

## PEDIATRIC REVIEW

# What works in school-based energy balance behaviour interventions and what does not? A systematic review of mediating mechanisms

MM van Stralen<sup>1</sup>, M Yildirim<sup>1</sup>, SJ te Velde<sup>2</sup>, J Brug<sup>2</sup>, W van Mechelen<sup>1</sup> and MJM Chinapaw<sup>1</sup>  
on behalf of the ENERGY-consortium

<sup>1</sup>Department of Public and Occupational Health, VU University Medical Center, EMGO Institute for Health and Care Research, Amsterdam, The Netherlands and <sup>2</sup>Department of Epidemiology and Biostatistics, VU University Medical Center, EMGO Institute for Health and Care Research, Amsterdam, The Netherlands

**Objective:** Obesity prevention requires effective interventions targeting the so-called energy balance-related behaviours (that is, physical activity, sedentary and dietary behaviours). To improve (cost-)effectiveness of these interventions, one needs to know the working mechanisms underlying behavioural change. Mediation analyses evaluate whether an intervention works via hypothesised working mechanisms. Identifying mediators can prompt intervention developers to strengthen effective intervention components and remove/adapt ineffective components. This systematic review aims to identify psychosocial and environmental mediators of energy balance-related behaviours interventions for youth.

**Method:** Studies were identified by a systematic search of electronic databases (Pubmed, Embase, PsycINFO, ERIC and SPORTDiscus). Studies were included if they (1) were school-based randomised controlled or quasi-experimental studies; (2) targeted energy balance behaviours; (3) conducted among children and adolescents (4–18 years of age); (4) written in English; and (5) conducted mediation analyses.

**Results:** A total of 24 studies were included. We found strong evidence for self-efficacy and moderate evidence for intention as mediators of physical activity interventions. Indications were found for attitude, knowledge and habit strength to be mediators of dietary behaviour interventions. The few sedentary behaviour interventions reporting on mediating effects prevented us from forming strong conclusions regarding mediators of sedentary behaviour interventions. The majority of interventions failed to significantly change hypothesised mediators because of ineffective intervention strategies, low power and/or use of insensitive measures.

**Conclusion:** Despite its importance, few studies published results of mediation analysis, and more high-quality research into relevant mediators is necessary. On the basis of the limited number of published studies, self-efficacy and intention appear to be relevant mediators for physical activity interventions. Future intervention developers are advised to provide information on the theoretical base of their intervention including the strategies applied to provide insight into which strategies are effective in changing relevant mediators. In addition, future research is advised to focus on the development, validity, reliability and sensitivity of mediator measures.

*International Journal of Obesity* (2011) **35**, 1251–1265; doi:10.1038/ijo.2011.68; published online 12 April 2011

**Keywords:** mediator; physical activity; diet; intervention; sedentary behaviour; youth

## Background

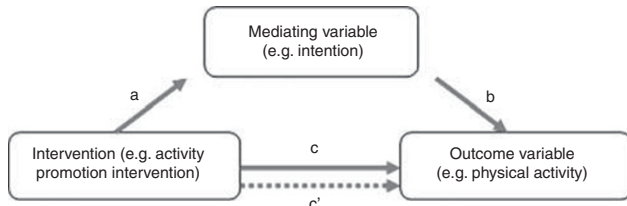
Prevention of obesity is one of today's major public health challenges.<sup>1</sup> Obesity prevention should start early in life,

because the prevalence of obesity among youth has increased steadily over the past several decades<sup>2,3</sup> and childhood obesity is associated with major health risks.<sup>4,5</sup> Overweight and obesity are the results of an enduring positive energy balance, that is, when energy intake is larger than energy expenditure. Hence, overweight and obesity prevention requires effective intervention programmes targeting behaviours that contribute to both sides of this energy balance. These so-called energy balance-related behaviours include dietary behaviours (for example, consumption of fruit and vegetables, or sugar-sweetened beverages),

Correspondence: Dr MJM Chinapaw, Department of Public and Occupational Health, VU University Medical Center, EMGO Institute for Health and Care Research, Amsterdam, The Netherlands.

E-mail: m.chinapaw@vumc.nl

Received 3 August 2010; revised 16 February 2011; accepted 20 February 2011; published online 12 April 2011



**Figure 1** Conceptual mediating framework.

sedentary behaviours (for example, television (TV) viewing or computer use) and physical activity behaviours (for example, sports or active commuting to school). The importance of effective interventions that aim at improving energy balance-related behaviours to prevent overweight and obesity in youth have been highlighted in previous reviews.<sup>6–9</sup>

Recent reviews showed that studies that focused on dietary or physical activity behaviour produce a significant and clinically meaningful reduction in body mass index status of children and adolescents both in preventing obesity<sup>10,11</sup> as well as treating obesity.<sup>12</sup> The effect sizes were, however, small. This might be due to not targeting potentially effective working mechanisms (that is, theoretical mediating variables) that are substantially related to the energy balance-related behaviours.<sup>13–15</sup> By specifying what works (that is, effective intervention components) and what does not work (that is, ineffective intervention components) in energy balance-related behaviour interventions, we can prompt future intervention developers to add effective intervention components and remove/ adapt ineffective intervention components. This will not only increase the effectiveness and clinical relevance of these interventions but also reduce their costs.<sup>17,18</sup>

Mediation analyses can be used to evaluate whether an intervention works via the hypothesised working mechanisms.<sup>13,15,16</sup> Mediating variables specify the causal sequence between an intervention and an outcome (for example, behaviour; Figure 1). Different approaches have been suggested to establish mediation (see Table 1 for an overview).<sup>19–21</sup> Basically, a mediation analysis consists of three tests:

1. The action theory test, which refers to how the independent variable changes the mediating variable (path a in Figure 1). For example, intervention participants have significantly increased their intention to be physically active when compared with control participants.
2. The conceptual theory test, which refers to how the mediating variable influences the outcome variable controlling for the independent variable (path b in Figure 1). For example, changes in intention are significantly associated with changes in physical activity behaviour independent of the intervention effect.
3. The mediated effect test: a simultaneous test of the action and conceptual theories, wherein the extent of the mediated effect on the intervention effect on energy balance behaviour is evaluated.

In a mediation analysis, a potential mediating variable is added to the model of an independent and outcome variable. As the independent variable is expected to exert its effect on the outcome variable via the mediating variable, adding the mediating variable to the model is expected to attenuate the association between the independent and outcome variable.<sup>19</sup> Inconsistent mediated effects, also called suppressor effects, are mediated effects with a different sign than other mediated or direct effects in a model.<sup>22</sup> This inconsistent mediator suppresses the intervention effects. In other words, the intervention would have been more successful when it had not changed the suppressor.<sup>22</sup> One of the conditions of mediation is causality in which it is assumed that changes in the mediator precede changes in the outcome.<sup>22</sup>

Mediation analyses can prompt future intervention developers to add effective intervention components or remove/ adapt ineffective intervention components.<sup>17,18</sup> Regarding the latter, assuming that the mediator was measured with a sensitive and valid measure, the study had enough power and the variability in the mediator was high, there are two possible explanations that a mediation effect is not observed.<sup>17</sup> First, despite a significant effect of the intervention on the mediator, it is possible that the changes in the mediator are unrelated to the outcome (that is, a nonsignificant conceptual theory test). In this case, the mediator may be irrelevant in changing the behaviour, and should not be included in future interventions. Second, it is possible that a potential mediator is related to the outcome but is not affected by the intervention (that is, a nonsignificant action theory test). In this case, intervention developers should be prompted to look for other intervention strategies targeting this potential mediator.<sup>17</sup>

At this time, we have insufficient knowledge about which psychosocial and environmental mediating variables are important for changing particular behaviours.<sup>23</sup> Current behaviour theories still assume that similar mediating variables underlie changes in different energy balance-related behaviours. To summarise the most important psychosocial and environmental mediators of interventions aimed at dietary, sedentary or physical activity behaviour, and to examine whether similar mediators underlie different energy balance-related sub-behaviours, we performed a combined systematic review. To date, two reviews of psychosocial and environmental mediators of energy balance behaviour interventions in youth have been published: one review examined physical activity interventions<sup>24</sup> and one review examined dietary interventions.<sup>25</sup> Each included seven intervention studies. Lubans *et al.*<sup>24</sup> found some support for the mediating role of self-efficacy and self-regulation strategies in physical activity interventions. The mediators of interventions targeting sedentary behaviour were not examined. Cerin *et al.*<sup>25</sup> found support for the mediating role of outcome expectancies on dietary behaviour promotion. When these reviews were conducted,<sup>18,19</sup> few studies performed mediation analyses. Neither review, therefore, was able to draw strong conclusions regarding relevant psychosocial

**Table 1** Definitions of mediation tests and significance tests of mediation

	Definition
<i>Approaches for mediation</i>	
Baron and Kenny approach <sup>19</sup>	In establishing mediation, four criteria must be met: (1) an independent variable ( <i>X</i> ) must be significantly associated with the dependent variable ( <i>Y</i> ); (2) and the potential mediator ( <i>M</i> ); (3) <i>M</i> must be significantly associated with <i>Y</i> after adjustment for <i>X</i> ; and (4) the effect of <i>X</i> on <i>Y</i> controlling for <i>M</i> should no longer significant or should be significantly attenuated. Mediation is present if each of the four steps of the Baron and Kenny approach is satisfied.
Product of coefficient test <sup>21,22</sup>	This approach assumes that mediation depends on the extent to which the independent variable <i>X</i> changes the mediating variable <i>M</i> ( <i>a</i> coefficient) and the extent to which <i>M</i> affects the dependent variable <i>Y</i> ( <i>b</i> coefficient). The mediated effect is the product of the two coefficients ( <i>a</i> × <i>b</i> ).
Difference in coefficient test <sup>64,65</sup>	This approach assumes that the mediated effect is the reduction in the effect of the independent variable <i>X</i> on the outcome variable <i>Y</i> when adjusted for the mediator <i>M</i> . The value of the mediated effect could be estimated by taking the difference in the coefficients of the effect of <i>X</i> on <i>Y</i> ( <i>c</i> ) and the effect of <i>X</i> on <i>Y</i> when controlling for <i>M</i> ( <i>c'</i> ). This difference in coefficient ( <i>c</i> – <i>c'</i> ) equals the product of coefficient ( <i>a</i> × <i>b</i> ) in ordinary least square regressions.
MacArthur mediation framework <sup>20</sup>	This approach is similar to the Baron and Kenny approach but in addition assumes that there could be an interaction between the <i>X</i> and the <i>M</i> variable. The MacArthur approach includes the interaction term between <i>X</i> and <i>M</i> in the model, and establishes mediation by demonstrating the presence of either a main effect of <i>M</i> or an interaction between <i>X</i> and <i>M</i> .
Confirmatory test of complete mediation <sup>66</sup>	Confirmatory test of complete versus partial mediation models and consists of testing whether the effect of <i>X</i> on <i>Y</i> when controlled for <i>M</i> ( <i>c'</i> coefficient) is statistically significant, and consists of two steps: (1) a complete or partial mediation model is hypothesised in which the <i>c'</i> coefficient is specified to be 0. (2). The path relating <i>X</i> to <i>M</i> ( <i>a</i> coefficient) and the path relating <i>M</i> to <i>Y</i> not adjusted for <i>X</i> ( <i>b</i> <sub>unadjusted</sub> ) should be statistically significant. Model fit is used as a statistical test.
<i>(Significance) tests of mediation</i>	
Joint significant test <sup>67</sup>	A variation of Baron and Kenny's causal-step test, which ignores the first step of the causal-step test and uses the significance of the path relating <i>X</i> to <i>M</i> ( <i>a</i> coefficient) and the path relation <i>M</i> to <i>Y</i> when controlled for <i>X</i> ( <i>b</i> coefficient) to analyse mediation. If both <i>a</i> and <i>b</i> coefficients are found to be significant, mediation is present.
Sobel first-order test <sup>68</sup>	This test is the most common product of coefficients test and assesses the statistical significance of a mediated effect by dividing the product of coefficients ( <i>a</i> × <i>b</i> ) by its standard error and compared with a standard normal distribution to establish whether the product of the effects is significantly different from 0.
PRODCLIN <sup>69</sup>	Approach that tests mediation by computing the critical values using a programme called PRODCLIN to create asymmetric confidence intervals based on the distribution of the product of two variables. This approach handles with a shortcoming of the product of coefficient tests that relies on normal theory. However, the distribution of the product of two normally distributed random variables, in this case <i>a</i> and <i>b</i> , is rarely normally distributed.
Bootstrapping <sup>70</sup>	Approach to statistical inference that takes a large number (> 1,000) of random samples (bootstrap samples) from the original data with replacement. For each bootstrap sample, the <i>a</i> , <i>b</i> and <i>ab</i> coefficients are estimated and the average mediated effect and 95% confidence intervals around it are computed across the bootstrap samples.

and environmental mediators of energy balance behaviour interventions. More recently, however, the mediation analysis field has been developing rapidly, resulting in further publications on mediation analyses. Therefore, we updated both reviews and compared mediators of interventions targeting sedentary, physical activity and/or dietary behaviours, emphasising implications for future interventions and research. Hence, the aim of this systematic literature review was to identify the psychosocial and environmental mediators of interventions targeting energy balance-related behaviours in school-aged children and adolescents.

## Materials and methods

### Literature Search

We systematically searched the electronic databases PubMed, EMBASE, PsycINFO, ERIC, Cochrane and Sportdiscus from January 1990 to July 2010. The search of manuscripts published in English included free text terms, in which search terms for children and adolescents (for example, child, schoolchild, adolescent and student) were used in AND-combinations with terms for energy balance-related

behaviours (for example, physical activity, exercise, sport, nutrition, food and diet), with terms for mediators (for example, mediator\*, indirect and 'structural equation modelling') and with terms representing intervention studies (for example, intervention, prevention, promotion, treatment). Supplementary file 2 shows the search strategy for the Pubmed database.

### Inclusion criteria

Studies were included if they (1) were school-based randomised controlled trials or quasi-experimental studies; (2) targeted energy balance-related behaviours such as physical activity behaviours (for example, sports, active transport, recreational activities, playing, walking and cycling), sedentary behaviours (for example, screen viewing and sitting) or dietary behaviours (for example, soft drink, fruit and vegetable consumption, snacking and having breakfast); (3) were conducted among children and adolescents aged between 4 and 18 years; (4) were written in English; and (5) had conducted an appropriate mediation analysis. We chose to only include school-based interventions, as they are promising, as they are able to reach almost all children and enable the combination of educational

and school-environmental strategies for health behaviour change.<sup>10</sup> In addition, we chose to include studies that targeted pupils aged 4-18 years, as this is school age. A mediation analysis was considered appropriate if it conducted one of the mediation analysis tests (for example, product of coefficient test, difference in coefficient test, Baron and Kenny's causal steps of mediation, MacArthur mediation framework or confirmatory test of complete mediation) and conducted one of the significance tests of mediation (for example, Baron and Kenny's causal-step test; joint significant test, Sobel first-order test, PRODCLIN or bootstrapping). Table 1 provides the definitions of each of these different approaches and statistical tests. Only full-text articles were included. Studies that included an outcome other than energy balance-related behaviours associated with overweight prevention (for example, dental health, sports nutrition) were excluded.

#### Selection process

Two authors (MVS and MY) independently reviewed article titles and abstracts to identify relevant articles. They also checked the full-text articles of potentially relevant articles for the eligibility criteria; extracted data from the remaining relevant articles; and performed a quality assessment.

#### Data extraction and quality assessment

The top row of Supplementary file 3 shows the data extracted from the relevant articles. Mediators were categorised into four groups: psychological (for example, self-efficacy), environmental (for example, availability), behavioural (for example, habitual behaviour and TV-viewing behaviour) and intervention-related mediators (for example, programme evaluation).

The quality of all included studies were examined using 10 quality criteria. These 10 criteria were based on the Delphi study of Verhagen *et al.*<sup>26</sup> or were applied in the reviews of Lubans *et al.*<sup>24</sup> or Cerin *et al.*<sup>25</sup> These criteria are described in the top row of Supplementary file 4. When a study did not report a power calculation, we assessed whether the study had enough power to detect mediation by the applied mediation test, based on the criteria set by Fritz and MacKinnon.<sup>27</sup> In case the text provided insufficient information, we contacted the authors for clarification. All 10 criteria have response options of 'yes' (= 1), 'no' (= 0) or 'don't know' (= 0). The 'don't know' answer format was used when the author did not provide information on the specific criteria (for example, did not test selectiveness of dropout). For each study, we calculated a total quality score by summing the scores for each individual quality item and dividing by the total number of quality criteria, resulting in a possible quality score of 0-100%. We considered a study to be of high quality if the methodological score was at least 0.70, that is, 70%. A lower score was defined as low quality.

#### Levels of scientific evidence

To synthesise the methodological quality of the studies and to be able to draw conclusions regarding the mediators of energy balance-related behaviour interventions, we applied a best evidence synthesis.<sup>28,29</sup> This rating system consists of three levels and takes into account the number, the methodological quality and the consistency of outcomes of the studies:

- Strong evidence: consistent findings in multiple ( $\geq 2$ ) high-quality studies.
- Moderate evidence: consistent findings in one high-quality study and at least one low-quality study, or consistent findings in multiple low-quality studies.
- Insufficient evidence: only one study available or inconsistent findings in multiple ( $\geq 2$ ) studies.

Similar to previous reviews applying this best evidence syntheses, we considered results to be consistent when at least 75% of the studies demonstrated results in the same direction, which was defined according to significance ( $P < 0.05$ ).<sup>28-30</sup> If there were two or more high-quality studies, we disregarded the studies of low methodological quality in the evidence synthesis; those studies were thus not incorporated in the conclusion.

## Results

#### Study characteristics

Supplementary file 1 presents the flow of the studies through the selection process. From the 6860 initially identified titles, 24 studies fulfilled our inclusion criteria. Most studies were excluded because they addressed health behaviours other than dietary, physical activity or sedentary behaviours (for example, smoking or alcohol consumption) or because they focused on a different target group (for example, pre-schoolers and adults). Supplementary file 3 presents the study characteristics. The included intervention studies were conducted in eight countries (in alphabetical order: Australia, Belgium, Iran, Italy, the Netherlands, Portugal, United Kingdom and the United States of America). The sample size ranged from 1 to 55 schools and from 78 to 2840 students. The majority was conducted in secondary schools. The shortest follow-up period was three weeks,<sup>31</sup> whereas the longest was three years.<sup>32</sup> Two studies did not report which mediation analysis was applied.<sup>33,34</sup> A total of 13 studies applied regression models,<sup>32,35-46</sup> four studies reported generalised linear modelling,<sup>31,34,47,48</sup> four studies reported using path analysis<sup>49-52</sup> and two studies reported using latent variable mediation modelling (that is, structural equation modelling)<sup>53,54</sup> to analyse mediation effects. In total, eight studies analysed multiple mediator models,<sup>39,40,43,44,49,50,53,54</sup> of which four reported both single and multiple mediator analyses.<sup>39,40,44,50</sup> To test the mediated effect, six studies used the Baron and Kenny causal-step test,<sup>35,36,38,41,45,47</sup> three studies used the joint

significance test,<sup>51,53,54</sup> twelve studies applied the Sobel test<sup>31,32,37,39,40,42,44,46,48–50,52</sup> and one study applied the PRODCLIN test.<sup>43</sup>

### Study quality

Supplementary file 4 presents the quality assessment; 10 studies were of high quality, and most ( $N=20$ ) applied randomised controlled trial designs with school level randomisation. Of the 21 studies that reported the dropout rate, half examined whether the dropout rate was selective. Most studies described social cognitive theory as the theoretical framework,<sup>32,34,36,39–44,47,48,50,51,53,54</sup> whereas four studies were based on the theory of planned behaviour.<sup>31,37,39,40</sup> Four studies were not explicitly guided by behavioural theory.<sup>33,35,38,45</sup> Except for four studies,<sup>31,35,38,51</sup> all studies reported using outcome measures with known reliability or validity. Seven studies reported using mediator measures of low to moderate reliability (Cronbach's  $\alpha < 0.70$ ).<sup>31,39,40,43,44,50,51</sup> Although some studies reported a power calculation, none of the studies reported a power calculation based on assessing mediation effects. Based on the criteria set by Fritz and MacKinnon, we assessed whether the studies were powered enough to detect mediation with the applied mediation test, resulting in nine underpowered studies.<sup>33–36,38,41,42,47,51</sup> Only one study<sup>49</sup> had measured changes in the mediating variables before the changes in the outcome variables.

### Study findings

**Intervention effect on outcome.** As shown in Supplementary file 3, 18 studies aimed to change physical activity,<sup>31–33,36–38,40–43,46–49,51–54</sup> and three studies aimed to improve sedentary behaviour.<sup>34,37,52</sup> Of the eight studies that aimed to change dietary behaviours, the majority ( $n=6$ ) targeted fruit and vegetable consumption,<sup>35,43–45,48,50</sup> one targeted soft drink consumption,<sup>37</sup> two targeted snacking/ fat intake<sup>37,39</sup> and one targeted total dietary behaviour.<sup>51</sup> Of these studies, four were aimed at changing both sides of the energy balance.<sup>37,43,48,51</sup> To be able to make stronger conclusions, and as few studies targeted a dietary behaviour other than fruit and vegetable consumption, we combined all dietary behaviour interventions.

All published studies found significant intervention effects on at least one of the examined energy balance behaviours. Shilts *et al.*<sup>51</sup> only observed a significant intervention effect among a subgroup that had set specific change goals during the intervention.

### Intervention effect on mediator (action theory test)

**Physical activity behaviour.** The action theory test<sup>21</sup> examines whether the intervention changed the potential mediator. Among the physical activity intervention studies, of the 107 action theory tests reported, only 44 were significant (see Table 2, column 3). The majority of the

interventions found a significant intervention effect on intention,<sup>31,36,49</sup> self-regulation skills,<sup>36,41,43,46,54</sup> enjoyment,<sup>47,54</sup> and intrinsic motivation<sup>49</sup> in the desired direction. About half of the interventions aimed at changing self-efficacy,<sup>31–33,36,37,40–43,46–48,51,53,54</sup> perceived benefits<sup>40,46</sup> and social norm<sup>31,37,46</sup> were successful. Physical activity interventions aimed at changing the potential mediators: attitude,<sup>31–33,36,37,40–42,53</sup> social support,<sup>32,40–42,46,47</sup> satisfaction,<sup>53</sup> counterconditioning,<sup>46</sup> stimulus control,<sup>46</sup> social modelling,<sup>46</sup> other physical activity-related behaviours<sup>32,38</sup> and habit strength<sup>37</sup> appeared to be less successful. Five physical activity promotion interventions affected a mediator in the undesired direction.<sup>32,32,40,47,48</sup> Notably, three out of five intervention studies aimed at changing barriers found an effect in the undesired direction,<sup>32,33,40,46,47</sup> wherein intervention participants perceived more barriers as a result of the intervention.

**Sedentary behaviour.** As shown in Table 3 (column 3), of the 10 action theory tests reported, only one was significant. In this TV-viewing intervention, the authors found a significant effect on intrinsic motivation.<sup>52</sup> No significant intervention effects were found on attitude,<sup>37,52</sup> self-efficacy,<sup>37</sup> social norm<sup>37</sup> or habit behaviour.<sup>37</sup>

**Dietary behaviour.** As shown in Table 4 (column 3), 15 of the 51 possible intervention effects on potential mediators were significant; 3 of these were in the unexpected direction (that is, perceived barriers;<sup>39</sup> self-efficacy;<sup>48</sup> and social norm<sup>44</sup>). The majority of the interventions were effective in changing knowledge<sup>35,44,50</sup> and attitude.<sup>37,39,44</sup> We found some studies showing intervention effects on habit behaviour,<sup>37</sup> parental consumption<sup>44,50</sup> and social norm.<sup>37,44,48</sup> All included studies that aimed at changing perceived benefits,<sup>39</sup> perceived barriers,<sup>39</sup> self-efficacy,<sup>37,39,43,44,48</sup> proxy efficacy,<sup>48</sup> social support<sup>39</sup> and availability<sup>43,44,50</sup> were unsuccessful.

### Effect of mediator on behaviour (conceptual theory test)

**Physical activity behaviour.** In the conceptual theory test,<sup>21</sup> the relationship between changes in the potential mediator and changes in the outcome variable is examined. Convincing support was found for the relationship between attitude,<sup>37,40,42,53</sup> perceived benefits,<sup>40,46</sup> perceived barriers,<sup>32,40,46,47</sup> self-efficacy,<sup>32,37,40,42,43,46,53,54</sup> self-regulation skills,<sup>41,43,46,54</sup> and social support<sup>40–43,46,47</sup> and physical activity behaviour (see Table 2, column 4). Some support was found for the association between satisfaction,<sup>53</sup> intention,<sup>49</sup> intrinsic motivation,<sup>49</sup> stimulus control,<sup>46</sup> social modelling<sup>46</sup> autonomy support,<sup>49</sup> habit strength<sup>37</sup> and physical activity. No evidence was found for a relationship between enjoyment,<sup>47,54</sup> social norm<sup>37</sup> or changing TV-viewing behaviour<sup>38</sup> and physical activity behaviour.

**Sedentary behaviour.** As shown in Table 3 (column 4), indications for relationships between attitude,<sup>37</sup> self-efficacy,<sup>37</sup>

**Table 2** Results of studies examining potential mediators of intervention schemes promoting physical activity in youth

Mediator	Quality score (%)	Action theory	Conceptual theory	Mediated effect	Outcome
<b>Psychological</b>					
<b>Attitude</b>					
Araujo-Soares <i>et al.</i> <sup>36</sup>	80	+	NR*	NR*	MVPA
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	–	NR*	Active transport boys
	80	NS	+	NR*	Active transport girls
Dishman <i>et al.</i> <sup>53</sup>	78	NS	+	NS	Total PA girls
Haerens <i>et al.</i> <sup>40a</sup>	60	–	+	Suppressor/suppressor	Total PA and PA at home and school
Haerens <i>et al.</i> <sup>40b</sup>	60	–	+	Suppressor/suppressor	Total PA and PA at home and school
Hill <i>et al.</i> <sup>31</sup>	60	+	NR	NR	Exercise
Hortz <i>et al.</i> <sup>41</sup>	60	NS	NR**	NS	MPA
Lubans <i>et al.</i> <sup>42</sup>	56	NS	NS	NS	MVPA boys
	56	NS	NS	NS	MVPA girls
Lytle <i>et al.</i> <sup>32</sup>	56	NR	NR	NS	MVPA girls weekdays
	56	NR	NR	NS	MVPA girls weekend
Zizzi <i>et al.</i> <sup>33</sup>	56	NS	NR**	NR**	Daily step count
<b>Satisfaction</b>					
Dishman <i>et al.</i> <sup>53</sup>	78	NS	+	NS	Total PA girls
<b>Perceived benefits</b>					
<b>Health</b>					
Haerens <i>et al.</i> <sup>40a</sup>	60	–	+	Suppressor/suppressor	PA at home and school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	+	NS	Total PA and PA at home and school
<b>Psychosocial</b>					
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	+	Suppressor/suppressor	Total PA and PA at home and school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	+	NS	Total PA and PA at home and school
<b>General</b>					
Taymoori <i>et al.</i> <sup>46a</sup>	70	+	+	Mediator	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	NR**	NR**	Total PA girls
<b>Perceived barriers</b>					
<b>General</b>					
Taymoori <i>et al.</i> <sup>46a</sup>	70	–	–	Mediator	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	NR**	NR**	Total PA girls
Zizzi <i>et al.</i> <sup>33</sup>	56	NS	NR**	NR**	Daily step count
<b>Health</b>					
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	NS	NS	Total PA and PA at home and school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	NS	NS	Total PA and PA at home and school
<b>Environmental/external</b>					
Dunton <i>et al.</i> <sup>47</sup>	60	+	NS	NS	VPA girls
Haerens <i>et al.</i> <sup>40a</sup>	60	+	–	Suppressor/suppressor	Total PA and PA at home and school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	–	NS	Total PA and PA at home and school
Lytle <i>et al.</i> <sup>32</sup>	56	+	–	Suppressor	MVPA girls weekdays
	56	+	–	Suppressor	MVPA girls weekend
<b>Motivational/internal</b>					
Dunton <i>et al.</i> <sup>47</sup>	60	+	NS	NS	VPA girls
Haerens <i>et al.</i> <sup>40a</sup>	60	+	–	Suppressor/suppressor	Total PA and PA at home and school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	–	NS	Total PA and PA at home and school
<b>PBC/self-efficacy</b>					
Araujo-Soares <i>et al.</i> <sup>36</sup>	80	NS	NR*	NR*	MVPA
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	NS	NR*	Active transport boys
	80	NS	NS	NR*	Active transport girls
Dishman <i>et al.</i> <sup>53</sup>	78	+	+	Mediator	Total PA girls
Dishman <i>et al.</i> <sup>54</sup>	89	+	+	Mediator	Total PA girls

Table 2 (continued)

Mediator	Quality score (%)	Action theory	Conceptual theory	Mediated effect	Outcome
Dunton <i>et al.</i> <sup>47</sup>	60	NS	NS	NS	VPA girls
Dzewaltowski <i>et al.</i> <sup>48</sup>	70	–	NR**	NR	VPA and MVPA
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	+	NS	PA at school
	60	–	+	Suppressor/suppressor	PA at home
Haerens <i>et al.</i> <sup>40b</sup>	60	+	+	Mediator/mediator	PA at school
	60	NS	+	NS	PA at home
Hill <i>et al.</i> <sup>31</sup>	60	+	NR	Mediator	Exercise
Hortz <i>et al.</i> <sup>41</sup>	60	NS	NR**	NS	MPA
Lubans <i>et al.</i> <sup>42</sup>	56	NS	NS	NR**	MVPA boys
	56	+	+	NS	MVPA girls
Lubans <i>et al.</i> <sup>43</sup>	89	NS	NS	NS	Total PA
Lytle <i>et al.</i> <sup>32</sup>	56	–	+	Suppressor	MVPA girls weekdays
	56	–	+	Suppressor	MVPA girls weekend
Shilts <i>et al.</i> <sup>51</sup>	40	+	NR	Mediator	Total PA
Taymoori <i>et al.</i> <sup>46a</sup>	70	+	+	Mediator	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	+	+	Mediator	Total PA girls
Zizzi <i>et al.</i> <sup>33</sup>	56	NS	NR**	NR**	Daily step count
Proxy efficacy					
Dzewaltowski <i>et al.</i> <sup>48</sup>					
School	70	+	NR	Mediator	VPA and MVPA
Parents	70	NS	NR**	NR**	VPA and MVPA
Peers	70	NS	NR**	NR**	VPA and MVPA
Counterconditioning					
Taymoori <i>et al.</i> <sup>46a</sup>	70	NS	NR**	NR**	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	NR**	NR**	Total PA girls
Intention					
Araujo-Soares <i>et al.</i> <sup>36</sup>	80	NS	NR*	NR*	MVPA
Chatzisarantis <i>et al.</i> <sup>49</sup>	89	+	+	Mediator	Leisure time PA
Hill <i>et al.</i> <sup>31</sup>	60	+	NR	Mediator	Exercise
Intrinsic motivation					
Chatzisarantis <i>et al.</i> <sup>49</sup>	89	+	+	Mediator	Leisure time PA
Enjoyment					
Physical education					
Dishman <i>et al.</i> <sup>54</sup>	89	+	NS	NS	Total PA girls
Physical activity					
Dishman <i>et al.</i> <sup>54</sup>	89	+	+	Mediator	Total PA girls
Dunton <i>et al.</i> <sup>47</sup>	60	NS	NS	NS	VPA girls
Self-regulation					
Araujo-Soares <i>et al.</i> <sup>36</sup>					
Action planning	80	NS	NR*	NR*	MVPA
Coping planning	80	+	NR*	NR*	MVPA
Dishman <i>et al.</i> <sup>54</sup>	89	+	NS	NS	Total PA girls
Hortz <i>et al.</i> <sup>41</sup>	60	+	+	Mediator	Moderate-intensity exercise
Lubans <i>et al.</i> <sup>43</sup>	89	NS	NS	NS	Total PA
Taymoori <i>et al.</i> <sup>46a</sup>	70	+	+	Mediator	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	+	+	Mediator	Total PA girls
Stimulus control					
Taymoori <i>et al.</i> <sup>46a</sup>	70	NS	+	NS	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	NR**	NR**	Total PA girls
Social and physical environment					
Social support					
General					
Hortz <i>et al.</i> <sup>41</sup>	60	+	+	Mediator	MPA
Taymoori <i>et al.</i> <sup>46a</sup>	70	NS	NR**	NR**	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	NR**	NR**	Total PA girls
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	+	NS	Total PA
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	+	NS	Total PA
Lytle <i>et al.</i> <sup>32</sup>	56	–	+	Suppressor	MVPA girls weekdays
	56	–	+	Suppressor	MVPA girls weekend

Table 2 (continued)

Mediator	Quality score (%)	Action theory	Conceptual theory	Mediated effect	Outcome
Family and friends					
Lubans <i>et al.</i> <sup>42</sup>	56	NS	NS	NS	MVPA boys
	56	+	NS	NS	MVPA girls
Dunton <i>et al.</i> <sup>47</sup>	60	NS	NS	NS	VPA girls
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	+	NS	PA at home
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	+	NS	PA at home
Friends and teacher					
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	+	NS	PA at school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	+	NS	PA at school
Lytle <i>et al.</i> <sup>32</sup>	56	–	+	Suppressor	MVPA girls weekdays
	56	–	+	Suppressor	MVPA girls weekend
Parents family					
Haerens <i>et al.</i> <sup>40a</sup>	60	NS	NS	NS	PA at school
Haerens <i>et al.</i> <sup>40b</sup>	60	NS	NS	NS	PA at school
Lubans <i>et al.</i> <sup>43</sup>	89	NS	NS	NS	Total PA
Lytle <i>et al.</i> <sup>32</sup>	56	NR***	NR***	NS	MVPA girls weekdays
	56	NR***	NR***	NS	MVPA girls weekend
Social norm					
Chinapaw <i>et al.</i> <sup>37</sup>	80	+	NS	NR*	Active transport boys
	80	NS	NS	NR*	Active transport girls
Hill <i>et al.</i> <sup>31</sup>	60	+	NR***	NR***	Exercise
Taymoori <i>et al.</i> <sup>46a</sup>	70	NS	NR**	NR**	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	NR**	NR**	Total PA girls
Social modelling					
Taymoori <i>et al.</i> <sup>46a</sup>	70	NS	NR**	NR**	Total PA girls
Taymoori <i>et al.</i> <sup>46b</sup>	70	NS	+	NS	Total PA girls
Autonomy support					
Chatzisarantis <i>et al.</i> <sup>49</sup>	89	+	+	Mediator	Leisure time PA
Access to facilities					
Lytle <i>et al.</i> <sup>32</sup>	56	NR***	NR***	NS	MVPA girls weekdays
	56	NR***	NR***	NS	MVPA girls weekend
Behavioural					
Participation in out-of-school PA programmes					
Lytle <i>et al.</i> <sup>32</sup>	56	NR***	NR***	NS	MVPA girls weekdays
	56	NR***	NR***	NS	MVPA girls weekend
Participation in sports programmes					
Lytle <i>et al.</i> <sup>32</sup>	56	NR***	NR***	NS	MVPA girls weekdays
	56	NR***	NR***	NS	MVPA girls weekend
TV viewing					
Graham <i>et al.</i> <sup>38</sup>	20	NS	NS	NS	VPA girls
Habit					
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	NS	NR*	Active transport boys
	80	NS	NS	NR*	Active transport girls

Abbreviations: MPA, moderate-intensity physical activity; MVPA, moderate and vigorous physical activity; NR\*, not reported because intervention effect on outcome was not significant; NR\*\*, not reported because intervention effect on mediator was not significant or in opposite direction; NR\*\*\*, not reported because no significant mediated effect was found; NS, not significant; PA, physical activity; PBC, perceived behaviour control; TV, television; VPA, vigorous physical activity. <sup>a</sup>Haerens: intervention without parental support; <sup>b</sup>Haerens: intervention with parental support; <sup>a</sup>Taymoori: intervention based on health promotion model and transtheoretical model; and <sup>b</sup>Taymoori: intervention based on health promotion model.

intrinsic motivation,<sup>52</sup> social norm,<sup>37</sup> habit strength<sup>37</sup> and sedentary behaviour were found. The association between social norm and sedentary behaviour was in the unexpected direction. Additionally, the relationships between attitude, social norm and screen-viewing behaviour were identified only among girls.

**Dietary behaviour.** As shown in Table 4 (column 4), convincing evidence was found for the association between

attitudes,<sup>37,39,44</sup> and habit strength<sup>37</sup> and dietary behaviour. Some evidence was found for an association between dietary behaviour and knowledge,<sup>35,44,50</sup> and self-efficacy,<sup>37,39,43,44</sup> as about half of the studies found a significant effect. No or insufficient evidence was found for an association between perceived benefits,<sup>39</sup> perceived barriers,<sup>39</sup> proxy efficacy,<sup>48</sup> social support,<sup>39</sup> social norm,<sup>37,44</sup> parent consumption,<sup>44,50</sup> eating together,<sup>44</sup> availability<sup>43,44,50</sup> and dietary behaviour.



**Table 3** Results of studies examining potential mediators of intervention schemes changing sedentary behaviour in youth

Mediator	Quality score (%)	Action theory	Conceptual theory	Mediated effect	Outcome
<b>Psychological</b>					
<b>Attitude</b>					
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	NS	NR*	Screen-viewing boys
	80	NS	–	NR*	Screen-viewing girls
Spruijt-Metz <i>et al.</i> <sup>52</sup>	78	NS	NR**	NR**	TV-viewing girls
<b>PBC/self-efficacy</b>					
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	–	NR*	Screen-viewing boys
	80	NS	–	NR*	Screen-viewing girls
<b>Intrinsic motivation</b>					
Spruijt-Metz <i>et al.</i> <sup>52</sup>	78	+	–	NS	TV-viewing girls
<b>Social and physical environment</b>					
<b>Social norm</b>					
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	NS	NR*	Screen-viewing boys
	80	NS	+	NR*	Screen-viewing girls
<b>Behavioural</b>					
<b>Habit</b>					
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	+	NR*	Screen-viewing boys
	80	NS	+	NR*	Screen-viewing girls
<b>Intervention related</b>					
<b>Parents read newsletter</b>					
Robinson <i>et al.</i> <sup>34</sup>	67	NR***	NR***	NS	Screen-viewing elementary school children
<b>TV allowance was used</b>					
Robinson <i>et al.</i> <sup>34</sup>	67	NR***	NR***	NS	Screen-viewing elementary school children
<b>TV allowance requested</b>					
Robinson <i>et al.</i> <sup>34</sup>	67	NR***	NR***	NS	Screen-viewing elementary school children
<b>Number of incentives</b>					
Robinson <i>et al.</i> <sup>34</sup>	67	NR***	NR***	NS	Screen-viewing elementary school children

Abbreviations: NR\*, not reported because intervention effect on outcome was not significant; NR\*\*, not reported because intervention effect on mediator was not significant or in opposite direction; NR\*\*\*, not reported because no significant mediated effect was found; NS, not significant; PBC, perceived behaviour control; TV, television.

### Mediated effects

**Physical activity behaviour.** Among the intervention studies aimed at changing physical activity behaviour, strong evidence was found for a mediating effect of self-efficacy, and moderate evidence was found for a mediating effect of intention (see table 2, column 5). Among the five high-quality studies that reported the mediated effect of self-efficacy, four found that changes in self-efficacy induced by the interventions were associated with significant increases in physical activity behaviour.<sup>43,46,53,54</sup> Both intervention studies that reported on the mediated effect of intention<sup>31,49</sup> found intention to be an important mediator of the effect of the intervention on physical activity behaviour.

Indications for a mediated effect of self-regulation,<sup>41,43,46,54</sup> intrinsic motivation,<sup>49</sup> enjoyment,<sup>47,54</sup> perceived benefits,<sup>40,46</sup> proxy efficacy<sup>48</sup> and autonomy support<sup>49</sup> on physical activity interventions were found, as half of the (high quality) studies, or only one high-quality study found a mediated effect. Moderate evidence for a lack of mediation was found for attitude,<sup>32,40–42,53</sup> perceived barriers<sup>32,40,46,47</sup> and social influences,<sup>32,40–43,46</sup> mostly because of the fact that the interventions were not able to change the presumed mediator in the desired direction. Studies examining the mediating effects of social modelling,<sup>46</sup> counterconditioning,<sup>46</sup> satisfaction,<sup>53</sup> stimulus control,<sup>46</sup> habit strength<sup>37</sup> or physical activity-related

behaviours (for example, TV viewing and participation in sports programmes)<sup>32,38</sup> found no support for mediating effects.

**Sedentary behaviour.** No mediated effects were identified for the interventions aimed at changing sedentary behaviour (see Table 3, column 5). This was partly due to studies that did not report the mediated effect because the intervention effect on sedentary behaviour<sup>37</sup> or on the potential mediator<sup>52</sup> was not significant. Studies that did report mediated effects, however, did not find mediated effects of intrinsic motivation<sup>52</sup> or intervention-related concepts (for example, parents read the newsletters and the number of incentives received by the child)<sup>34</sup> on sedentary behaviour interventions.

**Dietary behaviour.** With regard to dietary interventions, we found no convincing evidence for significant mediators. Indications for a mediating effect were found for knowledge (that is, one out of two high-quality studies<sup>44,50</sup>), attitude (that is, one out of two high-quality studies<sup>37,39,44</sup>) and habit strength (that is, one out of two high-quality studies<sup>37</sup>; see Table 4, column 5). Chinapaw *et al.*<sup>37</sup> and Reynolds *et al.*<sup>44</sup> found that attitude was a partial mediator of the intervention effect on soft drink consumption, and fruit and vegetable intake, respectively. Chinapaw *et al.*<sup>37</sup> identified the mediated effect among boys only, and Reynolds *et al.*<sup>44</sup> identified the mediated effect only in the single mediator

**Table 4** Results of studies examining potential mediators of intervention schemes promoting healthy diet in youth

Mediator	Quality score (%)	Action theory	Conceptual theory	Mediated effect	Outcome	
<b>Psychological</b>						
<b>Knowledge</b>						
Amaro <i>et al.</i> <sup>35</sup>	33	+	NS	NS	Vegetable intake	
Reynolds <i>et al.</i> <sup>44a</sup>	50	+	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>44b</sup>	50	+	+/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>50a</sup>	89	+	+ (+)	Mediator/mediator	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>50b</sup>	89	+	NS/NS	NS/NS	FV intake elementary school children	
<b>Attitude</b>						
Chinapaw <i>et al.</i> <sup>37</sup>	80	+	–	Mediator	Soft drink boys	
	80	NS	–	NS	Soft drink girls	
	80	NS	–	NR*	Snack boys	
	80	NS	–	NR*	Snack girls	
Haerens <i>et al.</i> <sup>39</sup>	60	NS	–/–	NS/NS	Fat intake girls	
Reynolds <i>et al.</i> <sup>44a</sup>	50	+	+/NS	Mediator/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>44b</sup>	50	+	NS/NS	NS/NS	FV intake elementary school children	
<b>Perceived benefits</b>						
Haerens <i>et al.</i> <sup>39</sup>	60	NS	NS/NS	NS/NS	Fat intake girls	
<b>Perceived barriers</b>						
Haerens <i>et al.</i> <sup>39</sup>	60	+	NS/NS	Suppressor/NS	Fat intake girls	
<b>PBC/self-efficacy</b>						
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	–	NS	Soft drink boys	
	80	NS	–	NS	Soft drink girls	
	80	NS	–	NR*	Snack boys	
	80	NS	–	NR*	Snack girls	
	Dzewaltowski <i>et al.</i> <sup>48</sup>	70	–	NR*	NS	FV intake
	Haerens <i>et al.</i> <sup>39</sup>	60	NS	NS	NS	Fat intake girls
	Lubans <i>et al.</i> <sup>43</sup>	89	NS	NS	NS	FV intake
	Reynolds <i>et al.</i> <sup>44a</sup>	50	NS	+/+	NS/NS	FV intake elementary school children
Reynolds <i>et al.</i> <sup>44b</sup>	50	NS	NS/NS	NS/NS	FV intake elementary school children	
Shilts <i>et al.</i> <sup>51</sup>	40	NS	NR	NS	Dietary behaviour	
<b>Proxy efficacy</b>						
<b>School</b>						
Dzewaltowski <i>et al.</i> <sup>48</sup>	70	NS	NR*	NS	FV intake	
<b>Parents</b>						
Dzewaltowski <i>et al.</i> <sup>48</sup>	70	NS	NR*	NS	FV intake	
<b>Social and physical environment</b>						
<b>Social support</b>						
Haerens <i>et al.</i> <sup>39</sup>	60	NS	NS/NS	NS/NS	Fat intake girls	
<b>Social norm</b>						
Chinapaw <i>et al.</i> <sup>37</sup>	80	NS	NS	NS	Soft drink boys	
	80	NS	NS	NS	Soft drink girls	
	80	+	NS	NR*	Snack boys	
	80	NS	NS	NR*	Snack girls	
	Dzewaltowski <i>et al.</i> <sup>48</sup>	70	+	NR*	NS	FV intake
	Reynolds <i>et al.</i> <sup>44a</sup>	50	NS	NS/NS	NS/NS family	FV intake elementary school children
Reynolds <i>et al.</i> <sup>44b</sup>	50	NS	NS	NS/NS peers	FV intake elementary school children	
	50	+	NS/NS	NS/NS teacher	FV intake elementary school children	
	50	–	NS/NS	NS/NS family	FV intake elementary school children	
	50	NS	NS/NS	NS/NS peers	FV intake elementary school children	
	50	NS	NS/NS	NS/NS teacher	FV intake elementary school children	
<b>Eating together</b>						
Reynolds <i>et al.</i> <sup>44a</sup>	50	NS	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>44b</sup>	50	NS	NS/NS	NS/NS	FV intake elementary school children	
<b>Parent consumption</b>						
Reynolds <i>et al.</i> <sup>44a</sup>	50	NS	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>44b</sup>	50	+	+/+	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>50a</sup>	89	NS	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>50b</sup>	89	NS	NS/NS	NS/NS	FV intake elementary school children	
<b>Availability</b>						
Lubans <i>et al.</i> <sup>43</sup>	89	NS	+	NS	FV intake	
Reynolds <i>et al.</i> <sup>44a</sup>	50	NS	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>44b</sup>	50	NS	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>50a</sup>	89	NS	NS/NS	NS/NS	FV intake elementary school children	
Reynolds <i>et al.</i> <sup>50b</sup>	89	NS	NS/NS	NS/NS	FV intake elementary school children	

Table 4 (continued)

Mediator	Quality score (%)	Action theory	Conceptual theory	Mediated effect	Outcome
Behavioural					
Habit					
Chinapaw <i>et al.</i> <sup>37</sup>	80	–	+	Mediator	Soft drink boys
	80	NS	+	NS	Soft drink girls
	80	NS	+	NR*	Snack boys
	80	NS	+	NR*	Snack girls
Intervention related					
Appreciation program					
Tak <i>et al.</i> <sup>45</sup>	30	+	+	Mediator	Fruit intake elementary school children

Abbreviations: FV intake, fruit and vegetable intake; NR\*, not reported because intervention effect on outcome was not significant; NS, not significant; PBC, perceived behaviour control. <sup>a</sup>Reynolds *et al.*: analysis on change from baseline to 1-year post-baseline. <sup>b</sup>Reynolds *et al.*: analysis on change from baseline to 2-year post-baseline. When both the single- and multiple mediation analyses were presented, results of multiple mediation are behind the '/'.

and short-term analysis. No support was found for the mediating effect of other potential mediators. Strong evidence for a lack of mediation by social influences (that is, social support, social norm, eating together, parent consumption,<sup>37,39,44,48,50</sup> availability<sup>43,44,50</sup> and self-efficacy<sup>37,39,43,44,48</sup>) was found. The lack of a mediating effect of self-efficacy was due to the limited ability of the interventions to change self-efficacy. For the other potential mediators, there was no support for the action theory or conceptual theory.

## Discussion

The aim of this study was to review the published literature on mediators of school-based interventions aimed at changing energy balance-related behaviours in youth. In total, 24 intervention studies were included: 18 studies aimed at changing physical activity, 3 studies aimed at improving sedentary behaviour and 8 studies aimed at changing dietary behaviours.

We found consistent evidence for self-efficacy and moderate evidence for intention as mediators of intervention effects on physical activity behaviour. In addition, we found indications that self-regulation, intrinsic motivation, enjoyment, autonomy support and proxy efficacy were mediators of the effects of physical activity interventions. Confirmation of the hypothesised mediating mechanisms can prompt developers of future interventions to strengthen or add the intervention components targeting these specific mediators. It is therefore recommended that future interventions aimed at changing physical activity behaviour among youth include effective intervention strategies aimed at improving self-efficacy and intention. Consistent evidence for a lack of mediation was found for social influences, perceived barriers, perceived benefits and attitude. This lack of mediation was mainly because of the fact that the interventions were not able to change these constructs. Moreover, the majority of interventions aimed at changing barriers increased the perceived barriers instead of decreasing them. This assumes that future interventions aimed at targeting social influ-

ences, perceived barriers, perceived benefits and attitude should include other strategies that are effective in changing these potential mediators. As these concepts were associated with physical activity behaviour, they have the potential to be a relevant mediator. To optimally inform future interventions, we need to know which interventions strategies are effective for which mediator. Unfortunately, lack of information on the theoretical basis of interventions and the wide variety of strategies makes it difficult to draw conclusions regarding which strategies are effective and which are not.<sup>55,56</sup> Abraham and Michie<sup>55</sup> developed a taxonomy and identified 26 strategies used in behaviour change interventions. Although this taxonomy is not exhaustive and needs further elaboration, we recommend that future intervention studies apply this taxonomy in their description of the intervention strategies, as done, for example, by Araújo-Soares *et al.*<sup>36</sup> On the basis of these detailed descriptions, the effectiveness of each intervention strategy in changing specific mediators can be determined, providing relevant information for future interventions.

For the sedentary behaviour interventions, no mediated effects were found. Few interventions targeted sedentary behaviours and few reported their mediation analyses, mainly because they did not find intervention effects on the outcome or potential mediator. Significant associations were found between sedentary behaviour and attitude, self-efficacy, intrinsic motivation and habit strength, confirming their potential as mediators. Thus, future sedentary behaviour interventions aimed at targeting these concepts should include other strategies that are effective in changing these potential mediators. Additionally, determinant studies suggest that, unlike physical activity, sedentary behaviours such as TV viewing may not be well-considered, planned behaviours among children and adolescents. Rather than being influenced by conscious cognitions, sedentary behaviour may instead be influenced by individual biological factors, habit strength and parental factors.<sup>57,58</sup> Future intervention research should, therefore, explore the mediation effects of potential social and physical environmental variables (for example, parental rules and number of TVs at home) in sedentary behaviour interventions.

With regard to dietary interventions, some evidence was found that knowledge, attitude, and habit may be relevant mediators of dietary intervention effects. Thus, future dietary interventions in youth are recommended to target knowledge, attitude and habit strength. However, more research is needed to confirm these mediating mechanisms. Consistent evidence for a lack of mediation was found for social influences, self-efficacy and availability. This lack of mediation could be because of the fact that the interventions were not able to affect self-efficacy, social influences (that is, social support, social norm and eating together) or availability (that is, nonsignificant action theory test), and that for social influences and availability, no association with dietary behaviour was found (nonsignificant conceptual theory test). These nonsignificant action and conceptual theory tests could be due to a lack of power; insensitive measures; or limited variability in the mediator. The development of relevant scales, tested on their reliability, validity and sensitivity, is important in future research.<sup>59</sup> Further, several studies did not conduct a conceptual theory test or calculate the mediated effect, for the reason that the intervention did not affect the behaviour<sup>31,37</sup> or mediator.<sup>33,42,46,48,52</sup> Conducting a conceptual theory test is, however, very informative for future interventions and should be included in further research.

A comparison between the results regarding physical activity and dietary behaviours suggests differences in working mechanisms between the two behaviours. Different intervention strategies may be required for changing the mediators of different energy balance behaviours. This is an interesting finding, considering the rapidly developing field of interventions targeting multiple energy balance-related behaviours, wherein similar mediators are targeted using similar intervention strategies for different behaviours.

Compared with the earlier reviews of Lubans *et al.*<sup>24</sup> and Cerin *et al.*,<sup>25</sup> this review conducted a more extensive literature search and used different inclusion criteria, resulting in more included studies (24 compared with a sum of 13 unique studies included in both previous reviews). We confirmed the finding of Lubans *et al.*<sup>24</sup> that self-efficacy is a relevant mediator of physical activity interventions; and we additionally found moderate support for the mediating role of intention in physical activity interventions. In addition, we identified self-regulation, intrinsic motivation, enjoyment, autonomy support and proxy efficacy as mediators of physical activity interventions. Perceived benefits, perceived barriers and social influences have the potential to be mediators of physical activity interventions; however, as none of the interventions was effective in changing these constructs, appropriate strategies are needed. In addition, we were able to identify some potential mediators of sedentary behaviour intervention; however, the small number of sedentary behaviour interventions reporting on mediating effects prevented us from forming strong conclusions. Compared with Cerin *et al.*,<sup>25</sup> our review confirmed the relevance of attitude and additionally identified knowledge

and habit strength as potential mediators of dietary interventions. In addition, we found strong evidence that social and environmental influences did not mediate dietary interventions, probably because of invalid or insensitive measurement instruments.

**Limitations.** As the quality of the literature review highly depends on the quality of the reviewed studies, some limitations have to be taken into account. First, the studies differed substantially in their intervention content, outcome behaviour, duration and measurement instruments. In addition, the included studies were conducted in eight different countries, with major differences in cultural, social and economical background. These differences may have influenced the acceptance and effectiveness of the interventions in changing the outcomes and mediators, and should be taken into account when interpreting the results. Second, recent evidence suggests that intervention effectiveness differs among age group<sup>60</sup> and by sex.<sup>60,61</sup> This suggests that the working mechanisms could differ between the subgroups (low age versus high age; boys versus girls). However, because of the low number of studies analysing the mediators in specific subgroups (that is, four studies were conducted in elementary schools; no studies were conducted among boys only), or analysing the mediators for separate subgroups (that is, only two studies analysed the mediators for boys and girls separately), no comparison between the specific subgroups could be made. This prevented us from drawing conclusions on the working mechanisms of obesity prevention in relevant subgroups.

Third, the quality of the majority of reviewed studies was moderate. Among these, four studies used a quasi-experimental design, making the test for mediation less ideal. In addition, four interventions were not based on a theoretical model, making it impossible to confirm or replicate the theoretical assumptions regarding the intervention development and evaluation. None of the included studies conducted a power analysis to examine whether they had included sufficient participants to enable mediation analyses. Fritz and MacKinnon<sup>27</sup> calculated that when applying the Baron and Kenny causal-step test, about 21 000 participants are needed to achieve an 80% power in condition of complete mediation and small effect size, whereas other statistical tests require smaller sample sizes between 460 and 670 participants.<sup>22,27</sup> Researchers conducting mediation analysis in future should therefore choose a test of mediation that is appropriate for their sample size and choose a test for mediation with increased power, such as bootstrapping tests, the joint significance test or the PRODCLIN test.<sup>27</sup> Regarding the measures used, four studies used behavioural measures with unknown validity or reliability, whereas eight studies used mediator measures with a low reliability. Latent variable modelling (for example, structural equation modelling) was applied in very few studies, whereas this method of analysis

deals better with unreliability of measurement instruments by conducting confirmatory factor analysis. In addition, structural equation modelling enables analyses of more complex models (for example, three-path-mediated effects, moderated mediation effects and latent growth modelling) in comparison with regression techniques.<sup>21,22,62</sup>

Fourth, to draw stronger conclusions, we combined all dietary interventions (for example, fruit, vegetable, soft drink and snack consumption), neglecting the possible differences between the sub-behaviours. As the majority of dietary interventions targeted fruit and vegetables, translating the conclusions to interventions targeting other sub-behaviours (for example, snacking or soft drink consumption) should be done with caution. Fifth, as in any review of published literature, publication bias may have influenced the results. The fact that all included studies found significant intervention effects and most studies did identify one or more mediators suggests that publication bias occurred. It is likely that studies that did not find a significant intervention effect did not conduct a mediation analyses or that studies that did not find significant mediated effects did not publish their results. Our findings might therefore not be representative for all energy balance-related behaviour interventions in youth. This should be taken into account when interpreting our results. Potential mediating effects can still be examined, even in the absence of a significant main effect (for example, intervention effect on behaviour).<sup>22,63</sup> As a significant intervention effect is not a requirement for mediation to occur, researchers of intervention studies are prompted to conduct a mediation analyses even when a significant main effect was not found. Sixth, because of the criteria of mediation analyses, we may have neglected several potential relevant mediators. Several potential mediators, such as perceived benefits, perceived barriers and social influences, were relevant to the outcome behaviour (significant conceptual theory), but were not affected by the intervention (nonsignificant action theory) and could therefore not be identified as a mediator. Finally, because of the high variety in (the measures of) the outcome variables, a systematic literature review was in our opinion the best way to examine the data. We, however, believe that in future, a meta-analytic review of the literature would be a next best step.

## Conclusion

Evidence was found for self-efficacy and intention as mediators of intervention effects of school-based physical activity promotion interventions. Some evidence was found for attitude, knowledge and habit strength as mediators of interventions aiming to change dietary behaviours. The few sedentary behaviour interventions reporting on mediating effects prevented us from forming strong conclusions regarding the most effective mediators of sedentary behaviour interventions. Another important finding was that the majority of

interventions failed to significantly change hypothesised mediators because of ineffective intervention strategies, low power and/ or the use of insensitive measures. Developers of future interventions are advised to provide information on the theoretical basis of their intervention including the strategies applied. This will provide more insight into the strategies that are effective in changing relevant mediators. In addition, future research should focus on the development, validity, reliability and sensitivity of mediator measures.

## Conflict of interest

The authors declare no conflict of interest.

## Acknowledgements

The authors thank Ilse Jansma, MSc, medical librarian at the VU University Library//Medical Library at the VU University Medical Center, for her support in performing the literature searches for this review. In addition, the authors thank Dr Alison Carver for having proofread their manuscript. The contribution of MVS was funded by the Netherlands Organization for Health Research and Development (ZonMw 121.520.002), the contribution of MY was funded by the World Cancer Research Fund (project number 2008/65). The ENERGY project is funded by the Seventh Framework Programme (CORDIS FP7) of the European Commission, HEALTH (FP7-HEALTH-2007-B). The content of this article reflects only the authors' views, and the European Community is not liable for any use that may be made of the information contained therein.

## References

- 1 Visscher TL, Seidell JC. The public health impact of obesity. *Annu Rev Public Health* 2001; **22**: 355–375.
- 2 Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes* 2006; **1**: 11–25.
- 3 Jackson-Leach R, Lobstein T. Estimated burden of paediatric obesity and co-morbidities in Europe. Part 1. The increase in the prevalence of child obesity in Europe is itself increasing. *Int J Pediatr Obes* 2006; **1**: 26–32.
- 4 Maffei C, Tato L. Long-term effects of childhood obesity on morbidity and mortality. *Horm Res* 2001; **55**(Suppl 1): 42–45.
- 5 World Health Organization Office for Europe. Food and nutrition policy for schools: a tool for the development of school nutrition programmes in the European Region, 2006; 1–58 .
- 6 Maffei C. Aetiology of overweight and obesity in children and adolescents. *Eur J Pediatr* 2000; **159**(Suppl 1): S35–S44.
- 7 Maziak W, Ward K, Stockton M. Childhood obesity: are we missing the big picture? *Obes Rev* 2008; **9**: 35–42.
- 8 Rennie KL, Johnson L, Jebb SA. Behavioural determinants of obesity. *Best Pract Res Clin Endocrinol Metab* 2005; **19**: 343–358.
- 9 Swinburn BA, Caterson I, Seidell JC, James WP. Diet, nutrition and the prevention of excess weight gain and obesity. *Public Health Nutr* 2004; **7**: 123–146.

- 10 Brown T, Summerbell C. Systematic review of school-based interventions that focus on changing dietary intake and physical activity levels to prevent childhood obesity: an update to the obesity guidance produced by the National Institute for Health and Clinical Excellence. *Obes Rev* 2009; **10**: 110–141.
- 11 Summerbell CD, Waters E, Edmunds LD, Kelly S, Brown T, Campbell KJ. Interventions for preventing obesity in children. *Cochrane Database Syst Rev* 2005; **3**.
- 12 Oude Luttikhuis H, Baur L, Jansen H, Shrewsbury VA, O'Malley C, Stolk RP *et al*. Interventions for treating obesity in children. *Cochrane Database Syst Rev* 2009; **1**: CD001872.
- 13 Baranowski T, Anderson C, Carmack C. Mediating variable framework in physical activity interventions. How are we doing? How might we do better? *Am J Prev Med* 1998; **15**: 266–297.
- 14 Baranowski T, Jago R. Understanding the mechanisms of change in children's physical activity programs. *Exerc Sport Sci Rev* 2005; **33**: 163–168.
- 15 Mackinnon DP. Analysis of mediating variables in prevention and intervention research. *NIDA Res Monogr* 1994; **139**: 127–153.
- 16 Bauman AE, Sallis JF, Dzawaltowski DA, Owen N. Toward a better understanding of the influences on physical activity: the role of determinants, correlates, causal variables, mediators, moderators, and confounders. *Am J Prev Med* 2002; **23**(Suppl 2): 5–14.
- 17 Hafeman DM, Schwartz S. Opening the Black Box: a motivation for the assessment of mediation. *Int J Epidemiol* 2009; **38**: 838–845.
- 18 Kraemer HC, Wilson GT, Fairburn CG, Agras WS. Mediators and moderators of treatment effects in randomized clinical trials. *Arch Gen Psychiatry* 2002; **59**: 877–883.
- 19 Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J Pers Soc Psychol* 1986; **51**: 1173–1182.
- 20 Kraemer HC, Kiernan M, Essex M, Kupfer DJ. How and why criteria defining moderators and mediators differ between the Baron & Kenny and MacArthur approaches. *Health Psychology* 2008; **27**: S101–S108.
- 21 Mackinnon DP. *Introduction to Statistical Mediation Analysis*. Lawrence Erlbaum Associates: New York, 2008.
- 22 Mackinnon DP, Fairchild AJ, Fritz MS. Mediation analysis. *Annu Rev Psychol* 2007; **58**: 593–614.
- 23 Baranowski T, Klesges LM, Cullen KW, Himes JH. Measurement of outcomes, mediators, and moderators in behavioral obesity prevention research. *Prev Med* 2004; **38**(Suppl): S1–13.
- 24 Lubans DR, Foster C, Biddle SJ. A review of mediators of behavior in interventions to promote physical activity among children and adolescents. *Prev Med* 2008; **47**: 463–470.
- 25 Cerin E, Barnett A, Baranowski T. Testing theories of dietary behavior change in youth using the mediating variable model with intervention programs. *J Nutr Educ Behav* 2009; **41**: 309–318.
- 26 Verhagen AP, de Vet HC, de Bie RA, Kessels AG, Boers M, Bouter LM *et al*. The Delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus. *J Clin Epidemiol* 1998; **51**: 1235–1241.
- 27 Fritz MS, Mackinnon DP. Required sample size to detect the mediated effect. *Psychol Sci* 2007; **18**: 233–239.
- 28 Hoogendoorn W, van Poppel M, Bongers P, Koes B, Bouter L. Systematic review of psychosocial factors at work and private life as risk factors for back pain. *Spine (Phila PA 1976)* 2000; **25**: 2114–2125.
- 29 Singh AS, Mulder C, Twisk J, Chinapaw M. Tracking of childhood overweight into adulthood: a systematic review of the literature. *Obes Rev* 2008; **9**: 474–488.
- 30 Proper K, Koning M, van der Beek A, Hildebrandt V, Bosscher R, van Mechelen W. The effectiveness of worksite physical activity programs on physical activity, physical fitness, and health. *Clin J Sport Med* 2003; **13**: 106–117.
- 31 Hill C, Abraham C, Wright DB. Can theory-based messages in combination with cognitive prompts promote exercise in classroom settings? *Soc Sci Med* 2007; **65**: 1049–1058.
- 32 Lytle LA, Murray DM, Evenson KR, Moody J, Pratt CA, Metcalfe L *et al*. Mediators affecting girls' levels of physical activity outside of school: findings from the trial of activity in adolescent girls. *Ann Behav Med* 2009; **38**: 124–136.
- 33 Zizzi A, Vitullo E, Rye J, O'Hara-Tompkins N, Abildso C, Fisher B *et al*. Impact of a three-week pedometer intervention on high school students' daily step counts and perceptions of physical activity. *Am J Health Educ* 2006; **37**: 35–40.
- 34 Robinson T, Borzekowski DLG. Effects of the SMART classroom curriculum to reduce child and family screen time. *J Commun* 2006; **56**: 1–26.
- 35 Amaro S, Viggiano A, Di CA, Madeo I, Viggiano A, Baccari ME *et al*. Kaledo, a new educational board-game, gives nutritional rudiments and encourages healthy eating in children: a pilot cluster randomized trial. *Eur J Pediatr* 2006; **165**: 630–635.
- 36 Araujo-Soares V, McIntyre T, MacLennan G, Sniehotta FF. Development and exploratory cluster-randomised opportunistic trial of a theory-based intervention to enhance physical activity among adolescents. *Psychol Health* 2009; **24**: 805–822.
- 37 Chinapaw M, Singh AS, Brug J, van Mechelen W. Why did soft drink consumption decrease but screen time not? Mediating mechanisms in a school-based obesity prevention program. *Int J Behav Nutr Phys Act* 2008; **5**: 41.
- 38 Graham DJ, Schneider M, Cooper DM. Television viewing: moderator or mediator of an adolescent physical activity intervention? *Am J Health Promot* 2008; **23**: 88–91.
- 39 Haerens L, Cerin E, Deforche B, Maes L, De Bourdeaudhuij I. Explaining the effects of a 1-year intervention promoting a low fat diet in adolescent girls: a mediation analysis. *Int J Behav Nutr Phys Act* 2007; **4**: 55.
- 40 Haerens L, Cerin E, Maes L, Cardon G, Deforche B, De Bourdeaudhuij I. Explaining the effect of a 1-year intervention promoting physical activity in middle schools: a mediation analysis. *Public Health Nutr* 2008; **11**: 501–512.
- 41 Hartz B, Petosa RL. Social cognitive theory variables mediation of moderate exercise. *Am J Health Behav* 2008; **32**: 305–314.
- 42 Lubans DR, Sylva K. Mediators of change following a senior school physical activity intervention. *J Sci Med Sport* 2009; **12**: 134–140.
- 43 Lubans DR, Morgan PJ, Callister R, Collins CE, Plotnikoff RC. Exploring the mechanisms of physical activity and dietary behavior change in the program x intervention for adolescents. *J Adolesc Health* 2010; **47**: 83–91.
- 44 Reynolds KD, Yaroch AL, Franklin FA, Maloy J. Testing mediating variables in a school-based nutrition intervention program. *Health Psychol* 2002; **21**: 51–60.
- 45 Tak NI, Te Velde SJ, Brug J. Long-term effects of the Dutch Schoolgruuten Project—promoting fruit and vegetable consumption among primary-school children. *Public Health Nutr* 2009; **12**: 1213–1223.
- 46 Taymoori P, Lubans DR. Mediators of behavior change in two tailored physical activity interventions for adolescent girls. *Psychol Sport Exerc* 2008; **9**: 605–619.
- 47 Dunton GF, Schneider M, Cooper DM. An investigation of psychosocial factors related to changes in physical activity and fitness among female adolescents. *Psychol Health* 2007; **22**: 929–944.
- 48 Dzawaltowski DA, Estabrooks PA, Welk G, Hill J, Milliken G, Karteroliotis K *et al*. Healthy youth places: a randomized controlled trial to determine the effectiveness of facilitating adult and youth leaders to promote physical activity and fruit and vegetable consumption in middle schools. *Health Educ Behav* 2009; **36**: 583–600.
- 49 Chatzisarantis NLD, Hagger MS. Effects of an intervention based on self-determination theory on self-reported leisure-time physical activity participation. *Psychol Health* 2009; **24**: 29–48.
- 50 Reynolds KD, Bishop DB, Chou CP, Xie B, Nebeling L, Perry CL. Contrasting mediating variables in two 5-a-day nutrition intervention programs. *Prev Med* 2004; **39**: 882–893.

- 51 Shilts MK, Horowitz M, Townsend MS. Guided goal setting: effectiveness in a dietary and physical activity intervention with low-income adolescents. *Int J Adolesc Med Health* 2009; **21**: 111–122.
- 52 Spruijt-Metz D, Nguyen-Michel ST, Goran MI, Chou CP, Huang TTK. Reducing sedentary behavior in minority girls via a theory-based, tailored classroom media intervention. *Int J Pediatr Obes* 2008; **3**: 240–248.
- 53 Dishman RK, Motl RW, Saunders R, Felton G, Ward DS, Dowda M *et al*. Self-efficacy partially mediates the effect of a school-based physical-activity intervention among adolescent girls. *Prev Med* 2004; **38**: 628–636.
- 54 Dishman RK, Motl RW, Saunders R, Felton G, Ward DS, Dowda M *et al*. Enjoyment mediates effects of a school-based physical-activity intervention. *Med Sci Sports Exerc* 2005; **37**: 478–487.
- 55 Abraham C, Michie S. A taxonomy of behavior change techniques used in interventions. *Health Psychol* 2008; **27**: 379–387.
- 56 Michie S, Abraham C. Interventions to change health behaviours: evidence-based or evidence-inspired? *Psychol Health* 2004; **19**: 29–49.
- 57 Gorely T, Marshall SJ, Biddle SJ. Couch kids: correlates of television viewing among youth. *Int J Behav Med* 2004; **11**: 152–163.
- 58 Hume C, van der Horst K, Brug J, Salmon J, Oenema A. Understanding the correlates of adolescents' TV viewing: A social ecological approach. *Int J Pediatr Obes* 2010; **5**: 161–168.
- 59 Brown H, Hume C, ChinAPaw M. Validity and reliability of instruments to assess potential mediators of children's physical activity: a systematic review. *J Sci Med Sport* 2009; **12**: 539–548.
- 60 Safron M, Cislak A, Gaspar T, Luszczynska A. Effects of School-based Interventions Targeting Obesity-Related Behaviors and Body Weight Change: a Systematic Umbrella Review. *Behav Med* 2011; **37**: 15–25.
- 61 Yildirim M, van Stralen MM, Chinapaw MJM, Brug J, van Mechelen W, Twisk J *et al*. For whom and under what circumstances do school-based interventions aimed at energy balance behaviour work? Systematic review on moderator. *Int J Pediatr Obes* 2011. (In press).
- 62 Iacobucci D, Saldanha N, Deng XY. A meditation on mediation: evidence that structural equations models perform better than regressions. *J Consum Psychol* 2007; **17**: 139–153.
- 63 Cerin E, Mackinnon DP. A commentary on current practice in mediating variable analyses in behavioural nutrition and physical activity. *Public Health Nutr* 2009; **12**: 1182–1188.
- 64 Freedman LS, Schatzkin A. Sample size for studying intermediate endpoints within intervention trials or observational studies. *Am J Epidemiol* 1992; **136**: 1148–1159.
- 65 Clogg CC, Petkova E, Shihadeh ES. Statistical methods for analyzing collapsibility in regression models. *J Educ Stat* 1992; **17**: 51–74.
- 66 James LR, Mulaik SA, Brett JM. A tale of two methods. *Organ Res Methods* 2006; **9**: 233–244.
- 67 Mackinnon DP, Lockwood CM, Hoffman JM, West SG, Sheets V. A comparison of methods to test mediation and other intervening variable effects. *Psychol Methods* 2002; **7**: 83–104.
- 68 Sobel ME. Asymptotic confidence intervals for indirect effects in structural equation models. In: Leinhardt S (ed). *Sociological Methodology*. American Sociological Association: Washington, DC, 1982. pp 290–312.
- 69 Mackinnon DP, Fritz MS, Williams J, Lockwood CM. Distribution of the product confidence limits for the indirect effect: program PRODCLIN. *Behav Res Methods* 2007; **39**: 384–389.
- 70 Efron B, Tibshirani TJ. *An Introduction to the Bootstrap*. Chapman & Hall: New York, 1993.



**This work is licensed under the Creative Commons Attribution-NonCommercial-No Derivative Works 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-nd/3.0/>**

Supplementary Information accompanies the paper on International Journal of Obesity website (<http://www.nature.com/ijo>)