) + 2.88 Asian – 1.19 A + 25.16 – 548.76 ($1/Z_{Tr}$)	0.867	4.45
GIRLS	WC + $1/Z_{Tr}$	–2440.38 (1/WC) – 2.51 Pacific + 2.02 Asian – 0.45 H + 0.42 W + 112.01 – 264.56 ($1/Z_{Tr}$)	0.739	5.49
	WHTR + $1/Z_{Tr}$	–15.02 (1/WHTR) – 2.91 Pacific + 0.63 A – 0.29 H + 0.40 W + 86.60 – 282.32 ($1/Z_{Tr}$)	0.733	5.54
	CI + $1/Z_{Tr}$	0.68 W – 2.89 Pacific + 0.77 A – 0.58 H + 83.20 – 276.06 ($1/Z_{Tr}$)	0.704	5.83
	BMI + $1/Z_{Tr}$	–1278.12 (1/BMI) – 3.24 Pacific + 3.54 Asian + 103.56 – 424.73 ($1/Z_{Tr}$)	0.795	4.84
	All† + $1/Z_{Tr}$	–1038.83 (1/WC) – 1075.07 (1/BMI) – 3.18 Pacific + 3.61 Asian + 107.83 – 423.15 ($1/Z_{Tr}$)	0.801	4.77

SEE=Standard error of estimate (%); WC=Waist circumference (cm); WHTR=Waist circumference (cm)/height (cm); CI=Conicity index; BMI=Body mass index (kg/m^2); Z_{Tr}=Trunk impedance (Ω); A=Age (years); H=Height (cm); W=Weight (kg); †All four anthropometric variables (WC, WHTR, CI and BMI) considered as potential predictors; Maori: coded as 0,1,0,0; Pacific: coded as 0,0,1,0; Asian: coded as 0,0,0,1 for European, Maori, Pacific Island and Asian ethnic groups, respectively.

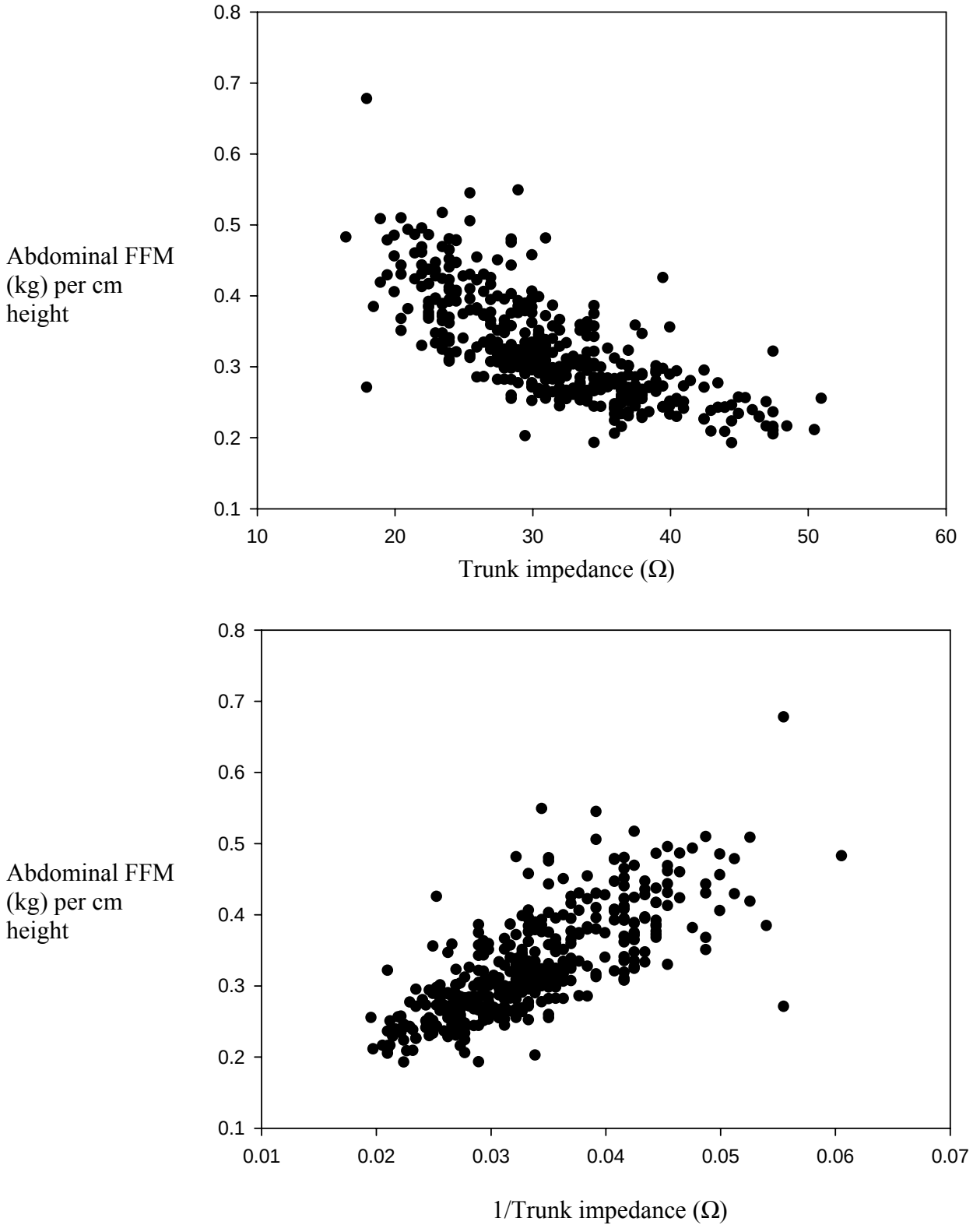


Figure 6.4. Relationship between abdominal fat-free mass (FFM) per cm height and: 1) trunk impedance (*upper panel*) and, 2) 1/trunk impedance (*lower panel*).

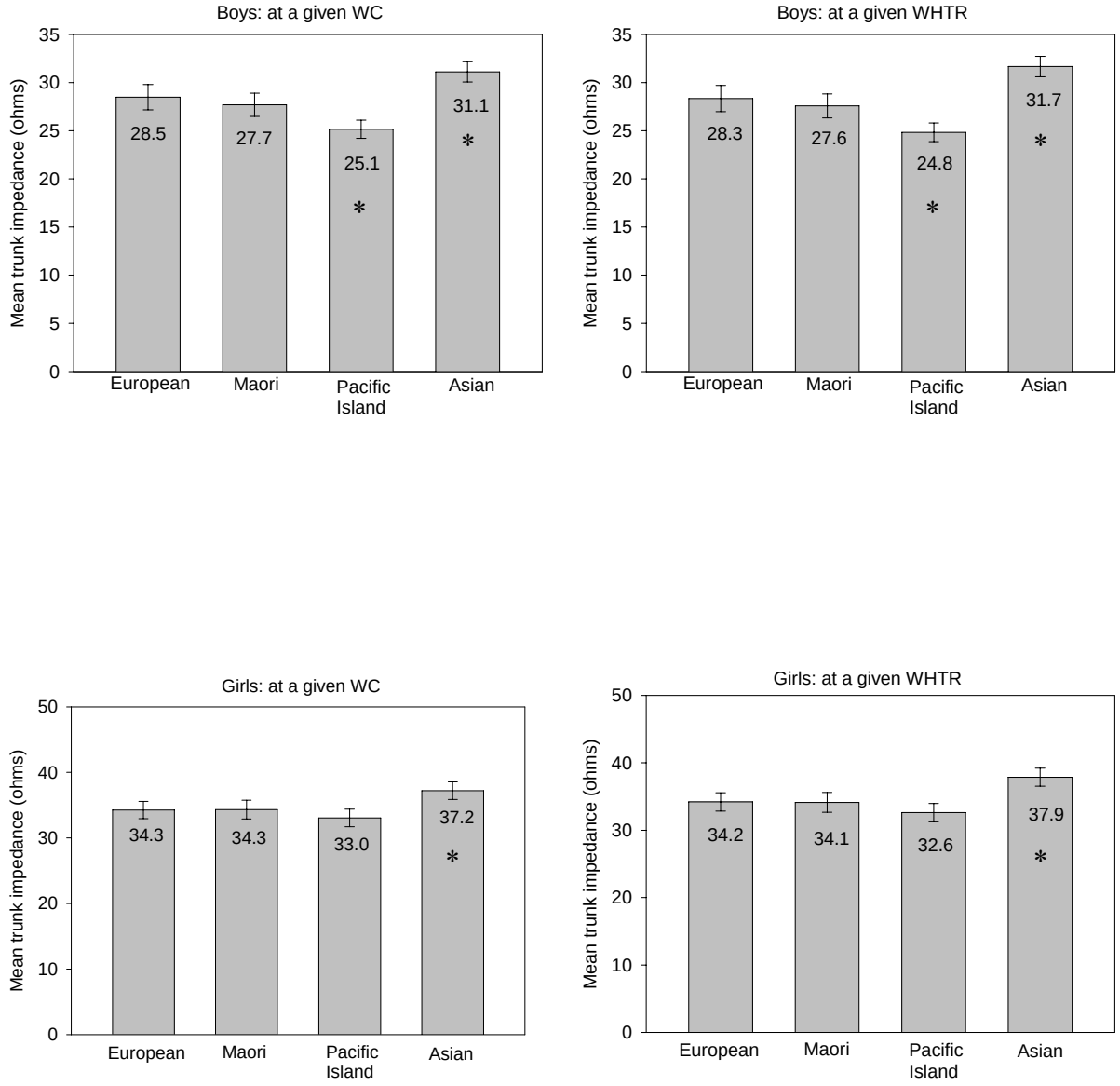


Figure 6.5. Trunk impedance levels after statistical adjustment for waist circumference (WC) or waist:height ratio (WHTR) across ethnic groups in boys (*upper panel*) and girls (*lower panel*). Error bars represent 95% confidence intervals; *P<0.05 compared to Europeans.

6.5 Summary

In this chapter, Section 6.2 showed that, compared to Europeans, for the same BMI, Asian Indians had more %BF, while Maori and Pacific Islanders had less %BF. In boys, readily measured variables, waist circumference/height and conicity index, had notable effects on the %BF ethnic differences. Other factors that contributed to these differences in boys and girls were variation in muscularity, bone mass, fat distribution and relative leg length.

As demonstrated in Section 6.3, BIA_8 estimated DXA-measured TFM, %BF and fat-free mass with significant bias. Bioimpedance-based prediction equations developed in the current study sample performed better than reliance on the manufacturer's equations and these equations depended upon ethnicity.

Finally, this chapter showed that, for the same waist circumference, compared to Europeans and Maori, Asians had more %AbFM and Pacific Islanders had less %AbFM (Section 6.4). Adjustment for trunk impedance removed or reduced these differences.

CHAPTER 7: METHODOLOGY OF OPIC STUDY

7.1 Introduction

This chapter will describe the methodology of the OPIC study. Rationales for choosing the methodology used in this study are given in this chapter in order to justify why a particular approach was chosen (e.g., why sugary drink consumption was measured with questionnaires). Section 7.2 will describe the sampling method, Section 7.3 will describe the measurements and Section 7.4 will describe the statistical analyses.

7.2 Sampling method

As mentioned in Chapter 1, the current study is an analysis of the baseline data collected in the OPIC study. The OPIC study is an obesity intervention study of youth that aimed to assess the effectiveness of a school-based obesity prevention program in youth. Interventions were aimed at reducing sedentary behaviour, increasing physical activity, encouraging breakfast consumption and reducing sugary drink and energy-dense snack food consumption; details of these interventions are given elsewhere (412). Participating schools either received the intervention (intervention schools) or did not receive the intervention (control schools). The sampling method of the OPIC study (which determines the sampling method for this thesis) is described elsewhere (50). A modified description of this, which relates more to the cross-sectional analysis of this thesis, is given below. Table 7.1 shows the demographic characteristics of the total study sample.

Choice of sampling method and schools

Ideally, to obtain a representative sample, one would aim to randomly sample individuals directly from a target population in order to maximise the representativeness of the sample. However, in the present study, schools were chosen as the sampling frame, instead of individuals. That is, cluster sampling was used. This is because sampling from schools: 1) is cheaper, 2) is easier (fewer schools are sampled from), 3) is expected to attract more support for the study from school staff, which is likely to lead to higher response rates, 4) makes it possible to reduce variability in SES by sampling from only a small number of schools and, 5) allows interventions at the school level.

In the present study, the intervention and control schools were purposively selected in order to meet certain criteria that were important for the success of the study and the ease of its methodology. The

criteria for choosing the intervention schools were: 1) adequate population size of accessible adolescents and, for New Zealand, a high proportion of Pacific Island students, 2) sense of community identity and cohesiveness among community members and organisation, 3) sufficient settings for interventions, 4) the presence of "champions" of change, 5) well-demarcated boundaries to define denominator population, 6) preferably within a single administrative area, 7) ease of access for research staff, and 8) ease of access for other organisations (50). The criteria for the selection of the control schools were that they needed to be comparable to the intervention schools (ethnicity, SES and likely trajectory of weight gain) and distant enough from the interventions schools to minimise contamination. The details of the sampling method for each country are described below (Sections 7.2.1-7.2.4).

Power calculations

Change in BMI was the primary outcome variable in the OPIC study. Accordingly, it is preferable to base sample size calculations on longitudinal changes in BMI over a few years among the study populations. Because this information was not available, sample size calculations were based on cross-sectional data from a survey that had a high number of Pacific Island adolescents (31). In this survey, the standard deviation of BMI was 5.22 kg/m^2 (50). Assuming a within-person correlation of 0.8, a sample size of 1000 each in the intervention and comparison arms of the study would give sufficient power (power=80%, α=0.05) to detect a difference in BMI of 0.41 kg/m^2. This would give a reasonable balance between expected effect size and study feasibility and cost for the OPIC study (50). To allow for dropouts, the target sample size was set at 1500 in each group (intervention and comparison). In Fiji, this group target sample size was set for each of the Fijian and Indo-Fijian ethnic groups because of the large number of students in each of these two ethnic groups.

7.2.1 New Zealand

In order to obtain sufficient numbers of Pacific Island students, participants were recruited from seven high schools in South Auckland that had a high percentage of Pacific Island students. These schools were purposively chosen as they had a high number of Pacific Island students and they were close together. These schools had decile ratings of either 1 or 2; school decile ratings reflect the SES of school areas and range from 1 (most deprived) to 10 (least deprived). Response rates per school, as determined from the school roll, ranged from 25% to 78% and averaged 58% (7).

Ethics approval was obtained from the University of Auckland Human Participants Ethics Committee. Consent to carry out the study in schools was obtained from the principal of each school.

At data collection, written consent was obtained from each student. For students aged under 16 years, written consent was obtained from a parent or guardian as well. However, due to the difficulties in getting participants to bring their consent forms from home to school, in a few cases, parents or guardians gave consent orally over the phone.

7.2.2 Australia

Australian participants were recruited from 5 high schools in East Geelong and 7 schools selected from a stratified (by size), random selection of schools across the rest of the Barwon-South Western region of Victoria. The Barwon-South region is one of nine regions in Victoria and covers the south-west part of the state across to the South Australia border. Compared to the remainder of Victoria, it is socio-economically disadvantaged. The areas where students were recruited from are of low SES and comprise people mainly of European descent. All students in Years 7-11 (Year 12 being the final school year) attending these schools were invited to participate. A total of 6508 students were eligible to participate, as determined from the school roll, and 3163 students participated, giving a response rate of 49% (range: 36% to 81%) (7).

Ethical approval was obtained from the Deakin University Human Research Ethics Committee and consent for the study was given by the principal of each school. Written consent was obtained from each student. For minors, written consent was obtained from a parent or guardian as well.

7.2.3 Fiji

Fijian participants were recruited from 8 high schools in the peri-urban area of Nasinu (near Suva) and 11 schools from towns in the west side of the main island of Viti Levu. All students in Forms 3-6 (Form 7 being the final school year) at these schools were invited to participate. A total of 9785 students were eligible to participate (determined from the school roll) and 7237 students participated, giving a response rate of 74% (range: 49% to 99%) (7). All students who were in class during the survey participated.

Ethical approval was obtained from the National Health Research Council (NHRC) and the Fiji National Research Ethics Review Committee (FNRERC) Ethics Committee. Each student gave written consent. For students aged under 16 years, written consent was obtained from a parent or guardian as well. In a few cases, however, parents or guardians gave consent orally over the phone.

7.2.4 Tonga

Tongan participants were recruited from 3 districts on the main island of Tongatapu (Kolonga, Nukunuku and Houma) and high schools on the northern island group of Vava'u. All students in Forms 1-6 (Form 7 being the final school year) who attended these high schools or who lived in the 3 districts were invited to participate. A total of 4448 students were eligible to participate (determined from the school roll) and 2535 students participated, giving a response rate of 57% (7).

Ethical approval was obtained from the Tonga National Health Ethics Research Committee (TNHERC) and the principal of each school gave consent for the study. Each student gave written consent prior to the study. For students aged under 16 years, additional consent (written) was obtained from a parent or guardian.

Table 7.1. Demographic characteristics of the total study sample*

Country	New Zealand				Fiji		Tonga	Australia
Ethnic group	Pacific Island	Maori	Asian	European	Indigenous Fijian	Fijian Indian	Tongan	Australian
Total number	2513	853	354	507	3077	3794	2053	3040
Age range	12.5-21.3	12.3-20.7	12.2-19.8	12.2-20.4	12.0-20.8	11.5-20.3	10.7-22.2	11.4-18.3
Gender								
Boys	1196	397	176	241	1401	1870	930	1706
Girls	1317	456	178	266	1676	1924	1123	1334
Intervention or control school								
Intervention	1627	322	244	134	986	1616	1004	1852
Control	886	531	110	373	2091	2178	1049	1188

*Sample numbers are for analyses after individuals with missing data were removed. In addition, data of participants living in Fiji whose ethnicity was "Other" – that is, neither Indigenous Fijian nor Fijian Indian – were removed, due to the small number of these participants for ethnic-specific analyses. Thus, although similar, the numbers do not exactly correspond to numbers given in the text, which include participants with missing data and those living in Fiji of "Other" ethnicity.

7.3 Measurements

Data collection

Although it is preferable to collect data simultaneously to remove potential seasonal or temporal effects on the results, this was not possible for practical reasons. This would have entailed more cost (more equipment, such as BIA machines, and more staff) and all schools to be available at the same time (students are not always available, due to events occurring within schools). Thus, staff aimed to collect data in a short time-frame and which suited the schools. All baseline data were collected between 2005 and 2006.

In New Zealand, Australia and Fiji, all information, including questionnaires and physical measurements, were collected by interviews of whole classes (up to 35 students) during single school periods (approximately 50 minutes). The author was extensively involved in the data collection: he collected data at all of the classes in the New Zealand high schools for two years. Demographic and lifestyle data were collected by a self-reported questionnaire (Appendix 2) using an electronic device (personal digital assistant, PDA). At the end of each day, data in the PDA were transferred to a computer. The use of PDAs has several advantages over the use of paper questionnaires: saves costs and time, errors associated with manually entering data, data cleaning and double data entry. To assess comprehension and survey completion time, the questionnaire was pre-tested in a pilot survey carried out in all four countries. In Tonga, the questionnaire was translated into Tongan and back translated to ensure its cultural validity.

Measurement of ethnicity is difficult (413, 414). In the current study, *ethnicity* was defined by self-identification because of its simplicity. In addition, as this approach (question) to ethnicity measurement has been used in previous studies that examined the association of lifestyle variables with fatness in South Pacific populations (Chapter 4), this would aid in making these studies comparable with the present one. Accordingly, in the OPIC study, each participant was asked what ethnicity he/she most strongly identified with. The answers were then categorised into Pacific Island (Samoan, Cook Island Maori, Tongan, Niuean or Other Pacific), Maori, European (NZ European or Other European) and Asian/Other (Chinese, Indian, Other).

Lifestyle variables

There are various methods for measuring TV watching (415). Direct observation by an interviewer, measurement by electronic equipment and self-reported diaries provide detailed information about

what is watched and do not rely on recall. However, they are affected by reactivity (social desirability bias: subjects may watch less TV as they know that their TV watching is being monitored) and subject compliance, are intrusive, require commitment from the subject and researcher, are subject to participant bias (objectively measuring one's TV viewing at home discourages participation) (416) and are not suitable for epidemiological studies. In contrast, measurement by a questionnaire requires less commitment from the subject and researcher, is non-intrusive and is practical for large-scale studies. Therefore, in the present study, *TV watching* was assessed by questions. These questions were, "In the last 5 school days, how many days did you watch TV, videos or DVDs (in your free time)" (responses described in Appendix 2), "On the last school day that you watched TV, videos or DVDs, how long did you watch for?" (responses ranging from <1 hour to >4 hours), "Last Saturday, how many hours did you spend watching TV, videos or DVDs" (responses described in Appendix 2) and "Last Sunday, how many hours did you spend watching TV, videos or DVDs" (responses described in Appendix 2). *Average daily TV viewing* was calculated as ((number of days of watching TV/videos/DVDs out of past 5 school days times the number of hours watched on the last school day) + (total number of hours spent watching TV, videos or DVDs last Saturday and Sunday combined))/7 days. The resulting values (hours per day) were categorised into three groups of approximate tertiles.

There are several methods for collecting dietary data (417). Laboratory methods are accurate, but are not suitable for epidemiological use. Food diaries provide detailed information about what was eaten and do not rely on recall; however, they are intrusive, affected by reactivity (social desirability bias: subjects may eat less as they know that their eating is being monitored) and subject compliance; are subject to participant bias (asking one to record his or her food intake at home discourages participation) and require commitment from the subject. In comparison, 24-hour recall, food frequency questionnaires (FFQs) and questions require less commitment from the subject, are non-intrusive and are more suitable for large, epidemiological studies. Because the current study did not aim to measure dietary intake (which would have required the use of a 24-hour recall or FFQ), soft drink and fruit drink/cordial consumption was assessed by questions specifically about these behaviours. These questions were, "In the last 5 school days (including time spent at home), on how many days did you have regular (non-diet) soft drinks?" (responses described in Appendix 2), "On the last school day, how many glasses or cans of soft drinks did you have?" (responses described in Appendix 2), "In the last 5 school days, on how many days did you have fruit drinks or cordial?" (responses described in Appendix 2), and "On the last school day, how many glasses of fruit drinks or cordial did you have?" (responses described in Appendix 2). *Average daily soft drink consumption*

(cans/day) was calculated as (number of days of soft drink consumption times consumption on the previous day)/5 days. Similarly, *average daily fruit drink/cordial consumption* (glasses/day) was calculated as (number of days of fruit drink consumption times consumption on the previous day)/5 days. Average daily soft drink consumption and average daily fruit drink/cordial consumption were separate variables because soft drinks and fruit drinks/cordial have a potentially differential effect on satiety, may be consumed with energy-dense foods to different extents and may displace milk consumption from the diet to different extents (Section 4.3). The amounts (cans or glasses per day) of both variables were categorised into three groups of approximate tertiles.

Frequency of breakfast consumption was assessed with a question, for the same reason given above for soft drink and fruit drink consumption. This question was, "In the last 5 school days, on how many days did you have something to eat for breakfast before school started?" (responses described in Appendix 2). The time period, the *last 5 school days*, was chosen as it aids recall (it is not difficult for students to remember breakfast consumption over the past week). Frequency of consumption (days) were categorised into tertiles, which were defined so as to ensure sufficient numbers in each category.

Several methods are available to measure physical activity in the field setting (324). Doubly labelled water and direct observation provide valid measures of physical activity, but they are both costly and difficult to administer, and direct observation is associated with reactivity (324). The use of heart rate monitors and motion sensors entail cost and commitment from the participant, and diaries are subject to reactivity (324). In contrast, questionnaires are cheap, do not require commitment from the participant and are suitable for large-scale studies. Therefore, questionnaires were chosen to measure physical activity in the current study. *After-school physical activity* was assessed by the question, "In the last 5 school days, on how many days after school, did you do sports, dance, cultural performances or play games in which you were active?" (responses, described in Appendix 2, were categorised into three groups of approximate tertiles). *Morning recess/interval physical activity* was assessed by the question, "Over the last 5 school days, what did you do most of the time at morning recess/interval (apart from eating)?" (responses, given in Appendix 2, were categorised into two groups). *Lunch-time physical activity* was assessed with the question, "In the last 5 school days, what did you do most of the time at lunch time (apart from eating)?" (responses, described in Appendix 2, were grouped into two categories). The after-school-, morning tea/recess and lunch-time physical activity categories (days) were chosen so as to ensure sufficient numbers in each category. For each question, the time period, the *last 5 school days*, was chosen as it aids recall (physical activity in the

past week is not difficult to remember). In addition, these questions were chosen as they ask about activity in *specific* time periods, which aids memory (418).

Covariates

Physical activity is a potential confounder because it may covary with TV watching, sugary drink consumption and breakfast consumption (256, 419, 420). Therefore, after-school physical activity, morning recess/interval physical activity, lunch-time physical activity (all 3 described above) and active transportation were measured and used in this thesis to adjust for physical activity in statistical models. *Active transportation* was assessed by asking the participant the number of trips that he/she made by walking or biking to or from school over the past 5 school days (responses described in Appendix 2). An additional physical activity measure, *perception of neighbourhood safety at night*, was assessed by the question, "How safe do you feel being out alone in your neighbourhood at night?" (responses described in Appendix 2). It is plausible that this may measure how conducive the neighbourhood is to physical activity and is a potentially better measure of "usual" physical activity patterns than other measures described above because variation in temporal patterns is expected to be less with this measure.

Although participants were recruited from areas of similar SES, which would reduce possible confounding by SES, differences in personal SES could still vary within each area. Therefore, *household size* was measured and used to adjust for personal SES, and was assessed by the question, "How many people usually live at your home, including yourself during the school week?" (responses described in Appendix 2). It is plausible that the greater the number of people living at home, as measured by this variable, the lower the amount of income per person and therefore the lower the SES. Of note, household size is easier to report than asking one to report household income. Previous studies of obesity research have used family size in the statistical adjustment of SES (421, 422).

For the analysis of Australian data, the Australian Bureau of Statistics' Socio-economic Indexes for Areas (SEIFA) scores were used as another measure of SES. SEIFA is an area-based measure of SES that incorporates attributes such as income, educational attainment and employment status. The SEIFA information was an index of advantage/disadvantage, based on data collected from the 2001 Australian census (423). SEIFA has previously been used to control for SES in Australian obesity research (336).

Energy-dense foods may be consumed while soft drinks are consumed (424) and sugary drink consumption may be a marker of an unhealthy lifestyle that includes fast food consumption (425, 426). Conversely, regular breakfast consumption may be a marker of a healthy lifestyle that includes less snacking (218). Thus, as has been done in previous studies that examined the association of SSBs (220, 427) and breakfast consumption (135) with fatness, fast food consumption and snack food consumption were used as covariates in statistical models. *Fast food consumption* was assessed by the question, "How often do you usually eat food from a takeaway?" (responses described in Appendix 2). *Snack food consumption* was assessed by the questions, "In the last 5 school days, on how many days did you buy snack food from a shop or takeaway after school?" (responses described in Appendix 2), "How often do you usually eat biscuits, potato chips or snacks such as instant noodles after school?" (responses described in Appendix 2), "How often do you usually eat pies, takeaways or fried foods such as french fries after school?" (responses described in Appendix 2) and "How often do you usually eat chocolates, lollies, sweets or ice cream after school?" (responses described in Appendix 2).

Assessment of puberty was considered in order to account for maturational stage in statistical models but was not measured for the same reasons given in Section 5.3. Season, another measure, has the potential to confound or moderate associations between lifestyle and fatness. For example, during winter, temperature is colder and daylight hours are shorter; this could reduce physical activity levels during winter. Therefore, season during which data collection took place (summer, autumn, winter or spring) was recorded.

Dieting and attempts to lose weight make it difficult to deduce from cross-sectional data whether lifestyle variables cause increased fatness (221). To account for this problem, *weight-change attempts* were assessed by asking each participant what he/she was doing about their weight. Students answered, "trying to lose weight", "trying to gain weight", "trying to stay at my current weight" or "not doing anything about my weight". For the analyses, the last two categories were combined into a "not change weight" category (221).

Physical activity may change as a *consequence* of being overweight/obese. Diagnosis of this effect would help to determine the directionality of associations between physical activity and fatness in the current study (a cross-sectional one). Overweight/obese individuals may be less likely to participate in sports due to difficulty with being physically active or because of fears of being teased (112). Therefore, if weight status did influence physical activity, difficulty being physically active or fear of

being teased may be mediators. To help determine this, questions about *difficulty being physically active* or *fear of being teased* were asked: 1) "How well can I walk or run?", 2) "It is difficult for me to walk more than 100 metres", 3) "It is difficult for me to run", 4) "It is difficult for me to play sport or do exercise" and, 5) "Other teenagers tease me". These questions were asked on a self-administered paper questionnaire; responses to each question are described in Appendix 3.

Measures of fatness

There are various field measures of body fat. Skinfold thickness measurements provide information on fat distribution (428, 429); however, they only measure subcutaneous fat, are intrusive, are relatively time-consuming, lack precision, can be difficult to measure in those with thicker skinfolds (leading to systematic measurement error) and depend on the skill of the measurer (430, 431). In contrast, measurement of height, weight and WC is less intrusive, quicker, more precise, less dependent on the skill of the measurer, and WC provides information on fat distribution (Section 6.2). Another type of measurement, BIA, has the added advantage of being able to differentiate fat mass from lean mass, as well as being quick and easy. Therefore, in the present study, height, weight, WC and BIA were used to measure fatness.

As mentioned above, physical measures of fatness were collected at the same time as the PDA questionnaire data. Height, weight, impedance and WC were measured by trained staff using standardised protocols. This reduces variation in measurement due to differences in measurement technique (measurement error). Height (±0.1 cm) was measured with a stadiometer at maximum inspiration (participants were asked to take a deep breath and hold it for a couple of seconds).

WC can be measured at several anatomical sites on the abdomen (100, 102, 432). Measurement at the narrowest waist can be complicated by the fact that there is no single narrowest point in some subjects (102). Taking one's WC midway between the lowest rib and the iliac crest is more time-consuming (requires locating and marking the two anatomical landmarks) (102). WC measurement immediately above the iliac crest is difficult, particularly in females (systematic measurement error; hard to stabilise tape on a sharply curved skin surface in females) (102). However, the umbilicus is easy to locate (432) and therefore was used as the anatomical site of measurement in the current study. WC (±0.1 cm) was measured with a standard, non-stretch tape and participants were asked to locate their "belly button" with a finger (432).

There are a variety of instruments available for BIA measurement (67). Drawbacks of several BIA machines are that they require careful placement of electrodes on anatomical landmarks (which introduces measurement error) and they require the subject to be in a supine position (67), and foot-to-foot BIA machines utilise an electric current that bypasses the arms and trunk (433, 434). In contrast, the Tanita BC-418 BIA device (Tanita Corp., Tokyo, Japan) does not require careful placement of electrodes on the skin, measures impedance in the standing position and utilises a foot-to-hand electrical pathway (91); therefore, this instrument was used to measure impedance. Impedance (±1 Ω) and body weight (±0.1 kg) were measured in light clothing (school uniform) and no socks or stockings.

BMI was calculated as body weight (kg)/height $(m)^2$. Although BMI z-scores take into account that BMI and its standard deviation varies with age and sex (435), they are problematic because there is difficulty in choosing appropriate reference populations and their cut-off points are arbitrary (11), and were thus not used as outcome variables in this thesis. FFM was derived from BIA prediction equations developed in Pacific Island, Maori, Asian and European adolescents from the validation study of this thesis (Section 7.3). Total fat mass (TFM) was calculated as weight-FFM and %BF was calculated as 100x(TFM)/weight.

A limitation of BMI, TFM and %BF as fatness measures is that they do not provide information on fat distribution, whereas waist girth measures do (Chapter 3). Two waist girth measures, waist:height ratio (WHTR) and conicity index (CI), act as good surrogates of fat distribution (Section 6.2) and were thus included as outcome variables. WHTR was calculated as WC (cm)/height (cm) and CI (400, 401) was calculated as:

$$\text{CI} = \text{Waist circumference (m)}/(0.109\sqrt{\text{weight (kg)/height (m)}}).$$

%AbFM was calculated from %AbFM prediction equations developed in Pacific Island, Maori, Asian and European adolescents from the validation study of this thesis (Section 7.4). These equations take into account that the relationships which WC and WHTR have with %AbFM are dependent on factors such as ethnicity (Section 7.4).

7.4 Statistical methods

In order to correct standard errors for any design effect that arose from clustered sampling, SUDAAN (version 10.0) was used for all analyses, unless otherwise stated. Statistical significance was set at $P<0.05$.

Boys and girls were combined in analyses because of the small numbers that would have otherwise resulted if analyses were carried out by gender. Demographic characteristics were generated by cross-tabulations and chi-square tests were used to examine significant differences between groups, adjusted for sex and age. All continuous variables were examined for normality.

Attempts to change weight have been shown to moderate relationships between lifestyle variables and fatness (221). That is, associations between lifestyle factors and BMI were found to be in expected directions among those not trying to change weight but in unexpected directions among those who were trying to lose or gain weight (221). This provides justification for restricting analysis to those not trying to change weight when examining lifestyle-fatness associations. Further justification is provided by considering that the moderating effects of weight-change attempts on lifestyle-fatness associations are plausible because they can influence reverse causation and systematic measurement error. Firstly, weight-loss practice can contribute to reverse causation because, for example, obese youth may be limiting their intake of soft drinks as a way of controlling their weight. It is important to minimise or eliminate this possibility because this thesis uses cross-sectional analyses for the OPIC study results. Secondly, weight-loss practice can create measurement error by changing lifestyle habits so that they no longer represent the typical lifestyle habits that contributed to the current weight, particularly if the changes occurred recently. For instance, if an individual consumed large quantities of soft drinks every day for many years, which contributed to weight gain, but consumption suddenly became low as a result of a recent attempt to reduce weight, the low consumption level would no longer represent the previous, long-term pattern of high consumption, thus making it difficult to establish the contribution of consumption to weight gain in the past. This measurement error is greater in overweight and obese students because analysis of the New Zealand OPIC dataset showed that overweight and obese students were more likely to be trying to lose weight than normal-weight students (221). Therefore, the measurement error is systematic. Restricting analysis to those who were not trying to change weight circumvents these problems: through exclusion of weight-change attempts, it reduces the possibility and influence of reverse causation and reduces systematic measurement error, and this increases internal validity (436). This

restriction may well reduce external validity (Section 9.3.2.1); however, as discussed by Rothman *et al* (436), the increase in internal validity (at the expense of sample representativeness) is important and justifies the constraint on the sample. Given all of this, it was hypothesised that it was most appropriate to restrict analysis to those who were not trying to change weight when examining lifestyle-fatness associations.

To verify this hypothesis, an interaction term consisting of the product of lifestyle and weight-change attempts (variable comprising the abovementioned "lose weight, "gain weight" and "not change weight" categories) was added to body composition prediction models, adjusted for sex, age, ethnicity, lifestyle factor and weight-change attempts. The interaction term was examined for significance to provide justification for restricting all subsequent analyses to those who were in the "not change weight" category. These associations were examined by multiple linear regression. All models were adjusted for sex and age. Models for country-specific analyses and for all ethnic groups combined were additionally adjusted for ethnicity. Several variables (described in Section 7.3) were added to models to reduce potential confounding and were subsequently removed from analyses if their inclusion in the models had minimal impact on effect sizes: 1) physical activity measures (after-school physical activity, lunch-time physical activity, active transportation, perception of neighbourhood safety at night), 2) SEIFA score (for Australian data) and household size (for data from each country) (added as covariates to account for variation in SES within schools), 3) fast food and snack food consumption variables (described in Section 7.3; additionally added to models as they potentially provide statistical adjustment for energy intake during beverage consumption and an unhealthy lifestyle) and, 4) season. For associations among Tongan adolescents, the island that the school was located on (either Tongatapu or Vava'u) was added as a covariate and removed from models if it had minimal influence on effect sizes. To determine whether weight status may influence physical activity level, physical activity-fatness models were statistically adjusted for *difficulty being physically active* or *fear of being teased* (questions described in Section 7.3) and resulting changes to physical activity regression coefficients were examined. The Wald F-test was used to assess whether associations were dose-dependent.

Using Review Manager version 5.0 (437), forest plots were constructed to illustrate the associations between the lifestyle and body composition variables. These showed the effect sizes and associated confidence intervals for each ethnic group. Overall estimates of the pooled relation were calculated using inverse-variance weighting and with the use of random-effects models. Random-effects models assume that not all of the associations are estimating the underlying common effect. The I^2 test was

used to assess heterogeneity (438). Sensitivity analyses were carried out by removing outlying associations from pooled analyses.

CHAPTER 8: OPIC STUDY RESULTS

8.1 Introduction

This chapter will describe the results of the OPIC study. First, the results for all participants will be examined (Section 8.2). This includes a description of their characteristics (Section 8.2.1) and associations of lifestyle variables with fatness (Section 8.2.2). As mentioned in Chapter 7, attempts to change weight have been shown to moderate relationships between lifestyle variables and fatness; so, results will be specifically provided for those who were in the "not change weight" category (Section 8.3) as well. This comprises results on participant characteristics (Section 8.3.1) and relationships between lifestyle variables and fatness (Section 8.3.2). For the latter (Section 8.3.2), the associations of TV watching, sugary drink consumption, breakfast consumption and physical activity with fatness among those not trying to change weight will be assessed in each ethnic group and country. As described in Chapter 7, fatness was measured by anthropometry and by body composition (DXA-measured) prediction equations developed in Chapter 6. The final section of this chapter, Section 8.4, will summarise the OPIC study findings.

8.2 All participants

Results for all participants will firstly focus on participant characteristics (Section 8.2.1). This will be followed by results on associations between lifestyle variables and fatness (Section 8.2.2).

8.2.1 Characteristics

This section will firstly describe ethnic differences in physical characteristics of all participants (Section 8.2.1.1). Ethnic differences in lifestyle variables will be examined afterwards (Section 8.2.1.2).

8.2.1.1 Physical characteristics

Table 8.1 shows the physical characteristics of all participants by ethnic group. There were large ethnic differences in BMI, %BF, TFM, WC, WHTR and %AbFM (all adjusted for sex and age). Pacific Islanders living in NZ had the highest BMI, followed by NZ Maori, Tongans, NZ Europeans, Indigenous Fijians, Australians, NZ Asians and then Fijian Indians. %BF and TFM varied significantly with ethnicity as well, with NZ Pacific Islanders having the highest levels too, followed by Maori. Of note, ethnic differences were not consistent across all three total-body fatness measures

– BMI, %BF and TFM. For instance, although Tongans and Indo-Fijians each had a higher BMI than Australians, they had less %BF and TFM.

Also in Table 8.1, marked differences in WC were observed, with NZ Pacific Islanders having the largest WC, followed by NZ Maori. Similarly, large ethnic differences in WHTR were seen; most notably, NZ Pacific Islanders had the largest WHTR, followed by NZ Maori. %AbFM was highest among NZ Pacific Islanders and NZ Maori as well. However, despite the fact that, compared to Australians, NZ Asians had the same WC, they had more %AbFM. Conversely, although Tongans had a larger WHTR than Australians, their %AbFM was not significantly different.

8.2.1.2 Lifestyle predictors of fatness

Lifestyle characteristics of all participants are described by ethnic group (Table 8.2) and by weight-control attempt (Table 8.3).

By ethnic group

Table 8.2 shows ethnic differences in lifestyle characteristics of all participants. TV watching (hours per day) was significantly associated with ethnicity ($P<0.0001$). Non-Australians, apart from Tongans, had a higher proportion who watched >2 hours of TV per day, compared to Australians.

Non-Australians had a higher fraction consuming >2 cans of soft drinks per day than Australians. Of note, NZ Pacific Islanders and Maori had the highest proportion of teenagers who consumed more than 2 cans of soft drinks per day. Fruit drink/cordial consumption varied with ethnicity as well ($P=0.0092$). Out of all ethnic groups, NZ Maori, Tongans and NZ Pacific Islanders had the highest proportion who consumed more than 2 glasses of fruit drink/cordial per day.

Frequency of breakfast consumption varied with ethnicity as well ($P<0.0001$). Out of all ethnic groups, NZ Pacific Islanders and Maori had the lowest proportion of adolescents eating breakfast on five out of the past five school days.

By weight-control attempt

Table 8.3 shows the sample sizes in lifestyle exposure groups stratified by weight-control attempt. These give the sample sizes in the lifestyle exposure groups for Figures 8.1-8.7, which will be described in the next section (Section 8.2.2). The number or proportion of participants trying to lose weight was similar to that of participants trying to change weight. In comparison, the number or

proportion of participants trying to gain weight was much lower. For example, the sample sizes for all three TV watching exposure groups combined was similar for the “lose weight” (n=5888) and “not change weight” (n=5650) categories, but notably smaller for the “gain weight” group (n=2413).

Table 8.1. Physical characteristics and ages of all participants by ethnic group*

	NZ Pacific (n=2474)	NZ Maori (n=823)	NZ Asian (n=316)	NZ European (n=488)	Indigenous Fijian (n=2967)	Fijian Indian (n=3668)	Tongan (n=2017)	Australian (n=2885)	*P-value*†
Age (years)	14.9±0.1[a]	14.8±0.1	15.3±0.2[a]	15.3±0.3[a]	15.8±0.3[a]	15.4±0.1[a]	15.0±0.2	14.6±0.1	<0.0001
Height (cm)	168.6±0.2[a]	168.0±0.2[a]	162.1±0.2[a]	166.4±0.2[a]	164.4±0.4[a]	160.6±0.3[a]	164.6±0.4[a]	165.6±0.2	<0.0001
Weight (kg)	77.6±0.4[a]	72.2±0.8[a]	57.7±0.4[a]	63.9±1.6	61.2±0.4	50.7±0.3[a]	64.9±0.6[a]	61.3±0.3	<0.0001
BMI (kg/m^2)	27.2±0.2[a]	25.4±0.3[a]	21.8±0.1[a]	22.9±0.6	22.6±0.1[a]	19.6±0.1[a]	23.8±0.2[a]	22.2±0.1	<0.0001
TFM (kg)	28.1±0.4[a]	24.3±0.7[a]	15.9±0.4[a]	19.1±1.2	14.2±0.2[a]	13.0±0.2[a]	17.0±0.4[a]	18.5±0.2	<0.0001
%BF	34.1±0.4[a]	31.3±0.5[a]	25.5±0.6[a]	27.9±1.0	22.5±0.3[a]	24.3±0.3[a]	25.1±0.5[a]	29.4±0.2	<0.0001
WC (cm)	89.6±0.6[a]	86.1±0.6[a]	78.3±0.3	80.9±1.4	76.2±0.3[a]	71.2±0.3[a]	79.7±0.5	78.6±0.3	<0.0001
WHTR	0.532±0.004[a]	0.512±0.004[a]	0.483±0.002[a]	0.486±0.008	0.464±0.002[a]	0.444±0.001[a]	0.484±0.003[a]	0.475±0.002	<0.0001
Conicity index	1.216±0.006[a]	1.208±0.006[a]	1.209±0.007[a]	1.203±0.007	1.151±0.003[a]	1.168±0.002[a]	1.172±0.005[a]	1.192±0.003	<0.0001
%AbFM	34.1±0.4[a]	34.0±0.4[a]	31.7±0.2[a]	29.9±1.1	24.8±0.3[a]	25.3±0.2[a]	27.5±0.4	28.3±0.2	<0.0001

BMI=Body mass index; %BF=Percent body fat; TFM=Total fat mass; WC=Waist circumference; WHTR=Waist circumference (cm)/height (cm); %AbFM=Percent abdominal fat mass; *Mean ± standard error. †ANCOVA, adjusting for sex (variable age) or for sex and age (all other variables); [a]Significantly different to Australian (P<0.05).

Table 8.2. Lifestyle characteristics of all participants by ethnic group

	NZ Pacific	NZ Maori	NZ Asian	NZ European	Indigenous Fijian	Fijian Indian	Tongan	Australian	*P-value*[†]
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	
Hours per day of TV watching									
<1 hour per day	820 (32.6)	225 (26.4)	85 (24.0)	189 (37.3)	905 (37.5)	734 (26.9)	1154 (56.4)	1215 (40.6)	<0.0001
1-2 hours per day	727 (28.9)	258 (30.3)	122 (34.5)	151 (29.8)	813 (33.7)	916 (33.6)	528 (25.8)	1010 (33.7)	
>2 hours per day	966 (38.4)	370 (43.4)	147 (41.5)	167 (32.9)	695 (28.8)	1076 (39.5)	365 (17.8)	771 (25.7)	
Soft drink consumption									
0 cans a day	408 (17.6)	183 (22.9)	114 (34.2)	208 (42.6)	594 (23.5)	710 (20.4)	657 (32.1)	1599 (53.3)	<0.0001
>0-2 cans a day	1512 (65.3)	482 (60.4)	187 (56.2)	245 (50.2)	1618 (63.9)	2294 (66.1)	1121 (54.7)	1272 (42.4)	
>2 cans a day	397 (17.1)	133 (16.7)	32 (9.6)	35 (7.2)	320 (12.6)	469 (13.5)	271 (13.2)	127 (4.2)	
Fruit drink/cordial consumption									
<1 glass a day	985 (43.0)	298 (37.6)	196 (60.7)	253 (52.9)	1288 (51.4)	2004 (59.9)	925 (45.2)	1686 (56.2)	0.0092
1-2 glasses a day	573 (25.0)	182 (23.0)	75 (23.2)	100 (20.9)	585 (23.3)	688 (20.6)	456 (22.3)	701 (23.4)	
>2 glasses a day	731 (31.9)	312 (39.4)	52 (16.1)	125 (26.2)	635 (25.3)	652 (19.5)	665 (32.5)	611 (20.4)	
Breakfast consumption*									
0-2 days	798 (35.4)	314 (40.8)	94 (30.5)	130 (27.9)	556 (22.0)	523 (15.1)	406 (19.8)	448 (14.9)	<0.0001
3-4 days	733 (32.5)	229 (29.7)	58 (18.8)	107 (23.0)	503 (19.9)	545 (15.8)	659 (32.2)	467 (15.6)	
5 days	724 (32.1)	227 (29.5)	156 (50.7)	229 (49.1)	1468 (58.1)	2391 (69.1)	985 (48.1)	2083 (69.5)	
Morning recess/interval physical activity									
Mostly played active games	797 (31.7)	236 (27.7)	76 (21.5)	86 (17.0)	437 (17.6)	491 (14.6)	533 (26.0)	767 (25.6)	0.0017
Mostly just sat down, stood or walked around	1716 (68.3)	617 (72.3)	278 (78.5)	421 (83.0)	2047 (82.4)	2865 (85.4)	1514 (74.0)	2229 (74.4)	
Lunch-time physical activity									
Mostly played active games	997 (39.7)	263 (30.8)	93 (26.3)	106 (20.9)	324 (13.0)	451 (13.4)	466 (22.8)	982 (32.8)	<0.0001
Mostly just sat down, stood or walked around	1516 (60.3)	590 (69.2)	261 (73.7)	401 (79.1)	2161 (87.0)	2905 (86.6)	1581 (77.2)	2014 (67.2)	
After-school physical activity*									
0-1 days	527 (21.0)	218 (25.6)	144 (40.7)	180 (35.5)	666 (26.8)	913 (27.2)	739 (36.1)	680 (22.7)	<0.0001
2-3 days	933 (37.1)	325 (38.1)	121 (34.2)	186 (36.7)	785 (31.6)	1208 (36.0)	660 (32.2)	1356 (45.3)	
4-5 days	1053 (41.9)	310 (36.3)	89 (25.1)	141 (27.8)	1034 (41.6)	1232 (36.7)	648 (31.7)	960 (32.0)	

*Days out of past 5 school days; [†]Chi-square test.

Table 8.3. Lifestyle characteristics of all participants by weight-control attempt

Lifestyle variable	Weight-control attempt			All (3 weight-control attempt groups combined)
	Lose weight	Gain weight	Not change weight	
	N (%)	N (%)	N (%)	N (%)
Hours per day of TV watching				
<1 hour per day	2284 (38.8)	712 (29.5)	2169 (38.4)	5165 (37.0)
1-2 hours per day	1791 (30.4)	815 (33.8)	1776 (31.4)	4382 (31.4)
>2 hours per day	1813 (30.8)	886 (36.7)	1705 (30.2)	4404 (31.6)
Soft drink consumption				
0 cans a day	1740 (30.2)	510 (20.7)	1885 (33.5)	4135 (29.8)
>0-2 cans a day	3419 (59.3)	1539 (62.3)	3095 (55.1)	8053 (58.1)
>2 cans a day	609 (10.6)	420 (17.0)	640 (11.4)	1669 (12.0)
Fruit drink/cordial consumption				
<1 glass a day	2899 (50.6)	1242 (50.7)	2851 (51.1)	6992 (50.8)
1-2 glasses a day	1322 (23.1)	546 (22.3)	1300 (23.3)	3168 (23.0)
>2 glasses a day	1506 (26.3)	664 (27.1)	1429 (25.6)	3599 (26.2)
Breakfast consumption*				
0-2 days	1569 (27.5)	458 (18.6)	1089 (19.6)	3116 (22.7)
3-4 days	1408 (24.7)	476 (19.3)	1225 (22.0)	3109 (22.7)
5 days	2724 (47.8)	1527 (62.1)	3247 (58.4)	7498 (54.6)
Morning recess/interval physical activity				
Mostly played active games	1253 (21.3)	556 (23.0)	1386 (24.5)	3195 (22.9)
Mostly just sat down, stood or walked around	4642 (78.7)	1865 (77.0)	4275 (75.5)	10782 (77.1)
Lunch-time physical activity				
Mostly played active games	1413 (24.0)	583 (24.1)	1474 (26.0)	3470 (24.8)
Mostly just sat down, stood or walked around	4483 (76.0)	1838 (75.9)	4187 (74.0)	10508 (75.2)
After-school physical activity*				
0-1 days	1516 (25.7)	618 (25.5)	1570 (27.7)	3704 (26.5)
2-3 days	2231 (37.8)	851 (35.2)	2101 (37.1)	5183 (37.1)
4-5 days	2149 (36.5)	952 (39.3)	1989 (35.1)	5090 (36.4)

*Days out of past 5 school days.

8.2.2 Associations of lifestyle variables with fatness

The relationships between lifestyle and body composition variables by weight-control attempt and among all participants are shown in Figures 8.1-8.7. TV watching had significantly positive associations with BMI (P=0.047), %BF (P=0.0077) and TFM (P=0.0031) among those not trying to change weight (Figure 8.1). In contrast, significant relationships were not observed in the other weight-control attempt categories ("lose weight" or "gain weight") or among all three categories combined (P-values ranging from 0.13 to 0.60). Further, for the BMI model, the interaction between weight-control attempt and TV watching was borderline significant (P=0.065).

Figure 8.2 shows the associations for soft drink consumption. Soft drink consumption had significantly positive relationships with BMI (P=0.0022), %BF (P=0.035) and TFM (P=0.0091) among those not trying to change weight. However, associations in other weight-control attempt groups and among all participants combined were non-significant. In fact, relationships among all participants and among those who were trying to lose weight were notably inverse – a striking contrast to the positive associations in the "not change weight" group. These findings are reflected in the fact that weight-control attempt significantly moderated the relationship between BMI (P=0.0075), %BF (P=0.010) and TFM (P=0.0067).

Fruit drink/cordial-fatness relationships are illustrated in Figure 8.3. Not one of these was statistically significant.

Figure 8.4 shows the associations for breakfast consumption. In each weight-control attempt group and among all participants, breakfast consumption had significantly inverse associations with BMI, %BF and TFM. However, the strength (slope) of relationships appeared to differ across groups. Of note, associations for the "not change weight" were weaker compared to among all participants combined. This is reflected in the findings of significant interactions between weight-control attempt and breakfast consumption for BMI (P=0.0001), %BF (P=0.020) and TFM (P<0.0001).

The relationships between morning recess/interval physical activity and body composition variables are illustrated in Figure 8.5. Morning recess/interval physical activity was significantly associated BMI among those not trying to change weight but not in the other weight-control groups. For %BF and TFM, not one significant relationship was observed.

Figure 8.6 shows the associations between lunch-time physical activity and body composition variables. Not one significant relationship was observed.

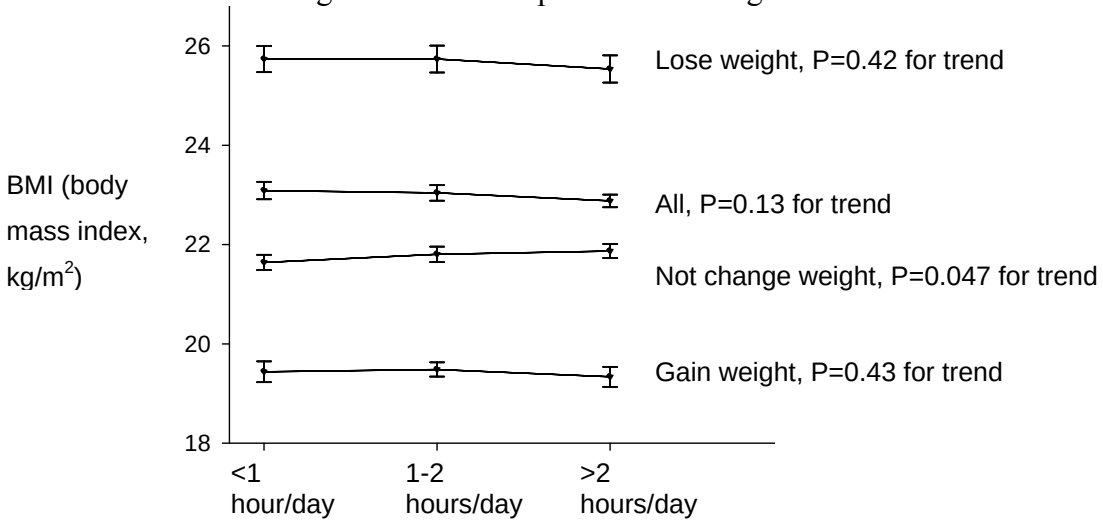
The relationships between after-school physical activity and body composition variables are shown in Figure 8.7. After-school physical activity had significantly positive relationships with all three body composition variables. However, the slopes of these associations seemed to differ across groups. That is, the positive relationships appeared steepest in the "not change weight" category; in comparison, the relationships were in the opposite direction among those trying to gain weight. This is reflected in the finding that weight-control attempt significantly moderated after-school physical activity-fatness associations (P-values ranging from 0.0002 to <0.0001).

Conclusion

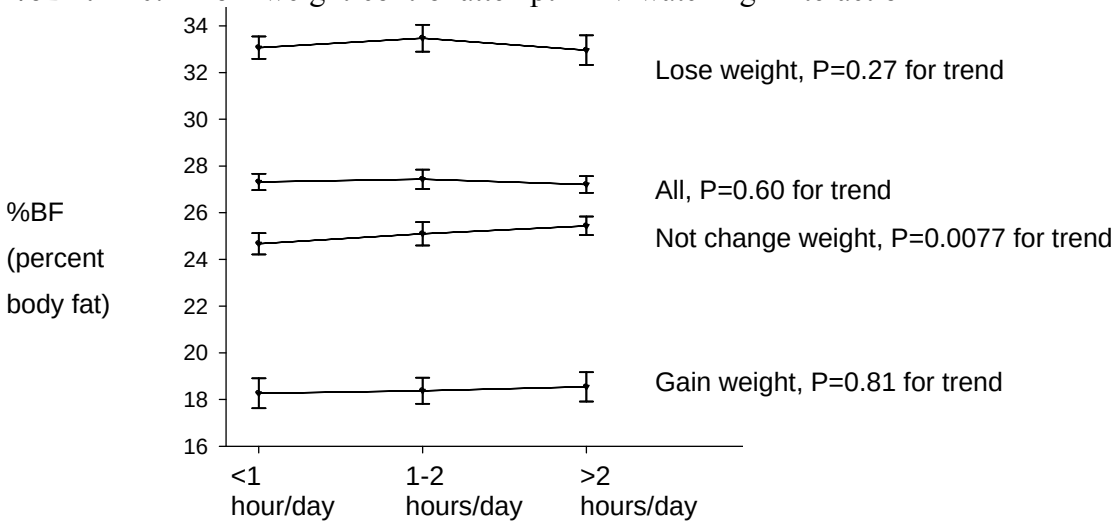
In conclusion, for most lifestyle variables, associations among those not trying to change weight differed from those in other weight-control groups and among all groups combined with respect to strength and/or direction. This is reflected in the observation that, in several cases, weight-control attempt significantly moderated relationships between lifestyle and body composition variables. These findings give justification for restricting analysis to those not trying to change weight – which, as discussed in Chapter 7, was hypothesised as most appropriate for examining the associations between lifestyle factors and fatness. Therefore, the next section will provide a detailed analysis of results for those who were not trying to change weight.

Figure 8.1. Relationships between TV watching and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

BMI: P=0.065 for "weight-control attempt x TV watching" interaction



%BF: P=0.22 for "weight-control attempt x TV watching" interaction



TFM: P=0.14 for "weight-control attempt x TV watching" interaction

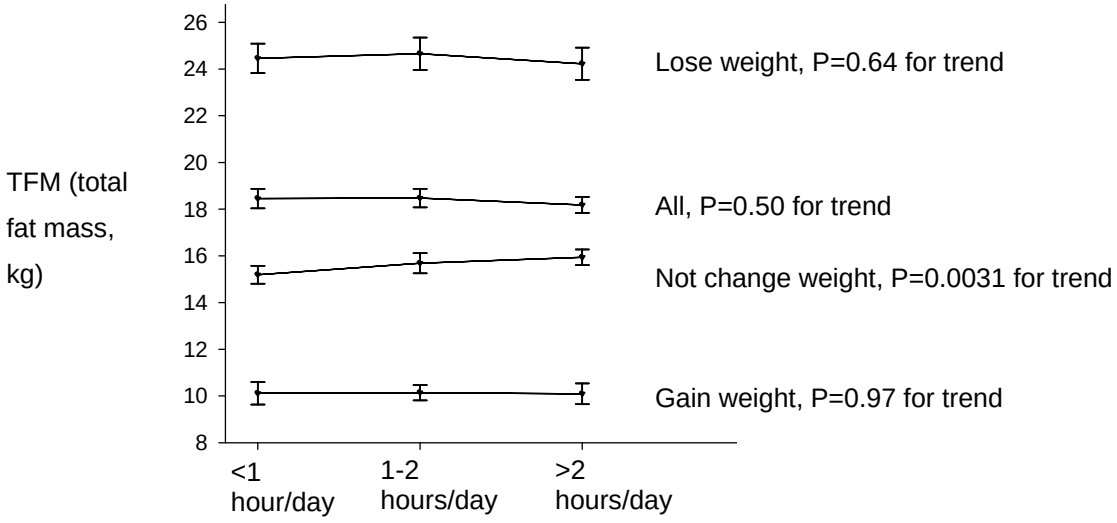
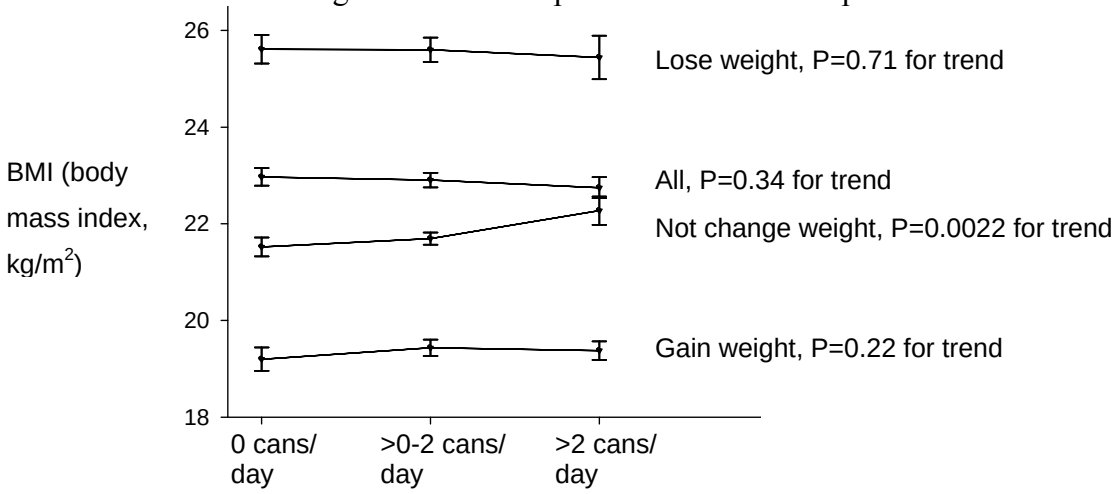
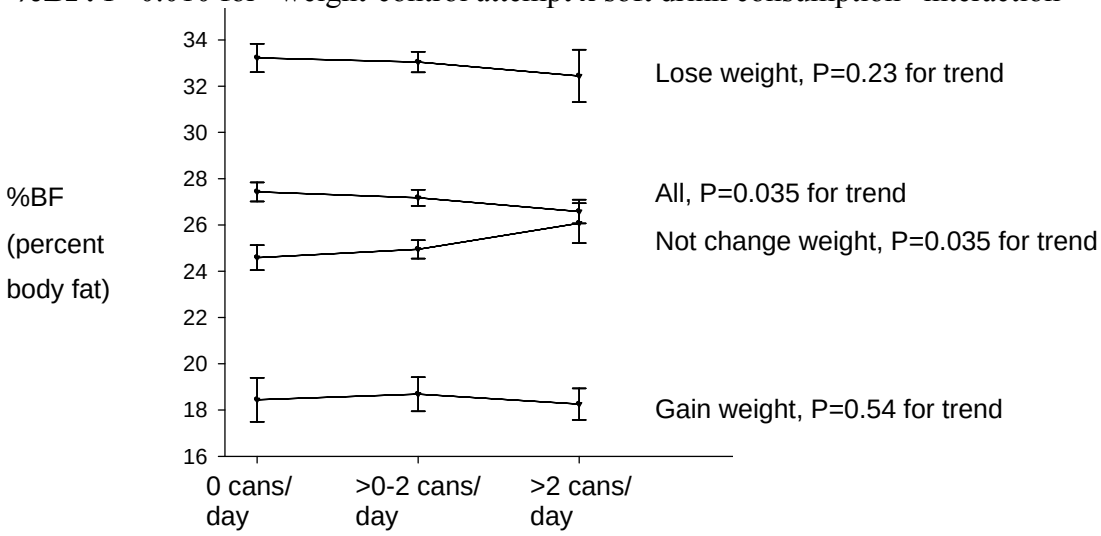


Figure 8.2. Relationships between soft drink consumption and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

BMI: P=0.0075 for "weight-control attempt x soft drink consumption" interaction



%BF: P=0.010 for "weight-control attempt x soft drink consumption" interaction



TFM: P=0.0067 for "weight-control attempt x soft drink consumption" interaction

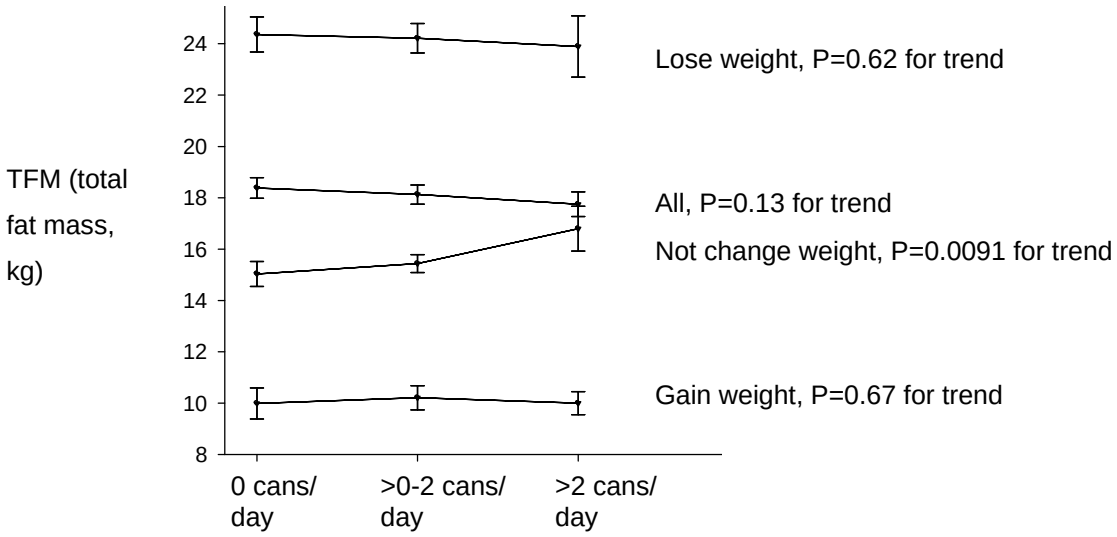
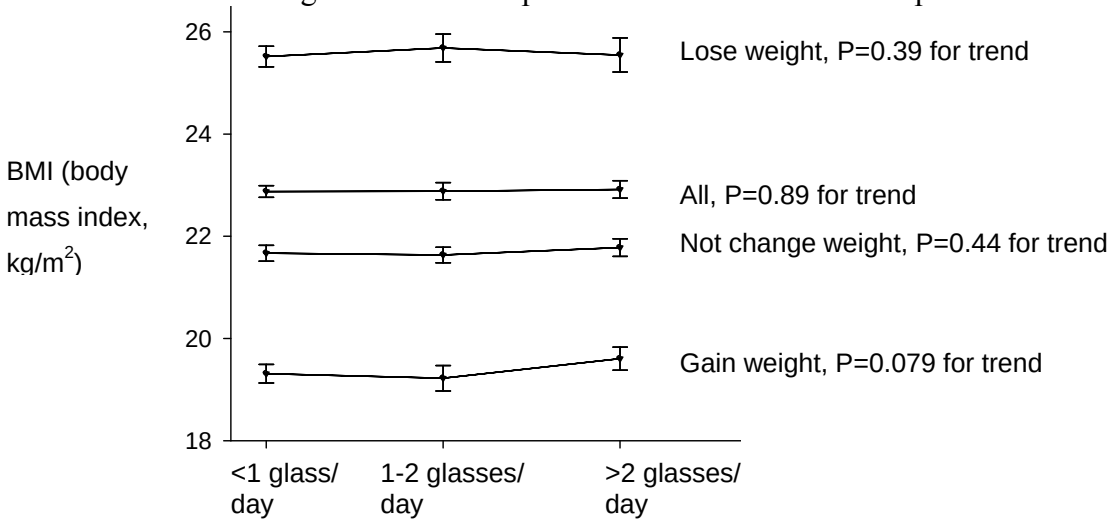
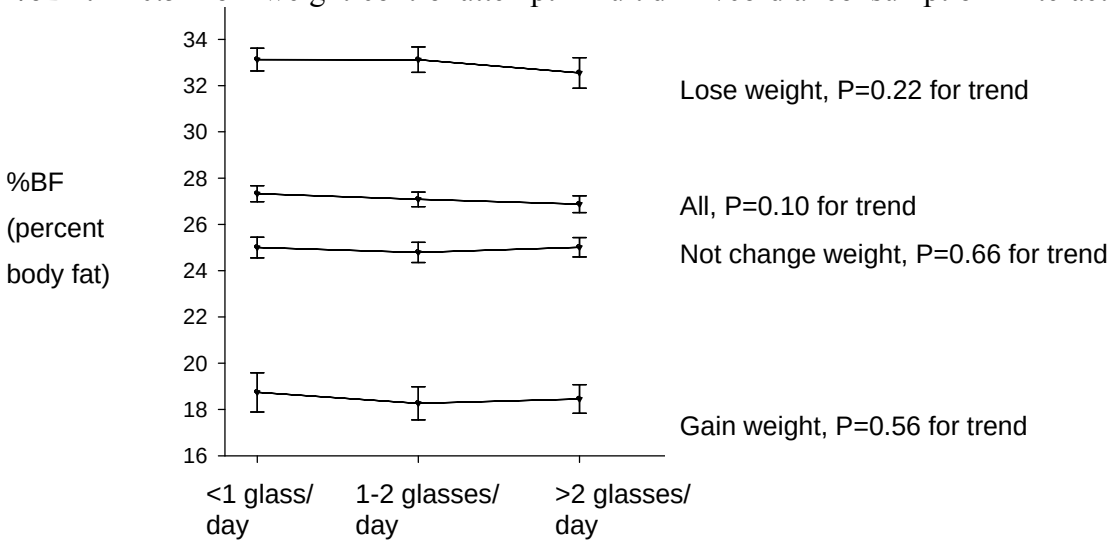


Figure 8.3. Relationships between fruit drink/cordial consumption and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

BMI: P=0.22 for "weight-control attempt x fruit drink/cordial consumption" interaction



%BF: P=0.54 for "weight-control attempt x fruit drink/cordial consumption" interaction



TFM: P=0.53 for "weight-control attempt x fruit drink/cordial consumption" interaction

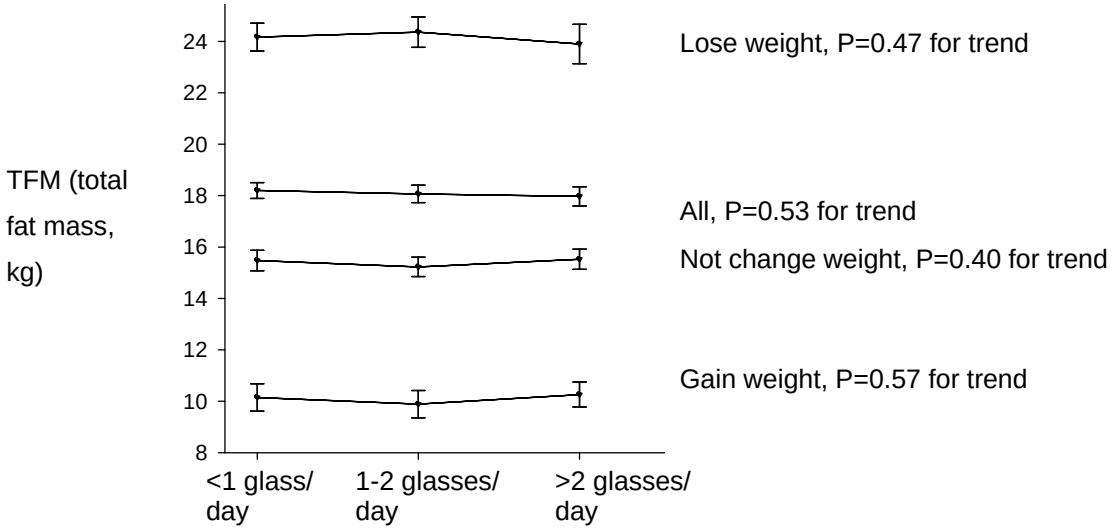
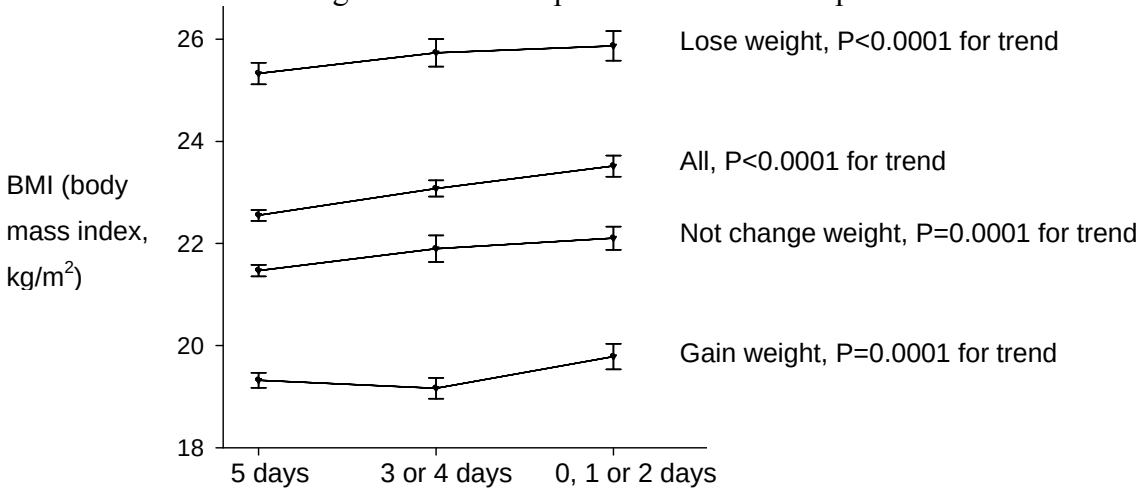
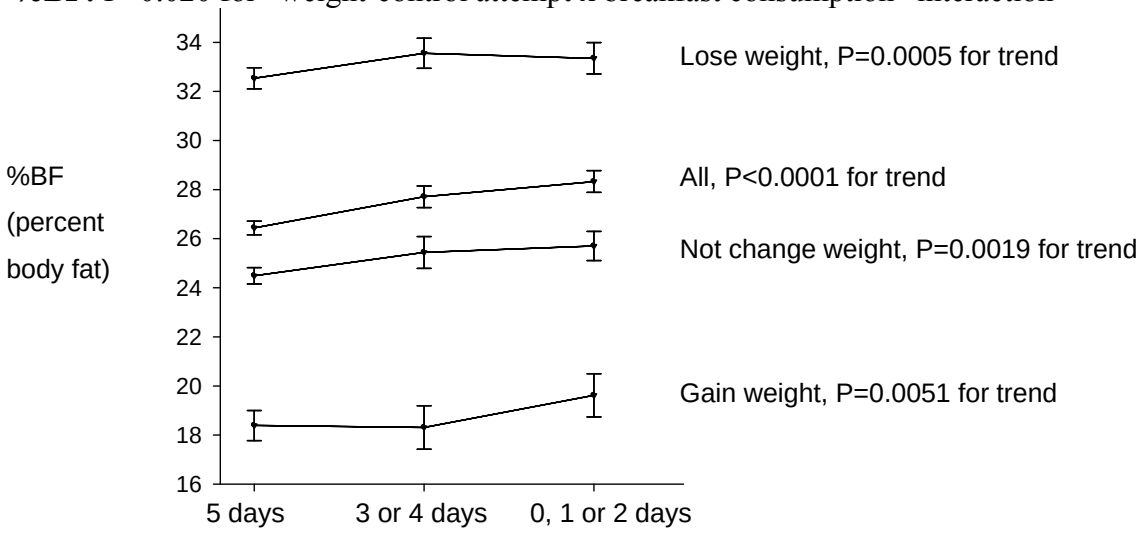


Figure 8.4. Relationships between breakfast consumption and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

BMI: P=0.0001 for "weight-control attempt x breakfast consumption" interaction



%BF: P=0.020 for "weight-control attempt x breakfast consumption" interaction



TFM: P<0.0001 for "weight-control attempt x breakfast consumption" interaction

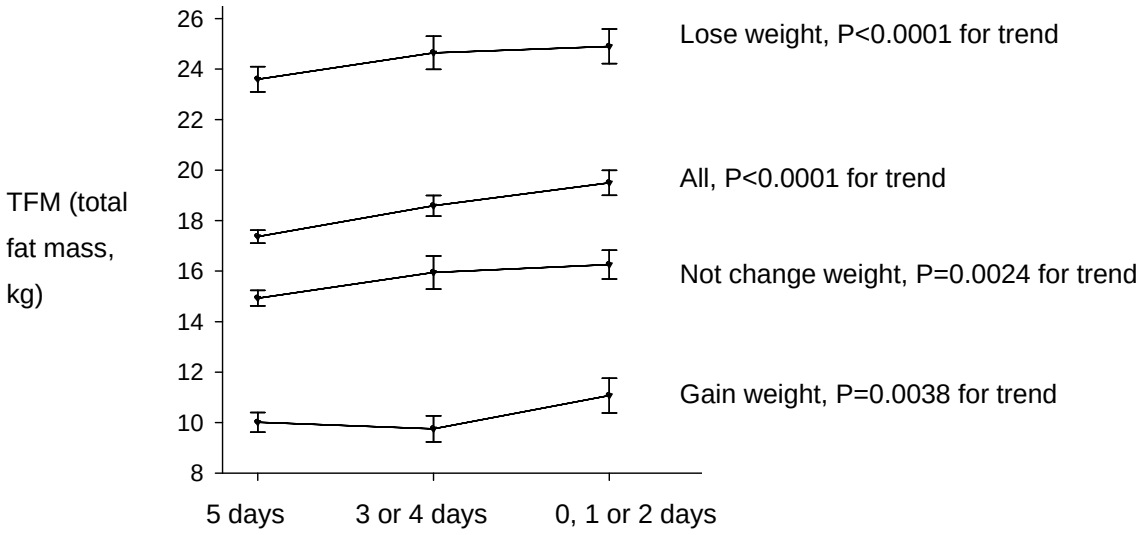
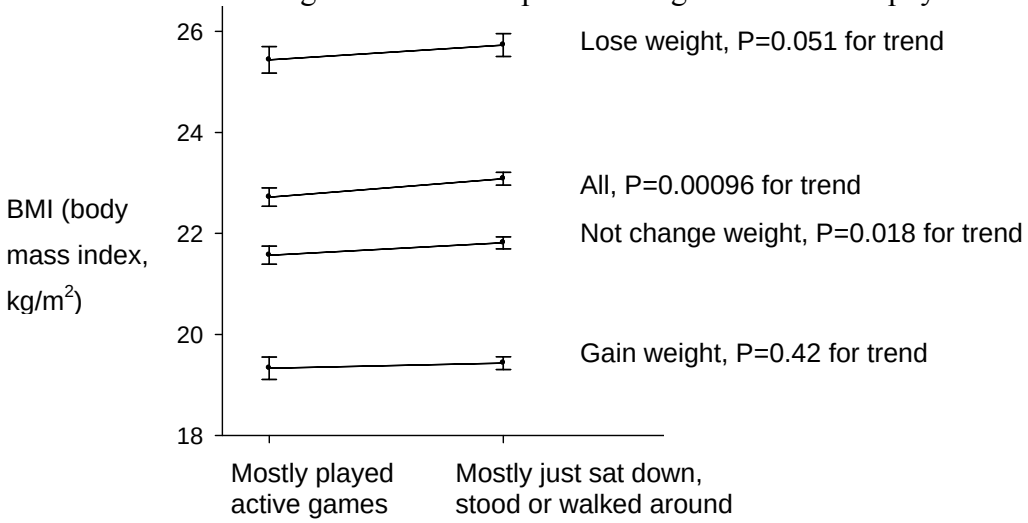
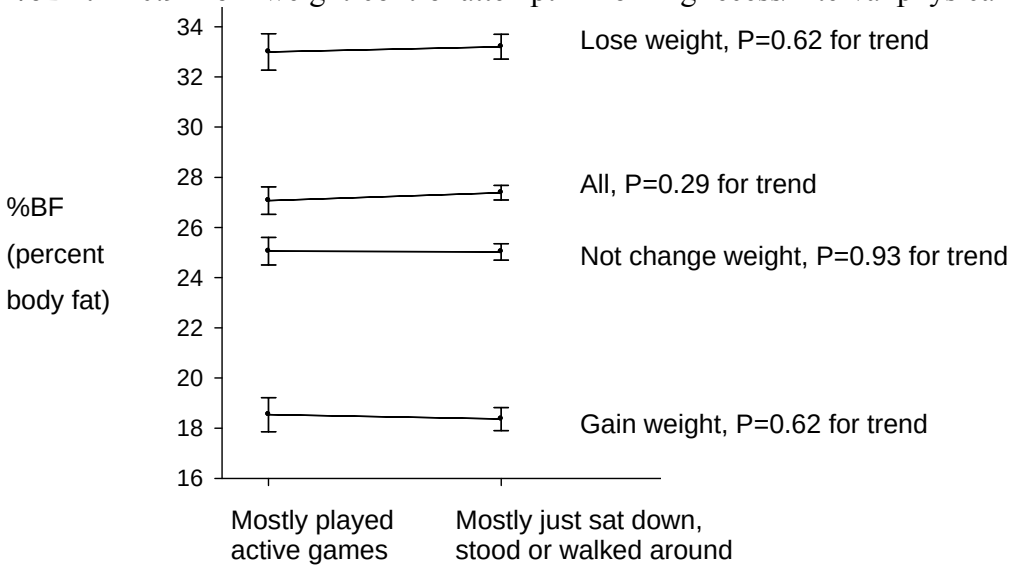


Figure 8.5. Relationships between morning recess/interval physical activity and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

BMI: P=0.98 for "weight-control attempt x morning recess/interval physical activity" interaction



%BF: P=0.91 for "weight-control attempt x morning recess/interval physical activity" interaction



TFM: P=0.41 for "weight-control attempt x morning recess/interval physical activity" interaction

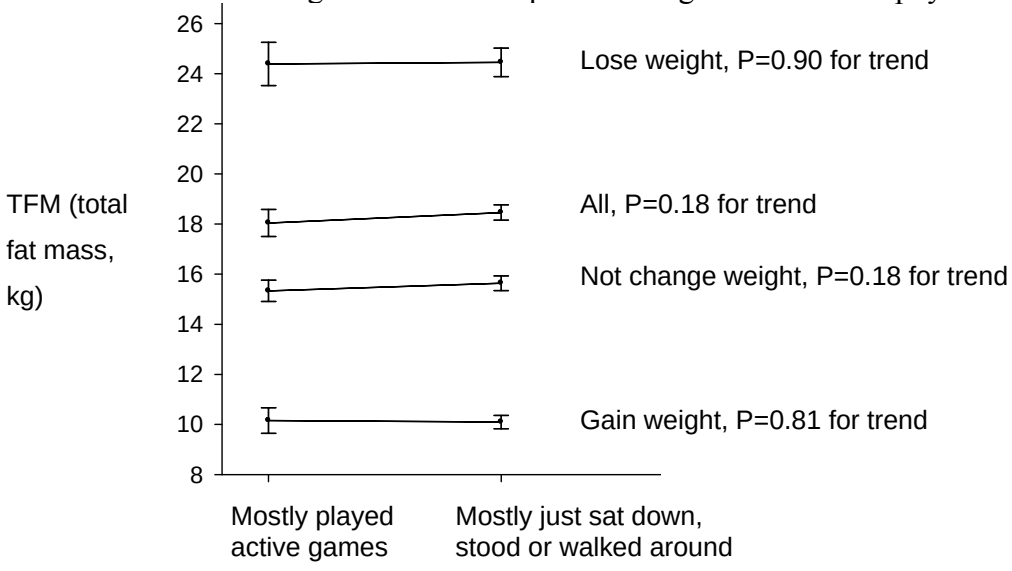
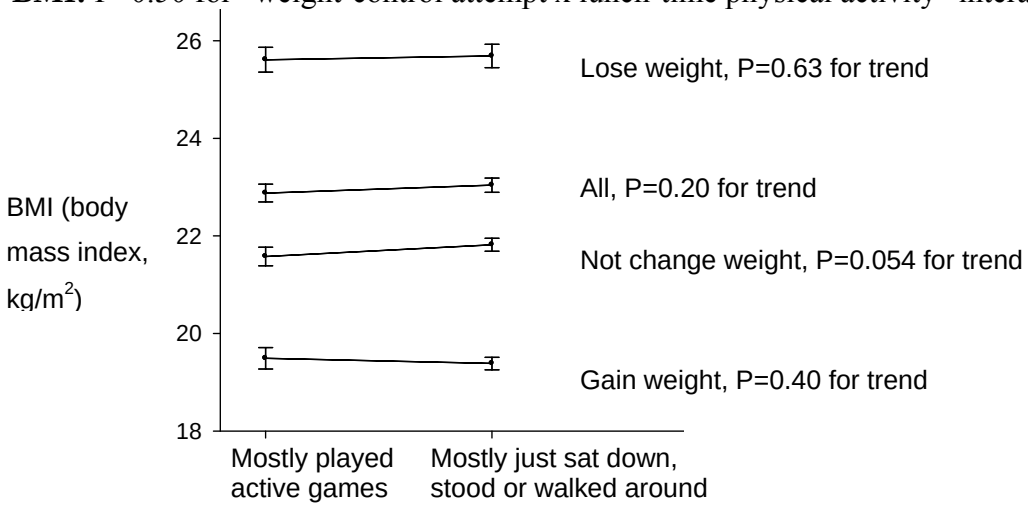
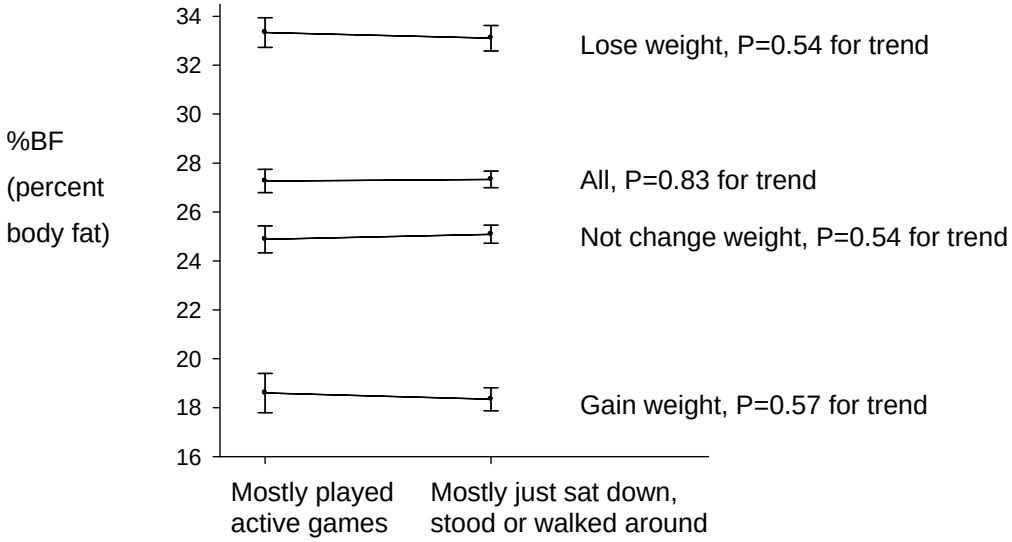


Figure 8.6. Relationships between lunch-time physical activity and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

BMI: P=0.50 for "weight-control attempt x lunch-time physical activity" interaction



%BF: P=0.16 for "weight-control attempt x lunch-time physical activity" interaction



TFM: P=0.014 for "weight-control attempt x lunch-time physical activity" interaction

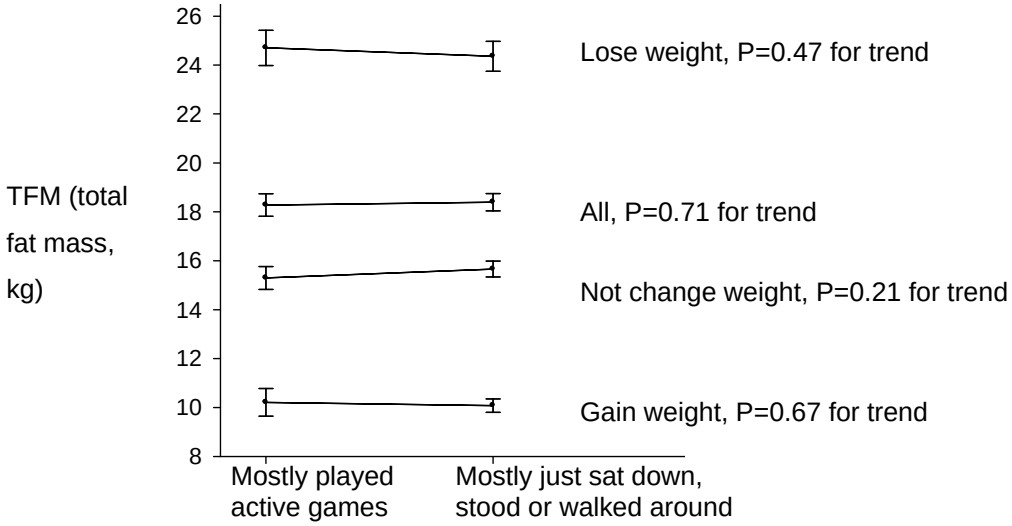
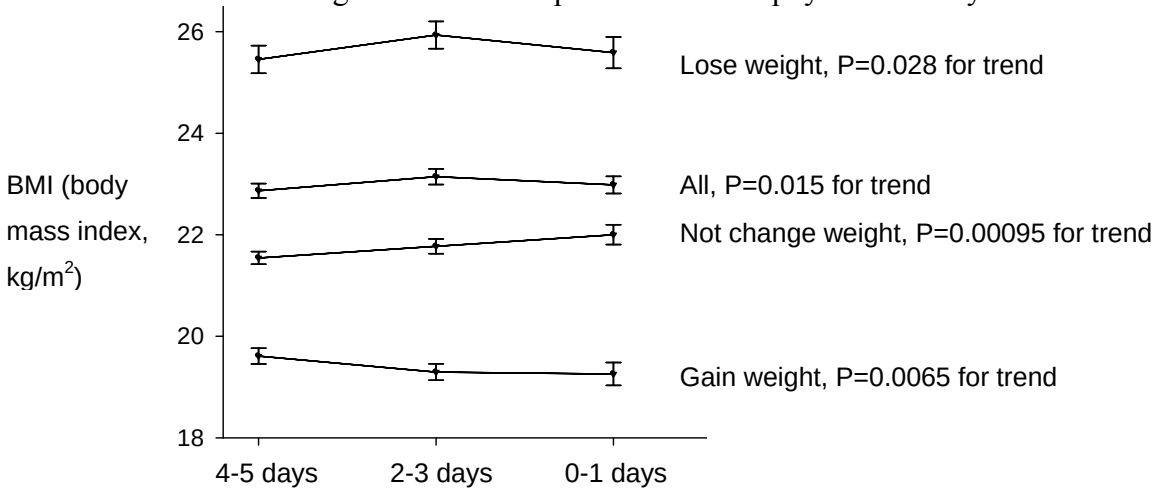
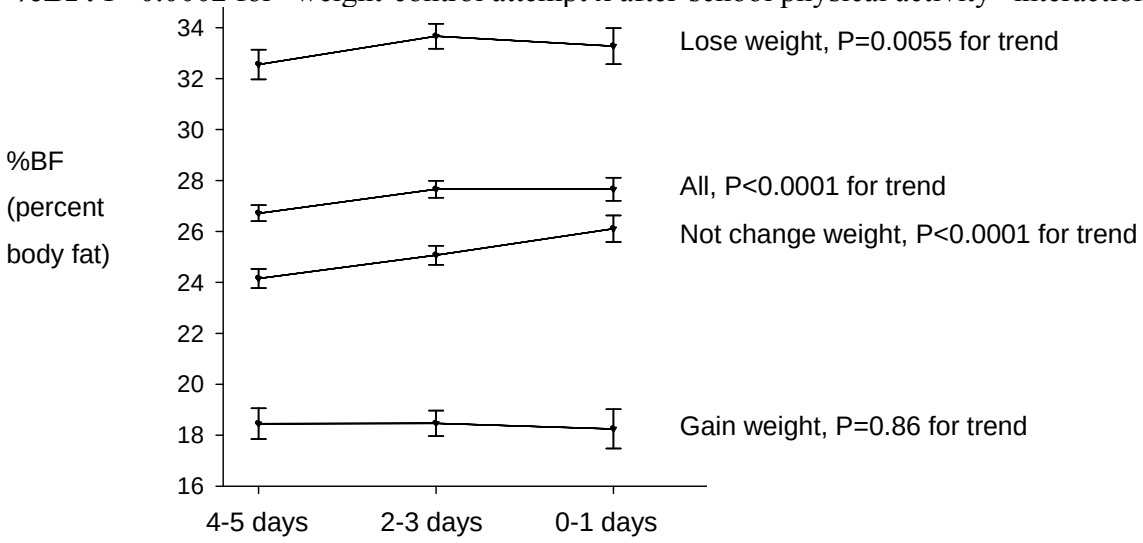


Figure 8.7. Relationships between after-school physical activity and body composition variables (adjusted for age, sex and ethnicity) by weight-control attempt and among all participants. Error bars indicate 95% confidence intervals

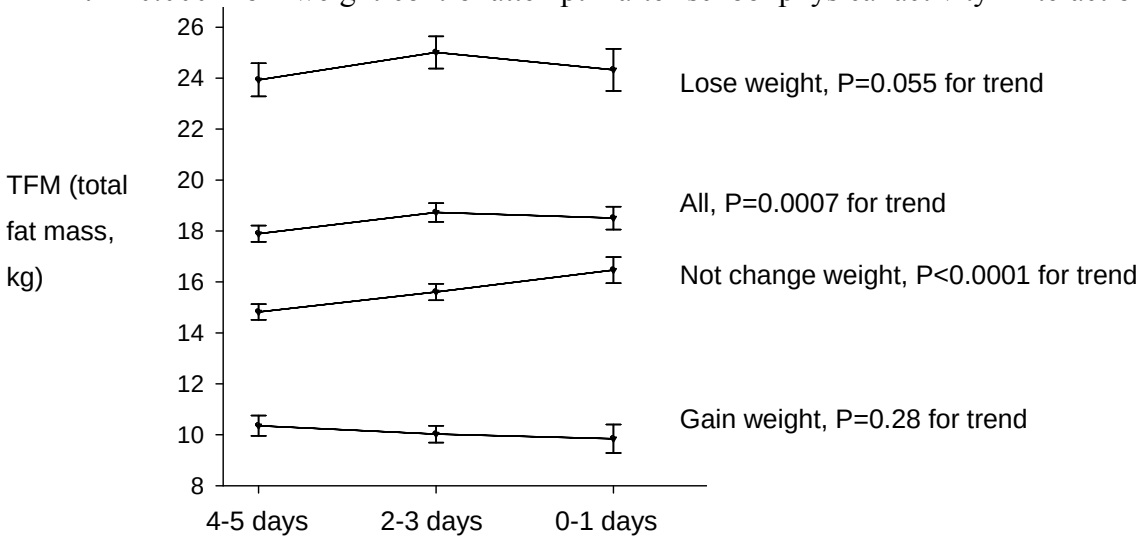
BMI: P<0.0001 for "weight-control attempt x after-school physical activity" interaction



%BF: P=0.0002 for "weight-control attempt x after-school physical activity" interaction



TFM: P<0.0001 for "weight-control attempt x after-school physical activity" interaction



8.3 Participants not trying to change weight

In this section, characteristics of participants who not trying to change weight will be described (Section 8.3.1). Following this, results on associations between lifestyle variables and fatness will be given (Section 8.3.2).

8.3.1 Characteristics

In this section, ethnic differences in physical characteristics of participants will be described first (Section 8.3.1.1). Following this, ethnic differences in lifestyle variables will be examined (Section 8.3.1.2).

8.3.1.1 Physical characteristics

Table 8.4 shows physical characteristics among participants who were not trying to change weight – that is, only those who were either trying to stay at their current weight or not doing anything about their weight. NZ Pacific Islanders had the highest BMI, followed by NZ Maori, Tongans, NZ Europeans, Indigenous Fijians, Australians, NZ Asians and then Fijian Indians. Large ethnic differences in %BF and TFM were evident, with NZ Pacific Islanders having the highest levels as well, followed by NZ Maori. However, while patterns across these total-body fatness measures were similar, they were not the same. For example, in spite of the fact that Tongans had a higher BMI than Australians, their mean TFM and %BF levels were lower.

Table 8.4 additionally shows that there were large ethnic differences in WC. NZ Pacific Islanders had the largest WC, followed by NZ Maori. Similarly, large ethnic differences in WHTR were observed, with NZ Pacific Islanders having the largest WHTR, followed by NZ Maori. %AbFM varied with ethnicity as well, with NZ Maori and NZ Pacific Islanders having the highest levels. Of note, though, %AbFM did not significantly differ between Australians and Tongans, yet the latter had a higher WHTR; and, strikingly, although NZ Asians had a smaller WC than Australians, their %AbFM was higher.

8.3.1.2 Lifestyle predictors of fatness

Table 8.5 illustrates ethnic differences in lifestyle characteristics among those who were not trying to change weight. TV watching was significantly associated with ethnicity (P=0.0003). Compared to Australians, the proportion of those who watched >2 hours of TV per day was higher in non-Australians, except in Tongans.

Sugary drink consumption significantly varied with ethnicity as well (P<0.0001 for soft drink consumption and P=0.0017 for fruit drink/cordial consumption). Compared to Australians, non-Australians had a greater proportion who consumed more than 2 cans of soft drink per day and most non-Australians had a greater percentage who consumed >2 glasses of fruit drink/cordial per day. Compared to other ethnic groups, NZ Pacific Islanders and Maori had a higher proportion of teenagers consuming more than 2 cans of soft drinks per day. Similarly, the proportion of participants consuming >2 glasses of fruit drinks/cordial per day was highest among NZ Pacific Islanders, Tongans and Maori.

Frequency of breakfast consumption varied with ethnicity as well (P<0.0001). The lowest proportion of adolescents who ate breakfast on five out of the past five school days was observed among NZ Pacific Islanders and Maori.

Table 8.4. Physical characteristics and ages of participants who were not trying to change weight by ethnic group*

	NZ Pacific (n=830)	NZ Maori (n=370)	NZ Asian (n=138)	NZ European (n=239)	Indigenous Fijian (n=611)	Fijian Indian (n=828)	Tongan (n=1018)	Australian (n=1667)	*P-value*[†]
Age (years)	15.0±0.1[a]	14.8±0.1	15.3±0.1[a]	15.4±0.2[a]	15.5±0.1[a]	15.4±0.1[a]	15.1±0.2[a]	14.6±0.1	<0.0001
Height (cm)	168.1±0.3[a]	168.5±0.4[a]	161.4±0.5[a]	165.7±0.2	164.7±0.6	160.6±0.4[a]	164.4±0.3[a]	165.6±0.2	<0.0001
Weight (kg)	71.5±0.4[a]	69.0±0.7[a]	53.2±1.0[a]	59.0±1.5	58.1±0.4	48.4±0.4[a]	60.8±0.4[a]	58.1±0.2	<0.0001
BMI (kg/m^2)	25.2±0.2[a]	24.2±0.2[a]	20.3±0.3[a]	21.4±0.5	21.3±0.1	18.7±0.1[a]	22.3±0.1[a]	21.0±0.1	<0.0001
TFM (kg)	22.9±0.3[a]	21.5±0.6[a]	11.9±0.8[a]	15.4±1.2	11.7±0.3[a]	10.8±0.2[a]	13.8±0.5[a]	15.8±0.2	<0.0001
%BF	30.3±0.2[a]	29.1±0.6[a]	21.4±1.0[a]	24.7±0.9[a]	20.0±0.5[a]	22.2±0.4[a]	22.2±0.6[a]	26.9±0.3	<0.0001
WC (cm)	84.7±0.6[a]	83.1±0.8[a]	74.5±0.2[a]	76.8±1.3	73.4±0.3[a]	69.0±0.3[a]	76.6±0.5	75.8±0.2	<0.0001
WHTR	0.504±0.004[a]	0.493±0.005[a]	0.461±0.002	0.463±0.008	0.446±0.003[a]	0.430±0.002[a]	0.466±0.004[a]	0.458±0.001	<0.0001
Conicity index	1.196±0.006[a]	1.195±0.008	1.196±0.010	1.185±0.007	1.140±0.005[a]	1.158±0.004[a]	1.164±0.006[a]	1.180±0.002	<0.0001
%AbFM	30.3±0.4[a]	31.3±0.5[a]	28.2±0.3[a]	26.3±1.1	22.0±0.4[a]	22.9±0.3[a]	24.5±0.4	25.5±0.2	<0.0001

BMI=Body mass index; %BF=Percent body fat; TFM=Total fat mass; WC=Waist circumference; WHTR=Waist circumference (cm)/height (cm); %AbFM=Percent abdominal fat mass; *Mean ± standard error. [†]ANCOVA, adjusting for sex (variable age) or for sex and age (all other variables); [a]Significantly different to Australian (P<0.05).

Table 8.5. Lifestyle characteristics of participants who were not trying to change weight by ethnic group

	NZ Pacific	NZ Maori	NZ Asian	NZ European	Indigenous Fijian	Fijian Indian	Tongan	Australian	*P-value*[†]
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	
TV watching									
<1 hour per day	252 (30.4)	97 (26.2)	26 (18.8)	88 (36.8)	224 (37.3)	205 (26.3)	579 (56.8)	698 (41.7)	0.0003
1-2 hours per day	241 (29.0)	120 (32.4)	51 (37.0)	66 (27.6)	196 (32.7)	272 (34.8)	268 (26.3)	562 (33.6)	
>2 hours per day	337 (40.6)	153 (41.4)	61 (44.2)	85 (35.6)	180 (30.0)	304 (38.9)	172 (16.9)	413 (24.7)	
Soft drink consumption									
0 cans a day	119 (15.5)	73 (21.0)	39 (29.1)	98 (42.1)	154 (25.2)	173 (20.8)	325 (31.9)	904 (54.0)	<0.0001
>0-2 cans a day	508 (66.0)	216 (62.1)	79 (59.0)	117 (50.2)	373 (61.1)	537 (64.5)	562 (55.2)	703 (42.0)	
>2 cans a day	143 (18.6)	59 (17.0)	16 (11.9)	18 (7.7)	84 (13.8)	122 (14.7)	132 (13.0)	66 (4.0)	
Fruit drink/cordial consumption									
<1 glass a day	337 (44.4)	132 (38.0)	78 (60.5)	114 (50.0)	292 (48.4)	488 (59.2)	463 (45.5)	947 (56.6)	0.0017
1-2 glasses a day	179 (23.6)	81 (23.3)	33 (25.6)	50 (21.9)	145 (24.1)	192 (23.3)	224 (22.0)	396 (23.7)	
>2 glasses a day	243 (32.0)	134 (38.6)	18 (14.0)	64 (28.1)	166 (27.5)	144 (17.5)	330 (32.5)	330 (19.7)	
Breakfast consumption*									
0-2 days	271 (36.1)	128 (38.1)	37 (30.3)	54 (24.6)	129 (21.1)	117 (14.1)	163 (16.0)	190 (11.4)	<0.0001
3-4 days	248 (33.1)	101 (30.1)	22 (18.0)	49 (22.3)	113 (18.5)	115 (13.9)	337 (33.1)	240 (14.4)	
5 days	231 (30.8)	107 (31.9)	63 (51.6)	117 (53.2)	370 (60.5)	597 (72.0)	519 (50.9)	1243 (74.3)	
Morning recess/interval physical activity									
Mostly played active games	271 (32.7)	99 (26.8)	28 (20.3)	38 (15.9)	108 (18.0)	103 (13.0)	281 (27.6)	458 (27.4)	0.0066
Mostly just sat down, stood or walked around	559 (67.4)	271 (73.2)	110 (79.7)	201 (84.1)	492 (82.0)	689 (87.0)	738 (72.4)	1215 (72.6)	
Lunch-time physical activity									
Mostly played active games	324 (39.0)	108 (29.2)	30 (21.7)	50 (20.9)	74 (12.3)	96 (12.1)	208 (20.4)	584 (34.9)	0.0001
Mostly just sat down, stood or walked around	506 (61.0)	262 (70.8)	108 (78.3)	189 (79.1)	526 (87.7)	696 (87.9)	811 (79.6)	1089 (65.1)	
After-school physical activity*									
0-1 days	199 (24.0)	101 (27.3)	63 (45.7)	97 (40.6)	165 (27.5)	222 (28.1)	362 (35.5)	361 (21.6)	0.0003
2-3 days	294 (35.4)	141 (38.1)	47 (34.1)	77 (32.2)	202 (33.7)	264 (33.4)	329 (32.3)	747 (44.7)	
4-5 days	337 (40.6)	128 (34.6)	28 (20.3)	65 (27.2)	233 (38.8)	305 (38.6)	328 (32.2)	565 (33.8)	

*Days out of past 5 school days; [†]Chi-square test.

8.3.2 Associations of lifestyle variables with fatness

The associations between lifestyle variables and body composition variables among participants who were not trying to change weight will be described in Sections 8.3.2.1-8.3.2.4 and are shown in Tables 8.6-8.12. In each table, the mean level of the body composition variable (reference group) is given in the left column, and columns to the right of this give the mean difference (compared to the reference group) with changes in the lifestyle variable. To visualise the overall effect and the consistency of relationships across ethnic groups, these lifestyle-fatness associations (adjusted for age and sex) are graphically represented in Figures 8.8-8.19 (forest plots). To compare the strength of lifestyle-fatness associations across body composition variables, the overall effects (for all ethnic groups combined) in Tables 8.6-8.12 were expressed as a percentage of mean values in the corresponding reference group category and the resulting values were illustrated in Figure 8.20.

Besides restricting analyses to those not trying to change weight, another approach to investigating lifestyle-fatness relationships in such participants is to carry out analyses among all participants but add a "weight-control attempt" variable and "weight-control attempt times lifestyle factor" interaction terms. Table 8.13 examines this. In this table, regression coefficients in bold represent effect sizes for those not trying to change weight (adjusted for age, sex and ethnicity). Thus, they correspond to the effect sizes for all ethnic groups combined illustrated in Tables 8.6-8.12. For example, compared to those who watched TV for <1 hour/day, those who watched for >2 hours/day had 0.22 kg/m^2 more BMI, according to Table 8.13, or 0.23 kg/m^2 more BMI, according to Table 8.6. All regression coefficients in bold from Table 8.13 will be compared with corresponding ones in Tables 8.6-8.12 to verify that similar results are obtained when different statistical approaches are used.

8.3.2.1 Television watching

Table 8.6 compares the mean BMI, %BF and TFM values among those watching TV for <1 hour per day (reference group), 1-2 hours per day and >2 hours per day. Among Tongans, watching TV for more than 2 hours/day was associated with a significantly higher BMI. In NZ Asians, BMI was significantly higher among those who watched TV for ≥1 hour per day; while, for NZ Europeans, there was a significant, dose-related effect of increasing BMI with increasing TV exposure (P<0.0001 for Wald F-test). Non-significant, positive associations between TV watching and BMI were observed in NZ Pacific and Australian groups. Among all ethnic groups combined, a significantly positive, dose-dependent trend was observed (P=0.047 for Wald F-test). Virtually

identical effect sizes were obtained from statistical models fitted with "weight-control attempt times lifestyle factor" interaction terms (0.16 and 0.23 kg/m^2 in Table 8.6; 0.16 and 0.22 kg/m^2 in Table 8.13). As reflected in Figure 8.9 (upper forest plot), the direction of the overall effect was positive and showed consistency across ethnic groups.

When %BF was used as a fatness measure instead of BMI, additional positive relationships were observed (Table 8.6 and middle forest plot of Figure 8.9). Hours per day of TV watching was positively associated with %BF among Australian, NZ Maori and NZ Pacific groups (non-significant associations). Among NZ Asians, those who watched TV for >2 hours per day had significantly and strikingly more %BF, compared to those who watched for <1 hour per day. In NZ European and Tongan groups, there was a significant, strong, dose-related effect of increasing %BF with increasing TV exposure (for Wald F-tests, P=0.0003 and 0.012, respectively). The overall (all ethnic groups together) estimates of the TV viewing-%BF association showed that %BF was significantly higher among those who watched TV for >2 hours per day than among those who watched for <1 hour per day (P=0.0019) and there was a dose-related effect of increasing %BF with increasing TV exposure (P=0.0077 for Wald F-test). The effect sizes for this trend are similar to those reported in Table 8.13 (0.43 and 0.77% in Table 8.6; 0.39 and 0.72% in Table 8.13). The consistency of the positive associations across ethnic groups and the significantly positive overall effect are evident in Figure 8.9 (middle forest plot).

Furthermore, in a dose-dependent manner, TV watching was positively associated with TFM among NZ Europeans and Tongans (for Wald F-tests, P<0.0001 and P=0.035, respectively). For these groups, and for NZ Asians, TFM was markedly higher when TV watching exceeded 2 hours per day (P=0.0003, 0.012 and 0.019 – for NZ Europeans, Tongans and NZ Asians, respectively). Positive TV watching-TFM trends were observed among Australian, Indigenous Fijian, NZ Maori and NZ Pacific groups as well, although these effects were not significant. Overall (all ethnic groups combined), TFM was significantly higher among those who watched TV for >2 hours per day than among those who watched for <1 hour per day (P=0.0007) and there was a positive, dose-related trend of increasing TFM with increasing TV viewing (P=0.0031 for Wald F-test). Similar effect sizes are evident in Table 8.13 (0.50 and 0.75 kg in Table 8.6; 0.45 and 0.63 kg in Table 8.13). As illustrated in Figure 8.9 (bottom forest plot), TV watching had a consistently positive relationship with TFM across ethnic groups and the overall effect was significantly positive.

Figure 8.20 compares the associations that TV watching had with BMI, %BF and TFM among all ethnic groups combined. As is evident from this figure, increases in TV exposure resulted in changes to body composition variables (as a proportion of their mean values in the reference category, *<1 hour per day*) that were greatest for TFM, followed by %BF and then BMI.

Conclusion

The direction of the overall association of TV watching with fatness was positive and showed consistency across ethnic groups. Among all ethnic groups combined (evident from both Tables 8.6 and 8.13), BMI, %BF and TFM were significantly higher among those who watched TV for >2 hours per day than among those who watched for <1 hour per day, and there were dose-related effects of increasing BMI, %BF and TFM with increasing TV exposure. Changes in body composition variables with respect to their mean values were greatest for TFM, followed by %BF and then BMI.

8.3.2.2 Sugary drink consumption

Soft drink consumption

Table 8.7 shows the relationship between soft drink consumption and body composition variables among those who were not trying to change weight. In a dose-dependent manner, BMI was positively and significantly associated with soft drink consumption (cans per day) among Tongans ($P<0.0001$ for Wald F-test). Positive soft drink consumption-BMI trends were observed for nearly all other ethnic groups as well, though the effects were significant for only NZ Maori and European. Among all ethnic groups combined, a positive, significant, dose-dependent association was observed ($P=0.0022$ for Wald F-test). Very similar effect sizes are evident in Table 8.13 (0.17 and 0.75 kg/m^2 in Table 8.7; 0.15 and 0.71 kg/m^2 in Table 8.13). As illustrated in the upper forest plots of Figures 8.10 and 8.11, soft drink consumption had consistently positive relationships with BMI across ethnic group and the overall effects were positive.

Further, soft drink consumption was positively, strongly and significantly associated with %BF in a dose-dependent manner ($P<0.0001$ for Wald F-test) among Tongans (Table 8.7). For NZ Maori, %BF was significantly and markedly higher among those who consumed more than 2 cans of soft drinks per day than among those who consumed fewer cans per day. Positive, non-significant soft drink-%BF relationships were found among other ethnic groups. Overall (all ethnic groups combined), %BF was significantly and notably higher among those who had >2 cans per day versus than among those who had 0 cans per day, and there was a dose-related trend of increasing %BF with

increasing soft drink consumption (P=0.035 for Wald F-test). These positive relationships were evident when illustrated graphically (middle forest plots of Figures 8.10 and 8.11). When Australians and Fijian Indians were removed from the pooled analysis, the I^2 for the middle forest plot in Figure 8.11 (>2 cans/day versus 0 cans/day) decreased by 16% (81% to 65%), while the overall effect for this association increased from 1.49% to 2.28% (95% CI: 0.61% to 3.95%). In addition, the overall (all ethnic groups combined) effect sizes (Table 8.7) are similar to those in Table 8.13 (0.36 and 1.49% in Table 8.7; 0.35 and 1.44% in Table 8.13).

Similarly, in a dose-dependent manner (P<0.0001 for Wald F-test), soft drink consumption was positively, strongly and significantly associated with TFM among Tongans (Table 8.7). Among NZ Maori and NZ Europeans, TFM was markedly and significantly higher among those who had more than 2 cans per day than among those who had 0 cans per day. In NZ Asians and Indigenous Fijians, TFM non-significantly though notably increased as soft drink consumption exceeded 2 cans per day. Among all ethnic groups combined, a strong, positive, dose-dependent association was observed (P=0.0091 for Wald F-test). The effect sizes for this trend are similar to those observed in Table 8.13 (0.40 and 1.76 kg in Table 8.7; 0.32 and 1.56 kg in Table 8.13). As illustrated in Figures 8.10-8.11 (bottom forest plots), soft drink consumption had a consistently positive relationship with TFM across ethnic groups and the overall effect was positive. When Australians and Fijian Indians were removed from the pooled analysis, the I^2 for the bottom forest plot in Figure 8.11 (>2 cans/day versus 0 cans/day) decreased by 28% (from 79% to 51%), while the overall effect for this association increased from 1.58 kg to 2.38 kg (95% CI: 1.05 kg to 3.71 kg).

A comparison of the associations that soft drink consumption had with BMI, %BF and TFM is shown in Figure 8.20. Among all ethnic groups combined, increases in soft drink consumption resulted in changes to body composition variables (expressed as a percentage of mean values in the reference group, *0 cans per day*) that were notably greatest for TFM, followed by %BF and then BMI.

Fruit drink/cordial consumption

Table 8.8 shows the relationship between fruit drink/cordial consumption and body composition variables. Fruit drink/cordial consumption was not significantly related to BMI, %BF and TFM across ethnic groups, and this is evident in Figures 8.12 and 8.13. Among all ethnic groups combined, there were no significant associations between consumption and body composition variables (Table 8.8). Effect sizes for these trends (-0.04 and 0.11 kg/m^2 for BMI, -0.21 and 0.01%

for %BF, and -0.25 and 0.05 kg for TFM) are very similar or identical to those shown in Table 8.13 (-0.03 and 0.12 kg/m^2 for BMI, -0.19 and 0.09% for %BF, and -0.25 and 0.04 kg for TFM). A comparison of the strength of associations (among all ethnic groups combined) across the three body composition variables is illustrated in Figure 8.20.

Conclusion

Across ethnic groups, soft drink consumption had a consistently positive relationship with fatness. In line with this pattern, among all ethnic groups combined, soft drink consumption had significant, positive, notable and dose-dependent associations with body composition variables. This trend was evident from Table 8.13, as well as from Table 8.7. Effect sizes in relation to mean values (in low-consumption reference category) were greatest for TFM, followed by %BF and then BMI. Overall (all ethnic groups together), fruit drink/cordial consumption was not significantly associated with fatness, which was observed from both Tables 8.8 and 8.13.

8.3.2.3 Breakfast consumption

The associations of frequency of breakfast consumption with BMI, %BF and TFM are illustrated in Table 8.9. Across all ethnic groups, having breakfast on fewer than 5 days was associated with a higher BMI (coefficients were positive), and these effects were significant for most ethnic groups. Among NZ Maori, BMI was notably higher when breakfast was consumed on fewer than 5 days. Having breakfast on fewer than 3 days was associated with higher BMI among NZ Asians, Fijian Indians and Australians. Breakfast consumption had a strong, significantly inverse, dose-dependent relationship with BMI in NZ Pacific youth (P=0.0001 for Wald F-test). Among all ethnic groups combined, breakfast consumption was significantly and inversely related to BMI in a dose-dependent manner (P=0.0001 for Wald F-test). Effect sizes for this trend are very similar to those evident in Table 8.13 (0.43 and 0.64 kg/m^2 in Table 8.9; 0.38 and 0.60 kg/m^2 in Table 8.13). As shown in Figures 8.14 and 8.15 (upper forest plots), inverse associations were notably consistent across ethnic groups and reflected in the overall effects.

Furthermore, across ethnic groups, %BF was higher (coefficients were positive) among those who consumed breakfast on fewer than 5 days, and these effects were significant among NZ Pacific Islanders, NZ Maori, NZ Europeans and Australians (Table 8.9). That is, among NZ Pacific and Australian groups, breakfast consumption was strongly associated with %BF in a dose-dependent manner (for Wald F-tests, P=0.020 and 0.0005, respectively), and %BF was markedly higher when breakfast was consumed on fewer than 5 days among NZ Maori and fewer than 3 days among NZ

Europeans. These associations were reflected in the overall (all ethnic groups combined) estimates, which indicated a strong, significantly inverse, dose-dependent breakfast consumption-%BF relationship (P=0.0019 for Wald F-test). Figures 8.14 and 8.15 (middle forest plots) show that this is clearly the case. Further, the effect sizes for all ethnic groups combined (Table 8.9: 0.95 and 1.21%) are nearly identical to those given in Table 8.13 (0.95 and 1.24%).

When TFM was the fatness measure, inverse relationships were evident across all ethnic groups as well, with associations reaching statistical significance among NZ Pacific, NZ Maori, NZ European and Australian groups (Table 8.9). For these relationships, there were strong, dose-dependent trends observed among NZ Pacific and Australian groups (for Wald F-tests, P=0.012 and 0.0016, respectively), and TFM was markedly higher when breakfast was consumed on fewer than 3 days among NZ Europeans and fewer than 5 days among NZ Maori. This is reflected in the fact that when all ethnic groups were combined, a strong, significantly inverse, dose-dependent association was observed (P=0.0024 for Wald F-test). These trends are obvious in the lower forest plots of Figures 8.14 and 8.15. In addition, the effect sizes for all ethnic groups combined (Table 8.9: 1.02 and 1.33 kg) are consistent with those given in Table 8.13 (0.82 and 1.11 kg).

Figure 8.20 compares the relationship that breakfast consumption had with BMI, %BF and TFM among all ethnic groups combined. As is evident from this figure, having breakfast on fewer than 5 days resulted in increases to the coefficients of body composition variables (as a fraction of their mean values in the reference group, *5 days*) that were greatest for TFM, followed by %BF and then BMI.

Conclusion

Across ethnic groups, the direction of the breakfast consumption-fatness relationship was consistently inverse. Among all ethnic groups combined, breakfast consumption had strong, significantly inverse, dose-dependent associations with body composition variables. In addition to being observed in Table 8.9, these trends were evident from Table 8.13. Effect sizes (size of coefficients in models) as a proportion of mean values (in high-consumption reference group) were greatest for TFM, followed by %BF and then BMI.

8.3.2.4 Physical activity

Morning recess/interval physical activity

Associations between morning recess/interval physical activity and body composition variables are shown in Table 8.10. Among all ethnic groups combined, while morning recess/interval physical activity was significantly associated was BMI, it was not significantly related to %BF and TFM. The effect sizes for these trends (0.25 kg/m^2 for BMI, -0.03% for %BF, and 0.31 kg for TFM) are very similar or nearly identical to those shown in Table 8.13 (0.24 kg/m^2 for BMI, -0.01% for %BF, and 0.38 kg for TFM). Figure 8.16 illustrates the pattern of associations across the different ethnic groups and a comparison of the strength of associations (among all ethnic groups combined) across the three body composition variables is shown in Figure 8.20.

Lunch-time physical activity

Table 8.11 shows associations between lunch-time physical activity and body composition variables. Lunch-time physical activity was not significantly associated with BMI, %BF and TFM among all ethnic groups combined. The magnitude of these relationships (0.24 kg/m^2 for BMI, 0.20% for %BF, and 0.36 kg for TFM) are similar or nearly identical to those illustrated in Table 8.13 (0.23 kg/m^2 for BMI, 0.22% for %BF, and 0.50 kg for TFM). The pattern of associations across ethnic groups is illustrated in Figure 8.17 and Figure 8.20 compares the strength of associations (among all ethnic groups combined) across the three body composition variables.

After-school physical activity

Relationships between after-school physical activity (days) and body composition variables are shown in Table 8.12. Engaging in after-school physical activity on fewer than 4 days was associated with a significantly higher BMI in NZ Pacific Islanders, Indigenous Fijians and Tongans. A similar trend was observed in other ethnic groups, though the effects were not significant. Among all ethnic groups combined, after-school physical activity was significantly and inversely related to BMI in a dose-dependent manner (P=0.0010 for Wald F-test). These patterns are evident in Figures 8.18 and 8.19 (upper forest plots). For all ethnic groups combined, nearly identical effect sizes are evident in Table 8.13 (0.23 and 0.46 kg/m^2 in Table 8.12; 0.23 and 0.43 kg/m^2 in Table 8.13).

When %BF was the response variable instead of BMI, significant and inverse associations were observed among other ethnic groups (Table 8.12). In a strong, dose-dependent manner, %BF increased with fewer days of after-school physical activity among NZ Pacific Islanders (P<0.0001 for Wald F-test). Among Australians, Tongans, Indigenous Fijians and NZ Asians, those that did

after-school physical activity on fewer than 2 days had significantly and notably more %BF than those who did it on at least 4 days. Similarly, out of NZ Europeans, those who engaged in activity on fewer than 4 days had significantly and markedly more %BF. Number of days of activity was inversely related with %BF among Fijian Indians as well, though this effect was not significant. The overall (all ethnic groups analysed together) estimates of the association revealed a significant, inverse, notable and dose-dependent relationship ($P<0.0001$ for Wald F-test). These trends are clear in the middle forest plots of Figures 8.18 and 8.19. In addition, very similar effect sizes are observed in Table 8.13 for all ethnic groups combined (0.92 and 1.96% in Table 8.12; 0.92 and 1.89% in Table 8.13).

Further, a significant, strong, dose-dependent, inverse association between days of activity and TFM was observed in NZ Pacific Islanders ($P<0.0001$ for Wald F-test) (Table 8.12). Among Australians, Indigenous Fijians and Tongans, TFM was significantly and notably higher among those who did activity on fewer than 2 days than among those who did it on ≥4 days. An inverse association was observed among NZ Europeans as well, with TFM being significantly and markedly higher among those who did activity on fewer than 4 days. These patterns are reflected in the finding of a significant, inverse, notable and dose-dependent relationship ($P<0.0001$ for Wald F-test) when all ethnic groups were combined. These trends are apparent in Figures 8.18 and 8.19 (lower forest plots). In addition, among all ethnic groups combined, very similar effect sizes are observed in Table 8.13 (0.78 and 1.64 kg in Table 8.12; 0.82 and 1.61 kg in Table 8.13).

Figure 8.20 compares the associations that after-school physical activity had with BMI, %BF and TFM among all ethnic groups combined. As is evident from this figure, decreases in days of after-school physical activity resulted in increases to mean values of body composition variables (as a percentage of their mean values in the reference category, *4-5 days*) that were greatest for TFM, followed by %BF and then BMI.

Conclusion

Among all ethnic groups combined, physical activity during lunch-time was not significantly associated with body composition variables, while morning recess/interval physical activity did not have significant relationships with %BF and TFM. In contrast, after-school physical activity consistently had an inverse association with body composition variables across ethnic groups. Among all ethnic groups combined, these relationships were significant, inverse, notable and dose-

dependent. As well as being observed in Tables 8.10-8.12, these trends were evident in Table 8.13. Overall associations were strongest for TFM, followed by %BF and then BMI.

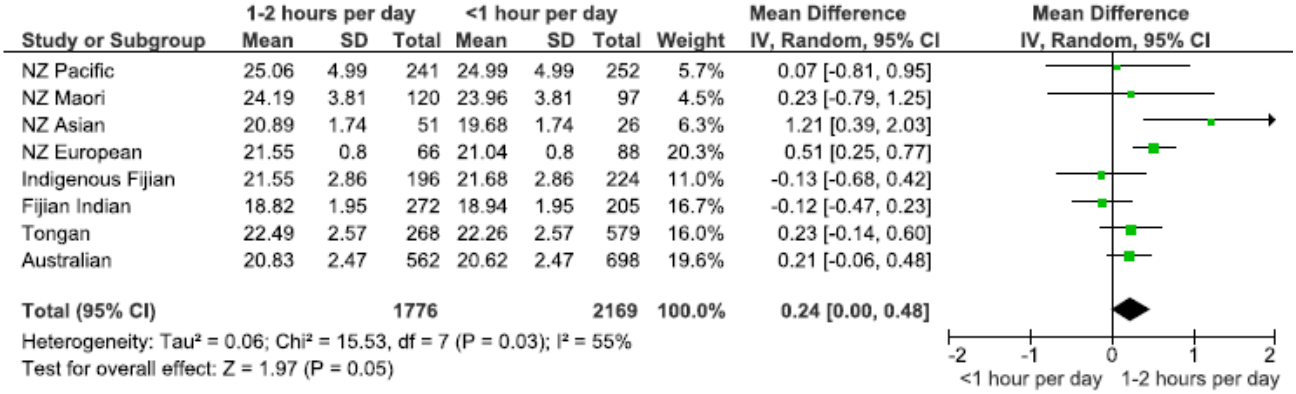
Table 8.6. Relationship between TV watching and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=830)	Maori (N=370)	Asian (N=138)	European (N=239)	All (N=1577)	Indigenous Fijian (N=600)	Fijian Indian (N=781)	All (N=1381)	Tongan (N=1019)	Australian (N=1673)	All (N=5650)
Mean BMI (SE)	<1 hour per day	24.99 (0.17)	23.96 (0.50)	19.68 (0.43)	21.04 (0.39)	23.68 (0.24)	21.68 (0.23)	18.94 (0.20)	20.13 (0.16)	22.26 (0.15)	20.62 (0.07)	21.64 (0.08)
Difference in BMI (SE)[2]	1-2 hours per day	0.06 (0.45)	0.23 (0.52)	1.21 (0.42)†	0.52 (0.13)‡	0.31 (0.26)	-0.13 (0.28)	-0.12 (0.18)	-0.13 (0.18)	0.23 (0.19)	0.21 (0.14)	0.16 (0.09)
	>2 hours per day	0.33 (0.29)	-0.00 (0.51)	0.69 (0.34)*	1.18 (0.29)‡	0.41 (0.26)	-0.00 (0.29)	-0.12 (0.21)	-0.08 (0.18)	0.43 (0.21)*	0.15 (0.10)	0.23 (0.09)*
Mean %BF (SE)	<1 hour per day	29.82 (0.52)	28.92 (1.44)	18.89 (1.35)	23.09 (1.15)	27.63 (0.52)	20.50 (0.62)	22.63 (0.60)	21.71 (0.43)	22.08 (0.60)	26.07 (0.36)	24.67 (0.23)
Difference in %BF (SE)[2]	1-2 hours per day	0.88 (1.22)	1.55 (1.47)	3.85 (2.51)	1.48 (1.68)	1.46 (0.77)	-0.40 (0.70)	-0.45 (0.65)	-0.45 (0.54)	0.54 (0.64)	0.11 (0.44)	0.43 (0.33)
	>2 hours per day	0.80 (0.73)	0.37 (1.59)	3.20 (1.32)*	3.43 (0.88)‡	1.28 (0.46)*	0.19 (0.67)	-0.63 (0.56)	-0.30 (0.44)	1.61 (0.53)†	0.37 (0.38)	0.77 (0.24)†
Mean TFM (SE)	<1 hour per day	22.35 (0.67)	20.95 (1.61)	9.98 (0.97)	14.26 (1.03)	19.69 (0.60)	12.27 (0.47)	11.27 (0.45)	11.72 (0.33)	13.69 (0.46)	14.76 (0.22)	15.19 (0.20)
Difference in TFM (SE)[2]	1-2 hours per day	0.64 (1.66)	1.33 (1.85)	3.33 (1.79)	1.25 (0.68)	1.21 (0.84)	-0.19 (0.58)	-0.20 (0.43)	-0.25 (0.43)	0.50 (0.48)	0.49 (0.36)	0.50 (0.28)
	>2 hours per day	0.98 (1.09)	0.36 (1.63)	2.28 (0.94)*	3.15 (0.83)‡	1.27 (0.54)	0.32 (0.61)	-0.31 (0.43)	-0.08 (0.34)	1.44 (0.55)*	0.47 (0.28)	0.75 (0.21)‡

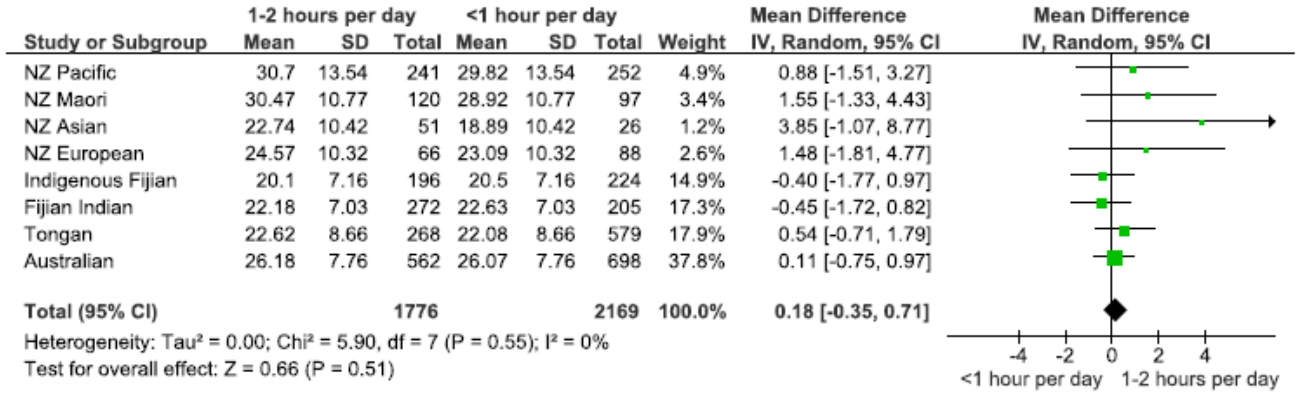
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "<1 hour per day" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.8. Forest plots of relationships between TV watching (<1 hour/day versus 1-2 hours/day) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

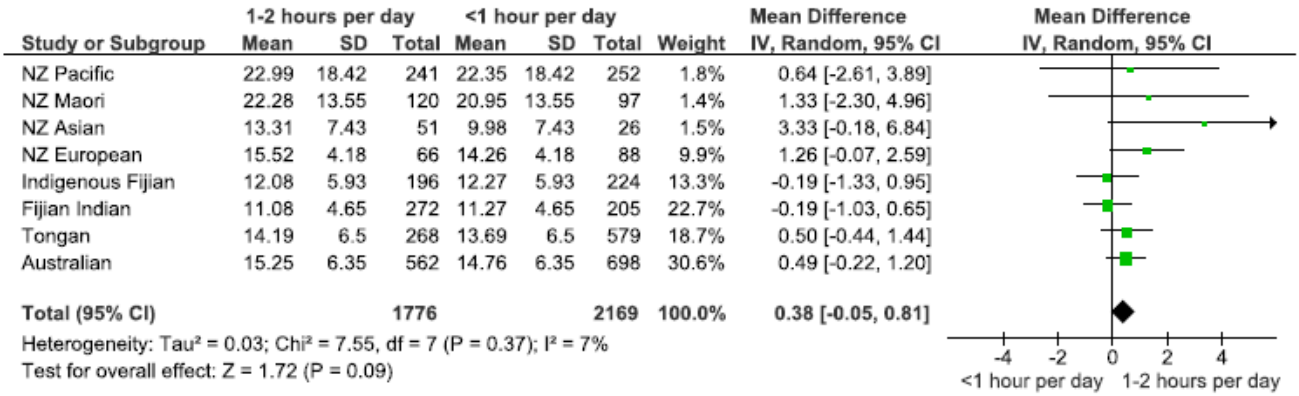
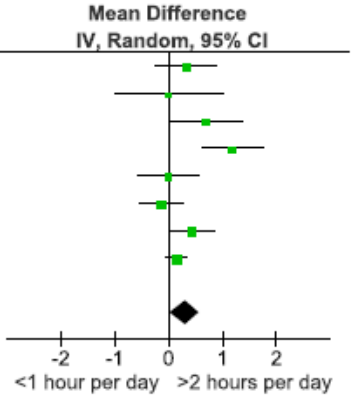


Figure 8.9. Forest plots of relationships between TV watching (<1 hour/day versus >2 hours/day) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI

Study or Subgroup	>2 hours per day Mean	SD	Total	<1 hour per day Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
NZ Pacific	25.32	3.48	337	24.99	3.48	252	11.4%	0.33 [-0.24, 0.90]
NZ Maori	23.96	3.93	153	23.96	3.93	97	5.5%	0.00 [-1.00, 1.00]
NZ Asian	20.37	1.45	61	19.68	1.45	26	9.6%	0.69 [0.02, 1.36]
NZ European	22.22	1.91	85	21.04	1.91	88	11.4%	1.18 [0.61, 1.75]
Indigenous Fijian	21.68	2.9	180	21.68	2.9	224	11.4%	0.00 [-0.57, 0.57]
Fijian Indian	18.81	2.32	304	18.94	2.32	205	15.0%	-0.13 [-0.54, 0.28]
Tongan	22.69	2.42	172	22.26	2.42	579	15.0%	0.43 [0.02, 0.84]
Australian	20.77	1.61	413	20.62	1.61	698	20.6%	0.15 [-0.05, 0.35]
Total (95% CI)			**1705**			**2169**	**100.0%**	**0.31 [0.04, 0.58]**

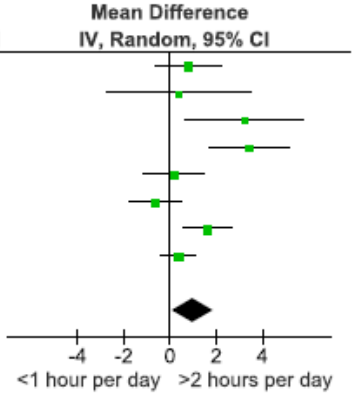
Heterogeneity: Tau² = 0.08; Chi² = 17.97, df = 7 (P = 0.01); I² = 61%
Test for overall effect: Z = 2.28 (P = 0.02)



%BF

Study or Subgroup	>2 hours per day Mean	SD	Total	<1 hour per day Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
NZ Pacific	30.62	8.77	337	29.82	8.77	252	13.1%	0.80 [-0.63, 2.23]
NZ Maori	29.29	12.25	153	28.92	12.25	97	5.7%	0.37 [-2.75, 3.49]
NZ Asian	22.1	5.64	61	18.89	5.64	26	7.4%	3.21 [0.62, 5.80]
NZ European	26.52	5.79	85	23.09	5.79	88	11.4%	3.43 [1.70, 5.16]
Indigenous Fijian	20.69	6.69	180	20.5	6.69	224	13.9%	0.19 [-1.12, 1.50]
Fijian Indian	22	6.2	304	22.63	6.2	205	15.3%	-0.63 [-1.73, 0.47]
Tongan	23.69	6.1	172	22.08	6.1	579	15.7%	1.61 [0.57, 2.65]
Australian	26.44	6.12	413	26.07	6.12	698	17.5%	0.37 [-0.37, 1.11]
Total (95% CI)			**1705**			**2169**	**100.0%**	**1.00 [0.12, 1.88]**

Heterogeneity: Tau² = 1.01; Chi² = 23.19, df = 7 (P = 0.002); I² = 70%
Test for overall effect: Z = 2.22 (P = 0.03)



TFM

Study or Subgroup	>2 hours per day Mean	SD	Total	<1 hour per day Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
NZ Pacific	23.32	13.09	337	22.35	13.09	252	7.9%	0.97 [-1.17, 3.11]
NZ Maori	21.32	12.56	153	20.95	12.56	97	4.4%	0.37 [-2.83, 3.57]
NZ Asian	12.25	4.01	61	9.98	4.01	26	9.5%	2.27 [0.43, 4.11]
NZ European	17.42	5.46	85	14.26	5.46	88	10.9%	3.16 [1.53, 4.79]
Indigenous Fijian	12.58	6.09	180	12.27	6.09	224	14.3%	0.31 [-0.88, 1.50]
Fijian Indian	10.96	4.76	304	11.27	4.76	205	17.5%	-0.31 [-1.15, 0.53]
Tongan	15.13	6.33	172	13.69	6.33	579	15.4%	1.44 [0.36, 2.52]
Australian	15.24	4.51	413	14.76	4.51	698	20.1%	0.48 [-0.07, 1.03]
Total (95% CI)			**1705**			**2169**	**100.0%**	**0.96 [0.22, 1.70]**

Heterogeneity: Tau² = 0.64; Chi² = 19.95, df = 7 (P = 0.006); I² = 65%
Test for overall effect: Z = 2.53 (P = 0.01)

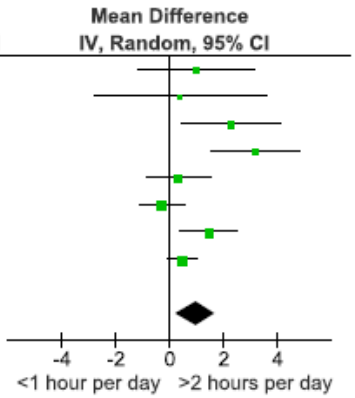


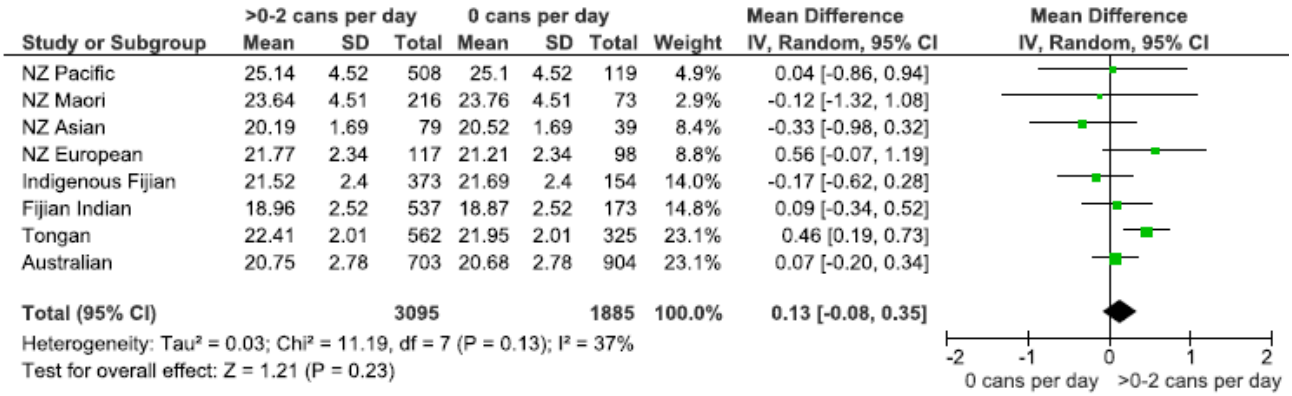
Table 8.7. Relationship between average daily soft drink consumption and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=770)	Maori (N=348)	Asian (N=134)	European (N=233)	All (N=1485)	Indigenous Fijian (N=611)	Fijian Indian (N=832)	All (N=1443)	Tongan (N=1019)	Australian (N=1673)	All (N=5620)
Mean BMI (SE)	0 cans per day	25.10 (0.40)	23.76 (0.63)	20.52 (0.40)	21.21 (0.27)	23.70 (0.35)	21.69 (0.26)	18.87 (0.20)	20.05 (0.15)	21.95 (0.14)	20.68 (0.10)	21.52 (0.10)
Difference in BMI (SE)[2]	>0-2 cans per day	0.04 (0.46)	-0.13 (0.61)	-0.33 (0.33)	0.56 (0.32)	0.11 (0.34)	-0.17 (0.23)	0.09 (0.22)	-0.01 (0.13)	0.46 (0.14)†	0.07 (0.14)	0.17 (0.10)
	>2 cans per day	0.12 (0.60)	2.03 (0.86)*	0.73 (0.63)	1.79 (0.69)*	0.88 (0.52)	0.52 (0.44)	-0.14 (0.38)	0.16 (0.29)	1.42 (0.25)‡	0.46 (0.23)*	0.75 (0.21)‡
Mean %BF (SE)	0 cans per day	31.10 (1.07)	28.94 (1.45)	21.96 (0.54)	24.22 (0.53)	28.48 (0.82)	20.78 (0.64)	22.29 (0.51)	21.61 (0.41)	21.16 (0.58)	26.30 (0.26)	24.59 (0.28)
Difference in %BF (SE)[2]	>0-2 cans per day	-0.88 (1.12)	-0.43 (1.28)	-0.59 (0.89)	0.27 (0.94)	-0.36 (0.85)	-0.70 (0.45)	0.23 (0.61)	-0.11 (0.38)	1.64 (0.47)‡	-0.22 (0.44)	0.36 (0.31)
	>2 cans per day	-0.81 (1.52)	5.38 (1.93)†	1.94 (1.23)	6.01 (3.38)	1.84 (1.48)	0.77 (1.04)	-0.50 (0.81)	0.13 (0.70)	3.32 (0.43)‡	-0.17 (0.70)	1.49 (0.56)*
Mean TFM (SE)	0 cans per day	22.91 (1.27)	20.67 (1.75)	12.34 (0.54)	15.11 (0.44)	20.07 (0.97)	12.53 (0.54)	11.19 (0.41)	11.69 (0.34)	12.89 (0.42)	15.05 (0.20)	15.03 (0.25)
Difference in TFM (SE)[2]	>0-2 cans per day	-0.04 (1.34)	-0.41 (1.69)	-0.49 (0.51)	0.56 (1.03)	0.06 (1.02)	-0.57 (0.44)	0.21 (0.47)	-0.04 (0.33)	1.38 (0.36)‡	-0.02 (0.31)	0.40 (0.28)
	>2 cans per day	0.32 (1.68)	6.23 (2.45)*	1.66 (0.94)	5.70 (2.83)*	2.58 (1.54)	1.11 (0.96)	-0.58 (0.70)	0.28 (0.63)	3.16 (0.45)‡	0.09 (0.64)	1.76 (0.55)†

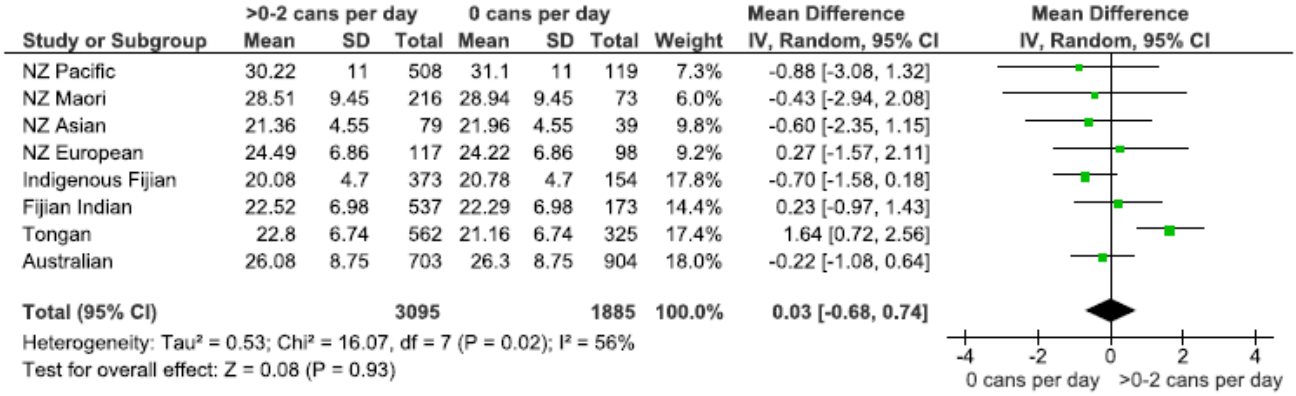
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "0 cans per day" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.10. Forest plots of relationships between soft drink consumption (0 cans/day versus >0-2 cans/day) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

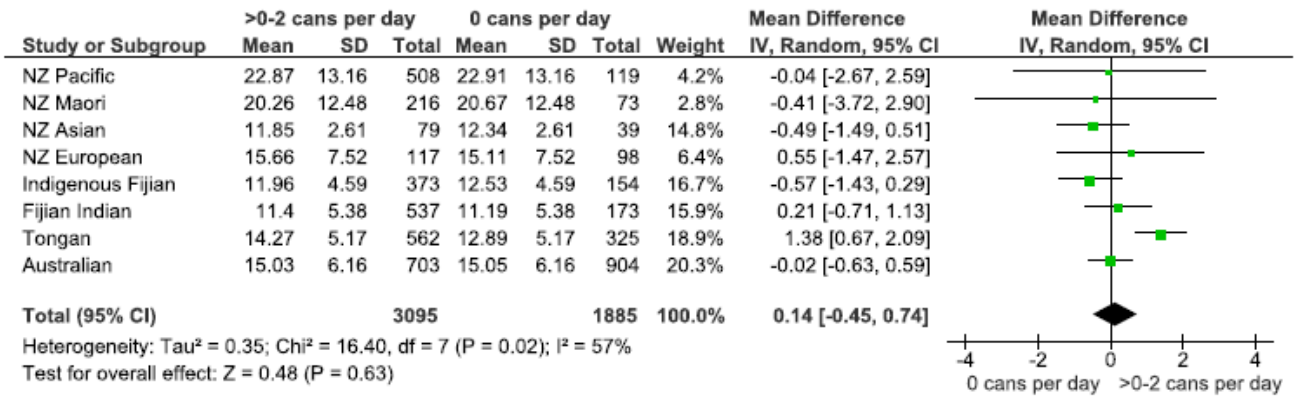
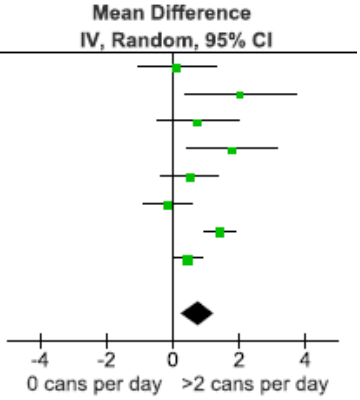


Figure 8.11. Forest plots of relationships between soft drink consumption (0 cans/day versus >2 cans/day) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI

Study or Subgroup	>2 cans per day Mean	SD	Total	0 cans per day Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
NZ Pacific	25.22	4.84	143	25.1	4.84	119	10.1%	0.12 [-1.06, 1.30]
NZ Maori	25.79	4.91	59	23.76	4.91	73	6.4%	2.03 [0.35, 3.71]
NZ Asian	21.26	2.12	16	20.52	2.12	39	9.5%	0.74 [-0.49, 1.97]
NZ European	23	2.69	18	21.21	2.69	98	8.6%	1.79 [0.44, 3.14]
Indigenous Fijian	22.21	3.24	84	21.69	3.24	154	13.5%	0.52 [-0.34, 1.38]
Fijian Indian	18.73	3.21	122	18.87	3.21	173	14.9%	-0.14 [-0.88, 0.60]
Tongan	23.37	2.42	132	21.95	2.42	325	18.3%	1.42 [0.93, 1.91]
Australian	21.15	1.8	66	20.68	1.8	904	18.8%	0.47 [0.02, 0.92]
Total (95% CI)			**640**			**1885**	**100.0%**	**0.76 [0.26, 1.27]**

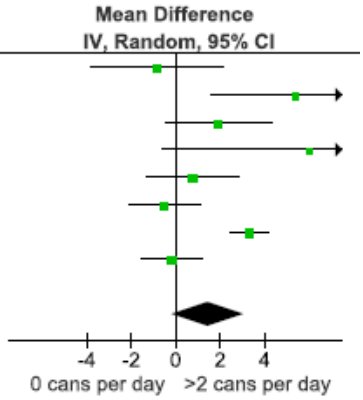
Heterogeneity: Tau² = 0.30; Chi² = 20.05, df = 7 (P = 0.005); I² = 65%
Test for overall effect: Z = 2.95 (P = 0.003)



%BF

Study or Subgroup	>2 cans per day Mean	SD	Total	0 cans per day Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
NZ Pacific	30.29	12.25	143	31.1	12.25	119	11.2%	-0.81 [-3.79, 2.17]
NZ Maori	34.32	11.02	59	28.94	11.02	73	9.1%	5.38 [1.60, 9.16]
NZ Asian	23.89	4.14	16	21.96	4.14	39	12.9%	1.93 [-0.48, 4.34]
NZ European	30.23	13.18	18	24.22	13.18	98	4.5%	6.01 [-0.61, 12.63]
Indigenous Fijian	21.55	7.67	84	20.78	7.67	154	14.0%	0.77 [-1.27, 2.81]
Fijian Indian	21.79	6.85	122	22.29	6.85	173	15.3%	-0.50 [-2.09, 1.09]
Tongan	24.49	4.17	132	21.16	4.17	325	17.1%	3.33 [2.49, 4.17]
Australian	26.13	5.49	66	26.3	5.49	904	15.9%	-0.17 [-1.54, 1.20]
Total (95% CI)			**640**			**1885**	**100.0%**	**1.49 [-0.13, 3.11]**

Heterogeneity: Tau² = 3.79; Chi² = 37.56, df = 7 (P < 0.00001); I² = 81%
Test for overall effect: Z = 1.80 (P = 0.07)



TFM

Study or Subgroup	>2 cans per day Mean	SD	Total	0 cans per day Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
NZ Pacific	23.23	13.54	143	22.91	13.54	119	9.6%	0.32 [-2.97, 3.61]
NZ Maori	26.9	13.99	59	20.67	13.99	73	6.2%	6.23 [1.43, 11.03]
NZ Asian	14	3.17	16	12.34	3.17	39	14.5%	1.66 [-0.18, 3.50]
NZ European	20.81	11.04	18	15.11	11.04	98	5.0%	5.70 [0.15, 11.25]
Indigenous Fijian	13.64	7.08	84	12.53	7.08	154	14.3%	1.11 [-0.77, 2.99]
Fijian Indian	10.61	5.92	122	11.19	5.92	173	16.2%	-0.58 [-1.95, 0.79]
Tongan	16.05	4.36	132	12.89	4.36	325	17.7%	3.16 [2.28, 4.04]
Australian	15.14	5.02	66	15.05	5.02	904	16.6%	0.09 [-1.16, 1.34]
Total (95% CI)			**640**			**1885**	**100.0%**	**1.58 [0.13, 3.03]**

Heterogeneity: Tau² = 2.90; Chi² = 33.80, df = 7 (P < 0.0001); I² = 79%
Test for overall effect: Z = 2.13 (P = 0.03)

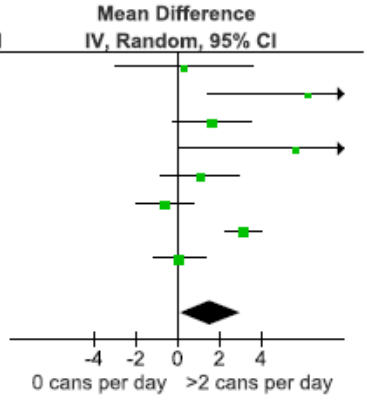


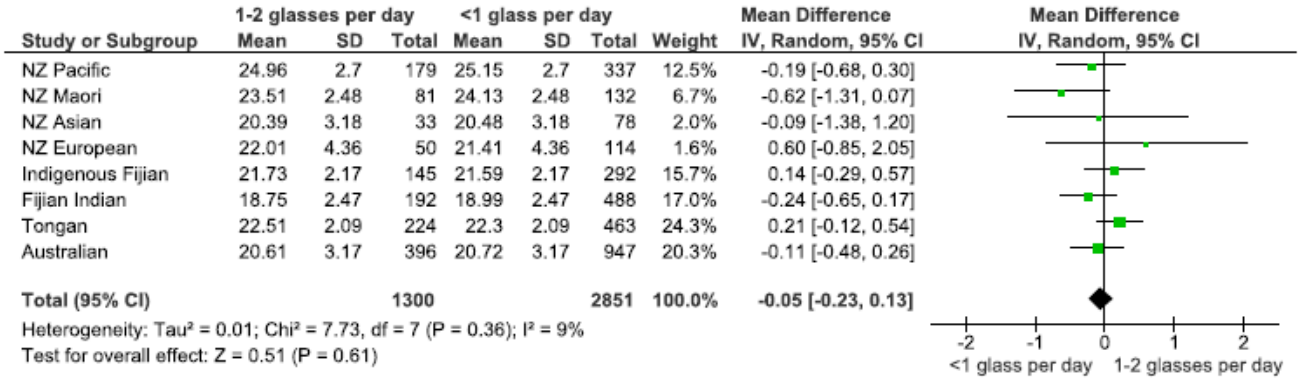
Table 8.8. Relationship between average daily fruit drink/cordial consumption and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=759)	Maori (N=347)	Asian (N=129)	European (N=228)	All (N=1463)	Indigenous Fijian (N=603)	Fijian Indian (N=824)	All (N=1427)	Tongan (N=1017)	Australian (N=1673)	All (N=5580)
Mean BMI (SE)	<1 glass per day	25.15 (0.23)	24.13 (0.40)	20.48 (0.28)	21.41 (0.29)	23.90 (0.22)	21.59 (0.19)	18.99 (0.12)	20.10 (0.12)	22.30 (0.15)	20.72 (0.12)	21.67 (0.08)
Difference in BMI (SE)[2]	1-2 glasses per day	-0.19 (0.25)	-0.62 (0.35)	-0.09 (0.66)	0.60 (0.74)	-0.14 (0.19)	0.14 (0.22)	-0.24 (0.21)	-0.08 (0.12)	0.21 (0.17)	-0.11 (0.19)	-0.04 (0.09)
	>2 glasses per day	-0.05 (0.41)	0.12 (0.41)	-0.38 (0.56)	0.27 (0.22)	0.04 (0.25)	0.02 (0.22)	-0.12 (0.25)	-0.08 (0.20)	0.14 (0.12)	0.18 (0.36)	0.11 (0.13)
Mean %BF (SE)	<1 glass per day	30.51 (0.42)	29.35 (0.73)	22.09 (0.75)	25.36 (0.62)	28.69 (0.44)	20.75 (0.46)	22.60 (0.38)	21.83 (0.33)	22.39 (0.65)	26.19 (0.42)	25.00 (0.23)
Difference in %BF (SE)[2]	1-2 glasses per day	-0.60 (1.07)	-1.35 (1.10)	0.06 (1.65)	-1.72 (1.99)	-0.83 (0.66)	-0.42 (0.44)	-0.54 (0.42)	-0.48 (0.31)	0.47 (0.46)	0.08 (0.42)	-0.21 (0.26)
	>2 glasses per day	-0.17 (0.83)	1.51 (1.09)	-2.36 (2.74)	-0.76 (0.59)	0.11 (0.57)	-0.68 (0.64)	-0.39 (0.53)	-0.62 (0.45)	-0.02 (0.37)	-0.04 (0.75)	0.01 (0.28)
Mean TFM (SE)	<1 glass per day	23.04 (0.43)	21.59 (1.23)	12.54 (0.61)	15.73 (0.67)	20.62 (0.52)	12.45 (0.37)	11.44 (0.26)	11.90 (0.26)	14.01 (0.51)	15.03 (0.32)	15.47 (0.20)
Difference in TFM (SE)[2]	1-2 glasses per day	-0.78 (0.89)	-2.44 (1.40)	-0.32 (1.29)	0.58 (2.07)	-0.87 (0.54)	-0.09 (0.42)	-0.54 (0.33)	-0.35 (0.25)	0.30 (0.38)	-0.05 (0.40)	-0.25 (0.23)
	>2 glasses per day	-0.24 (0.85)	1.22 (1.70)	-1.84 (1.75)	-0.35 (0.61)	0.11 (0.59)	-0.42 (0.50)	-0.31 (0.48)	-0.50 (0.39)	-0.05 (0.28)	0.12 (0.80)	0.05 (0.29)

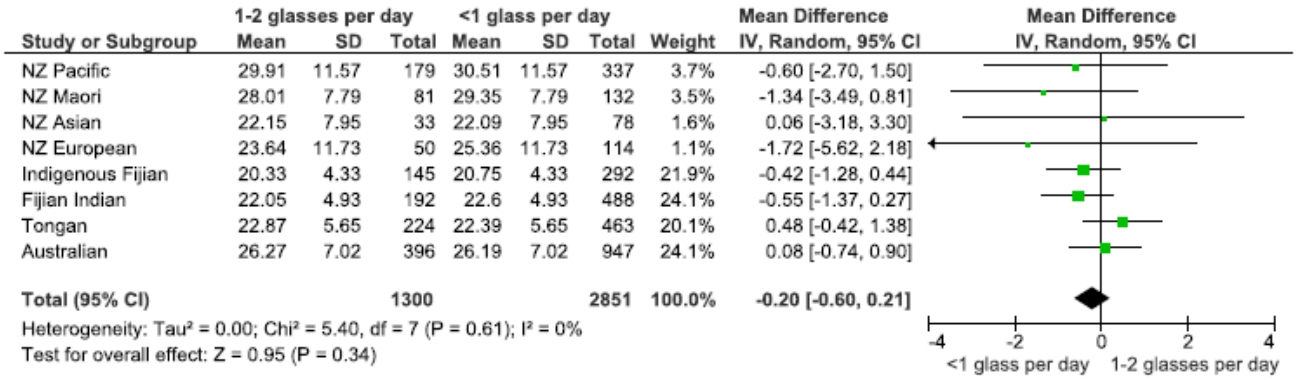
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "<1 glass per day" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.12. Forest plots of relationships between fruit drink/cordial consumption (<1 glass/day versus 1-2 glasses/day) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

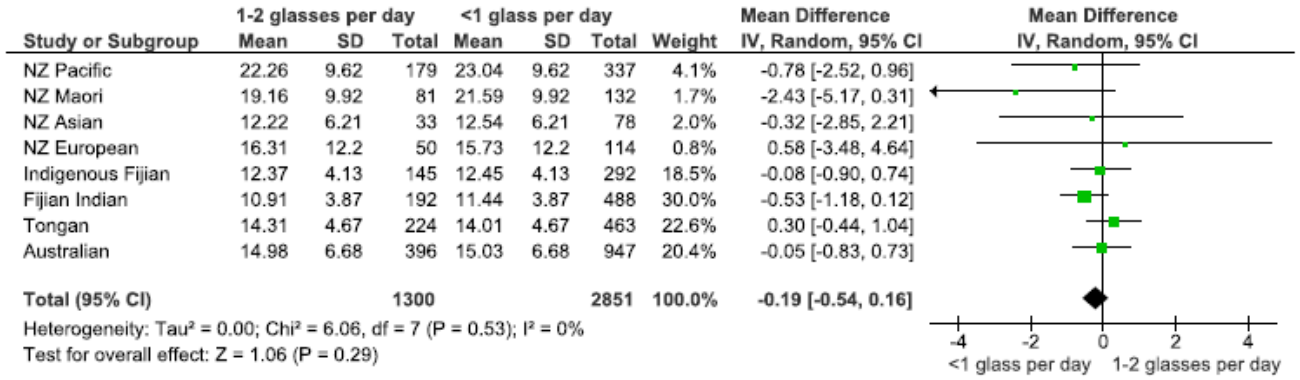
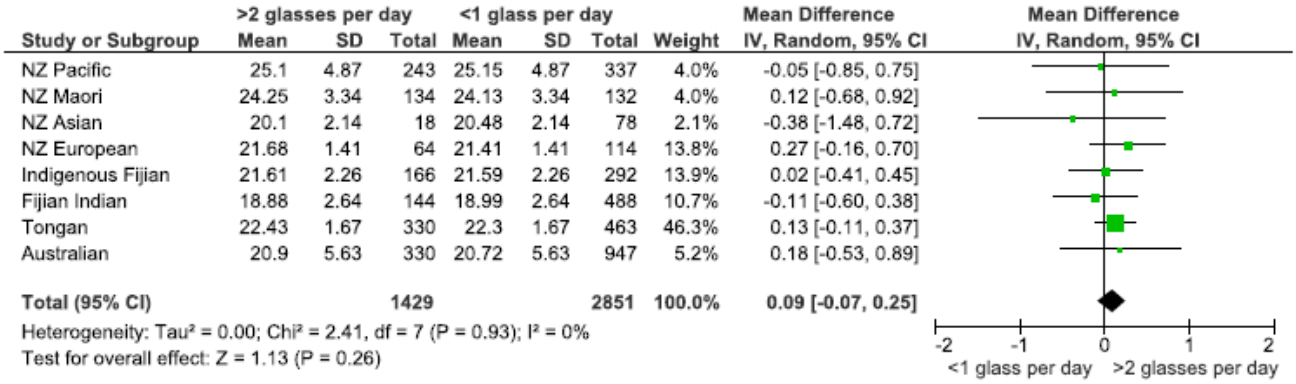
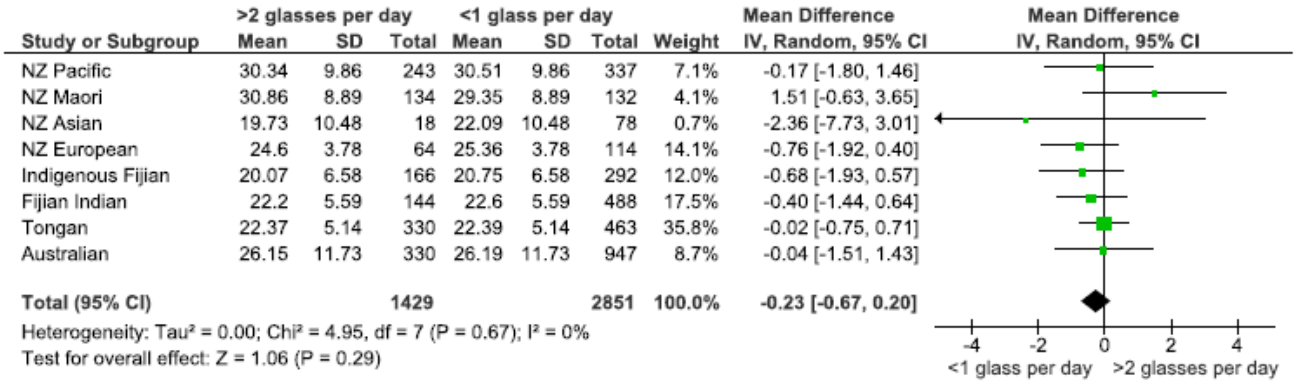


Figure 8.13. Forest plots of relationships between fruit drink/cordial consumption (<1 glass/day versus >2 glasses/day) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

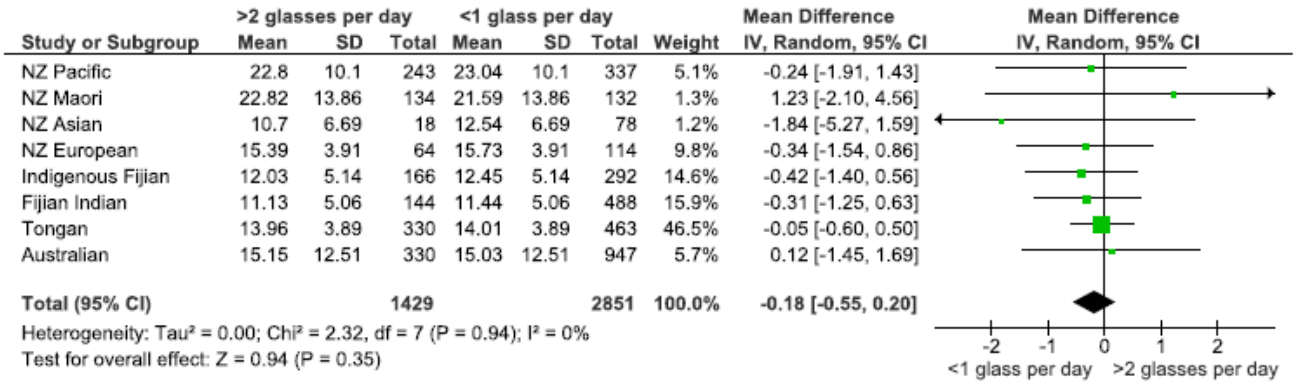


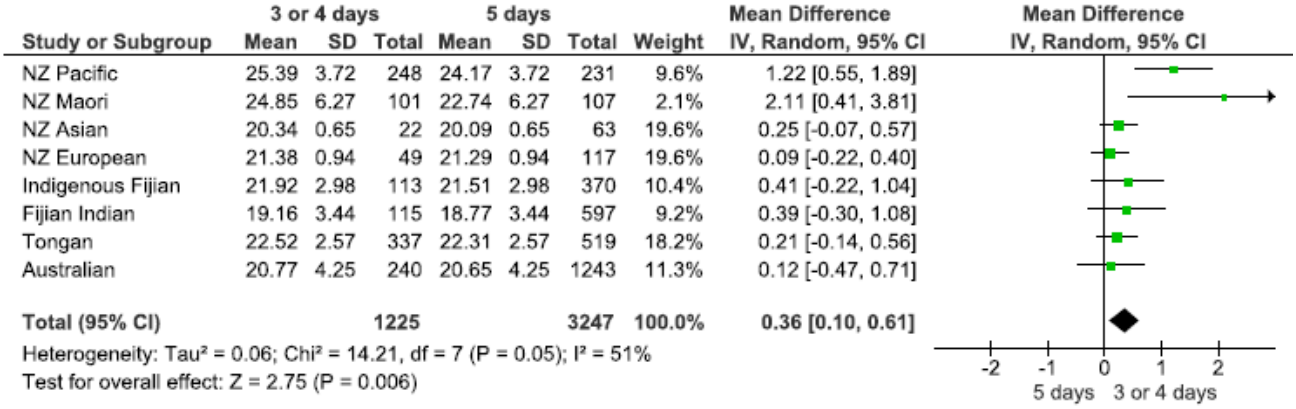
Table 8.9. Relationship between frequency of breakfast consumption and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=750)	Maori (N=336)	Asian (N=122)	European (N=220)	All (N=1428)	Indigenous Fijian (N=612)	Fijian Indian (N=829)	All (N=1441)	Tongan (N=1019)	Australian (N=1673)	All (N=5561)
Mean BMI (SE)	5 days	24.17 (0.18)	22.74 (0.33)	20.09 (0.24)	21.29 (0.28)	23.10 (0.08)	21.51 (0.13)	18.77 (0.12)	19.94 (0.09)	22.31 (0.12)	20.65 (0.07)	21.47 (0.06)
Difference in BMI (SE)[2]	3 or 4 days	1.22 (0.34)‡	2.10 (0.87)*	0.25 (0.16)	0.09 (0.16)	1.16 (0.30)†	0.41 (0.32)	0.39 (0.35)	0.36 (0.23)	0.22 (0.18)	0.12 (0.30)	0.43 (0.15)†
	0, 1 or 2 days	1.60 (0.35)‡	1.88 (0.57)†	0.94 (0.20)‡	0.75 (0.61)	1.43 (0.20)‡	0.34 (0.25)	0.53 (0.25)*	0.42 (0.20)	0.09 (0.24)	0.57 (0.18)†	0.64 (0.14)‡
Mean %BF (SE)	5 days	28.81 (0.72)	26.81 (0.74)	22.31 (0.75)	23.81 (0.47)	27.14 (0.49)	20.30 (0.42)	22.09 (0.41)	21.34 (0.34)	22.21 (0.58)	25.93 (0.23)	24.49 (0.17)
Difference in %BF (SE)[2]	3 or 4 days	2.18 (1.14)	4.54 (1.76)*	-2.14 (1.25)	-0.44 (0.86)	2.04 (0.84)	0.74 (0.56)	1.07 (0.83)	0.78 (0.47)	0.68 (0.42)	0.30 (0.77)	0.95 (0.33)†
	0, 1 or 2 days	2.55 (0.99)*	3.99 (1.35)†	0.18 (0.98)	2.89 (1.31)*	2.58 (0.83)*	0.06 (0.42)	0.77 (0.54)	0.41 (0.40)	0.41 (0.66)	1.96 (0.51)‡	1.21 (0.34)‡
Mean TFM (SE)	5 days	20.54 (0.84)	18.21 (0.76)	12.17 (0.48)	14.81 (0.56)	18.55 (0.48)	12.14 (0.30)	10.99 (0.31)	11.50 (0.26)	13.86 (0.41)	14.86 (0.15)	14.93 (0.16)
Difference in TFM (SE)[2]	3 or 4 days	3.31 (1.27)*	5.09 (2.28)*	-0.76 (0.59)	-0.14 (0.63)	2.91 (0.88)*	0.92 (0.64)	0.78 (0.75)	0.69 (0.49)	0.54 (0.35)	0.25 (0.67)	1.02 (0.35)†
	0, 1 or 2 days	3.60 (1.18)†	4.78 (1.43)†	0.94 (0.51)	2.98 (1.46)*	3.37 (0.81)†	0.13 (0.46)	0.89 (0.54)	0.51 (0.40)	0.17 (0.51)	1.31 (0.44)†	1.33 (0.37)‡

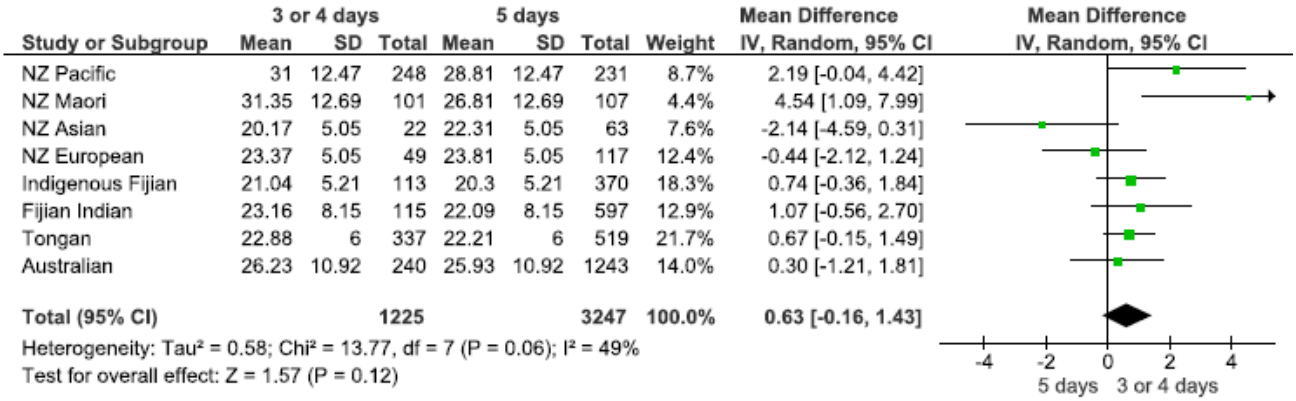
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "5 days" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.14. Forest plots of relationships between breakfast consumption (5 days versus 3 or 4 days) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

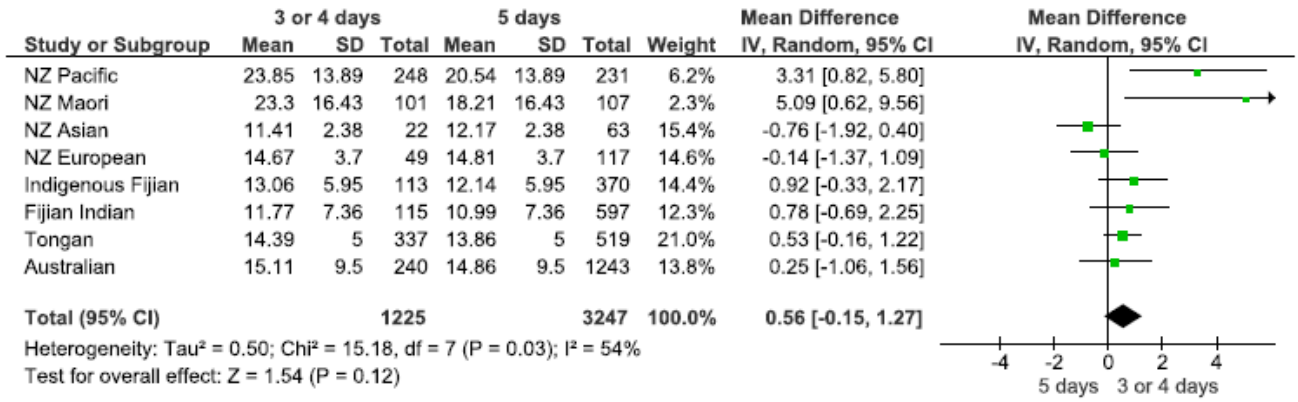
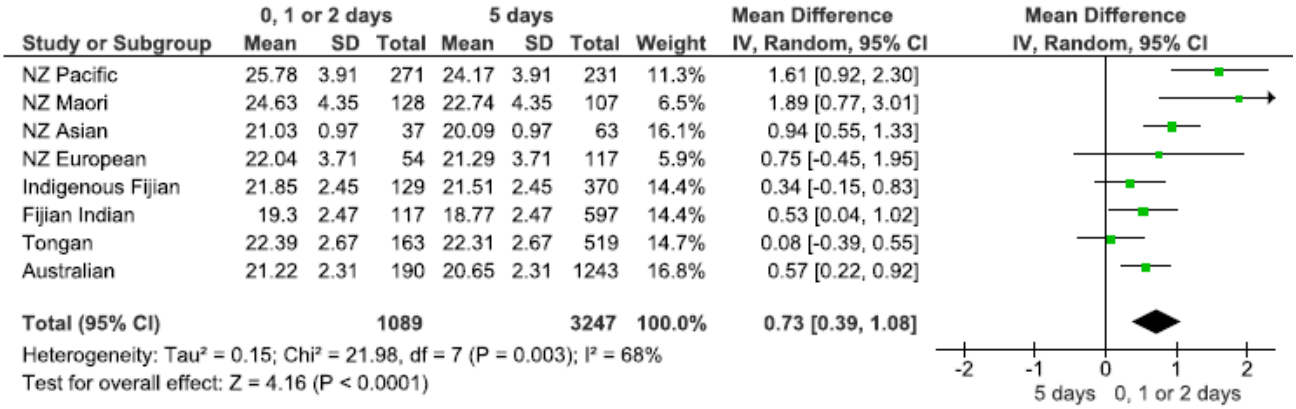
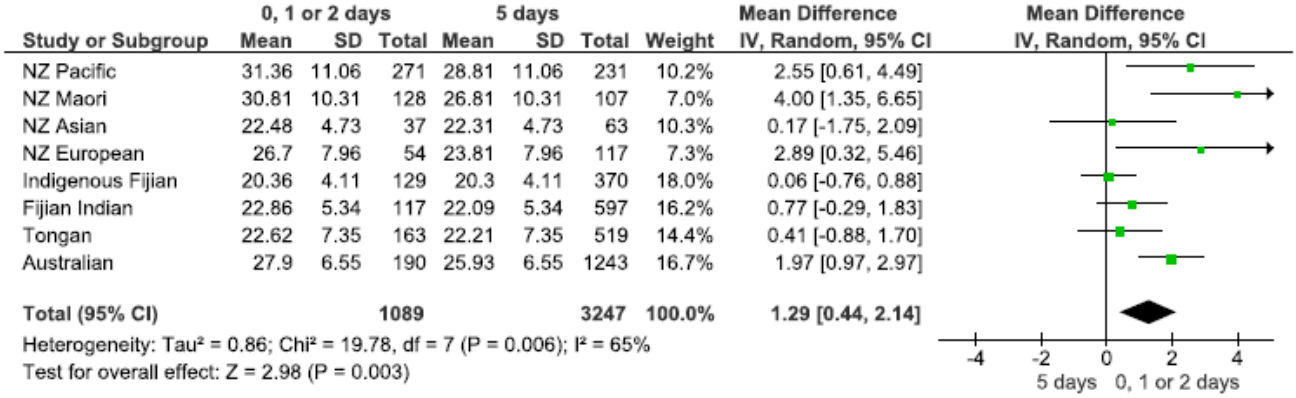


Figure 8.15. Forest plots of relationships between breakfast consumption (5 days versus 0, 1 or 2 days) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

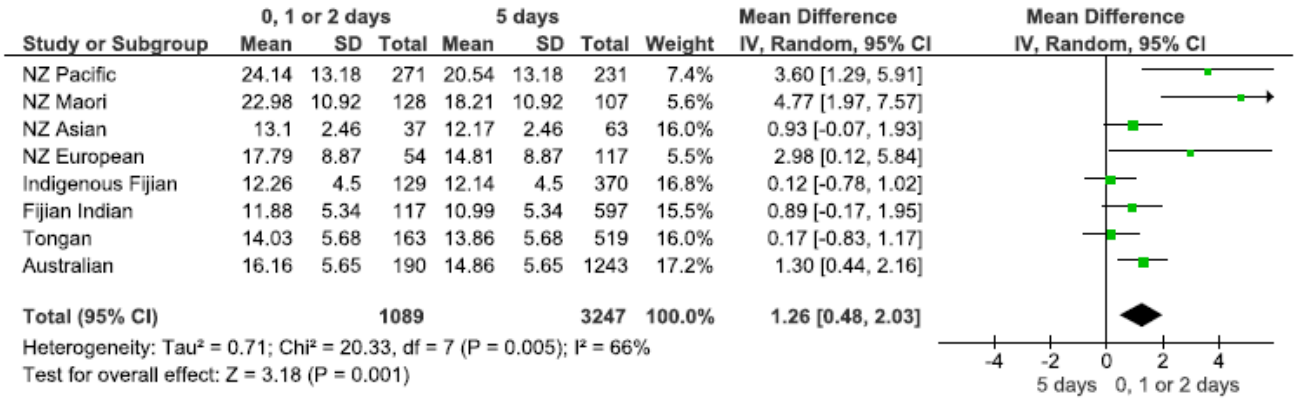


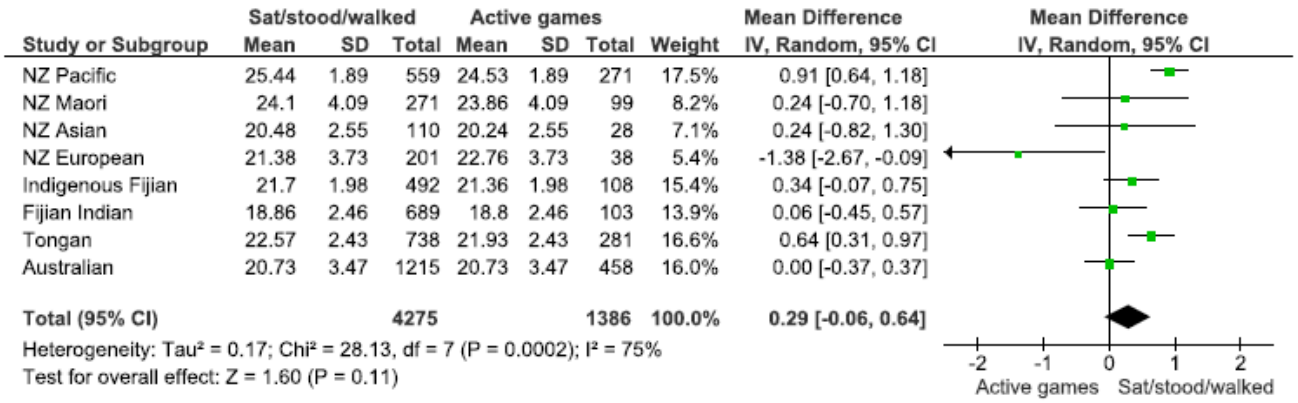
Table 8.10. Relationship between morning recess/interval physical activity and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=830)	Maori (N=370)	Asian (N=138)	European (N=239)	All (N=1577)	Indigenous Fijian (N=600)	Fijian Indian (N=792)	All (N=1392)	Tongan (N=1019)	Australian (N=1673)	All (N=5661)
Mean BMI (SE)	Mostly played active games	24.53 (0.20)	23.86 (0.48)	20.24 (0.33)	22.76 (0.94)	23.59 (0.19)	21.36 (0.21)	18.80 (0.27)	19.92 (0.19)	21.93 (0.19)	20.73 (0.16)	21.57 (0.09)
Difference in BMI (SE)[2]	Mostly just sat down, stood or walked around	0.91 (0.14)‡	0.24 (0.48)	0.25 (0.54)	-1.38 (0.66)*	0.48 (0.19)*	0.33 (0.21)	0.05 (0.26)	0.16 (0.21)	0.63 (0.17)‡	0.00 (0.19)	0.25 (0.10)*
Mean %BF (SE)	Mostly played active games	29.02 (0.60)	29.94 (1.20)	20.80 (0.94)	27.10 (2.54)	27.92 (0.50)	19.51 (0.72)	22.54 (0.82)	21.24 (0.58)	22.03 (0.72)	26.29 (0.48)	25.05 (0.28)
Difference in %BF (SE)[2]	Mostly just sat down, stood or walked around	2.05 (0.70)†	-0.49 (1.37)	1.17 (1.66)	-2.83 (2.15)	0.92 (0.58)	1.12 (0.43)*	-0.33 (0.85)	0.26 (0.51)	0.64 (0.48)	-0.12 (0.36)	-0.03 (0.29)
Mean TFM (SE)	Mostly played active games	21.51 (0.63)	21.93 (1.29)	11.69 (0.65)	18.59 (2.65)	19.97 (0.51)	11.57 (0.51)	10.95 (0.59)	11.31 (0.40)	13.43 (0.54)	14.87 (0.35)	15.33 (0.22)
Difference in TFM (SE)[2]	Mostly just sat down, stood or walked around	2.11 (0.62)†	-0.55 (1.31)	0.66 (1.34)	-3.40 (1.99)	0.84 (0.52)	0.89 (0.36)*	0.17 (0.58)	0.36 (0.37)	0.88 (0.39)*	0.24 (0.36)	0.31 (0.23)

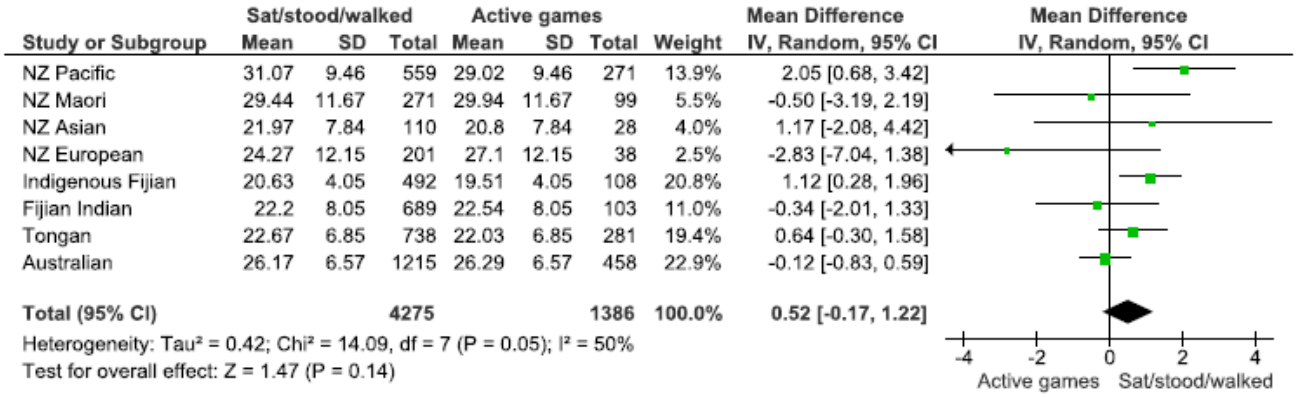
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "Mostly played active games" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.16. Forest plot of the relationship between morning recess/interval physical activity and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

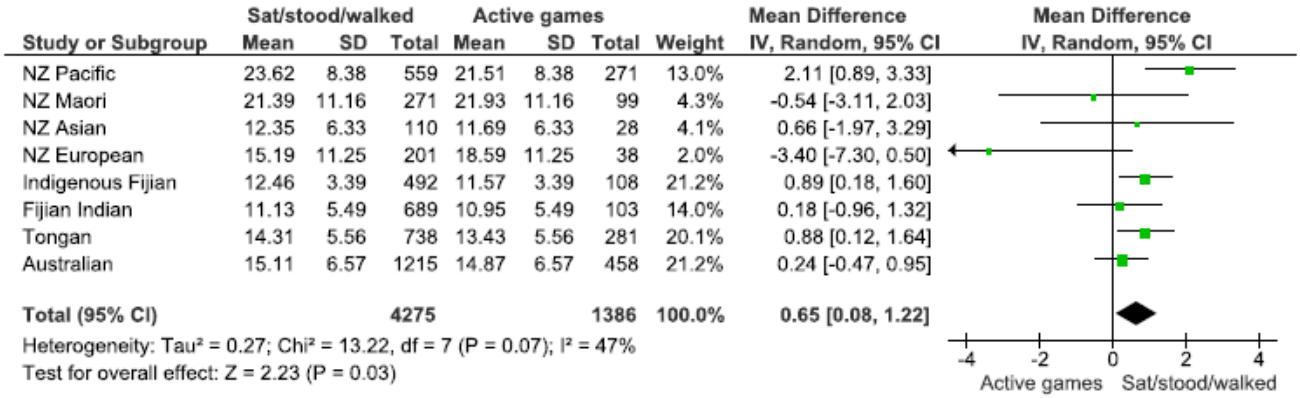


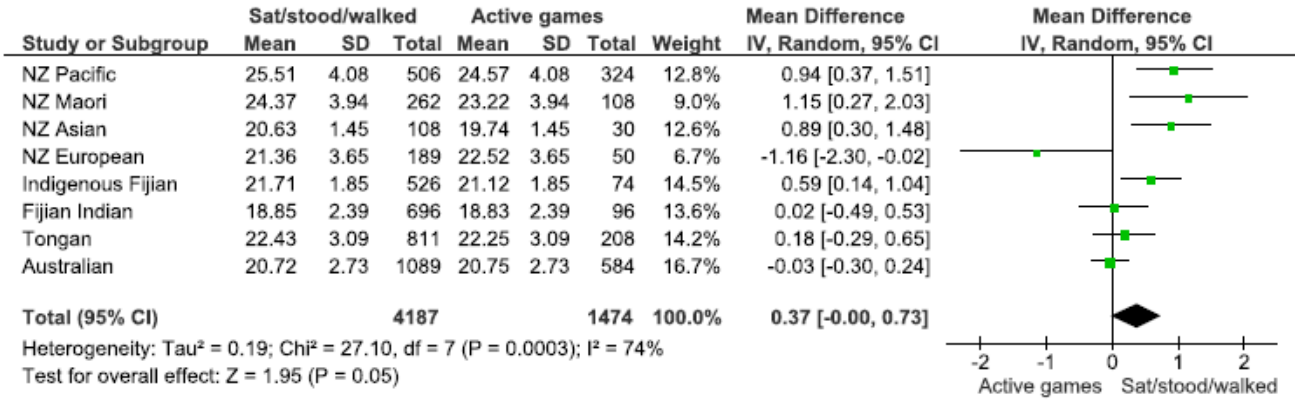
Table 8.11. Relationship between lunch-time physical activity and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=830)	Maori (N=370)	Asian (N=138)	European (N=239)	All (N=1577)	Indigenous Fijian (N=600)	Fijian Indian (N=792)	All (N=1392)	Tongan (N=1019)	Australian (N=1673)	All (N=5661)
Mean BMI (SE)	Mostly played active games	24.57 (0.28)	23.22 (0.38)	19.74 (0.30)	22.52 (0.81)	23.44 (0.17)	21.12 (0.21)	18.83 (0.24)	19.81 (0.20)	22.25 (0.25)	20.75 (0.11)	21.58 (0.10)
Difference in BMI (SE)[2]	Mostly just sat down, stood or walked around	0.93 (0.29)†	1.16 (0.45)*	0.89 (0.30)†	-1.16 (0.58)*	0.73 (0.20)*	0.59 (0.23)*	0.03 (0.26)	0.28 (0.23)	0.17 (0.24)	-0.03 (0.14)	0.24 (0.12)
Mean %BF (SE)	Mostly played active games	29.20 (0.74)	28.81 (1.06)	21.10 (0.76)	25.90 (1.62)	27.73 (0.40)	19.20 (0.78)	22.28 (0.60)	20.94 (0.54)	23.07 (0.78)	25.92 (0.43)	24.88 (0.28)
Difference in %BF (SE)[2]	Mostly just sat down, stood or walked around	1.96 (1.05)	1.09 (1.37)	0.81 (1.20)	-1.50 (1.33)	1.27 (0.55)	1.41 (0.67)*	-0.04 (0.66)	0.60 (0.53)	-0.72 (0.68)	0.44 (0.40)	0.20 (0.33)
Mean TFM (SE)	Mostly played active games	21.83 (0.85)	20.21 (1.08)	11.40 (0.59)	17.67 (1.94)	19.73 (0.49)	11.19 (0.51)	10.97 (0.52)	11.05 (0.45)	14.18 (0.60)	14.83 (0.29)	15.30 (0.24)
Difference in TFM (SE)[2]	Mostly just sat down, stood or walked around	1.80 (1.06)	1.87 (1.37)	1.04 (0.86)	-2.45 (1.46)	1.25 (0.59)	1.27 (0.45)†	0.15 (0.52)	0.65 (0.44)	-0.15 (0.56)	0.32 (0.31)	0.36 (0.29)

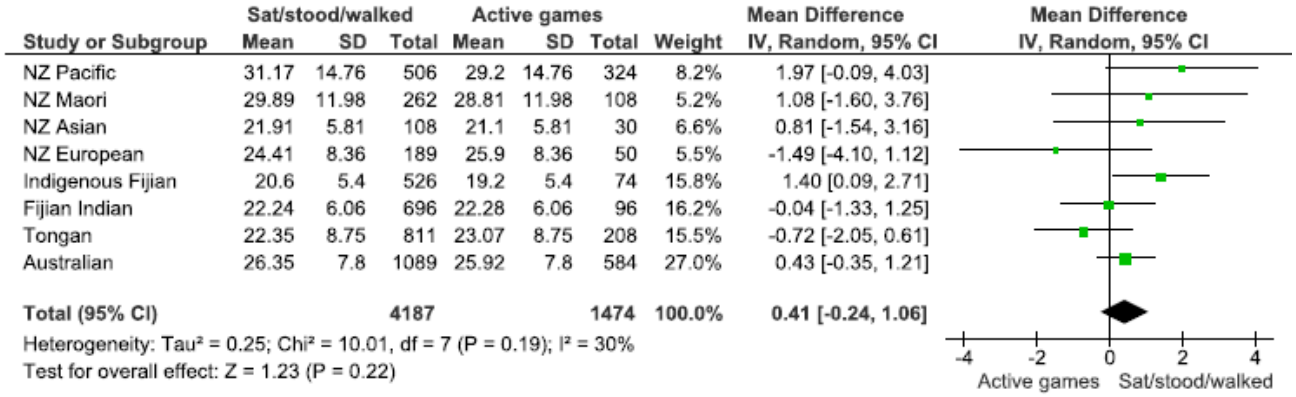
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "Mostly played active games" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.17. Forest plot of the relationship between lunch-time physical activity and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

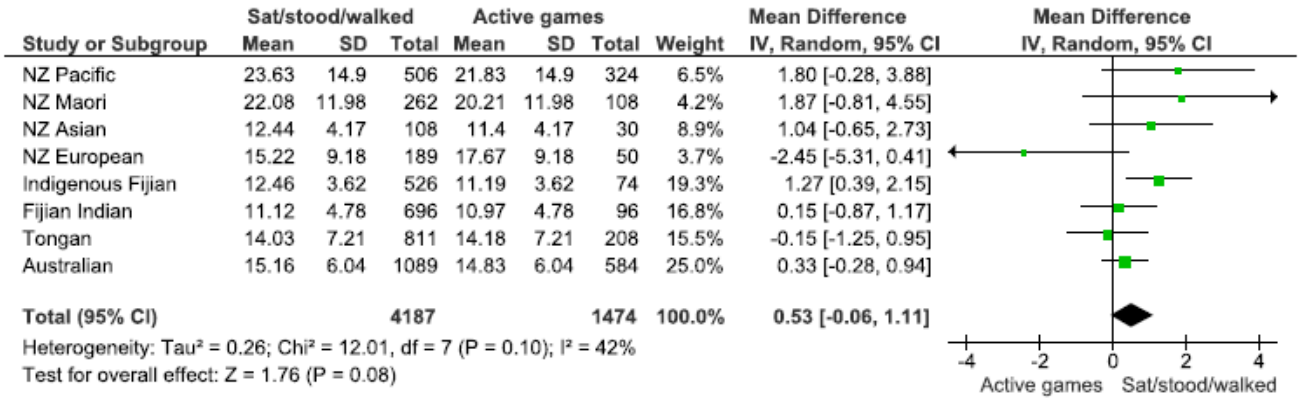


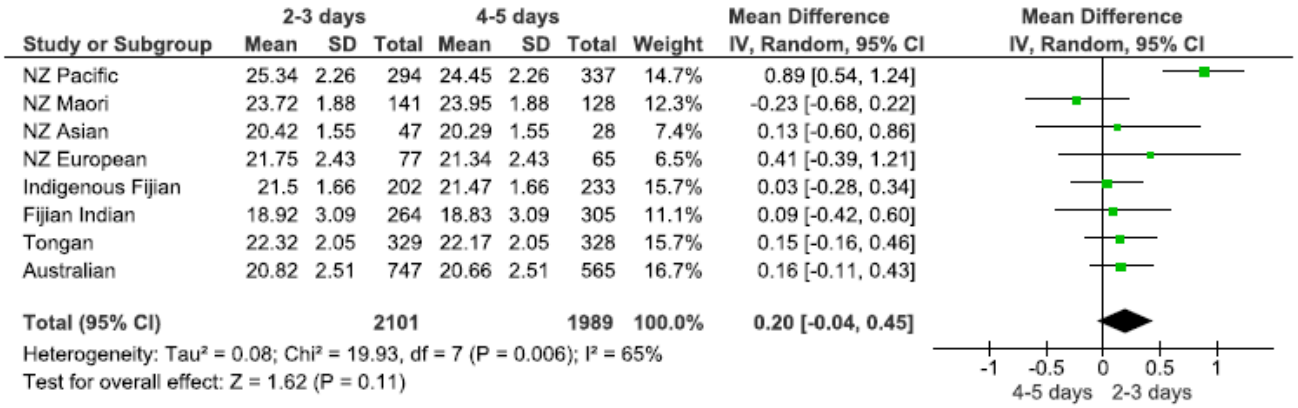
Table 8.12. Relationship between after-school physical activity and body composition variables among those not trying to change weight[1]

	Country	New Zealand					Fiji			Tonga	Australia	All
	Ethnic group	Pacific Islander (N=830)	Maori (N=370)	Asian (N=138)	European (N=239)	All (N=1577)	Indigenous Fijian (N=600)	Fijian Indian (N=791)	All (N=1391)	Tongan (N=1019)	Australian (N=1673)	All (N=5660)
Mean BMI (SE)	4-5 days	24.45 (0.20)	23.95 (0.21)	20.29 (0.43)	21.34 (0.33)	23.47 (0.15)	21.47 (0.11)	18.83 (0.15)	19.98 (0.10)	22.17 (0.14)	20.66 (0.10)	21.54 (0.06)
Difference in BMI (SE)[2]	2-3 days	0.89 (0.18)‡	-0.24 (0.23)	0.13 (0.37)	0.41 (0.41)	0.50 (0.18)*	0.03 (0.16)	0.09 (0.26)	0.05 (0.14)	0.16 (0.16)	0.16 (0.14)	0.23 (0.08)†
	0-1 days	1.58 (0.15)‡	0.63 (0.39)	0.22 (0.42)	0.33 (0.20)	0.97 (0.23)†	0.57 (0.25)*	-0.02 (0.21)	0.21 (0.18)	0.49 (0.17)†	-0.01 (0.09)	0.46 (0.12)‡
Mean %BF (SE)	4-5 days	29.06 (0.32)	29.67 (0.52)	20.63 (1.50)	23.09 (1.11)	27.62 (0.28)	19.60 (0.39)	22.06 (0.36)	21.04 (0.30)	21.36 (0.64)	25.55 (0.43)	24.15 (0.19)
Difference in %BF (SE)[2]	2-3 days	1.16 (0.42)†	-0.27 (0.50)	0.93 (1.50)	3.03 (0.94)†	0.99 (0.31)*	0.77 (0.47)	0.38 (0.79)	0.50 (0.45)	0.89 (0.46)	0.81 (0.43)	0.92 (0.21)‡
	0-1 days	3.88 (0.56)‡	0.02 (1.03)	1.72 (0.82)*	1.61 (0.50)†	2.12 (0.63)*	2.06 (0.60)†	0.25 (0.58)	0.94 (0.41)*	2.39 (0.50)‡	1.32 (0.47)†	1.96 (0.29)‡
Mean TFM (SE)	4-5 days	21.27 (0.50)	21.44 (0.62)	11.36 (1.30)	14.36 (1.20)	19.42 (0.35)	11.68 (0.31)	10.94 (0.31)	11.30 (0.25)	13.23 (0.44)	14.59 (0.28)	14.82 (0.16)
Difference in TFM (SE)[2]	2-3 days	1.69 (0.53)†	-0.45 (0.38)	0.80 (1.17)	2.64 (0.82)†	1.18 (0.35)*	0.51 (0.37)	0.33 (0.55)	0.36 (0.31)	0.66 (0.37)	0.66 (0.36)	0.78 (0.18)‡
	0-1 days	4.42 (0.57)‡	0.97 (1.31)	1.29 (0.76)	1.28 (0.63)*	2.53 (0.64)†	1.62 (0.53)†	0.20 (0.43)	0.71 (0.36)	1.76 (0.42)‡	0.76 (0.26)†	1.64 (0.29)‡

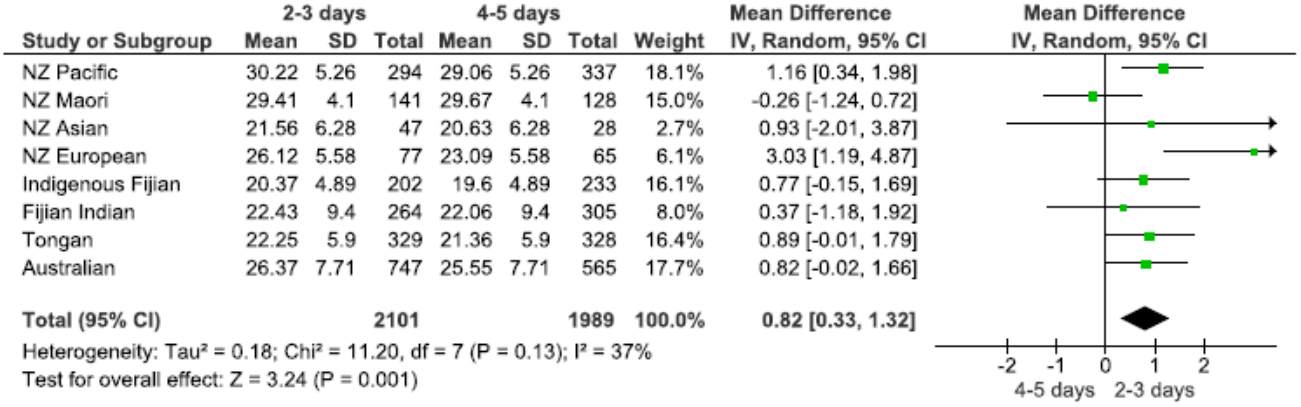
[1]Adjusted for age and sex; however, "NZ All", "Fiji All" and "All countries" were further adjusted for ethnicity. [2]Compared to "4-5 days" (reference category); BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); SE = Standard error; *P<0.05; †P<0.01; ‡P<0.001.

Figure 8.18. Forest plots of relationships between after-school physical activity (4-5 days versus 2-3 days) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



%BF



TFM

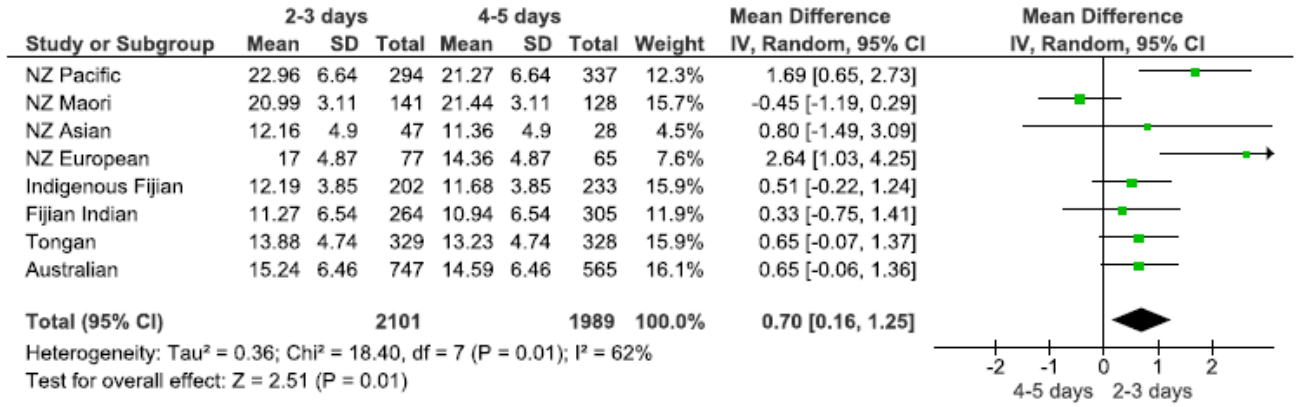
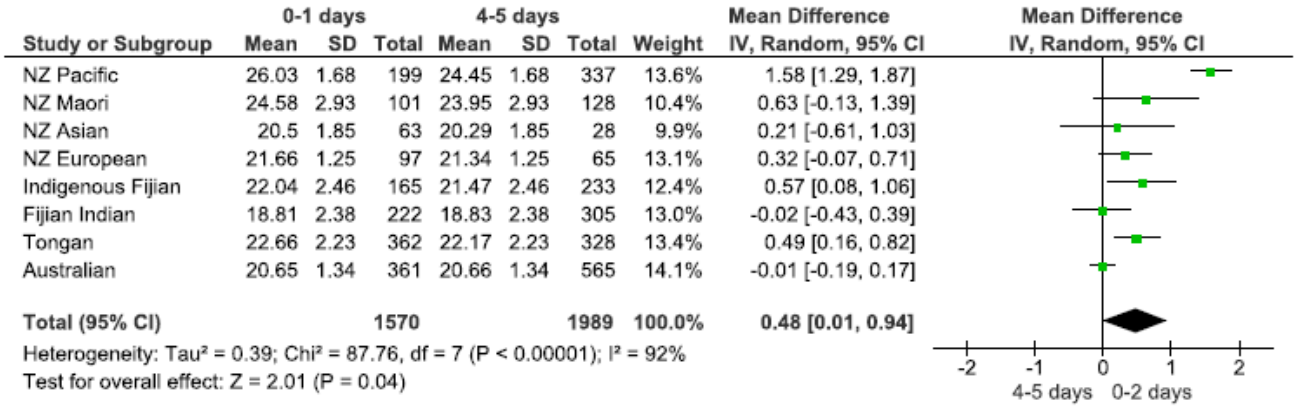


Figure 8.19. Forest plots of relationships between after-school physical activity (4-5 days versus 0-1 days) and body composition variables (adjusted for age and sex) among those not trying to change weight

BMI



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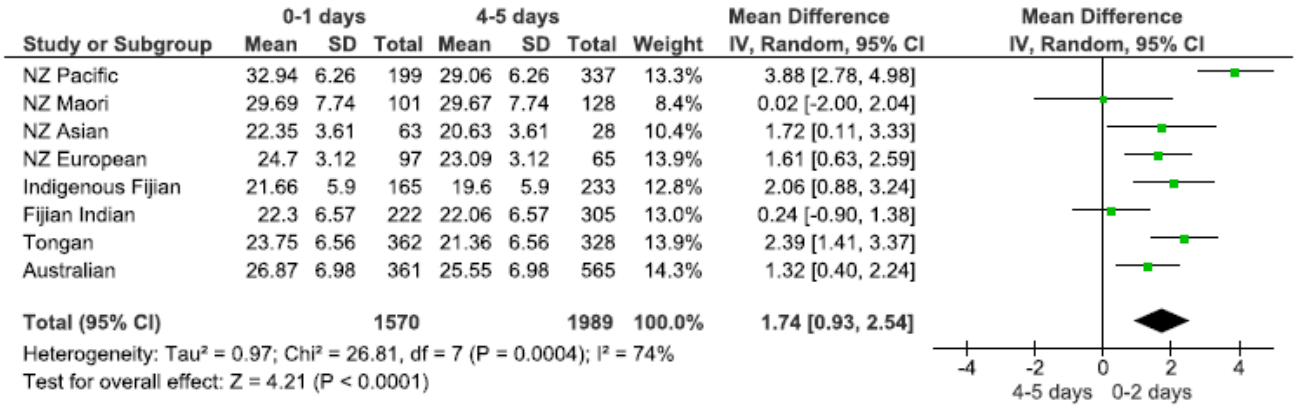


TFM

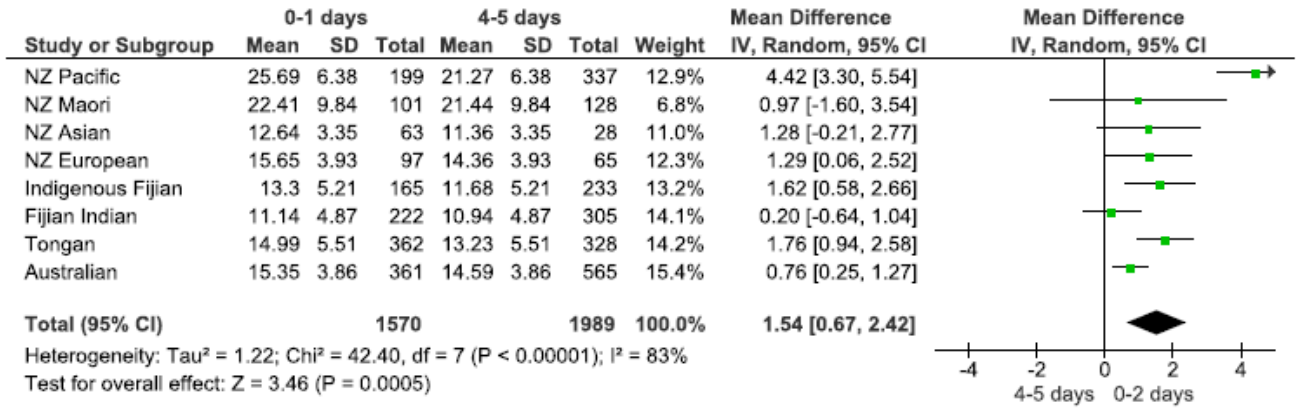


Figure 8.20. Relationships between lifestyle and body composition variables (as a % of mean values of reference group from Tables 8.6-8.12) in all ethnic groups combined. BMI = Body mass index; %BF = Percent body fat; TFM = Total fat mass

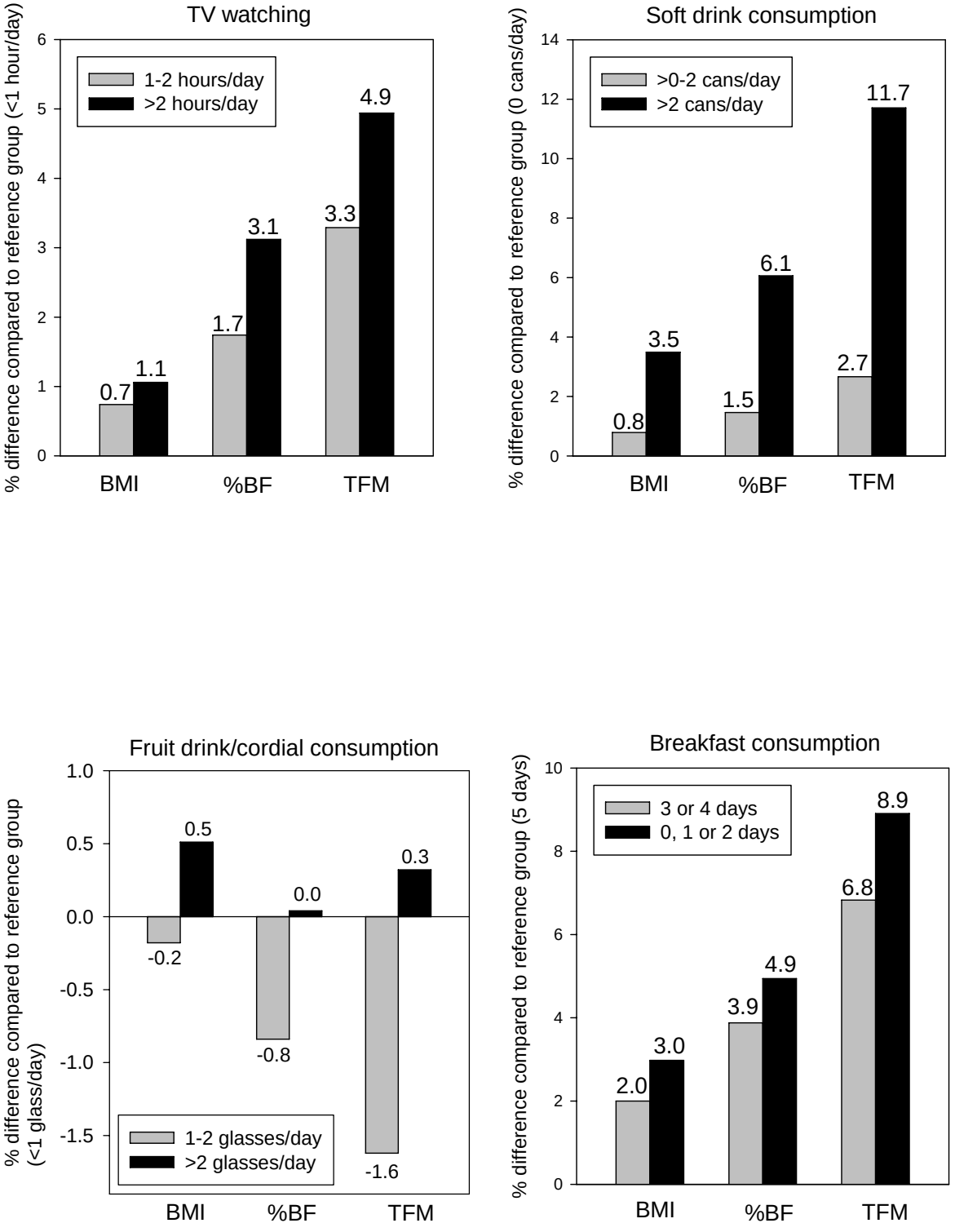
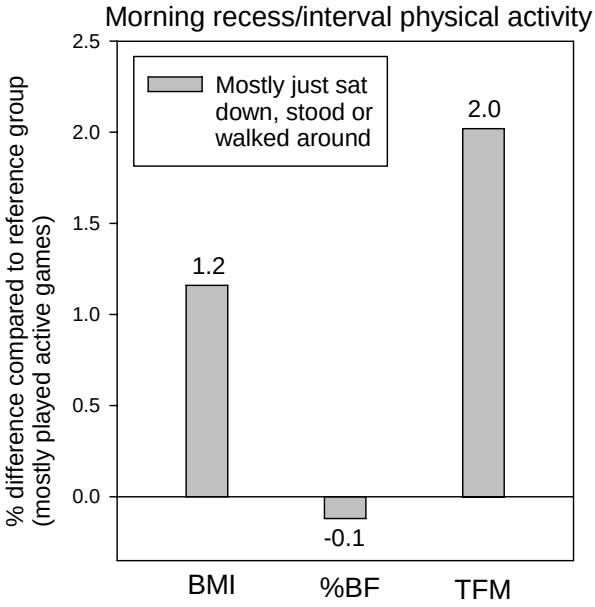
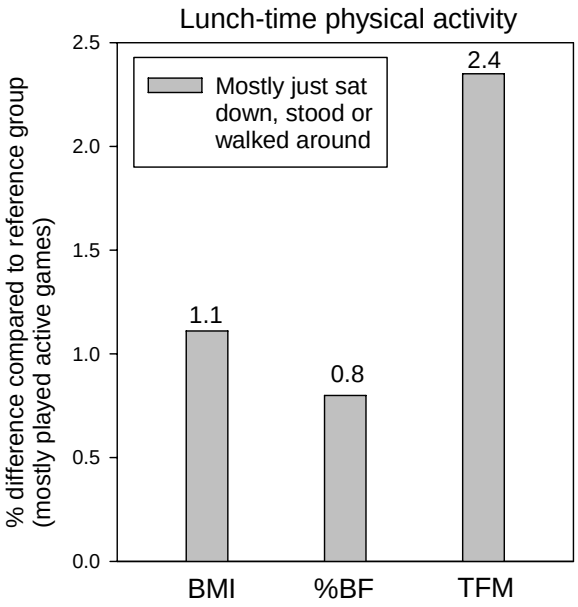


Figure 8.20 (continued).





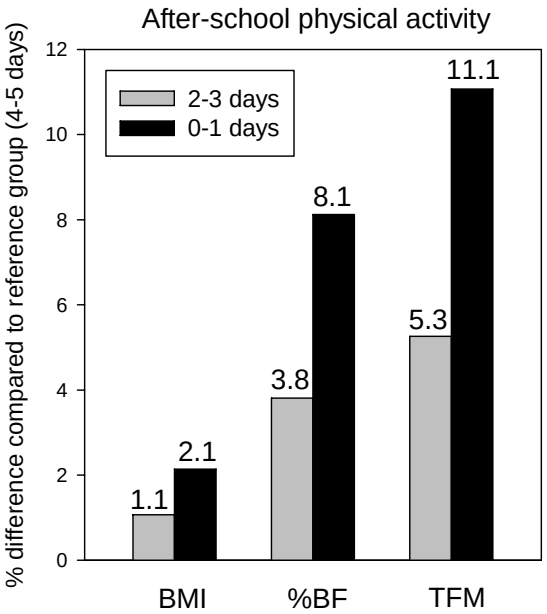


Table 8.13. Statistical models examining the relationship between lifestyle and body composition variables, fitted with "weight-control attempt times lifestyle factor" interaction terms[1]

Lifestyle factor	Variable	Parameter	Beta-coefficient (standard error)		
			BMI	%BF	TFM
TV watching	Weight-control attempt[2]	Gain weight	-1.43 (0.15)‡	-3.53 (0.42)‡	-2.72 (0.40)‡
		Lose weight	3.86 (0.17)‡	7.83 (0.39)‡	8.69 (0.48)‡
	TV watching[3]	1-2 hours per day	**0.16 (0.10)**	**0.39 (0.33)**	**0.45 (0.29)**
		>2 hours per day	**0.22 (0.10)***	**0.72 (0.26)†**	**0.63 (0.23)†**
	Weight-control attempt x TV watching[4]	Gain weight x 1-2 hours per day	-0.15 (0.15)	-0.45 (0.45)	-0.50 (0.37)
		Gain weight x >2 hours per day	-0.56 (0.21)†	-1.09 (0.54)*	-1.32 (0.51)*
		Lose weight x 1-2 hours per day	-0.15 (0.19)	0.18 (0.54)	-0.17 (0.54)
		Lose weight x >2 hours per day	-0.37 (0.21)	-0.61 (0.45)	-0.70 (0.47)
Soft drink consumption	Weight-control attempt[2]	Gain weight	-1.58 (0.18)‡	-3.59 (0.56)‡	-2.87 (0.49)‡
		Lose weight	3.86 (0.16)‡	8.21 (0.35)‡	8.82 (0.41)‡
	Soft drink consumption[3]	>0-2 cans per day	**0.15 (0.10)**	**0.35 (0.29)**	**0.32 (0.27)**
		>2 cans per day	**0.71 (0.21)†**	**1.44 (0.56)***	**1.56 (0.55)†**
	Weight-control attempt x soft drink consumption[4]	Gain weight x >0-2 cans per day	0.08 (0.17)	0.06 (0.55)	-0.02 (0.44)
		Gain weight x >2 cans per day	-0.64 (0.28)*	-1.89 (0.86)*	-2.01 (0.75)†
		Lose weight x >0-2 cans per day	-0.16 (0.18)	-0.60 (0.35)	-0.51 (0.40)
		Lose weight x >2 cans per day	-0.84 (0.28)†	-2.19 (0.83)*	-1.89 (0.89)*
Fruit drink/cordial consumption	Weight-control attempt[2]	Gain weight	-1.60 (0.15)‡	-3.59 (0.53)‡	-3.03 (0.44)‡
		Lose weight	3.63 (0.13)‡	7.75 (0.33)‡	8.20 (0.38)‡
	Fruit drink/cordial consumption[3]	1-2 glasses per day	**-0.03 (0.09)**	**-0.19 (0.26)**	**-0.25 (0.23)**
		>2 glasses per day	**0.12 (0.14)**	**0.09 (0.32)**	**0.04 (0.32)**
	Weight-control attempt x fruit drink/cordial consumption[4]	Gain weight x 1-2 glasses per day	-0.08 (0.16)	-0.13 (0.53)	0.00 (0.40)
		Gain weight x >2 glasses per day	0.09 (0.20)	-0.46 (0.61)	-0.21 (0.52)
		Lose weight x 1-2 glasses per day	0.20 (0.15)	0.10 (0.37)	0.47 (0.37)
		Lose weight x >2 glasses per day	-0.07 (0.26)	-0.73 (0.52)	-0.22 (0.63)
Breakfast consumption	Weight-control attempt[2]	Gain weight	-1.38 (0.12)‡	-3.43 (0.41)‡	-2.52 (0.33)‡
		Lose weight	3.60 (0.14)‡	7.63 (0.33)‡	7.98 (0.42)‡
	Breakfast consumption[3]	3 or 4 days	**0.38 (0.14)†**	**0.95 (0.32)†**	**0.82 (0.32)***
		0, 1 or 2 days	**0.60 (0.13)‡**	**1.24 (0.32)‡**	**1.11 (0.34)†**
	Weight-control attempt x breakfast consumption[4]	Gain weight x 3 or 4 days	-0.73 (0.21)‡	-1.09 (0.51)*	-1.81 (0.56)†
		Gain weight x 0, 1 or 2 days	-0.33 (0.21)	-0.22 (0.44)	-0.86 (0.46)
		Lose weight x 3 or 4 days	0.09 (0.21)	0.04 (0.43)	0.50 (0.47)
		Lose weight x 0, 1 or 2 days	0.03 (0.18)	-0.36 (0.39)	0.57 (0.44)
Morning recess/interval physical activity	Weight-control attempt[2]	Gain weight	-1.65 (0.23)‡	-4.14 (0.51)‡	-3.32 (0.60)‡
		Lose weight	3.68 (0.17)‡	7.59 (0.38)‡	8.85 (0.56)‡
	Morning recess/interval physical activity[3]	Mostly just sat down, stood or walked around	**0.24 (0.11)***	**-0.01 (0.28)**	**0.38 (0.25)**
	Weight-control attempt x morning recess/interval physical activity[4]	Gain weight x morning recess/interval physical activity	-0.02 (0.18)	0.13 (0.42)	-0.03 (0.38)
		Lose weight x morning recess/interval physical activity	0.02 (0.16)	0.12 (0.35)	-0.57 (0.43)
Lunch-time physical activity	Weight-control attempt[2]	Gain weight	-1.65 (0.20)‡	-4.26 (0.60)‡	-3.69 (0.64)‡
		Lose weight	3.87 (0.16)‡	8.18 (0.37)‡	9.37 (0.52)‡
	Lunch-time physical activity[3]	Mostly just sat down, stood or walked around	**0.23 (0.12)**	**0.22 (0.31)**	**0.50 (0.30)**
	Weight-control attempt x lunch-time physical activity[4]	Gain weight x lunch-time physical activity	-0.02 (0.14)	0.28 (0.49)	0.46 (0.40)
		Lose weight x lunch-time physical activity	-0.22 (0.19)	-0.65 (0.41)	-1.26 (0.50)*

After-school physical activity	Weight-control attempt[2]	Gain weight	-1.28 (0.13)‡	-3.29 (0.47)‡	-2.48 (0.43)‡
		Lose weight	3.68 (0.16)‡	7.94 (0.36)‡	8.65 (0.49)‡
	After-school physical activity[3]	2-3 days	**0.23 (0.08)†**	**0.92 (0.20)‡**	**0.82 (0.19)‡**
		0-1 days	**0.43 (0.11)‡**	**1.89 (0.28)‡**	**1.61 (0.28)‡**
	Weight-control attempt x after-school physical activity[4]	Gain weight x 2-3 days	-0.57 (0.12)‡	-0.79 (0.37)	-1.06 (0.28)‡
		Gain weight x 0-1 days	-0.72 (0.18)‡	-1.76 (0.52)†	-1.82 (0.46)‡
		Lose weight x 2-3 days	0.28 (0.21)	0.23 (0.43)	0.30 (0.50)
		Lose weight x 0-1 days	-0.29 (0.19)	-1.22 (0.44)†	-1.30 (0.52)*

[1]Adjusted for age, sex and ethnicity. Sample sizes for lifestyle exposure groups are given in Table 8.3; [2]Beta-coefficient for reference group – "not change weight" category – is 0; [3]Beta-coefficient for reference group – "<1 hour per day" for TV watching, "0 cans per day" for soft drink consumption, "<1 glass per day" for fruit drink/cordial consumption, "5 days" for breakfast consumption, "mostly played active games" for morning recess/interval and lunch-time physical activity, and "4-5 days" for after-school physical activity – is 0. Coefficients in bold represent differences in fatness compared to reference group among those not trying to change weight; [4]Beta-coefficients for reference groups – unlisted groups – are 0; BMI = Body mass index (kg/m^2); %BF = Percent body fat (%); TFM = Total fat mass (kg); *P<0.05, †P<0.01 and ‡P<0.001 compared to reference group(s).

8.4 Summary

This chapter showed that Pacific Islanders had markedly higher fatness levels than other groups, including when %BF, TFM and %AbFM were used as fatness measures. Section 8.2.2 showed that lifestyle-fatness associations in those not trying to change weight differed from those with other weight-loss practice intentions. This justified the need to restrict subsequent analyses to those not trying to change weight.

Results for those not trying to change weight (Section 8.3) were the main focus of this chapter, from which conclusions will be made in the Discussion (next chapter). That is, among all ethnic groups combined, TV watching had a significantly positive, dose-dependent relationship with fatness. Overall effects showed significant, strong, dose-dependent associations between fatness and soft drink consumption (positive relationship), breakfast consumption (inverse relationship) and after-school physical activity (inverse relationship). These results were observed both when analyses were restricted to those not trying to change weight (Tables 8.6, 8.7, 8.9 and 8.12) and when analyses with "weight-control attempt times lifestyle factor" interaction terms were carried out among all participants (Table 8.13). The direction of each abovementioned association was consistently observed across ethnic groups. Finally, changes to lifestyle obesity risk factors were associated with percentage changes in body composition variables that were greatest for TFM, followed by %BF and then BMI.

CHAPTER 9: DISCUSSION

9.1 Introduction

This chapter will discuss the results of the validation study (Section 9.2) and OPIC study (Section 9.3). The findings of each study will be compared with those of similar studies or related literature in Sections 9.2.1 (for the validation study) and 9.3.1 (for the OPIC study). Following this, the limitations and strengths of each study will be discussed (Sections 9.2.2 and 9.3.2). Next, the findings from both studies that have been discussed in Sections 9.2 and 9.3 will be summarised in the *Conclusion* (Section 9.4). Finally, for each study, the utility of findings and suggested suitable areas for future research will be discussed (Section 9.5).

9.2 Validation study

This section will discuss the results of Chapter 6 (*Validation study results*). It will begin in Section 9.2.1 by comparing these findings with those of previous studies.

9.2.1 Comparison of results with literature

This section will discuss findings of the validation study. Section 9.2.1.1 will discuss results shown in Section 6.2 (*Body mass index and percent body fat*), Section 9.2.1.2 will discuss results shown in Section 6.3 (*Bioimpedance analysis and body composition*) and Section 9.2.1.3 will discuss results shown in Section 6.4 (*Waist circumference and trunk impedance*).

9.2.1.1 Body mass index

This is the first study to both compare %BF for a given BMI in European, Maori, Pacific Island and Asian Indian adolescents and investigate factors which may affect this relationship. This study suggests that, in adolescents, BMI is not an equivalent measure of %BF between these four ethnic groups, with markedly different %BF observed in these ethnic groups at similar BMI values. Further, variation in muscularity, bone mass, relative leg length, fat distribution and body shape contributed to these ethnic differences. In particular, skeletal muscle, bone and fat distribution variables when included in the %BF-BMI relationships significantly reduced the ethnic differences in these relationships. Readily measured variables, WC, WHTR and CI, which relate to fat distribution appeared to act as surrogates for DXA-measured abdominal fat. This was particularly true for CI.

The results for Maori and Pacific Islanders are consistent with other work which has shown that, compared to Europeans, BMI overestimates %BF in Maori and Pacific Island 5-14 year-old girls (32) and women (66, 68, 72), and Pacific Island men (70). In line with the findings of the current study, Duncan *et al* (75) reported that, in a sample of girls aged 5-16 years, Pacific Islanders had less %BF than Europeans at a given BMI. However, the authors did not find a significant difference in %BF at the same BMI between European and Maori girls, which may be attributed to the fact that the %BF estimates in that study were derived from a BIA prediction equation (75). Findings in the present study confirm those of three other studies in adults, which showed that BMI-adjusted %BF (70, 72) or FM (73) values are lower in Maori and Pacific Islanders than in Europeans. Rush *et al* (32) were not able to demonstrate ethnic differences in the BMI-%BF relationship between European, Maori and Pacific Island boys aged 5-14 y, possibly because of the limited %BF and BMI range for their European boys.

In this study, for the same BMI (and age in boys), Asian Indians had the highest %BF. A study of girls aged 5-16 years found that, at a given BMI, South Asians had 4.5% more %BF (derived from a BIA prediction equation) than Europeans (75). In a study of children aged between 5 and 11 years, Tyrrell *et al* (29) also found that Asian Indians had a higher %BF at a given BMI, compared to Europeans. A limitation of that study is that %BF was derived from a bioimpedance prediction equation that was not developed for Indian (or Asian) children. In a study of children aged 7-12 y (63), compared to Dutch children, Singaporean children had 4.3% more %BF after adjusting for sex, age and BMI. Mehta *et al* (64) showed that, after adjusting for BMI, South Asian adolescent (14-16 y) boys had 4.5% more %BF measured by bioimpedance analysis than white adolescent boys. In adolescents aged 16-18 y, after adjusting for age and BMI, Singaporean adolescents had more %BF than Dutch adolescents (65). That study used skinfold equations to derive %BF and the ethnic difference of %BF ranged from 4.1-9.1 % for boys and 5.2-7.2 % for girls, depending on the prediction equation used (65). A large cross-sectional study of British children and adolescents aged 5-18 y (74) found that, after adjustment for body weight, South Asians had higher %BF than whites at an early age before puberty and this difference increased during the teenage years. In adults, for the same BMI, Asian Indians had higher %BF than Europeans, Maori and Pacific Islanders (69, 72).

This study showed marked ethnic differences in the relationship between BMI and %BF. For example, at a given BMI and age, Asian Indian and Pacific Island boys differed in %BF by 8.7%, which was over a third of the average %BF for boys in this sample. In girls, at a fixed BMI, these

two ethnic groups differed in %BF by 7.7%, which, in this sample, was close to one quarter of the mean %BF for girls. These are substantial and clinically relevant differences.

Polynesians are recognised as having a large, muscular physique (56), and, for a given weight, height and age, ASMM, BMC and BMD are higher in Polynesians than in Europeans or Asian Indians (69, 70). ASMM and BMC contributed to ethnic differences in the relationship between BMI and %BF in adults (69) and it was hypothesised that this effect may impact on this relationship in adolescents. In the present study, correction for ASMM substantially reduced ethnic differences in %BF between all ethnic groups, at a fixed BMI and age in boys and at a fixed BMI in girls. Further, higher ASMM, BMC and BMD were associated with overestimation of %BF prediction by BMI. This indicates that measurement of arm and leg girths (for limb skeletal muscle mass estimation) or body build or frame size (for bone mass estimation) may improve BMI prediction of %BF (76, 77, 439).

Rush *et al* (69) found that, among adults, correction for absolute fat distribution variables markedly reduced ethnic differences in BMI-adjusted %BF between European, Maori, Pacific Island and Asian Indians. This was observed in the current study. Adjustment for abdominal fat had a notable effect on the difference in %BF between Pacific Island and Asian Indian boys (Table 6.5), consistent with these two groups having the lowest and highest abdominal fat, respectively, for a given age, height and weight (Table 6.3).

In boys, the three body shape variables (WC, WHTR and CI) had independent effects on the relationship between BMI and %BF. This is especially useful and significant because these three parameters can be routinely measured. After adjusting for age and ethnicity, BMI underestimated %BF with increasing WC, WHTR and CI. In boys, but not in girls, for a given age, height and weight, Maori and Pacific Islanders had a smaller WC, WHTR and CI than Europeans and Asian Indians, and correspondingly greater muscularity (56, 69, 70). Thus, it is not unexpected that correction for these body shape variables markedly reduced %BF differences between these ethnic groups in boys. WC, WHTR and CI increased the explained variance of %BF by 2.9%, 4.9% and 5.3%, respectively (Table 6.5). Daniels *et al* (60) showed in children and adolescents (7-17 y) that, after controlling for BMI, gender, race and maturation stage, BMI underestimates %BF with increasing waist:hip ratio, and this girth measure added 3% to the explained variance of %BF in that model. CI, which assesses waist girth in relation to weight and height, has seldom been studied and, to my knowledge, this is the first study to show that CI has an independent effect on the relationship between BMI and %BF in adolescents. In adolescents, although CI predicts trunk fat mass (78), it

correlates poorly with total body weight (440) and is not highly correlated with BMI but is a predictor of %BF and cardiovascular disease risk (441). Compared to WC and WHTR, CI had a much lower correlation with BMI, which may make this variable particularly useful in total body fat estimation. Therefore, this study supports the measurement of waist circumference, along with weight and height, when assessing %BF.

Others have shown that relative sitting height did not have a major impact on %BF-BMI (76) and BMI-%BF (77) relationships in adults. Although this study found that BMI underestimated %BF in boys with relatively longer legs (Section 6.2) when the %BF prediction equations were adjusted for LL/height, the effects of relative leg length on the %BF ethnic differences (boys or girls) were modest.

In addition to predicting adiposity, BMI predicts muscularity (442); increased muscle mass being required to support the excess fat mass associated with increased BMI (443). Increasing BMI results from the combination of both increasing fat mass, which increases %BF, and increasing FFM, which decreases %BF, leading to a non-linear relationship between %BF and BMI. As demonstrated by Norgan (444) and Webster *et al* (445), the slope of the %BF-BMI curve becomes increasingly less as BMI increases, and %BF approaches a maximum value. The current study and others in the literature where high BMI ranges have been investigated have found curvilinear relationships between BMI and %BF (446, 447) and both $\log_{10}$ (32, 68-70) and reciprocal (448, 449) transformations have been applied to BMI to attain linearity.

Conclusion

In conclusion, this study showed, in a sample of adolescents, that BMI is not a uniform measure of fatness across European, Maori, Pacific Island and Asian Indian ethnic groups. To more accurately reflect %BF, BMI cut-offs for obesity may need to be set at different points for Maori, Pacific Islanders and Asian Indians. This is important for studies of adolescents from different ethnic groups which use body size as a measure of fatness (7). Improved prediction of %BF by BMI may be obtained by including measurements of waist circumference and fat distribution (by, for example, skinfold thicknesses). These additional measurements may provide a more accurate assessment of health risk than reliance on BMI alone.

9.2.1.2 Bioimpedance analysis

The BIA_8 instrument provides hand-to-foot bioimpedance measurements for subjects in the standing position and is therefore a practical field method for estimating body composition. The manufacturer's equations were not valid for the estimation of body fat in European, Maori, Pacific Island and Asian adolescents. The manufacturer's equations tended to overestimate FM (both absolute and percent) at low body fatness and underestimate this parameter at high fatness levels. On average, BIA_8 underestimated FM and %BF and overestimated FFM (Section 6.3).

To the author's knowledge, this is the first study to examine the validity of BIA_8 in a multi-ethnic group of adolescents. This study extends other work on the applicability of the BIA_8 instrument which showed that this machine underestimated FM (88) and %BF (88, 90) in obese adult females. These results are consistent with findings of the current study and those of Pietrobelli *et al* (91) in a study of males and females aged 6 – 64 y in which BIA_8 tended to overestimate %BF in leaner subjects and underestimate in fatter subjects. A larger study of 133 Gambian children (5-17 y) showed that BIA_8 overestimated %BF (derived by isotope dilution) toward the lower end of %BF (92). In the multi-ethnic sample of the present study, this dependence of the BIA_8 measurement bias on fatness level also applied within each sex and ethnic group. A recent study in both normal- and over-weight adults showed that the BIA_8 instrument underestimated %BF (87).

Apart from the study that used isotope dilution (92), these published studies and the present one used DXA as the reference body composition method. While DXA, regarded as a gold standard for bone measurement, is not without limitations for body fat estimation (450), it is widely available and more easily applied and acceptable to volunteers than other reference methods such as those based on hydrodensitometry or isotope dilution. The four-compartment model (451), as the preferred reference technique, has rarely been applied in children and adolescents for the development of equations based on BIA (452). DXA and isotope dilution have been widely used as is evident from the summary provided by Nielsen *et al* (67). The latter approach, however, requires consideration of the variation in hydration of the fat-free mass with maturation (453) and with adiposity (454) whereas DXA provides estimates of fat mass which are relatively independent of hydration (454). Bray *et al* (454), in their children's study, have compared performance of several equations developed from BIA measurements in children with their body composition results based on multiple techniques including DXA, isotope dilution, skinfold anthropometry and the 4-compartment model.

BIA technology is designed to estimate total body water and provides only an indirect measure of FFM. FFM composition is affected by maturational stage (428) and rate of maturation may differ between ethnic groups. This study did not measure pubertal status, which may have improved predictive accuracy. However, the author is not aware of any published studies in healthy adolescents that have included pubertal status in BIA prediction equations with the exception of Horlick *et al* (84), where Tanner stage was included in the model for a multi-ethnic group of 4-18 year-olds.

FFM was the outcome variable rather than FM or %BF, because of the functional relationship between bioimpedance and the hydrated lean tissue of the body. Using body weight, the equations developed in this study can easily be used to calculate FM and %BF. Although these equations were developed across a wide %BF range, their predictions of FM and %BF showed good agreement with measurements by DXA. To the best of the author's knowledge, fatness-specific equations have not been developed for adolescents.

In both equations, H^2/Z explained a high proportion of the variability in FFM (86% for boys, 87% for girls) (Section 6.3). As there may be differences in relative leg lengths between populations (455) and differences in body geometry may affect the electrical properties of the body (456), this study measured leg length and sitting height and showed that, consistent with previous work (32), they did not add significantly to the models developed. Age was a significant predictor for the equation for boys but not for girls. In both sexes, Pacific Islanders (and Maori in boys) had more FFM than Europeans and Asians (and Maori in girls), after controlling for all other predictors. This ethnic effect is not surprising, since previous work suggests that, compared to Europeans, Pacific Island children enter puberty or mature earlier (45-47) and are leaner for a given body size (32). In adults, for the same BMI, Maori (69, 73) and Pacific Islanders (68-70, 73) have less FM or %BF than Europeans or Asian Indians. A multi-ethnic (black, white and other races) sample of adolescent girls was also studied by Phillips *et al* (457) and the equations they developed based on BIA prediction of FFM (derived by isotope dilution) were similar to those of the current study. In both premenarcheal and postmenarcheal girls the best predictors found by Phillips *et al* (457) were height^2/resistance, weight, height, black race and other race. In the current study, for the same impedance index, height and weight, Pacific Island girls have 1.6 kg more FFM than European, Maori and Asian girls. This result is similar to that found in the study of girls aged 10-15 y by Going *et al* (458), in which prediction equations for adolescent girls from different ethnic groups (black, Hispanic, white and other races) were developed (with pubertal status not accounted for) and for the same age, weight and height^2/resistance, black girls had approximately 1.6 kg more FFM compared to non-black girls.

One recent study of abdominally obese women (459) showed that BIA_8 was not superior to a 4-electrode BIA system, BMI or waist circumference in detecting metabolic risk factors. However, in participants in that study (459), BIA_8 did not provide valid estimates of FM and %BF (88). Equations developed in the current study may have a role in epidemiological studies designed to predict health risk from fatness; however, cohort studies are required that demonstrate that %BF is a better predictor of obesity-related morbidity than BMI.

In conclusion, using a double cross-validation procedure, robust equations for body fat estimation using an 8-electrode BIA device that are applicable to European, Maori, Pacific Island and Asian adolescents in the 12-19 y age range, were developed. These equations perform better than reliance on the manufacturer's estimates and show that ethnicity is important in BIA prediction of body fat in adolescents. As BMI does not differentiate between fat and lean mass and is not an equivalent measure of fatness across ethnic groups (32, 63-65, 68-70, 73), these equations have particular value for multi-ethnic adolescent populations (7), where a more accurate assessment of fatness is needed. Longitudinal studies are required to show if, in adolescents, these equations can accurately determine individual changes in body composition.

9.2.1.3 Waist circumference and trunk impedance

This is the first study to examine the relationship between WC and %AbFM (Section 6.4). This association was dependent upon ethnicity, age, height and weight. Previous work suggests that anthropometry-based equations have the potential to accurately predict %AbFM, as suggested by results from studies which measured %TF (Tables 3.6 and 3.7), and findings of this thesis confirm this. This study shows for the first time that, using a practical technique, trunk impedance predicts abdominal fatness in adolescents. This was notably evident when ethnic differences in %AbFM at a fixed WC were attenuated after correction for trunk impedance, especially in boys (Section 6.4). In fact, at a given WC, Z_{Tr} appeared to reflect the quantity of %AbFM.

This thesis extends the work of several studies in both children and adults which have found that WC predicts %TF measured by DXA (95-102). However, this current study has shown for the first time using a cross-validation technique, in a large group of adolescents, over wide ranges of WC and %AbFM, that equations based on WC and WHTR are also good predictors of %AbFM when combined in models with age, height and weight (Table 6.8).

In females, BMI was correlated with %TF (96, 99, 101) and more so than WC (96, 99). In the present study, BMI was a better predictor of %AbFM than WC variables in girls but not in boys, which is consistent with studies showing that BMI is more reflective of FFM in the latter. This thesis builds on the findings of the above studies (96, 99, 101) by illustrating, for the first time, that the relationship between BMI and %AbFM is dependent upon ethnicity, age, height and WHTR (Table 6.8).

Other studies have found that, for a given WC or WHTR, Asians have more %TF or visceral adipose tissue than Caucasians, but these have been carried out in adults (95, 460, 461). In the present study of adolescents, after adjustment for age (boys and girls), and height and weight (in girls) for the same WHTR, Asians have higher and Pacific Islanders have lower %AbFM than Europeans and Maori (Table 6.8). Similarly, in each sex, after adjustment for height and age (boys and girls), and weight (in girls), for the same WC, Asians have higher and Pacific Islanders have lower %AbFM than Europeans and Maori (Table 6.8). These ethnic effects are not surprising, because, compared to Europeans, for a given BMI, Pacific Islanders have less %BF (32, 66, 68-70) and TFM (73) while Asians have more %BF (64, 65, 69, 70).

Experimental studies of electrical conductivity with materials (e.g., copper wire) predict that an area of an electrical conductor is proportional to 1/resistance. This means that the expected relationship between abdominal FFM per cm height and trunk impedance is a reciprocal one. Data from this study indicated that abdominal FFM per cm height was proportional to 1/trunk impedance (Figure 6.4), indicating that trunk impedance predicts abdominal FFM in a manner that is consistent with theory.

Ethnic differences in %AbFM were reduced by adjustment for trunk impedance, and the size of this decrease was smaller in girls than in boys (Table 6.9). This is possibly due to the fact that the abdominal FFM per cm height range was narrower in girls than in boys (Table 6.2). Had the abdominal FFM per cm height range for girls been wider, trunk impedance may have had a stronger effect on the %AbFM ethnic differences in this group.

A study of adults found that the correlation between abdominal VFA and anthropometry-based equations (using sagittal abdominal diameter, waist:hip ratio, gender, age and weight) was 0.906, and when impedance was added to the model, the correlation increased by up to 0.014, depending on the posture of the subjects, the distance between electrodes and current frequency (106). Those

improvements to abdominal VFA prediction are in the range of improvements to %AbFM estimation that was found in this thesis when $1/Z_{Tr}$ was included as a predictor in models for girls (Tables 7.8 and 7.10). However, the increases to the R^2 for the boys' models are greater than these improvements (Tables 7.8 and 7.10). These discrepancies may be due to a difference in methodology, in that the outcome variable for abdominal VFA estimation is VFA, and may further be due to the use of different predictors and the different demographic characteristics of the study participants (106). Of note, the increase in R^2 for the BMI model for boys in the current study was 0.088 (Tables 7.8 and 7.10); this supports the measurement of trunk impedance when assessing abdominal obesity with BMI. Results showed that ethnic differences in the relationship between anthropometric variables and %AbFM was reduced after correction for $1/Z_{Tr}$, suggesting that adjustment for trunk impedance allows these anthropometric variables to more accurately reflect abdominal obesity across ethnic groups. For example, visceral and subcutaneous adipose tissue differ in amount across ethnic groups at a given WC (103, 460, 461) and trunk impedance measure may have a role in estimating these more accurately. Studies should examine this, as well as those that assess the ability of trunk impedance measure to predict health risk.

In this thesis, WC was measured at the level of the umbilicus. Studies of children and adolescents show that WC measures taken at the umbilicus do not substantially differ from WC measures taken at other sites (100, 432). In addition, the correlation between WC and %TF is not largely different to the correlation between WC taken at certain other sites and %TF (100, 102). Findings from this thesis, therefore, are expected to have acceptable applicability to studies that measure WC at sites other than the umbilicus.

WC, WHTR and BMI were transformed ($\log_{10}$ for boys and reciprocal for girls) to linearise their curvilinear relationships with %AbFM. Both abdominal FM and FFM contribute to WC, WHTR and BMI. Therefore, because increasing abdominal FM increases %AbFM and increasing abdominal FFM decreases %AbFM, a curvilinear relationship between these anthropometric variables and %AbFM is expected. Curvilinear WC-%TF and BMI-%TF relationships were reported in Hong Kong Chinese women and a reciprocal transformation was applied to account for this (99).

Conclusion

In conclusion, the current study shows that the relationship between WC and %AbFM is affected by age, height, weight and ethnicity. This thesis has demonstrated that %AbFM can be accurately

predicted from equations based on WC. Measurement of trunk impedance provides a new and simple means of quantifying abdominal obesity more accurately than relying on WC alone.

9.2.2 Limitations and strengths

The limitations of the validation study are discussed in Section 9.2.2.1. Strengths are discussed in Section 9.2.2.2.

9.2.2.1 Limitations of this study

1) Measurement error

There are measurement errors associated with: 1) anthropometric and BIA measurements, 2) ethnicity identification and, 3) DXA measurements.

Anthropometric and BIA measurements

The weight, height, waist circumference and impedance measurements are subject to error from poor test-retest reliability. However, this error was minimised by carrying out these measurements twice and using the average of these measurements for the analysis, as described in Section 5.3.

Ethnicity

The ethnicity determination does not account for variation in admixture. This means that ethnic differences in the relationship between readily measured physical measurements and body composition may be greater than that observed in this thesis, had the degree of admixture been large.

DXA measurements

DXA-measured %AbFM, does not distinguish between visceral and subcutaneous fat, which have been shown to have differential relationships with disease risk factors (59). Nevertheless, as DXA-measured abdominal and trunk fat correlate with metabolic risk factors (459, 462-466), the associations between readily measured variables and %AbFM reported in Section 6.4 have potential use in better quantifying health risk.

2) Confounding

An important limitation of the analysis that examined the relationship between BMI and %BF (Section 6.2) is that pubertal stage was not measured. Pubertal stage may (60) (though not necessarily (467)) have been a more important covariate than age. Even though the ethnic groups did

not differ in age, they may have differed in maturational stage, which may have contributed to the observed ethnic effects (428). The influence this may have had on these ethnic effects depends on how pubertal status varied across the ethnic groups in the validation study sample. If, for instance, the Pacific and Maori participants were at a higher maturational stage at a given BMI and age relative to the European participants, this may have resulted in the Pacific and Maori participants having less %BF for a BMI and consequently higher BMI for a given %BF. However, ethnic differences in body composition and body size, as seen in adults (Tables 3.2.2 and 3.2.3), that are independent of pubertal status and not necessarily related to biological age are expected. It is recognised that controlling for maturational stage may improve the %BF predictions and that differences in physical activity levels (468) and dietary habits between the ethnic groups may also contribute. For these reasons, the BMI cut-offs provided in Table 6.4 must be regarded as approximate until full account is taken of these potential confounders. To control for pubertal stage, future work could acquire a large sample size and carry out analyses in narrow age groups to minimise possible confounding from puberty. Another approach could be to develop valid pubertal measures for the ethnic groups in this thesis (by "updating" the Tanner staging criteria so that they are representative of these groups) (403), assess pubertal stage with these and statistically adjust for this.

Similarly, variation in physical activity level and dietary habits may have contributed to ethnic differences in the relationship between WC and %AbFM (Section 6.4). For example, with regard to physical activity, it is possible that the Pacific Island participants may have been more physically active than the non-Pacific participants, and this difference may have contributed to their having the lowest %AbFM at a given WC. This may limit the ability to make generalisations about ethnic differences in the %AbFM models developed in this thesis. Ethnic differences in maturational stage is another potential confounder (469). However, studies have found that pubertal stage does not predict VAT independently of WC (470, 471) but adult studies show that ethnicity does (460, 461).

9.2.2.2 Strengths of this study

A strength of this study is that the measurement of body fat by the study's reference method, DXA, is not affected by ethnicity (395, 396). Another strength is that a community sample, that included wide ranges of anthropometric variables (including BMI and WC) and DXA-measured variables (including %BF and %AbFM), was recruited. Subjects in the current study were similar in weight, height, BMI and WC to the participants in the OPIC study (7).

A strength related to the findings for the associations between trunk impedance and body composition variables (Section 6.4) is the method of trunk impedance measurement. Research indicates that when trunk impedance is measured from electrodes placed directly on the skin in the abdomen, the value is dependent upon the positioning of the electrodes, which introduces measurement error (394). The difficulty of keeping electrode placement constant was overcome in the present study because trunk impedance was calculated as total impedance less the sum of left arm and left leg impedance by contact electrodes that were at a fixed distance apart. Thus, no positioning of electrodes was required and trunk impedance measurement was standardised, which reduced measurement error.

9.3 OPIC study

In this section, the results of Chapter 8 (*OPIC study results*) will be discussed. Although results were provided for all participants (Section 8.2.2), only results specifically for those not trying to change weight (Section 8.3.2) will be discussed in this section. The rationale for this has been previously given in Chapter 8.

9.3.1 Comparison of results with literature

This section will describe the OPIC study findings and discuss these in relation to those of previous studies. Section 9.3.1.1 will discuss the findings from Section 8.3.2.1 (*Television watching*), Section 9.3.1.2 will discuss the findings from Section 8.3.2.2 (*Sugary drink consumption*), Section 9.3.1.3 will discuss the findings from Section 8.3.2.3 (*Breakfast consumption*) and Section 9.3.1.4 will discuss the findings from Section 8.3.2.4 (*Physical activity*). In the final section, Section 9.3.1.5, the variable strength of association with differences measures of fatness that was observed in Section 8.3.2 will be discussed.

9.3.1.1 Television watching

This thesis showed that, in all ethnic groups combined, TV viewing was positively related to body composition variables, with BMI, %BF and TFM being significantly higher among those who watched TV for >2 hours per day than among those who watched for <1 hour per day (Section 8.3.2.1). Increases in hours per day of TV viewing were associated with percentage changes in body composition variables that were greatest for TFM, followed by %BF (Figure 8.20).

These findings extend the work of other studies that have examined the association between TV watching and fatness in Australia, Pacific Island and New Zealand.

Australian studies

Consistent with the overall TV viewing-fatness relationship observed in this thesis, previous Australian studies have reported positive associations between TV viewing and fatness (115-117). In these studies, the samples had limited representativeness and the participants were young (aged <13 years) (115-117).

Pacific Island studies

A study of Tongan adolescents found a non-significant, positive association between TV watching with odds of overweight/obesity (113). However, that study had a relatively small sample size (n=443) and used only weight status based on BMI to measure fatness. That study may have observed a significantly positive association had the sample size been larger and if %BF or TFM were used as response variables.

New Zealand studies

Previous New Zealand studies have reported significant, positive associations between TV watching and fatness (31, 44, 118-122). These studies comprised young participants (44, 118, 121), had a sample that was of limited representativeness (119-122), comprised a small sample size (n=102) (121), used only BMI (or weight status based on BMI) as a fatness measure (44, 118-120) and one study estimated %BF from a prediction equation (32) that had not been developed for its target population (31). Nevertheless, their findings (31, 44, 118-122) are consistent with those of the current study, which also found a significant, positive relationship between TV viewing and fatness among all ethnic groups combined.

Conclusion

TV viewing was significantly and positively related to fatness in South Pacific youth and this association was strongest for TFM and %BF. These findings showed consistency with previous studies carried out in the South Pacific.

9.3.1.2 Sugary drink consumption

Across ethnic groups, soft drink consumption had a consistently positive association with fatness. Among all ethnic groups combined, soft drink consumption had significant, positive, notable and

dose-dependent associations with body composition variables. This was particularly true when TFM was the response variable (Section 8.3.2.2).

In comparison, overall (all ethnic groups together) associations showed that fruit drink/cordial consumption was not significantly associated with fatness (Section 8.3.2.2). A possible reason is that it did not differentiate between diet and non-diet consumption (see questions in Appendix 2). Had this study specifically measured *non-diet* fruit drink/cordial consumption, a significantly positive association may have been observed.

The abovementioned findings relate to those of similar studies carried out in Australia, Pacific Islands and New Zealand.

Australian studies

The positive relationships between soft drink consumption and body composition variables in all ethnic groups combined are consistent with those of an Australian study, which found that soft drink/cordial intake was positively related to excess weight gain (based on BMI) (219). That study comprised a sample of small size (n=281) and limited representativeness, and the participants were children (219). Further, that study did not find an association between carbohydrate consumed from fruit juice/fruit drinks and BMI status (219). This is consistent with the absence of a significant association between fruit drink/cordial consumption and fatness reported in the current study.

Pacific Island studies

Among Tongan adolescents, soft drink consumption was reported to be positively associated with odds of overweight, but this effect was not significant (113). However, that study was relatively small (n=403), used only weight status based on BMI to measure fatness and did not adjust for dieting or portion size in analyses (113). It may be that if that study was carried out in a larger sample, used TFM or %BF as body composition variables and controlled for dieting and portion size, a significantly positive association may have been observed, as was found in the current study.

New Zealand studies

Previous New Zealand studies found that sugary drink consumption was significantly and positively related with fatness (44, 220, 221). Each of these studies had smaller sample size (44, 220, 221) than that of the current study. Further, they used only BMI as a fatness measure (44, 221), did not adjust for dieting (44, 220) and studied children (44, 220). In spite of this, those findings are in line with the

significantly positive associations between soft drink consumption and fatness that were observed among all ethnic groups combined in the present study.

Conclusion

This thesis showed that, among all ethnic groups combined, soft drink consumption had significant, strong, positive and dose-dependent associations with body composition variables. Such associations were strongest for TFM, followed by %BF and then BMI. These findings are consistent with those of similar studies previously carried out in Australia and New Zealand. Finally, fruit drink/cordial consumption did not appear to be significantly related to fatness, possibly due to the fact that its definition included *diet* consumption.

9.3.1.3 Breakfast consumption

This study showed that in all ethnic groups combined, frequency of breakfast consumption had inverse associations with body composition variables. For these associations, percentage changes in body composition variables were greatest for TFM, followed by %BF and then TFM (Figure 8.20). These findings extend the work of previous Australian, Pacific Island and New Zealand studies that have examined the association between breakfast consumption and fatness.

Australian studies

In a relatively small sample (n=508) of Australian males aged 18 years and of limited representativeness, BMI and waist:hip ratio were significantly lower among those who had a continental or cooked breakfast on both days than among those who did not have this (272). This finding is subject to confounding, however, as weight-control attempts were not adjusted for (272). In view of this, the current study adds to this Australian study finding by showing that an inverse association similarly exists when weight-control attempts are adjusted for.

Pacific Island studies

In a sample that was relatively small (n=517) and of limited representativeness, a study of Fijian adolescent girls found that breakfast skipping was significantly and positively associated with odds of overweight (273). The significant effect reported in that study (273) is consistent with the significantly inverse association observed in this thesis. While the present study controlled for dieting, the Fijian study did not (273), indicating that this thesis has added to the Pacific Island literature.

New Zealand studies

This thesis showed that, among all New Zealand youth, as breakfast consumption frequency decreased, fatness levels significantly increased (Table 8.9). This is consistent with an earlier analysis of the New Zealand OPIC dataset, which showed that, among those who were not trying to change weight, breakfast consumption (days per school week) had a significant, inverse association with BMI (221). Extending this study finding, this thesis has shown that, in a larger sample of adolescents (all ethnic groups combined), frequency of breakfast consumption is significantly and inversely related to BMI, %BF and TFM.

Other New Zealand studies have found that breakfast consumption is inversely related to fatness (44, 218, 220). These studies did not adjust for dieting (44, 218, 220), used only BMI as a fatness measure (44, 218, 221) and their samples comprised primary school-aged children (44, 218, 220). Nevertheless, their findings concur with the inverse breakfast consumption-fatness associations observed in this thesis.

Conclusion

In South Pacific youth, breakfast consumption had inverse associations with body composition variables, and these relationships were strongest for TFM and weakest for BMI. Other South Pacific studies similarly found that breakfast consumption is significantly and inversely related to fatness. In view of the abovementioned limitations of these studies, such as the use of only BMI to measure fatness and the lack of adjustment for dieting, this thesis adds to the literature on the association between breakfast consumption and fatness in South Pacific adolescents.

9.3.1.4 Physical activity

Across ethnic groups, after-school physical activity consistently had an inverse relationship with body composition variables. Overall associations were significant, inverse, notable and dose-dependent. In all ethnic groups combined, relationships were strongest for TFM, followed by %BF and then BMI (Section 8.3.2.4). In contrast, physical activity during lunch-time was not significantly associated with body composition variables, while physical activity during morning recess/interval was not significantly related to %BF and TFM (Section 8.3.2.4).

The fact that after-school physical activity but not physical activity during morning recess/interval or lunch-time was significantly related to fatness is not an unexpected finding. School recess/interval

and lunch-time are not long time periods, which limits the opportunity for physical activity to influence fatness. In comparison, as after-school is a longer duration, physical activity at this time may be longer in duration and thus may have a more important influence on fatness. Furthermore, as after-school physical activity may measure training/practice sessions, it may be also measure physical activity that occurs on weekends.

These thesis findings relate to those of previous South Pacific studies that have examined the association between physical activity and fatness.

Australian studies

The inverse relationships between after-school physical activity and body composition variables in all ethnic groups combined are consistent with those of previous Australian studies (117, 325, 327, 330-334, 336), which have found that physical activity is inversely associated with fatness. Of these studies (117, 325, 327, 330-334, 336), some were small (n=47 (330) and n=297 (332)), most used only BMI (or weight-status based on BMI) as a fatness measure (117, 325, 327, 332, 336), not one adjusted for weight-control attempts, most studied children (<14 years) (117, 327, 330, 331, 334, 336) and the majority were not nationally representative (117, 327, 330-334, 336). Nevertheless, their findings are in line with the inverse physical activity-fatness associations observed among all ethnic groups in the current study.

Pacific Island studies

A study of Tongan adolescents found that exercise frequency/duration was negatively associated with overweight/obesity (113). Although the sample size was small (n=443), used only weight status based on BMI to measure fatness and did not adjust for weight-control attempts (113), this finding is consistent with those of the present study, which found a negative correlation between physical activity and fatness.

New Zealand studies

Previous New Zealand studies found that physical activity was inversely related with fatness (122, 220, 337-339, 341). The sample sizes of all of these studies (122, 220, 337-339, 341) were smaller than that of the current one. In addition, they used only BMI as a fatness measure (337), did not adjust for weight-control attempts (122, 220, 337-339) and studied only children (122, 220, 338, 339). Nevertheless, their findings are consistent with the inverse physical activity-fatness associations reported among all ethnic groups combined in the present study. An analysis of the CN202 showed that physical activity was not significantly correlated with BMI after adjustment for

lifestyle variables; this may be due to the fact that physical activity was measured subjectively (with a questionnaire), BMI was used to measure fatness and/or weight-control attempts were not adjusted for (44).

Conclusion

South Pacific literature has indicated that physical activity level is inversely related to fatness in children (117, 122, 220, 327, 330, 331, 334, 336, 338, 339) and youth (113, 325, 332, 333, 337). This thesis has shown this to be the case in a larger sample of South Pacific adolescents – after-school physical activity was negatively correlated with body composition variables – and that the association was particularly true when %BF and TFM were used as fatness measures instead of body size. Previous South Pacific studies have a limited ability to show this because of their abovementioned limitations, including the reliance on only BMI to measure fatness and the failure to adjust for weight-control attempts. Finally, this thesis showed that physical activity during lunch-time was not significantly associated with fatness and physical activity during morning recess/interval did not have significant relationships with %BF and TFM, possibly due to the limited duration of activity possible at those times.

9.3.1.5 Variable strength of association with different measures of fatness

This thesis showed that changes in lifestyle variables were associated with percentage changes in body composition that varied in size from one body composition variable to another. That is, percentage change was greater for TFM than for %BF, which was greater than for BMI (Figure 8.20).

These findings are consistent with those of the AHHS, which examined associations between TV watching and both BMI and %BF (31). The AHHS found that, compared to those who watched for ≤14 hours/week, BMI was not significantly higher while %BF was 0.96% higher among those who watched between 14 and 29 hours/week. Thus, %BF was more strongly related to the change in TV exposure (≤14 hours/week versus 14-29 hours/week) than BMI. Further, compared to those who watched for ≤14 hours/week, among those who watched for ≥29 hours/week, BMI was 0.68 kg/m^2 higher, which represents 2.8% of the mean BMI in that study, while %BF was 1.65% higher, which represents 6.6% of the mean %BF for that study. Therefore, %BF was more strongly related to the change in TV exposure (≤14 hours/week versus ≥29 hours/week) than BMI. A limitation of the AHHS findings (31) is that %BF was estimated from a BIA prediction equation developed in a sample of young children (32), which adds uncertainty to the validity of the AHHS findings.

However, the current study shows that, in South Pacific youth, TV watching is more strongly associated with percentage changes in %BF than those of BMI.

In the current study, the fact that the percentage changes were greatest for TFM reflects the plasticity of adipose tissue as an energy storage compartment that varies in mass with changes in nutritional status (472). Fat mass is an energy-storage compartment that is influenced by energy intake and expenditure.

The validation study showed that there is a lot of variation in %BF at a given BMI (Section 6.2). Therefore, BMI has a limited ability to reflect adiposity. This was reflected in finding that BMI had a weaker association with lifestyle variables than %BF (Figure 8.20). In addition, %BF and BMI are both influenced by FFM, which would weaken their association with lifestyle variables. Thus, it is not unexpected that lifestyle variables had weaker associations with BMI and %BF than TFM.

Another reason why it is not surprising that %BF had a weaker association with lifestyle variables than TFM is due to how it is defined. %BF is numerically equal to FM/(FM+FFM); the numerator and denominator of this equation including FM. Thus, an increase in FM will increase the numerator (FM), leading to an increase in %BF; but will also increase the denominator (FM+FFM), leading to a simultaneous decrease in %BF. In other words, an increase in FM will be underestimated by an increase in %BF.

Conclusion

In South Pacific youth, lifestyle variables were most strongly related to TFM, followed by %BF and then BMI. This is an original finding. Changes in lifestyle obesity risk factors change fat stores through a change in energy intake and expenditure. %BF and, in particular, BMI have a limited ability to reflect these changes in body composition. A reason for this is that they are influenced by FFM.

9.3.2 Limitations and strengths

The limitations of the OPIC study are discussed below in Section 9.3.2.1. The strengths of this study are subsequently discussed in Section 9.3.2.2. After this, the influence of these limitations and strengths on OPIC study findings will be summarised (*Conclusion* section).

9.3.2.1 Limitations of this study

1) Study design (temporality)

As this study is cross-sectional, it is unable to determine causation. The development of obesity is a result of body composition changes over years. To better determine causality, longitudinal studies, which follow up changes in lifestyle variables with changes in body composition or obesity prevalence, are needed. Importantly, longitudinal studies indicate that TV watching and sugary drink consumption are longitudinally related to body composition (Tables 4.2.1, 4.2.3, 4.2.4, 4.3.1 and 4.3.4).

2) Sampling method

In the current study, participants were sampled from selected schools rather than a population of adolescents; that is, clustered sampling was used. This sampling approach reduces the random variation between participants and consequently reduces standard errors of variables in statistical models. However, this effect was accounted for in statistical analyses through the use of SUDAAN.

Another limitation of this sampling method is that it was not able to sample from school leavers. This does not reflect unfavourably on this study when compared with the literature, though, because previous studies examined in the literature review of this thesis (Chapter 4) also did not sample from school leavers. In addition, the limitation is not of great significance, given that school leavers make a small proportion of high school-aged students (473-475).

Because the participating schools of this study were purposively sampled from specific areas (e.g., South Auckland for the New Zealand data), this suggests that the samples are not nationally representative. Of note, however, because a high proportion (two-thirds (476)) of Pacific Island students in New Zealand live in South Auckland, it is indeed possible that, at best, the New Zealand Pacific Island sample is nationally representative. Another limitation that relates to the sampling method is that, because participants were recruited from schools in low socio-economic areas, the ability of the current study findings to be extrapolated to less deprived areas is limited.

3) Response rate

This study is subject to selection bias. Consequently, those that participated may be different to those who were eligible to participate. That is, it is possible that the non-participants may have differed in some way to the participants. This is more likely to occur if the response rate is lower. The response rates per country ranged from 49% to 74% (denominator is number of students on the school roll)

(Section 7.2). While these are not ideal, they are not very low and they compare well against those of other studies (Chapter 4).

4) Random measurement error

The findings of this thesis are affected by random measurement error. This exists when measurement error is equal between comparison groups. Random measurement error dilutes (weakens) associations (112, 477).

The measurements of weight, height, waist circumference and impedance are subject to random measurement error. As these measurements depend on the skill of the interviewer, the measurements are subject to error from poor test-retest reliability and poor between-person reliability. Taking waist girth measurement requires particular care and is subject to poor repeatability if measurers are not consistent with their measurement technique. However, possible measurement error from waist circumference and other physical measurements was minimised in the present study by some important provisions. Staff members who carried out measurements were trained to take quality physical measurements. Each staff member was given an identification number and this was written down when they measured a subject in order to monitor the quality of the measurements taken by him or her. In addition, two sets of waist circumference measurements were taken. In the context of the literature, the quality of the physical measurement data in this study is superior to that of many other studies which relied on self-reported physical measurements (43, 138, 143, 160, 168, 182, 217, 223, 244, 280, 282, 285, 287, 294, 300, 301, 306).

Another source of random measurement error arises from the fact that the OPIC questionnaire does not capture day-to-day variation in lifestyle habits. For example, on the day of data collection, a student who normally eats breakfast may have got up late in the morning and chose not to eat breakfast in order to arrive at school on time; or a person who usually does after-school physical activity may have been unable to do activity after school during the 5 days preceding the day of data collection because of illness. Another source of random measurement error arises from that possibility that TV viewing time reported may include time when the TV is on but not being viewed.

Random measurement error additionally results from imperfect memory to remember and answer survey questions. However, the size of this error was reduced by asking about lifestyle habits: 1) during *specified* times of the day (for example, *after-school* physical activity), 2) in the *past week* (not, for example, TV viewing or sugary drink consumption in the past 4 weeks, which is harder to

recall) and, 3) on *specified* days – participants were asked about TV watching on *weekdays*, *Saturdays* and *Sundays*, and were asked about glasses/cans of sugary drinks consumed on the *last* school day. These things would have aided recall (418).

Nearly all studies that have examined the association of TV watching with fatness have not measured TV content (419) and many studies did not separate TV watching from video watching (43, 135, 138, 145, 153, 161, 182, 185, 192). As is a limitation in just about all studies, the current study did not measure TV content. That is, information on the programmes watched was not collected. The definition of TV viewing included watching videos and DVDs, which may have lacked food advertising content. TV advertising content is not conducive to nutritious dietary intake in children (209, 210) and it has been shown that commercial but not non-commercial TV viewing is associated with BMI z-score in children (179). Therefore, TV watching may have had a stronger, positive association with fatness, compared to that reported in this thesis, if the programmes watched by the participants in the current study contained more food advertising.

In conclusion, there were several sources of random measurement error. The size of this error was partly reduced by the methodology employed, as described above. However, random measurement error is likely to have been present and would have an important influence on the measurement of lifestyle variables. Consequently, observed associations between lifestyle and body composition would have been weakened, meaning that the "true" sizes of these associations were stronger than those observed in this thesis.

5) Systematic measurement error

Another form of measurement error that may have influenced findings is systematic measurement error, which exists when measurement error is different between comparison groups. Systematic measurement error either strengthens or weaken associations (477).

A source of systematic measurement error is social desirability bias. There may have been deliberate mis-reporting of TV data: subjects who watched a lot of TV may have under-reported the amount of TV they watched because it may have been viewed that it is socially acceptable to watch less TV. Inactive participants may have over-reported frequency of after-school physical activity as it may have been seen as socially acceptable to do more physical activity. Obese adolescents may have under-reported their intake of soft drinks, as has been shown in previous studies (478), because of their unhealthy connotation. However, any influence on the results from this source of error was

minimised by: 1) indicating to the students that all collected data were confidential and, 2) having each student answer survey questions alone.

Another source of systematic measurement error arises from ability to remember serving sizes of sugary drinks consumed. Research suggests that people have difficulty recalling portion sizes as portion size increases (479). Therefore, it is possible that beverage serving size – and therefore beverage consumption – may be underestimated among those who consume large serving sizes of drinks. However, as participants were asked about sugary drink serving size (glasses/cans) on the *last* school day, this would have aided recall, thereby minimising measurement error.

In conclusion, the abovementioned sources of systematic measurement error were only few in number. The size of this error was minimised by the methodology employed, as described above. Therefore, systematic measurement error would have had minimal influence on associations between lifestyle and body composition, as well as other thesis findings.

6) Confounding

The cross-sectional nature of this study means that the results are subject to reverse causation. For instance, TV watching may have caused BMI to increase by decreasing physical activity; or it may be that obese adolescents are unable to participate in sports, leading to an increase in weight. As another example, it may be that obesity is a marker of depression, which predicts increased TV watching. However, longitudinal studies support the possibility that changes in TV watching and sugary drink consumption precede changes in fatness (Tables 4.2.1, 4.2.3, 4.2.4, 4.3.1 and 4.3.4). In addition, in this thesis, as an attempt to minimise the effect of reverse causation, analyses were performed among those not trying to change weight. This accounted for the influence of dieting and weight-control attempts on lifestyle.

Furthermore, if weight status did influence physical activity level, difficulty being physically active or fear of being teased may be mediators (Section 7.3). If so, adjustment of physical activity-fatness models for these mediators may strongly attenuate associations (480). Some of these potential mediators ("How well can I walk or run?", "It is difficult for me to run" and "It is difficult for me to play sport or do exercise") attenuated relationships between after-school physical activity and body composition variables (data not shown). However, the associations remained significant (data not shown). Therefore, this is some evidence to suggest that, if it did exist, reverse causation did not fully explain the association between physical activity and fatness.

Another observation that suggests that physical activity causes fatness, rather than vice versa, is the hierarchical strength of physical activity-body composition variables associations. That is, physical activity was most strongly related to TFM, followed by %BF and then BMI (Section 9.3.1.4). This hierarchical pattern would result from physical activity influencing fat mass (Section 9.3.1.5) instead of reverse causation.

This study did not measure income for each subject and so is not able to fully control for differences in personal SES status. However, possible confounding by SES was minimised through the sampling strategy employed: participants were recruited from areas of similar SES. Second, in the areas sampled from in New Zealand, there was low variation in personal SES (481), which would have further reduced the potential confounding effect of SES. Third, as an attempt to minimise any potential confounding by SES, SEIFA score (for Australian data) and household size (for data from each country) were statistically adjusted for in models (as mentioned in Section 7.3), but these did not notably alter the effect sizes of associations between lifestyle and body composition variables (data not shown).

Fast food meals often contain soft drinks (424), indicating that energy-dense foods may be consumed while soft drinks are being consumed. Therefore, it is plausible that the consumption of energy-dense foods may confound the relationship between sugary drink consumption and fatness. In addition, it is possible that high sugary drink consumption (425, 426), low breakfast consumption (218, 313, 482, 483) and low physical activity may be markers of an unhealthy lifestyle that includes high fast food consumption, regular snacking and/or low frequency of meal consumption. Consequently, an unhealthy lifestyle may confound the effect of sugary drink consumption, breakfast consumption and after-school physical activity on fatness. However, this did not seem to be the case as the inclusion of fast food consumption, snack food consumption, morning tea consumption frequency and lunch consumption frequency variables (all measured in the OPIC study, as mentioned in Section 7.3) in statistical models did not alter effect sizes (data not shown).

7) Restricting analyses to those not trying to change weight

The fact that analysis was restricted to those who were not trying to change weight may well have limited the ability to extrapolate the OPIC study findings to those trying to change weight. As discussed in Section 7.4, because of the increase in internal validity it provided, this restriction was considered to be – by the author and Rothman *et al* (436) – important and justifiable. However, the

findings have at least some applicability to the "change weight" group because individuals from this group probably would have previously made no attempts to change weight. In other words, the findings suggest that lifestyle factors may well have contributed to weight gain of individuals before they tried to change weight.

9.3.2.2 Strengths of this study

One of the strengths of this study is the large sample size. A second and important strength is that this study controlled for weight-control attempts. As shown in Chapter 4, a limitation of previous studies is that dieting was not adjusted for in analyses. This reduced the possibility of the associations being influenced by reverse causation, as mentioned above, and reduced systematic measurement error, as discussed in Section 7.4.

Another strength is the objective measurement of anthropometric variables. Previous studies that have examined the associations of TV watching (42, 138, 143, 160, 168, 182), sugary drink consumption (43, 217, 223, 238, 244, 246) and breakfast consumption (246, 280, 282, 285, 287, 294, 300, 301, 306) with fatness relied on self-reported height and weight. These studies are subject to measurement error of fatness because subjects tend to underestimate their weight and overestimate their height (484), which leads to an underestimation of BMI. Therefore, the use of objective measurement of weight, height and WC in this thesis strengthens the quality of its findings.

The use of accurate %BF and TFM measures in analyses is another strength of this thesis. In the AHHS (31), %BF was estimated from a BIA prediction equation developed in mainly primary school- and intermediate school-aged children (32). In contrast, this thesis obtained %BF and TFM measurements from a prediction equation developed in the study population of this thesis (Section 6.3), which strengthens the validity of its %BF and TFM measurements.

Conclusion

In view of the abovementioned limitations and strengths, the quality of the study findings compares well against those of previous studies. Potential confounders were well accounted for in analyses. Given the existence of random measurement error associated with lifestyle variables, the relationships between lifestyle and body composition variables may be stronger than that observed from the thesis results. In support of this, a meta-analysis of studies that examined the relationship between physical activity with fatness found stronger associations were observed when activity was measured by observation than when measured by questionnaires (382).

9.4 Conclusion

In conclusion, the validation study showed that:

- In South Pacific youth, the relationship between BMI and %BF varies with ethnicity.
- BMC, ASMM, fat distribution variables and body shape variables (WC, WHTR and CI) predicted %BF independently of BMI. In fact, when these variables were statistically adjusted for in %BF-BMI models, they eliminated or notably reduced ethnic differences in %BF.
- Therefore, this thesis developed BIA prediction equations that apply to adolescents living in the South Pacific so that body fat could be more accurately quantified. These equations depended upon ethnicity.
- Ethnicity influences the relationship between WC and %AbFM in this population. However, trunk impedance can be used to quantify %AbFM more accurately.

With regard to the OPIC study, the following conclusions can be made:

- Lifestyle variables that were significantly related to fatness were TV watching and soft drink consumption (both positively associated with fatness), and breakfast consumption and after-school physical activity (both inversely associated with fatness).
- As discussed in Section 9.3.1, these findings showed consistency with those of previous South Pacific studies.
- These associations were strongest when TFM was used as a fatness measure and weakest when BMI was used.
- Across ethnic groups, the direction of the TV watching and soft drink consumption associations were consistently positive, while the direction of the breakfast consumption and after-school physical activity associations were consistently inverse. TV watching relationships were dose-dependent, while soft drink consumption, breakfast consumption and after-school physical activity relationships were strong plus dose-dependent. When viewed from the lens of the Bradford-Hill criteria (114), this gives evidence that the associations may well be causal.
- In the light of intervention studies (Chapter 4), these results support the view that TV watching, soft drink consumption, breakfast consumption and after-school physical activity are determinants of fatness in South Pacific youth.

9.5 Implications and recommendations

9.5.1 Validation study

Findings from the validation study have important implications. Although some recommendations that have been made in Section 9.2.1, they will be elaborated on here.

1) Recognise that BMI cut-offs for obesity and WC cut-offs for abdominal obesity may need to be ethnic-specific

To more accurately reflect %BF, BMI cut-offs for obesity may need to be set higher in Pacific Island and Maori adolescents and lower in Asian adolescents (Table 6.4). Studies (485), particularly cohort ones, are required to examine whether these adjustments more accurately predict disease risk as well.

For the same WC or WHTR, out of all ethnic groups, Pacific Islanders had the lowest %AbFM, while Asians had the most %AbFM. Of note, there was a 5.3% difference in %AbFM between Pacific Island and Asian boys at the same WC (Table 6.8), which was 22% of the mean %AbFM value for boys (mean %AbFM values are shown in Table 6.2). Among girls, at the same WC, there was also a 5.3% difference in %AbFM between Pacific Islanders and Asians (Table 6.8), which was 15% of the mean %AbFM value for girls (mean %AbFM values are shown in Table 6.2). These are substantial and clinically relevant differences. Therefore, it is important to recognise that, to more accurately reflect %AbFM, WC-cut offs for abdominal obesity may need to be set higher in Pacific Island youth and lower in Asian youth.

2) Recognise that frame size, skinfold thickness, WC and other girth measures can be used to quantify %BF more accurately

As BMC, ASMM, fat distribution variables and body shape variables (WC, WHTR and CI) predicted %BF independently of BMI (Section 6.2), these variables can be used to quantify %BF better when used in combination with BMI. For example, if BMI does not change but WC-based variables (WC, WHTR or CI) increase, then %BF may have increased.

As shown in Section 6.2, ethnic differences in %BF at a given BMI were eliminated or notably reduced after adjustment for WC-based variables. At a given age, height and weight, Pacific Island boys had the lowest WC, WHTR and CI (Table 6.3) and lowest %BF (text of Section 6.2). This implies that making comparisons of WC, WHTR and CI at a given age, height and weight seems to

be a method that can be used to give some indication of whether BMI cut-offs for obesity may need to be raised (in the case of Pacific Island boys, who have less WC, WHTR and CI and hence %BF at the same BMI) or lowered. Similarly, frame size, skinfold thickness and girth measures other than WC could additionally be used as criteria on which to base BMI cut-offs for %BF; as ASMM, BMC and fat distribution variables notably influenced ethnic differences in the relationship between BMI and %BF.

3) Recognise that ethnicity is important in using BIA to estimate body composition

In the total-body BIA prediction equations for FFM estimation, ethnicity was a significant predictor (Section 6.3). Therefore, as mentioned in Section 9.2.1.2, it should be recognised that ethnicity can influence the relationship between BIA and body composition.

4) Use trunk impedance to quantify abdominal obesity more accurately

As trunk impedance provides information about the composition of the abdomen independently of WC and WHTR (Section 6.4), it can be used to quantify abdominal obesity more accurately. The author has applied this implication to the design of the *Fanau* ("OPIC 2") study, an obesity intervention for Pacific Island families (Health Research Council of New Zealand reference number 10/077). That is, in the *Fanau* study, trunk impedance will be measured, with the view that it may quantify abdominal obesity more accurately. Further, studies (particularly cohort studies) should examine whether trunk impedance predicts disease risk independently of WC or WHTR.

As shown in Section 6.4, ethnic differences in %AbFM at a given WC or WHTR were removed or notably attenuated after adjustment for trunk impedance. Of note, in boys, the difference in %AbFM between Pacific Islanders and Asians at a given WC or WHTR was reduced by 2.8% after adjustment for trunk impedance (Table 6.9). This reduction represents 12% of the mean %AbFM value for boys (mean %AbFM values are shown in Table 6.2). This is a large and clinically relevant effect size. Further, at the same WC or WHTR, Pacific Island boys had the lowest %AbFM (Table 6.8) and lowest trunk impedance (Section 6.4). In comparison, at a given WC or WHTR, Asians had the highest %AbFM (Table 6.8) and highest trunk impedance (Section 6.4). This suggests that making comparisons of trunk impedance at a given WC or WHTR seems to provide a way of deciding whether WC cut-offs for abdominal obesity may need to be raised (in the case of Pacific Island boys, who have less trunk impedance and hence %AbFM at the same WC) or lowered (in the case of Asians, who have less trunk impedance and hence %AbFM at the same WC). In other words, trunk impedance may be used as a criterion on which to base WC cut-offs for abdominal obesity.

9.5.2 OPIC study

Findings from the OPIC study give evidence to inform appropriate areas for obesity interventions and have important implications for future research.

1) Limit the amount of TV watched

This study showed that, among all ethnic groups combined, TV viewing had significantly positive, dose-dependent associations with BMI, %BF and TFM. This finding, in the light of successful intervention studies (Chapter 4), supports the view that limiting the amount of TV watched is a suitable strategy.

2) Reduce soft drink intake and increase water consumption

This study found that soft drink consumption had a significant, positive, strong and dose-dependent association with fatness. Of note, those that consumed more than 2 cans of soft drink per day had 11.7% more TFM than those who consumed 0 cans per day (Figure 8.20). This is a large and clinically relevant effect size. This finding, given previous successful intervention studies (Chapter 4), supports the view that reducing soft drink consumption is an appropriate area for obesity interventions to target. This is especially important for New Zealand Pacific Island and Maori youth, who particularly consumed large amounts of soft drinks (Tables 8.3 and 8.4).

3) Encourage regular breakfast consumption

As demonstrated in this thesis, breakfast consumption was strongly and inversely associated with fatness in a dose-dependent manner among all ethnic groups combined. Consequently, this supports the encouragement of regular breakfast consumption. This recommendation is particularly important for NZ Pacific Island and Maori adolescents since breakfast skipping is disproportionately prevalent in these groups (Tables 8.3 and 8.4).

4) Encourage regular physical activity

This thesis showed that, consistent with findings of previous South Pacific studies, physical activity (frequency) was significantly and inversely associated with fatness. In all ethnic groups combined, effect sizes were large and dose-dependent. Therefore, this supports the encouragement of regular physical activity, particularly after school.

5) Use TFM and %BF as fatness measures

Changes in lifestyle variables were associated with changes in body composition variables (expressed as a percentage of the mean value of the reference category) that were greater for TFM and %BF than BMI and greater for TFM than %BF (Figure 8.20). Obesity interventions and studies should recognise that changes in BMI, proportionally, will be weaker than that of changes in %BF and, in particular, TFM. For instance, studies that have examined the association between lifestyle variables (e.g., soft drink consumption (252, 253)) and BMI may have underestimated the "true" size of the effect on adiposity. This supports the measurement of TFM and %BF – and the use of BIA prediction equations developed in the validation study (Section 6.3) to estimate these in South Pacific youth – when assessing changes in body composition.

Conclusion

In conclusion, interventions that reduce TV watching, reduce soft drink consumption and increase both physical activity and breakfast consumption are recommended. Intervention studies are required to ascertain effective ways of delivering or carrying out these recommendations. In addition to quantifying body size, obesity interventions and studies should quantify TFM and %BF.

APPENDICES

Appendix 1: Literature search

The table below shows an example of a search carried out in *Medline In-process & Other non-indexed Citations and Medline.*

#	**Search history**	**Results**
1	body mass index.mp or body mass index/	91279
2	Waist-hip ratio/ or waist circumference/ or waist.mp	14904
3	Skinfold thickness/ or skinfold.mp	7776
4	body fat.mp or Fat Body/	17542
5	Obesity/ or obesity.mp	135767
6	overweight.mp or Overweight/	24872
7	Television.mp or Television/	14172
8	TV.mp	6247
9	beverage.mp or Beverages/	11269
10	Carbonated beverages/ or sugary drink.mp	1324
11	soft drink.mp	529
12	fruit drink.mp	54
13	breakfast.mp or Cereals/	14594
14	cereal.mp	5577
15	Ethnic Groups/ or ethnic.mp	65692
16	race.mp or Continental Population Groups/	58132
17	pacific.mp or Pacific Islands/	15796
18	Australia.mp or Australia/	83004
19	New Zealand.mp or New Zealand/	41118
20	1 or 2 or 3 or 4 or 5 or 6	214056
21	7 or 8 or 9 or 10 or 11 or 12 or 13 or 14	48528
22	17 or 18 or 19	132681
23	20 and 21	3326
24	limit 23 to “all child (0 to 18 years)”	1685
25	22 and 24	89

Appendix 2: OPIC PDA questionnaire

The questionnaire illustrated below was used for New Zealand participants. When it was used for participants in Australia, Fiji and Tonga, some responses were modified to suit the country (e.g., for the Australian questionnaire, responses for the question, "What is the name of the school?" comprised schools in Australia). The questionnaire below only shows variables that were used for the analyses in this thesis; all other variables have been removed.

Question	**Response**
Is this today's date? day	1-31
Is this today's date? month	1-12
Is this today's date? year	2004-2008
Which country is this?	1,Australia 2,Fiji Islands 3,New Zealand
What is the name of the school?	1,Aorere College 2,Southern Cross Campus 3,Mangere College 4,Auckland SDA High 5,Hillary Collegiate 6,James Cook High School 7,Papakura
Which ethnic group do you most identify with? (Choose one)	1,Maori 2,Samoan 3,Cook Island Maori 4,Tongan 5,Niuean 6,Other Pacific 7,NZ European / Pakeha 8,Other European eg. English/Dutch 9,Chinese 10,Indian 11,Other
I am...	1,Male 2,Female
What is your date of birth? day	1-31
What is your date of birth? month	1,Jan 2,Feb 3,March 4,April 5,May 6,June 7,July 8,Aug 9,Sept 10,Oct 11,Nov 12,Dec
What is your date of birth? year	1,1985

	2,1986 3,1987 4,1988 5,1989 6,1990 7,1991 8,1992 9,1993
How many people usually live at your home, including yourself during the school week?	1,1 2,2 3,3 4,4 5,5 6,6 7,7 8,8 9,9 10,10 11,11
In the last 5 school days, on how many days did you have something to eat for BREAKFAST before school started?	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
In the last 5 school days, on how many days did you eat at morning recess/tea/ interval?	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
In the last 5 school days, on how many days did you eat lunch at lunchtime?	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
In the last 5 school days (including time spent at home), on how many days did you have regular (non-diet) soft drinks? (Soft drinks = drinks like Coke, Sprite, Fanta)	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
On the last school day, how many glasses or cans of soft drinks did you have?	1,None 2,1 small glass / half a can (150ml) 3,2 small glasses / 1 can (300ml) 4,3 small glasses / 2 cans (600ml) 5,4-5 glasses / 3 cans (1 litre) 6,6 glasses / 4 cans (1.5 litres) 7,7-8 glasses / 6 cans (2 litres) 8,More than 2 litres
In the last 5 school days, on how many days did you have fruit drinks or cordial? (such as Ribena, Raro, Just Juice, Freshup)	1,0 days 2,1 day 3,2 days 4,3 days

	5,4 days 6,5 days
On the last school day, how many glasses of fruit drinks or cordial did you have?	1,0 2,1 3,2 4,3 5,4 6,5 7,6 8,7 9,8 10,9
How often do you usually eat food from a takeaway? (eg. McDonalds, KFC, Subway, fried chicken, fish and chips, hamburgers, Chinese takeaway)	1,Once a month or less 2,2-3 times a month 3,Once a week 4,2-3 times a week 5,Most days
In the last 5 school days, on how many days did you buy snack food from a shop or takeaway after school?	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
How often do you usually eat bread, toast, buns or sandwiches after school?	1,Everyday or almost everyday 2,Most days 3,Some days 4,Hardly ever or never
How often do you usually eat biscuits, potato chips or snacks such as instant noodles after school?	1,Everyday or almost everyday 2,Most days 3,Some days 4,Hardly ever or never
How often do you usually eat pies, takeaways or fried foods such as french fries after school?	1,Everyday or almost everyday 2,Most days 3,Some days 4,Hardly ever or never
How often do you usually eat chocolates, lollies, sweets or ice cream after school?	1,Everyday or almost everyday 2,Most days 3,Some days 4,Hardly ever or never
In the last 5 school days, how many times did you walk or bike to or from school? (walking from home to school and back on 1 day is 2 times: walking to school and taking the bus home is 1 time)	1,0 2,1 3,2 4,3 5,4 6,5 7,6 8,7 9,8 10,9 11,10 12,more than 10
Over the last 5 school days, what did you do most of the time at morning recess/ interval (apart from eating)?	1,Mostly just sat down 2,Mostly stood or walked around 3,Mostly played active games
In the last 5 school days, what did you do most	1,Mostly just sat down

of the time at lunch time (apart from eating)?	2,Mostly stood or walked around 3,Mostly played active games
In the last 5 school days, on how many days after school, did you do sports, dance, cultural performances or play games in which you were active?	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
In the last 5 school days, how many days did you watch TV, videos or DVDs (in your free time)?	1,0 days 2,1 day 3,2 days 4,3 days 5,4 days 6,5 days
On the last school day that you watched TV, videos or DVDs, how long did you watch for?	1,Less than 1 hour 2,1 hour 3,2 hours 4,3 hours 5,4 hours 6,More than 4 hours
Last Saturday, how many hours did you spend watching TV, videos or DVDs?	1,0 2,1 3,2 4,3 5,4 6,5 7,6 8,7 9,8 10,9 11,10 12,more than 10
Last SUNDAY, how many hours did you spend watching TV, videos or DVDs?	1,0 2,1 3,2 4,3 5,4 6,5 7,6 8,7 9,8 10,9 11,10 12,more than 10
Which of these statements most closely applies to you? I am...	1,trying to lose weight 2,trying to gain weight 3,trying to stay at my current weight 4,not doing anything about my weight
How often do you have food from a takeaway shop for dinner?	1,More than once a week 2,About once a week 3,2-3 times a month 4,Once a month or less
How safe do you feel being out alone in your neighbourhood at night?	1,Very safe 2,Safe 3,Unsafe

	4,Very unsafe

Appendix 3: OPIC paper questionnaire

Below is a list of questions from the OPIC paper questionnaire that were used for the analyses in this thesis.

Q3 How well can I walk or run?

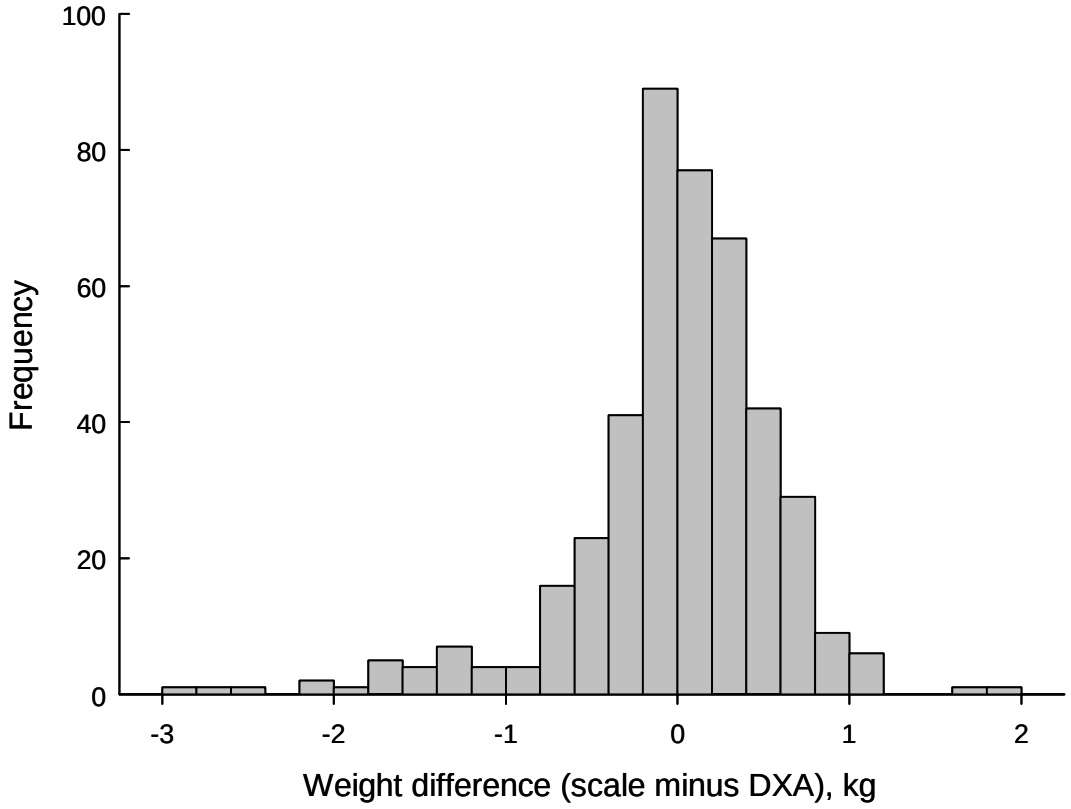
1. I find walking or running very easy.
2. I have no real difficulty with walking or running.
3. I find walking or running slightly difficult.
   (*I cannot run to catch a bus or train, I find walking uphill difficult*.)
4. Walking is difficult for me.
   (*I walk short distances only. I have difficulty walking up stairs.)*
5. I have great difficulty walking.
   (*I cannot walk without a walking stick or frame, or someone to help me*.)
6. I am bedridden.

A. About My Health and Activities (PROBLEMS WITH…)	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1. It is difficult for me to walk more than 100 metres	0	1	2	3	4
2. It is difficult for me to run	0	1	2	3	4
3. It is difficult for me to play sport or do exercise	0	1	2	3	4

C. How I Get Along with Others (PROBLEMS WITH…)	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
3. Other teenagers tease me	0	1	2	3	4

Appendix 4: Histogram

The graph below is a histogram of differences between body weight determined by the Tanita BC-418 device and dual-energy X-ray absorptiometry (DXA) for 431 adolescents.



Appendix 5: Publications

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3. Sluyter JD, Schaaf D, Scragg RKR, Plank LD. Body mass index and percent body fat in a New Zealand multi-ethnic adolescent population. *Int J Pediatr Obes* 2011; **6:** 36-44.

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