

Obesity Comorbidity

Is the relationship between sedentary behaviour and cardiometabolic health in adolescents independent of dietary intake? A systematic review

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Summary

Screen time, but not overall sedentary behaviour, is consistently related to cardiometabolic health in adolescents. Because of the associations screen time has with dietary intake, diet may be an important factor in the screen time and health relationship; however, evidence has not previously been synthesized. Thus, the aim of this systematic review was to explore whether the associations between various sedentary behaviours and cardiometabolic risk markers are independent of dietary intake in adolescents. Online databases and personal libraries were searched for peer-reviewed original research articles published in English before March 2014. Included studies assessed associations between sedentary behaviour and cardiometabolic markers in 12- to 18-year-olds and adjusted for dietary intake. Twenty-five studies met the inclusion criteria. From the 21 studies examining sedentary behaviour and adiposity, the majority found significant positive associations between television viewing, screen time and self-reported overall sedentary behaviour with markers of adiposity, independent of dietary intake. No significant associations between screen time with blood pressure and cholesterol were reported. Sedentary behaviour appears to be associated with adiposity in adolescents, irrespective of dietary intake. However, the variability of dietary variables between studies suggests further work is needed to understand the role of dietary intake when examining these associations in youth.

Keywords: Adolescents, cardiometabolic, diet, screen time.

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Introduction

Cardiometabolic risk factors, specifically obesity, insulin resistance, hypertension and dyslipidaemia, are becoming more prevalent among adolescents (1,2). In Western countries, 25–33% of adolescents are overweight or obese (3–5) and 5–10% of adolescents have one or more of the other cardiometabolic markers (1). Spending large amounts of time using screen-based media, in particular time spent watching television, has been consistently associated with cardiometabolic health in children and adolescents (6–10). This is concerning since current figures indicate that

62–83% of adolescents from Westernized countries are exceeding the screen-based recommendations of no more than 2 h of screen time per day (5,11,12).

In contrast to the consistent links shown for television viewing and screen time, there is inconsistent evidence of associations between overall sedentary time (usually measured by accelerometry) and cardiometabolic risk markers in youth (13,14). This inconsistency suggests that some of the observed associations between screen time and health may be explained by other factors, rather than time spent sedentary or 'sitting' *per se*. There is a possibility that the differences may be simply due to different measures used,

with self-reported measures and objective measures reported to have low to moderate correlations (−0.71 to 0.96) (15).

Alternatively, there may be other lifestyle behaviours such as physical activity and dietary intake that may explain the stronger relationship seen between screen time and health. For example, there is some evidence indicating that adolescents who spend more time in screen time behaviours are less physically active (16,17). However, findings from a recent systematic review reveal screen time and physical activity among youth are not strongly inversely associated ($r = 0.080$, 95% CI −0.101, −0.060) (18), suggesting they are independent behaviours. Additionally, most studies that report associations between screen time and health outcomes in this age group account for physical activity levels (9,19).

In youth, there is consistent evidence that television viewing is linked to elements of a less healthy diet such as lower fruit and vegetable consumption, higher consumption of energy-dense snacks, drinks, and fast foods, and higher total energy intake (20). This suggests that dietary intake may play a role in the relationship between television viewing and cardiometabolic health. However, the mediating role of dietary intake has rarely been examined in youth, while the few studies among adults have found no consistent relationship (21–24). There is now an emerging amount of literature that has examined the relationship between sedentary behaviour and cardiometabolic risk markers in adolescents that has accounted for dietary intake in the analyses. However, there have been no systematic reviews to determine whether these associations are consistent, independent of dietary intake, or whether the studies are of sufficiently high quality. With the majority of Western adolescents not meeting the current screen time guidelines (5,11,12) and the increase in prevalence of cardiometabolic conditions such as obesity, type 2 diabetes and cardiovascular disease (1,2), adolescence is an important time to encourage healthy behaviour changes. Therefore, the aim of this systematic review was to identify and synthesize evidence from studies that have accounted for dietary intake when examining the relationship between sedentary behaviour and cardiometabolic health in 12- to 18-year-old adolescents.

Methods

This review is registered with PROSPERO, CRD42014010359.

Search strategy

Online databases (Medline, Global Health, PsycInfo, Web of Science and Embase), reference lists and personal libraries were searched for peer-reviewed original research

articles published in English before 25 March 2014. The following keyword combinations were used for *sedentary behaviour* (sedentar*, sitting, indoor*, screen time, computer*, television, inactivit*, video game*, internet), *dietary intake* (diet*, nutrition, food*, snack*, drink*, beverage*, eating, energy intake*, meals), *health outcome* (overweight, obes*, adiposity, waist circumference*, waist-hip ratio, body mass index, blood pressure, hypertens*, glucose intolerance, blood glucose, insulin, cholesterol, lipoprotein, triglycerides, lipid metabolism, cardiometabolic, metabolic syndrome, cardiovascular disease*) and *age* (youth, adolescen*, child*, young people). The search terms were restricted to title and abstract only.

Inclusion and exclusion criteria

To be included in the review, studies were required to meet the following criteria: (i) be published as a peer-reviewed original research article, with full-text availability; (ii) the study participants' mean age was between 12 and 18 years, or for longitudinal studies the mean age was between 12 and 18 years at baseline or at follow-up; (iii) the study included a measure of sedentary behaviour as an independent variable defined by 'any waking behaviours characterized by low energy expenditure (≤ 1.5 METS) while in a sitting or reclining posture' (25), and not the absence of sufficient levels of physical activity; (iv) the statistical analyses included an adjustment for dietary intake as defined by the intakes of energy, macronutrients, foods, and/or beverages) and (v) the study assessed at least one cardiometabolic risk marker as the main outcome (i.e. adiposity, blood pressure; insulin sensitivity; glucose tolerance or lipid levels) or included a chronic cardiometabolic condition (i.e. metabolic syndrome, cardiovascular disease or type 2 diabetes).

The exclusion criteria included the following: (i) the study included all three measures of interest but did not include them simultaneously in the statistical analyses; (ii) the study included only special populations (e.g. participants with type 1 diabetes); (iii) the study was not original research and/or (iv) the reviewers could not access the full text after contacting the corresponding author.

Identification of relevant studies

Two reviewers (EF, RL) independently reviewed all articles based on title and abstract initially, then assessed full text for eligibility. For articles that needed further clarification in order to assess their eligibility for the present review, the corresponding author was contacted. Any discrepancies between reviewers about article eligibility were discussed with all authors until a final consensus decision was reached.

Data extraction and coding

Data extraction was performed by one reviewer (EF) using a predetermined data extraction template. The following information was extracted from each article: (i) study design and length (for longitudinal studies only); (ii) participant characteristics (sample size, % males, age range, mean age, % overweight/obese and location); (iii) measures used to assess sedentary behaviour, dietary intake and cardiometabolic risk markers; (iv) statistical analysis methods (e.g. statistical models used, variables included in model) and (v) main findings in regard to sedentary behaviour, dietary intake and cardiometabolic risk markers. Where studies combined multiple domains of sedentary behaviours (e.g. television viewing, video watching and video playing), this was coded as 'screen time' in the results table. This method was also applied to dietary variables where multiple drinks were assessed and coded as 'sugar sweetened beverages'. For this review, only dietary vari-

ables related to food and drinks consumed, energy intake or macronutrient intakes were reported.

Methodological quality assessment

The methodological quality of the included studies was independently examined by two reviewers (EF, RL) using an adapted 15-item quality criteria checklist (26,27) (Table 1). The 15-item checklist consisted of assessing various methodological aspects (e.g. study design and sample, data sources and measurement of variables, statistical methods used) and involved a yes (0.5 or 1 point) or no/unclear (0 point) answer format. The change made to the original quality criteria checklist was mainly regarding the measurement questions, where the reliability and validity of the three measurements of interest were examined separately, as opposed to assessing the reliability and validity of one measurement. A quality score ranging from 0 to 15 points was calculated for each study. This score was

Table 1 Criteria list for assessment of the methodological quality of observational studies (based on Tooth *et al.* (26) and Singh *et al.* (27))

Criteria (rating of criteria: 0.5 or 1 = yes, 0 = no or unclear)	Score (total 15)
Study design	
1. Is the study design presented	___ /0.5
AND is the study design longitudinal and not cross-sectional?	___ /0.5
Target population	
2. Do the authors describe the target population they wanted to research?	___ / 1
Sample	
3. Was a random sample of the target population taken/described	___ /0.5
AND/OR was the response rate 60% or more?	___ /0.5
4. Is participant selection described, or referred to?	___ / 1
5. Is participant recruitment described, or referred to?	___ / 1
6. Are the inclusion and/or exclusion criteria stated, or referred to?	___ / 1
7. Is the study sample described? (minimum description = size, gender, age, BMI)	___ / 1
8. Are the numbers of participants at each stage of the study reported? (authors should report at least numbers eligible, numbers recruited and numbers with complete data)	___ / 1
Variables	
9. Are the measures of sedentary behaviour, dietary intake and the health outcome sufficiently described in detail?	___ / 1
Data sources and collection	
10. Do authors describe the source of their data? (e.g. registry, health survey)	___ /0.5
AND did authors describe how the data were collected? (e.g. by mail, by survey)	___ /0.5
Measurements	
11. Was the validity of sedentary behaviour mentioned or referred to?	___ /0.5
AND/OR was the reliability of sedentary behaviour mentioned or referred to?	___ /0.5
(if measured by accelerometry, automatically full points)	___ /0.5
12. Was the validity of dietary behaviour mentioned or referred to?	___ /0.5
(if measured by 24-h food recall, automatically full points)	___ /0.5
13. Was the health outcome measured objectively and not by self-report?	___ / 1
Statistical methods	
14. Were appropriate statistical methods used and adequately described (including taking into account number of participants and clustering effects)?	___ /0.5
AND/OR did the statistical methods address confounders?	___ /0.5
15. Were the numbers/percentages of participants with missing data for sitting and the health outcome indicated?	___ /0.5
AND if more than 20% of data in the primary analyses were missing, were methods used to address missing data?	___ /0.5

divided by 15 points to calculate a percentage from 0 to 100% and a study was considered to be of high quality if the score was >50% (27).

Synthesis of studies

All findings relating to sedentary behaviour and cardiometabolic health from each study were categorized and tabulated into two categories: (i) no association between sedentary behaviour and the cardiometabolic risk marker (denoted by '0') or (ii) a significant positive or negative association between sedentary behaviour and cardiometabolic risk marker, independent of dietary intake (denoted by '+' or '-'). Following the 'quality rating system' by Singh *et al.* (27), the overall findings were synthesized into four levels of scientific evidence. However, because of all studies in this review being considered to be of 'high quality', cut-off percentages were given to differentiate the level of 'strong' and 'moderate' evidence. Thus, the four levels of scientific evidence used in this review are as follows: (i) *strong evidence* where ≥ 2 high-quality studies have $\geq 70\%$ consistent findings; (ii) *moderate evidence*

where ≥ 2 high-quality studies have between 50 and 69% of consistent findings; (iii) *inconsistent evidence* where ≥ 2 studies have <49% of consistent findings and (iv) *insufficient evidence* where only one study was available.

Results

Search results

The literature search identified a total of 539 records (Figure 1). After removing 12 duplicates and checking the titles, abstracts and full-text articles, 18 articles met the inclusion criteria. A further seven articles were identified from other sources (e.g. reference lists and personal libraries), resulting in a total of 25 articles being included in this systematic review.

Study characteristics

All 25 articles reported on 25 unique study samples. Twenty-one articles reported cross-sectional results and four reported longitudinal study results (ranging from 1 to

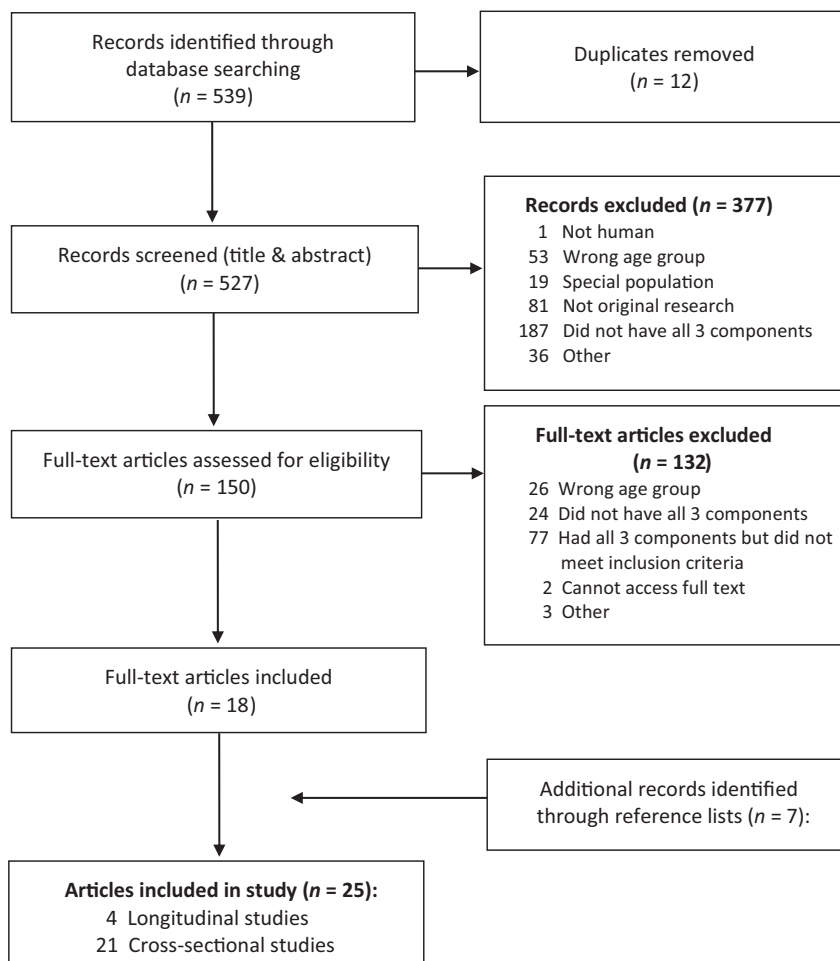


Figure 1 Flow diagram of the identification of literature for inclusion in this systematic review.

4 years of follow-up). The majority of studies originated from the United States ($n = 9$), Canada ($n = 3$) or China ($n = 3$). The number of participants ranged from 282 to 39,011 with most studies including an approximately even ratio of males to females, and only one study including females only (28). The age of participants ranged from 10 to 19 years (mean 14.4 years) and the majority were of healthy weight, with the body mass index (BMI) ranging from 18 to 24 kg m⁻². Nearly all studies used some form of regression analyses (e.g. linear, logistic, longitudinal, multilevel) to examine the associations between sedentary behaviour and a cardiometabolic health outcome, adjusting for dietary intake in the model, with one study conducting a mediation analysis with dietary intake as the mediator (29). The characteristics and the main findings of studies are presented in the Supporting Information (Table S1).

Overview of measures

The most common sedentary behaviour measure was television viewing (29–41), followed by total screen time (28,30,42–49), personal computer use (31,32,36,37,40,41), and video game playing or video viewing (37,40,49). Three studies measured total sedentary behaviour (28,50,51) and only one measured a non-screen time behaviour such as homework time (results not reported in the review) (31). The majority of sedentary behaviours were measured via a self-reported questionnaire, with two studies using a proxy report for those aged 12 or below (45,52), and one study each used a 24-h activity recall (28) or interview-administered questionnaire (47). The dietary variables that were included in the analyses varied widely, with the majority of studies ($n = 19$) simultaneously adjusting for multiple dietary variables. The most common variables included total energy intake (34,35,40,41,46,47,49–51) and the consumption of energy-dense snacks (29,30,32,36,39,42–45,48), sugar-sweetened beverages (28,30–33,36,37,44,45,50), fruits and vegetables (28,31,32,36,38,42,43,50), and fast food (30,42,45,50), with few studies measuring macronutrient intakes (28,35,40,47) or specific food items (e.g. cereals, meat) (50,52). Adiposity was the most commonly reported cardiometabolic risk marker, with 21 studies measuring adiposity mostly by weight status. Only four studies assessed other cardiometabolic markers such as blood pressure, insulin resistance, glucose tolerance and lipid levels (40,46–48).

Methodological quality assessment

A summary of the methodological quality of the studies is presented in the Supporting Information (Table S2). The initial discrepancy between the two reviewers when scoring

the 25 articles was 6.3%. The majority of disagreements were resolved after discussion, with 9 of the 33 discrepancies being discussed with all authors. The quality scores of the papers ranged from 60 to 84%. The most common reasons why studies did not get a quality score of 100% were the study 'did not use methods to address missing data' and 'did not report the inclusion and exclusion criteria of the sample'. According to the quality criteria (27), all studies were considered to be of high quality (>50%) with eight studies scoring 80% or more (28,30,31,41,42,46,47,49).

Fifteen of the 25 studies included a random sample of the target population (29–34,36,38,39,41–43,45–48,50) with 14 studies reporting a response rate of 60% or more (29–31,33,34,38,41–44,46,47,49,50). All studies used either self-administered questionnaires or interviews to measure sedentary behaviour with four studies reporting the validity (28,29,48,49) and two studies reporting the reliability (28,48) of the measure used. In total, seven studies used a 24-h food recall to assess dietary intake (33–35,41,46,47,50), with five studies reporting the recall data from one occasion, and one study each reporting the recall data from either two (41) or three (35) occasions. Other commonly used measures were self-administered questionnaires ($n = 10$) or food frequency questionnaires ($n = 8$), with four studies reporting both the reliability and validity of these measures (31,40,44,49) and one study reporting only the validity (52). Out of the 21 studies that measured adiposity, nearly all studies used objective measures with only four studies using self-reported height and weight to calculate BMI (36,38,43,49). Four studies measured blood biochemistry profiles (40,46–48), with one of those studies reporting the risk of the metabolic syndrome (46). Regarding the analyses, only 10 studies both adequately described and used appropriate statistical methods (including taking into account clustering effects due to sampling design) and addressed missing data where relevant (28–31,36,41,42,47–49).

Main findings

The associations between sedentary behaviour and cardiometabolic markers adjusting for dietary intake are reported in Tables 2 and 3. Because of the majority of studies reporting on adiposity outcomes, results for adiposity and other cardiometabolic outcomes were presented separately. Table 2 summarizes the associations between various screen time behaviours and total sedentary behaviour with measures of adiposity (e.g. BMI, waist circumference), adjusting for dietary intake. Table 3 summarizes the studies reporting on associations between screen time behaviours with the other cardiometabolic outcomes (e.g. blood pressure, blood glucose, lipids), adjusting for dietary intake.

Table 2 Associations between various sedentary behaviours and adiposity, adjusting for dietary intake

Author [quality %]	Dietary factors included in analysis*	TV	Video use or VG	PC	Total ST	Total SB
Arango (30) [80]	Soft drink, high-fat foods, fast foods	0 TV ^g _{WC} +TV ^b _{WC}			0 ST ^g _{WC} + ST ^b _{BMI} + ST ^b _{WC} + ST ^g _{SR-BMI}	
Berkey (49) [†] [80]	EI		+ Vid ^b _{SR-BMI}		+ ST _{BMI}	
Hsu (42) [80]	FV, sweets, snacks, fast food					
Peart (41) [80]	EI, fat intake	+ TV _{BMI}		0 PC _{BMI}		
Tang (31) [80]	Soft drink, FV	+ TV _{BMI}		0 PC _{BMI}		
Must (28) [†] [80]	% CHO, protein and fat, FV, soft drink				0 ST _{BMI} 0 ST _{%BF}	0 SB _{BMI}
Nasreddine (50) [74]	EI, cereals, dairies, meat, legumes/nuts, FV, added fats/oils, fast food, sugar/sweets, SSBs					+ SB _{BMI} + SB _{WC} + SB _{WtH}
Al-Haifi (32) [74]	FV, SSBs (including energy drinks), milk, fast food, cakes/doughnuts, sweets	0 TV _{BMI} 0 TV _{WC}		0 PC _{BMI} 0 PC _{WC}		
Kunesova (52) [74]	Fish intake/meat fat intake			+ PC _{BMI}		
Forshee (33) [74]	All beverages (including SSBs, coffee/tea, beer)	0 TV _{BMI}				
Crespo (34) [74]	EI	+ TV ^{b/g} _{BMI}				
Carson (29) [70]	Junk food (including sweets, soft drinks, cakes/pastries, potato chips, French fries)	+ TV _{BMI}				
Vik (43) [70]	FV, unhealthy snacks (including soft drinks, candy and potato chips)				+ ST _{SR-BMI}	
Zhang (35) [67]	EI, % fat intake	0 TV _{BMI}				0 SB _{FMI}
Fulton (51) [†] [64]	EI					+ SB _{BMI} + SB _{FFM}
Hume (44) [64]	SSBs, unhealthy snacks (including soda, candy, potato chips)				0 ST ^{b/g} _{BMI} 0 ST ^{b/g} _{SF} 0 ST ^b _{WC} + ST ^g _{WC}	
Janssen (36) [64]	FV, sweets, soft drink, cake, potato chips	+ TV ^{b/g} _{SR-BMI}		0 PC ^{b/g} _{SR-BMI}		
Giammettei (37) [64]	Soft drink	+ TV _{BMI}	0 VG _{BMI}	0 PC _{BMI}		
Shan (45) [60]	Fast food, snacks, SSBs, alcohol				+ ST _{BMI}	
Delva (38) [60]	FV	+TV ^{b/g} _{SR-BMI}				
Elgar (39) [†] [60]	Snacks	+ TV _{BMI}				
Summary of results						
	0 No significant association	5	1	6	6	2
	+ Significant association, independent of diet	9	1	1	7	5

[†]Longitudinal study.

*Dietary variables adjusted for in the analyses involving the sedentary behaviour and health outcome variables.

%BF, % body fat; +, significant positive association, independent of diet; 0, no significant association; ^b, boys only; BMI, objectively measured BMI; EI, energy intake; FFM, fat-free mass; FMI, fat mass index; FV, fruits and vegetables; ^g, girls only; SF, skin-folds; SR-BMI, self-reported BMI; SSB, sugar-sweetened beverage; WC, waist circumference; WtH, waist to hip ratio.

As shown in Table 2, strong evidence was observed between computer use and adiposity. Six of the seven studies (86%) examining computer use found no significant association with adiposity, with the regression analyses adjusting mainly for soft drink, energy-dense snacks, and/or fruit and vegetable intake (31,32,36,37,41). Moderate evidence was found between both television viewing and total screen time with adiposity, with 64% (29–31,34,36–39,41) and 54% of the analyses (30,42–45,49) respectively finding a significant

and positive relationship, independent of dietary intake. However, no consistent pattern was observed according to the types of dietary variables adjusted for in the analyses. Additionally, there was moderate evidence to support a significant and positive relationship between total self-reported sedentary behaviour and adiposity (50,51), independent of total energy intake and other various food items. There was insufficient evidence of the relationship between video viewing and video game use (37,49).

Table 3 Associations between screen time behaviours with cardiometabolic risk markers and the metabolic syndrome, adjusting for dietary intake

Author	Dietary factors included in analysis*	Cardiometabolic risk markers								Met syndrome
		SBP	DBP	Insulin	Glucose	Total-C	LDL-C	HDL-C	C-Ratio	
Kang (46) [84]	EI									0 ¹ ST + ² ST
Sugiyama (47) [80]	EI, CHO, protein and fat intake	+ ST	0 ST							
Goldfield (40) [77]	EI, % fat intake	0 TV	0 TV			0 TV	0 TV	0 TV	0 TV	
		+ VG	0 VG			0 VG	0 VG	0 PC	+ VG	
		0 PC	0 PC			0 PC	0 PC	0 ST	0 PC	
		0 ST	0 ST			0 ST	0 ST		0 ST	
Hardy (48) [77]	EDNP foods (including confectionary, hot chips, salty snacks)	0 ST ^{b/g}		0 ST ^g	0 ST ^b		0 ST ^{b/g}	0 ST ^{b/g}		
				+ ST ^b						
Summary of results										
	0 No significant association	4	5	1	1	4	5	4	3	1
	+ Significant association, independent of diet	2	0	1	0	0	0	0	1	1

*Dietary variables adjusted for in the analyses involving the sedentary behaviour and health outcome variables.

+, significant positive association, independent of diet; 0, no significant association; ¹, weekday only; ², weekend day only; ^b, boys only; CHO, carbohydrate intake; C-Ratio, cholesterol ratio (total cholesterol/HDL-cholesterol); DBP, diastolic blood pressure; EDNP, energy-dense nutritionally poor (foods); EI, energy intake; ^g, girls only; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; Total-C, total cholesterol.

When examining the findings from the four longitudinal studies, no consistent relationship was observed (28,39,49,51). Berkey *et al.* (49) and Elgar *et al.* (39) both reported positive longitudinal associations between screen time behaviours with adiposity, independent of total energy intake and intake of snacks, respectively; whereas Fulton *et al.* (51) and Must *et al.* (28) found no associations between overall sedentary behaviour and screen time with adiposity measures, independent of energy intake and percentage of macronutrient intake, respectively.

As shown in Table 3, three studies examined screen time behaviours with other cardiometabolic risk markers, such as blood pressure, insulin resistance, glucose tolerance and lipid levels (40,47,48), and one study examined total screen time and the risk of developing the metabolic syndrome (46). Overall, there was moderate (67%) to strong evidence (100%) to show no significant association between various screen time behaviours (e.g. television viewing, computer use) with systolic blood pressure (40,48), diastolic blood pressure (40,47), low-density lipoprotein (LDL)-cholesterol and high-density lipoprotein (HDL)-cholesterol (40,48). Because of the limited number of studies performed, there was insufficient evidence to draw conclusions on the remaining cardiometabolic risk markers as well as the association between screen time and the risk of metabolic syndrome (46).

Additionally, as there were a limited number of studies reporting the unadjusted and adjusted findings, it was not possible to draw conclusions on whether dietary intake attenuated the sedentary behaviour and health relationship. However, of the three studies that did report the unadjusted findings, screen time was no longer associated with dias-

tolic blood pressure (48) or the metabolic syndrome (46), and video game use was no longer negatively associated with HDL-cholesterol (40) after adjusting for either energy-dense, nutrient-poor foods (48) or total energy and macronutrient intake (40,46).

Discussion

This systematic review identified and summarized all studies published prior to March 2014 that have accounted for dietary intake when exploring the association between sedentary behaviour and cardiometabolic health markers in adolescents. According to the 15-item quality criteria checklist (26,27), all 25 studies identified were considered to be of high quality. From the 21 studies examining adiposity outcomes, there was moderate to strong evidence to show significant and positive associations between television viewing, screen time and overall sedentary behaviour with adiposity, independent of dietary intake. This is concerning since the majority of Western adolescents are already exceeding the screen time recommendations (5,11,12), thus placing them at an increased risk of becoming overweight or obese. However, findings from the four papers examining other cardiometabolic markers found no significant associations between screen time behaviours with blood pressure, LDL-cholesterol and HDL-cholesterol.

Most studies found television viewing was associated with obesity in adolescents, irrespective of dietary intake. These findings are similar to other reviews involving children and adolescents, where positive associations between television viewing and adiposity have consistently been

reported (6,53–56). For example, in the review by Tremblay *et al.*, among the 170 studies examining body composition, the majority of studies found positive associations between sedentary behaviour (mainly assessed by television viewing) and BMI (6). Similarly, findings from a meta-analysis revealed a small but significant relationship of 0.066 (95% CI = 0.056–0.078) between television viewing and body fatness among nearly 45,000 youth (53). However, although the majority of papers included in these reviews adjusted for physical activity, it is unknown whether the findings are also independent of dietary intake (6,53).

Although television viewing was shown to be independently associated with adiposity, computer use was not. This is consistent with previous literature involving children and adolescents, where they report a lack of association between computer use and obesity (53,54,57). There may be a couple of reasons for this difference. Firstly, television viewing is at the lowest end of the energy expenditure spectrum and requires less energy expenditure than computer use (58). Secondly, there is increased exposure to junk food advertising while watching television, as opposed to using a computer. This exposure to junk food advertising has been consistently linked with between-meal snacking (59). Further, ‘mindless eating’ where children pay less attention to how much they consume is more likely to occur while watching television as opposed to using the computer (60).

Of the four studies that examined those cardiometabolic markers other than adiposity, no associations were reported between screen time behaviours with blood pressure, LDL-cholesterol and HDL-cholesterol. This finding is in contrast to a previous review by Tremblay *et al.* who reported consistent evidence on the positive association between screen time and blood pressure and total cholesterol in school-age children and youth (6). However, it was not clear whether the studies included in that review adjusted for dietary covariates. A review by Chinapaw *et al.* reported similar findings to the current review where there was little evidence to draw conclusions on associations between ‘sedentary time’ (mainly measured by television viewing) and blood pressure or blood lipids (61).

The lack of findings in the present review could be attributed to a number of factors. It could be simply due to the limited number of studies available that have adjusted for dietary intake when reporting on cardiometabolic markers in young people. Alternatively, it could be due to the lack of lifetime exposure this age group has had to establish the risk markers for chronic disease, or to the lack of sensitive measures used in the studies (such as a one-off fasted blood test) to capture the small adverse effects in their cardiometabolic profile. Thus, for future studies examining cardiometabolic markers in children or adolescents, it is recommended to use more sensitive measures such as a

continuous glucose monitoring system or flow mediation dilation that are likely to detect the smaller fluctuations seen in a younger population group (62).

This review found that the majority of evidence relating to adiposity was independent of dietary intake. A possible explanation for this could be that the dietary variables adjusted for may not have been sufficient to attenuate the relationship. However, in the present review, because of the number of dietary variables examined across the included studies, it made it difficult to determine if independent (or null) associations were more commonly identified for one group of dietary variables over another (e.g. total energy intakes vs. macronutrient content). Additionally, because of the limited number of studies reporting the unadjusted and adjusted results (for dietary intake), it was not possible to draw conclusion as to whether a particular dietary variable attenuated the relationship (40,46,48). Further, it is also unknown whether these dietary variables reported were examined while participants were engaged in the screen time behaviours. If the behaviours were not measured concurrently, this suggests that dietary intake may be an indicator of an unhealthy lifestyle, rather than due to a direct association. Currently, there is limited research examining what dietary variables should be considered as covariates and what dietary variables, if any, mediate the relationship between sedentary behaviour and health in youth.

Another reason for the independent associations observed could be that dietary intake is simply not a strong driver of the relationship between screen time and adiposity. However, this explanation is at odds with previous literature where it is consistently reported that there are links between television viewing and elements of an unhealthy diet, such as lower fruit and vegetable consumption, higher consumption of energy-dense snacks, drinks, and fast foods, and higher total energy intake (20). However, there are mixed findings on whether the same unhealthy dietary behaviours are linked with other sedentary behaviours such as video game use (63–65) and objectively measured total sedentary time (66).

Limitations of the studies in the review

Despite the high quality of studies included in this review, it is important to acknowledge that there were several methodological limitations. Firstly, the majority of papers included in the review were cross-sectional, with the four longitudinal studies identified reporting inconsistent findings (28,39,49,51). Therefore, it is unknown whether sedentary behaviour and dietary intake are predictive of health outcomes longitudinally. Secondly, there were considerable variations in how sedentary behaviour and dietary intake were examined and assessed. All of the studies included in our review used subjective measures to assess sedentary

behaviour. Although these measures are useful to assess specific sedentary behaviour domains that could be targeted for interventions (e.g. reducing television viewing, or total screen time), they do not accurately capture the total time spent being sedentary. Thus, future studies are needed that also include an objective measure of overall sedentary time, such as accelerometers or inclinometers, to assess whether overall sedentary time has the same health implications as screen time behaviours.

Regarding dietary intake, there were two key limitations of the studies; the majority of studies only reported adjusted results and the studies reported on a vast array of dietary variables. By examining only the adjusted results, it is unknown whether the dietary variables attenuated the relationship between sedentary behaviour and adiposity. For future studies, it would be useful to report both the unadjusted and adjusted results when examining similar outcomes. Conducting mediation analyses would also help better understand the role of dietary intake in the sedentary behaviour and health relationship. For instance, was the relationship between sedentary behaviour and health explained partially or fully by dietary intake? The vast array of dietary variables made it difficult to identify common dietary variables adjusted for in the analyses among studies reporting positive vs. null findings. Future studies are needed examining the different types of dietary variables that may influence the sedentary behaviour and cardiometabolic health relationship. A suggested starting point would be to examine the dietary factors that have previously been shown to be associated with sedentary behaviour (e.g. total energy intake, fast food intake and snacking) (20) and adverse cardiometabolic health (e.g. energy-dense foods and sugar-sweetened beverages) (67–69). By examining specific dietary factors, it will provide much needed information on what dietary confounders to adjust for and thus provide greater consistency in future analyses.

Finally, there were inconsistencies in the analyses. For example, not all studies accounted for missing data where relevant or for clustering in their sampling design, thus potentially overestimating the statistical power of their findings. Additionally, not all studies adjusted for the same covariates, with only half of the studies adjusting for physical activity. However, it is interesting to note that there were no differences in findings between the studies that adjusted for physical activity and those studies that did not.

Strengths and limitations of review

Strengths of the review include broad search criteria examining many electronic sources, and a large number of studies were screened for eligibility by two reviewers. Additionally, an adapted quality assessment (26,27) was applied to distinguish low- and high-quality studies and was per-

formed independently by two reviewers. However, we acknowledge that the cut-off value to distinguish low and high quality is arbitrary. Other quality assessment tools such as the Effective Public Health Practice Project (70) and Downs & Black (71) were considered; however, these quality tools were mostly developed to assess randomized controlled trials and not observational studies. It is also possible that studies with significant findings were more likely to be included in the review. This was due to the inclusion criteria we applied to the review where studies were only included if they examined all three measures of interest in the analyses (sedentary behaviour, dietary intake and a cardiometabolic health outcome). However, if sedentary behaviour or dietary intake was previously found to be not significant in the initial correlation analyses with the health outcome, then typically these variables were not included in the regression analyses.

Conclusion

This systematic review found moderate to strong evidence of the relationships between self-reported television viewing, total screen time and overall sedentary behaviour with adiposity, independent of dietary intake. It is important to understand the nature of these independent relationships to help with informing the design of future interventions. For example, how much focus needs to be on reducing sedentary behaviours or whether targeting both sedentary behaviour and dietary intake would be more beneficial. However, further research is still needed to examine whether the independent associations remain when using objective measures to assess overall sedentary time. Additionally, exploratory and longitudinal studies would help with understanding whether these behaviours are occurring simultaneously, and whether one behaviour potentially influences the other over time.

Conflict of interest statement

The authors have no conflicts of interest to disclose.

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Supporting information

Additional Supporting Information may be found in the online version of this article, <http://dx.doi.org/10.1111/obr.12302>

Table S1. Description of the characteristics and main findings.

Table S2. Overall scores of the methodological quality assessment (ranked from highest to lowest).

References

- Johnson WD, Kroon JM, Greenway FL *et al.* Prevalence of risk factors for metabolic syndrome in adolescents: national health and nutrition examination survey (NHANES), 2001–2006. *Arch Pediatr Adolesc Med* 2009; **163**: 371–377.
- Camhi SM, Katzmarzyk PT. Prevalence of cardiometabolic risk factor clustering and body mass index in adolescents. *J Pediatr* 2011; **159**: 303–307.
- Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the united states, 2011–2012. *JAMA* 2014; **311**: 806–814.
- Roberts KC, Shields M, de Groh M, Aziz A, Gilbert JA. Overweight and obesity in children and adolescents: results from the 2009 to 2011 Canadian Health Measures Survey. *Health Rep* 2012; **23**: 37–41.
- Australian Bureau of Statistics. Australian Health Survey: Physical Activity, 2011–12. 2013.
- Tremblay M, LeBlanc A, Kho M *et al.* Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *Int J Behav Nutr Phys Act* 2011; **8**: 98.
- Henderson M, Gray-Donald K, Mathieu ME *et al.* How are physical activity, fitness, and sedentary behavior associated with insulin sensitivity in children? *Diabetes Care* 2012; **35**: 1272–1278.
- Gopinath B, Hardy LL, Kifley A, Baur LA, Mitchell P. Activity behaviors in schoolchildren and subsequent 5-yr change in blood pressure. *Med Sci Sports Exerc* 2014; **46**: 724–729.
- Chaput J-P, Saunders TJ, Mathieu M-È *et al.* Combined associations between moderate to vigorous physical activity and sedentary behaviour with cardiometabolic risk factors in children. *Appl Physiol Nutr Metab* 2013; **38**: 477–483.
- Cliff DP, Okely AD, Burrows TL *et al.* Objectively measured sedentary behavior, physical activity, and plasma lipids in overweight and obese children. *Obesity (Silver Spring)* 2013; **21**: 382–385.
- Huang JS, Gottschalk M, Norman GJ *et al.* Compliance with behavioral guidelines for diet, physical activity and sedentary behaviors is related to insulin resistance among overweight and obese youth. *BMC Res Notes* 2011; **4**: 29.
- Foley LS, Maddison R, Jiang Y, Olds T, Ridley K. It's not just the television: survey analysis of sedentary behaviour in New Zealand young people. *Int J Behav Nutr Phys Act* 2011; **8**: 132.
- Saunders TJ, Chaput JP, Tremblay MS. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. *Can J Diabetes* 2014; **38**: 53–61.
- Ekelund U, Luan J, Sherar LB *et al.* Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA* 2012; **307**: 704–712.
- Prince SA, Adamo KB, Hamel ME *et al.* A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act* 2008; **5**: 56.
- Mutz D, Robers D, Vuuren DP. Reconsidering the displacement hypothesis: television's influence on children's time use. *Commun Res* 1993; **20**: 51–75.
- Jenvey VB. The relationship between television viewing and obesity in young children: a review of existing explanations. *Early Child Dev Care* 2007; **177**: 809–820.
- Pearson N, Braithwaite RE, Biddle SJH, van Sluijs EMF, Atkin AJ. Associations between sedentary behaviour and physical activity in children and adolescents: a meta-analysis. *Obes Rev* 2014; **15**: 666–675.
- Goldfield GS, Saunders TJ, Kenny GP *et al.* Screen viewing and diabetes risk factors in overweight and obese adolescents. *Am J Prev Med* 2013; **44**: S364–S370.
- Pearson N, Biddle S. Sedentary behavior and dietary intake in children, adolescents, and adults: a systematic review. *Am J Prev Med* 2011; **41**: 178–188.
- Cleland VJ, Schmidt MD, Dwyer T, Venn AJ. Television viewing and abdominal obesity in young adults: is the association mediated by food and beverage consumption during viewing time or reduced leisure-time physical activity? *Am J Clin Nutr* 2008; **87**: 1148–1155.
- Thomson M, Spence JC, Raine K, Laing L. The association of television viewing with snacking behavior and body weight of young adults. *Am J Health Promot* 2008; **22**: 329–335.
- Thorp AA, McNaughton SA, Owen N, Dunstan DW. Independent and joint associations of TV viewing time and snack food consumption with the metabolic syndrome and its components; a cross-sectional study in Australian adults. *Int J Behav Nutr Phys Act* 2013; **10**: 96.
- Reeves MM, Healy GN, Owen N *et al.* Joint associations of poor diet quality and prolonged television viewing time with abnormal glucose metabolism in Australian men and women. *Prev Med* 2013; **57**: 471–476.
- Sedentary Behaviour Research Network. Letter to the editor: standardized use of the terms 'sedentary' and 'sedentary behaviours'. *Appl Physiol Nutr Metab* 2012; **37**: 540–542.
- Tooth L, Ware R, Bain C, Purdie DM, Dobson A. Quality of reporting of observational longitudinal research. *Am J Epidemiol* 2005; **161**: 280–288.
- Singh AS, Mulder C, Twisk JW, van Mechelen W, Chinapaw MJ. Tracking of childhood overweight into adulthood: a systematic review of the literature. *Obes Rev* 2008; **9**: 474–488.
- Must A, Bandini LG, Tybor DJ *et al.* Activity, inactivity, and screen time in relation to weight and fatness over adolescence in girls. *Obesity (Silver Spring)* 2007; **15**: 1774–1781.
- Carson V, Janssen I. The mediating effects of dietary habits on the relationship between television viewing and body mass index among youth. *Pediatr Obes* 2012; **7**: 391–398.
- Arango CM, Parra DC, Gomez LF *et al.* Screen time, cardiorespiratory fitness and adiposity among school-age children from Monteria, Colombia. *J Sports Sci Med* 2013; **17**: 491–495.
- Tang KH, Nguyen HH, Dibley MJ *et al.* Factors associated with adolescent overweight/obesity in Ho Chi Minh city. *Int J Pediatr Obes* 2010; **5**: 396–403.
- Al-Haifi AR, Al-Fayez MA, Al-Athari BI *et al.* Relative contribution of physical activity, sedentary behaviors, and dietary habits to the prevalence of obesity among Kuwaiti adolescents. *Food Nutr Bull* 2013; **34**: 6–13.
- Forshee RA, Anderson PA, Storey ML. The role of beverage consumption, physical activity, sedentary behavior, and demographics on body mass index of adolescents. *Int J Food Sci Nutr* 2004; **55**: 463–478.
- Crespo CJ, Smit E, Troiano RP *et al.* Television watching, energy intake, and obesity in US children – results from the Third

- National Health and Nutrition Examination Survey, 1988–1994. *Arch Pediatr Adolesc Med* 2001; 155: 360–365.
35. Zhang J, Seo D-C, Kolbe L, Middlestadt S, Zhao W. Trends in overweight among school children and adolescents in seven Chinese provinces, from 1991–2004. *Int J Pediatr Obes* 2010; 5: 375–382.
36. Janssen I, Katzmarzyk PT, Boyce WF, King MA, Pickett W. Overweight and obesity in Canadian adolescents and their associations with dietary habits and physical activity patterns. *J Adolesc Health* 2004; 35: 360–367.
37. Giammattei J, Blix G, Marshak HH, Wollitzer AO, Pettitt DJ. Television watching and soft drink consumption: associations with obesity in 11- to 13-year-old schoolchildren. *Arch Pediatr Adolesc Med* 2003; 157: 882–886.
38. Delva J, Johnston LD, O'Malley PM. The epidemiology of overweight and related lifestyle behaviors: racial/ethnic and socioeconomic status differences among American youth. *Am J Prev Med* 2007; 33: S178–S186.
39. Elgar FJ, Roberts C, Moore L, Tudor-Smith C. Sedentary behaviour, physical activity and weight problems in adolescents in Wales. *Public Health* 2005; 119: 518–524.
40. Goldfield GS, Kenny GP, Hadjiyannakis S *et al*. Video game playing is independently associated with blood pressure and lipids in overweight and obese adolescents. *PLoS ONE* 2011; 6: 1.
41. Peart T, Velasco Mondragon HE, Rohm-Young D, Bronner Y, Hossain MB. Weight status in US youth: the role of activity, diet, and sedentary behaviors. *Am J Health Behav* 2011; 35: 756–765.
42. Hsu Y-W, Johnson CA, Chou C-P *et al*. Correlates of overweight status in Chinese youth: an East-West paradox. *Am J Health Behav* 2011; 35: 496–506.
43. Vik FN, Øverby NC, Lien N, Bere E. Number of meals eaten in relation to weight status among Norwegian adolescents. *Scand J Public Health* 2010; 38: 13–18.
44. Hume C, Singh A, Brug J, van Mechelen W, Chinapaw M. Dose-response associations between screen time and overweight among youth. *Int J Pediatr Obes* 2009; 4: 61–64.
45. Shan X-Y, Xi B, Cheng H *et al*. Prevalence and behavioral risk factors of overweight and obesity among children aged 2–18 in Beijing, China. *Int J Pediatr Obes* 2010; 5: 383–389.
46. Kang HT, Lee HR, Shim JY *et al*. Association between screen time and metabolic syndrome in children and adolescents in Korea: the 2005 Korean National Health and Nutrition Examination Survey. *Diabetes Res Clin Pract* 2010; 89: 72–78.
47. Sugiyama T, Xie D, Graham-Maar RC *et al*. Dietary and lifestyle factors associated with blood pressure among U.S. adolescents. *J Adolesc Health* 2007; 40: 166–172.
48. Hardy LL, Denney-Wilson E, Thrift AP, Okely AD, Baur LA. Screen time and metabolic risk factors among adolescents. *Arch Pediatr Adolesc Med* 2010; 164: 643–649.
49. Berkey CS, Rockett HRH, Gillman MW, Colditz GA. One-year changes in activity and in inactivity among 10- to 15-year-old boys and girls: relationship to change in body mass index. *Pediatrics* 2003; 111: 836–843.
50. Nasreddine L, Naja F, Akl C *et al*. Dietary, lifestyle and socioeconomic correlates of overweight, obesity and central adiposity in Lebanese children and adolescents. *Nutrients* 2014; 6: 1038–1062.
51. Fulton JE, Dai SF, Steffen LM *et al*. Physical activity, energy intake, sedentary behavior, and adiposity in youth. *Am J Prev Med* 2009; 37: S40–S49.
52. Kunesova M, Vignerova J, Steflová A *et al*. Obesity of Czech children and adolescents: relation to parental obesity and socioeconomic factors. *J Public Health* 2007; 15: 163–170.
53. Marshall SJ, Biddle SJ, Gorely T, Cameron N, Murdey I. Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. *Int J Obes Relat Metab Disord* 2004; 28: 1238–1246.
54. Rey-López JP, Vicente-Rodríguez G, Biosca M, Moreno LA. Sedentary behaviour and obesity development in children and adolescents. *Nutr Metab Cardiovasc Dis* 2008; 18: 242–251.
55. Prentice-Dunn H, Prentice-Dunn S. Physical activity, sedentary behavior, and childhood obesity: a review of cross-sectional studies. *Psychol Health Med* 2012; 17: 255–273.
56. Costigan SA, Barnett L, Plotnikoff RC, Lubans DR. The health indicators associated with screen-based sedentary behavior among adolescent girls: a systematic review. *J Adolesc Health* 2013; 52: 382–392.
57. Carson V, Janssen I. Volume, patterns, and types of sedentary behavior and cardio-metabolic health in children and adolescents: a cross-sectional study. *BMC Public Health* 2011; 11: 274.
58. Klesges RC, Shelton ML, Klesges LM. Effects of television on metabolic rate: potential implications for childhood obesity. *Pediatrics* 1993; 91: 281–286.
59. Andreyeva T, Kelly IR, Harris JL. Exposure to food advertising on television: associations with children's fast food and soft drink consumption and obesity. *Econ Hum Biol* 2011; 9: 221–233.
60. Boulos R, Vikre EK, Oppenheimer S, Chang H, Kanarek RB. ObesiTV: how television is influencing the obesity epidemic. *Physiol Behav* 2012; 107: 146–153.
61. Chinapaw MJ, Proper KI, Brug J, van Mechelen W, Singh AS. Relationship between young people's sedentary behaviour and bio-medical health indicators: a systematic review of prospective studies. *Obes Rev* 2011; 12: e621–e632.
62. Celermajor DS, Ayer JGJ. Childhood risk factors for adult cardiovascular disease and primary prevention in childhood. *Heart* 2006; 92: 1701–1706.
63. Chaput JP, Visby T, Nyby S *et al*. Video game playing increases food intake in adolescents: a randomized crossover study. *Am J Clin Nutr* 2011; 93: 1196–1203.
64. Lyons EJ, Tate DF, Ward DS, Wang X. Energy intake and expenditure during sedentary screen time and motion-controlled video gaming. *Am J Clin Nutr* 2012; 96: 234–239.
65. Mellecker RR, Lanningham-Foster L, Levine JA, McManus AM. Energy intake during activity enhanced video game play. *Appetite* 2010; 55: 343–347.
66. Borghese MM, Tremblay MS, Leduc G *et al*. Independent and combined associations of total sedentary time and television viewing time with food intake patterns of 9- to 11-year-old Canadian children. *Appl Physiol Nutr Metab* 2014; 39: 937–943.
67. Nicklas TA, Yang SJ, Baranowski T, Zakeri I, Berenson G. Eating patterns and obesity in children. The Bogalusa Heart Study. *Am J Prev Med* 2003; 25: 9–16.
68. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. *Am J Clin Nutr* 2006; 84: 274–288.
69. Ludwig DS, Peterson KE, Gortmaker SL. Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective, observational analysis. *Lancet* 2001; 357: 505–508.
70. National Collaborating Centre for Methods and Tools. Quality Assessment Tool for Quantitative Studies. Hamilton, ON: McMaster University. 2008. [WWW document]. URL <http://www.nccmt.ca/registry/view/eng/14.html> (accessed April 2010).
71. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* 1998; 52: 377–384.