PEDIATRIC REVIEW

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

MM van Stralen¹, M Yildirim¹, SJ te Velde², J Brug², W van Mechelen¹ and MJM Chinapaw¹ on behalf of the ENERGY-consortium

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 evaluates 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.

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

Background

Prevention of obesity is one of today’s major public health challenges. Obesity prevention should start early in life, because the prevalence of obesity among youth has increased steadily over the past several decades ²,³ and childhood obesity is associated with major health risks.⁴,⁵ 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),
Mediators of energy balance behaviour interventions

MM van Stralen et al

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. Inconsistent mediated effects, also called suppressor effects, are mediated effects with a different sign than other mediated or direct effects in a model. This inconsistent mediator suppresses the intervention effects. In other words, the intervention would have been more successful when it had not changed the suppressor. One of the conditions of mediation is causality in which it is assumed that changes in the mediator precede changes in the outcome.

Mediation analyses can prompt future intervention developers to add effective intervention components or remove/adapt ineffective intervention components. 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. 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.

At this time, we have insufficient knowledge about which psychosocial and environmental mediating variables are important for changing particular behaviours. 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 and one review examined dietary interventions. Each included seven intervention studies. Lubans et al. 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. found support for the mediating role of outcome expectancies on dietary behaviour promotion. When these reviews were conducted, few studies performed mediation analyses. Neither review, therefore, was able to draw strong conclusions regarding relevant psychosocial

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Figure 1 Conceptual mediating framework.

Mediating variable (e.g. intention)

Intervention (e.g. activity promotion intervention)

Outcome variable (e.g. physical activity)

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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.

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 as well as treating obesity. 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. By specifying what works variables underlie changes in different energy balance-related sub-behaviours, we performed 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.

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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, mediat*, 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 contexts.
and school-environmental strategies for health behaviour change. 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.26 or were applied in the reviews of Lubans et al.24 or Cerin et al.25 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.27 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.28,29 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 (>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 (>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).28–30 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, preschoolers 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,31 whereas the longest was three years.32 Two studies did not report which mediation analysis was applied.33,34 A total of 13 studies applied regression models,32,35–46 four studies reported generalised linear modelling,31,34,47,48 four studies reported using path analysis49–52 and two studies reported using latent variable mediation modelling (that is, structural equation modelling).53,54 to analyse mediation effects. In total, eight studies analysed multiple mediator models,39,40,43,44,49,50,53,54 of which four reported both single and multiple mediator analyses.39,40,44,50 To test the mediated effect, six studies used the Baron and Kenny causal-step test,45,36,38,41,45,47 three studies used the joint
consumption, two targeted snacking/fat intake, and one intervention.

**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, whereas four studies were based on the theory of planned behaviour. Four studies were not explicitly guided by behaviour theory. Except for four studies, all studies reported using outcome measures with known reliability or validity. Seven studies reported using mediator measures of low to moderate reliability (Cronbach's α < 0.70). 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. Only one study 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, and three studies aimed to improve sedentary behaviour. Of the eight studies that aimed to change dietary behaviours, the majority (n = 6) targeted fruit and vegetable consumption, one targeted soft drink consumption, two targeted snacking/fat intake and one targeted total dietary behaviour. Of these studies, four were aimed at changing both sides of the energy balance. 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. 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 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, self-regulation skills, enjoyment, and intrinsic motivation in the desired direction. About half of the interventions aimed at changing self-efficacy, perceived benefits, social support, satisfaction, counterconditioning, stimulus control, social modelling, other physical activity-related behaviours and habit strength appeared to be less successful. Five physical activity promotion interventions affected a mediator in the undesired direction, 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. No significant intervention effects were found on attitude, self-efficacy, social norm or habit behaviour.

**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; self-efficacy; and social norm). The majority of the interventions were effective in changing knowledge and attitude. We found some studies showing intervention effects on habit behaviour, parental consumption and social norm. All included studies that aimed at changing perceived benefits, perceived barriers, self-efficacy, proxy efficacy, social support and availability were unsuccessful.

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

**Physical activity behaviour.** In the conceptual theory test, 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 and perceived benefits, perceived barriers, self-efficacy, self-regulation skills, social support and physical activity behaviour (see Table 2, column 4). Some support was found for the association between satisfaction, intention, intrinsic motivation, stimulus control, social modelling, autonomy support, habit strength and physical activity. No evidence was found for a relationship between enjoyment, social norm or changing TV-viewing behaviour and physical activity behaviour.

**Sedentary behaviour.** As shown in Table 3 (column 4), indications for relationships between attitude, self-efficacy, and...
| Mediator                                      | Quality score (%) | Action theory | Conceptual theory | Mediated effect                  | Outcome                          |
|----------------------------------------------|-------------------|---------------|-------------------|----------------------------------|----------------------------------|
| Psychological                                |                   |               |                   |                                 |                                  |
| Attitude                                     |                   |               |                   |                                 |                                  |
| Araujo-Soares et al. [36]                    | 80                | +             | NR*               | NR*                             | MVPA                             |
| Chinapaw et al. [37]                         | 80                | NS            | –                 | NR*                             | Active transport boys            |
| Dishman et al. [53]                          | 80                | NS            | +                 | NR*                             | Active transport girls           |
| Haerens et al. [40a]                         | 78                | NS            | +                 | NS                              | Total PA girls                   |
| Haerens et al. [40b]                         | 60                | –             | +                 | Suppressor/suppressor           | Total PA and PA at home and school|
| Hill et al. [51]                             | 60                | +             | NR                | NR                              | Exercise                         |
| Hortz et al. [41]                            | 60                | NS            | NR*               | NS                              | MPA                              |
| Lubans et al. [42]                           | 56                | NS            | NS                | NS                              | MVPA boys                        |
| Lytle et al. [32]                            | 56                | NR            | NR                | NS                              | MVPA girls weekdays              |
| Zizzi et al. [33]                            | 56                | NS            | NR**              | NR**                            | MVPA girls weekends              |
| Satisfaction                                 |                   |               |                   |                                 |                                  |
| Dishman et al. [53]                          | 78                | NS            | +                 | NS                              | Total PA girls                   |
| Perceived benefits                           |                   |               |                   |                                 |                                  |
| Health                                       |                   |               |                   |                                 |                                  |
| Haerens et al. [40a]                         | 60                | –             | +                 | Suppressor/suppressor           | PA at home and school            |
| Haerens et al. [40b]                         | 60                | NS            | +                 | NS                              | Total PA and PA at home and school|
| Psychosocial                                 |                   |               |                   |                                 |                                  |
| Haerens et al. [40a]                         | 60                | NS            | +                 | Suppressor/suppressor           | Total PA and PA at home and school|
| Haerens et al. [40b]                         | 60                | NS            | +                 | NS                              | Total PA and PA at home and school|
| General                                      |                   |               |                   |                                 |                                  |
| Taymoori et al. [46a]                        | 70                | +             | +                 | Mediator                        | Total PA girls                   |
| Taymoori et al. [46b]                        | 70                | NS            | NR**              | NR**                            | Total PA girls                   |
| Zizzi et al. [33]                            | 56                | NS            | NR**              | NR**                            | Daily step count                 |
| Perceived barriers                           |                   |               |                   |                                 |                                  |
| General                                      |                   |               |                   |                                 |                                  |
| Taymoori et al. [46a]                        | 70                | –             | –                 | Mediator                        | Total PA girls                   |
| Taymoori et al. [46b]                        | 70                | NS            | NR**              | NR**                            | Total PA girls                   |
| Zizzi et al. [33]                            | 56                | NS            | NR**              | NR**                            | Daily step count                 |
| Health                                       |                   |               |                   |                                 |                                  |
| Haerens et al. [40a]                         | 60                | NS            | NS                | NS                              | Total PA and PA at home and school|
| Haerens et al. [40b]                         | 60                | NS            | NS                | NS                              | Total PA and PA at home and school|
| Environmental/external                       |                   |               |                   |                                 |                                  |
| Dunton et al. [47]                           | 60                | +             | NS                | NS                              | VPA girls                        |
| Haerens et al. [40a]                         | 60                | +             | –                 | Suppressor/suppressor           | Total PA and PA at home and school|
| Haerens et al. [40b]                         | 60                | NS            | –                 | NS                              | Total PA and PA at home and school|
| Lytle et al. [32]                            | 56                | +             | –                 | Suppressor                      | MVPA girls weekdays              |
| Motivational/internal                        |                   |               |                   |                                 |                                  |
| Dunton et al. [47]                           | 60                | +             | NS                | NS                              | VPA girls                        |
| Haerens et al. [40a]                         | 60                | +             | –                 | Suppressor/suppressor           | Total PA and PA at home and school|
| Haerens et al. [40b]                         | 60                | NS            | –                 | NS                              | Total PA and PA at home and school|
| PBC/self-efficacy                            |                   |               |                   |                                 |                                  |
| Araujo-Soares et al. [36]                    | 80                | NS            | NR*               | NR*                             | MVPA                             |
| Chinapaw et al. [37]                         | 80                | NS            | NS                | NR*                             | Active transport boys            |
| Dishman et al. [33]                          | 78                | +             | +                 | Mediator                        | Total PA girls                   |
| Dishman et al. [54]                          | 89                | +             | +                 | Mediator                        | Total PA girls                   |
| Mediator | Quality score (%) | Action theory | Conceptual theory | Mediated effect | Outcome |
|----------|-------------------|---------------|-------------------|-----------------|---------|
| Dunton et al. | 60 | NS | NS | NS | VPA girls |
| Dzewaltowski et al. | 70 | – | NR** | NR | VPA and MVPA |
| Haerens et al. | 60 | NS | + | NS | PA at school |
| Haerens et al. | 60 | + | + | Mediator/mediator | PA at school |
| Haerens et al. | 60 | NS | + | NS | PA at home |
| Hill et al. | 60 | + | NR | Mediator | Exercise |
| Hertz et al. | 60 | NS | NR** | NS | MPA |
| Lubans et al. | 56 | NS | NS | NR** | MVPA boys |
| Lubans et al. | 56 | + | + | NS | Total PA |
| Lubans et al. | 89 | NS | NS | NS | MVPA girls weekdays |
| Lytle et al. | 56 | – | + | Suppressor | MVPA girls weekend |
| Shilts et al. | 40 | + | NR | Mediator | Total PA |
| Taymoori et al. | 70 | + | + | Mediator | Total PA girls |
| Taymoori et al. | 70 | + | + | Mediator | Total PA girls |
| Zizzi et al. | 56 | NS | NR** | NR** | Daily step count |

**Proxy efficacy**

Dzewaltowski et al. | 70 | + | NR | Mediator | VPA and MVPA |

School | 70 | NS | NR** | NR** | VPA and MVPA |

Parents | 70 | NS | NR** | NR** | VPA and MVPA |

Peers | 70 | NS | NR** | NR** | VPA and MVPA |

**Counterconditioning**

Taymoori et al. | 70 | NS | NR** | NR** | Total PA girls |

Taymoori et al. | 70 | NS | NR** | NR** | Total PA girls |

**Intention**

Araujo-Soares et al. | 80 | NS | NR* | NR* | MVPA |

Chatzisarantis et al. | 89 | + | + | Mediator | Leisure time PA |

Hill et al. | 60 | + | NR | Mediator | Exercise |

**Intrinsic motivation**

Chatzisarantis et al. | 89 | + | + | Mediator | Leisure time PA |

**Enjoyment**

Physical education | 89 | + | NS | NS | Total PA girls |

Dishman et al. | 89 | + | + | Mediator | Total PA girls |

Dunton et al. | 60 | NS | NS | NS | VPA girls |

**Self-regulation**

Araujo-Soares et al. | 80 | NS | NR* | NR* | MVPA |

Coping planning | 80 | + | NR* | NR* | MVPA |

Dishman et al. | 89 | + | NS | NS | Total PA girls |

Hertz et al. | 60 | + | + | Mediator | Moderate-intensity exercise |

Lubans et al. | 89 | NS | NS | NS | Total PA |

Taymoori et al. | 70 | + | + | Mediator | Total PA girls |

Taymoori et al. | 70 | + | + | Mediator | Total PA girls |

**Stimulus control**

Taymoori et al. | 70 | NS | + | NS | Total PA girls |

Taymoori et al. | 70 | NS | NR** | NR** | Total PA girls |

**Social and physical environment**

**Social support**

General

Hertz et al. | 60 | + | + | Mediator | MPA |

Taymoori et al. | 70 | NS | NR** | NR** | Total PA girls |

Haerens et al. | 70 | NS | NR** | NR** | Total PA girls |

Haerens et al. | 60 | NS | + | NS | Total PA |

Lytle et al. | 56 | – | + | Suppressor | MVPA girls weekdays |

56 | – | + | Suppressor | MVPA girls weekend |
intrinsic motivation, social norm, habit strength 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 and habit strength and dietary behaviour. Some evidence was found for an association between dietary behaviour and knowledge, self-efficacy as about half of the studies found a significant effect. No or insufficient evidence was found for an association between perceived benefits, perceived barriers, proxy efficacy, social support, parent consumption, eating together, availability and dietary behaviour.
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. Both intervention studies that reported on the mediated effect of intention 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, intrinsic motivation, enjoyment, perceived benefits, proxy efficacy and autonomy support 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, perceived barriers and social influences, 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, counterconditioning, satisfaction, stimulus control, habit strength or physical activity-related behaviours (for example, TV viewing and participation in sports programmes) 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 or on the potential 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.

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), attitude (that is, one out of two high-quality studies) and habit strength (that is, one out of two high-quality studies; see Table 4, column 5). Chinapaw et al. found that attitude was a partial mediator of the intervention effect on soft drink consumption, and fruit and vegetable intake, respectively. Chinapaw et al. identified the mediated effect among boys only, and Reynolds et al. 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 |
|----------|------------------|---------------|------------------|----------------|---------|
| **Psychological** | | | | | |
| Knowledge | Amaro et al. | 35 | + | NS | NS | Vegetable intake |
| | Reynolds et al. | 50 | + | N/S | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 50 | + | +/NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 89 | + | + (+) | Mediator/mediator | FV intake elementary school children |
| | Reynolds et al. | 89 | + | N/S:NS | NS:NS | FV intake elementary school children |
| Attitude | Chinapaw et al. | 80 | + | NS | NS | Soft drink boys |
| | Haerens et al. | 80 | NS | + | NS:NR* | Snack boys |
| | Reynolds et al. | 80 | NS | + | NS:NS | Snack girls |
| | Reynolds et al. | 50 | + | +/NS | Mediator/NS | FV intake elementary school children |
| | Reynolds et al. | 50 | + | NS:NS | NS:NS | FV intake elementary school children |
| Perceived benefits | Haerens et al. | 60 | NS | NS:NS | NS:NS | Fat intake girls |
| Perceived barriers | Haerens et al. | 60 | + | N/S:NS | NS:NS | Fat intake girls |
| | Chinapaw et al. | 80 | NS | - | NS | Soft drink boys |
| | Lubans et al. | 80 | NS | + | NS:NS | Soft drink girls |
| | Reynolds et al. | 80 | NS | - | NS:NS | Snack boys |
| | Reynolds et al. | 80 | NS | - | NS:NS | Snack girls |
| | Shilts et al. | 70 | NS | - | NS:NS | Snack boys |
| | Lubans et al. | 89 | + | NS | FV intake |
| | Reynolds et al. | 50 | NS | +/NS | NS:NS | Fat intake girls |
| | Reynolds et al. | 50 | NS | NS:NS | NS:NS | FV intake elementary school children |
| | Shilts et al. | 50 | NS | N/S | FV intake elementary school children |
| **Proxy efficacy** | School | Dzewaltowski et al. | 70 | + | NR* | NS | FV intake |
| | Parents | Dzewaltowski et al. | 70 | NS | NR* | NS | FV intake |
| **Social and physical environment** | Social support | Haerens et al. | 60 | NS | NS:NS | NS:NS | Fat intake girls |
| | Chinapaw et al. | 80 | NS | NS | NS | Soft drink boys |
| | Lubans et al. | 80 | NS | NS | NS | Soft drink girls |
| | Reynolds et al. | 80 | NS | + | NS:NS | Snack boys |
| | Reynolds et al. | 80 | NS | - | NS:NS | Snack girls |
| | Reynolds et al. | 50 | NS | + | N/S:NS | Snack boys |
| | Lubans et al. | 50 | NS | +/NS | NS:NS | Snack girls |
| | Lubans et al. | 50 | NS | NS:NS | NS:NS | Snack boys |
| | Reynolds et al. | 50 | NS | N/S:NS | NS:NS | Snack girls |
| | Reynolds et al. | 50 | NS | NS:NS | NS:NS | Snack boys |
| Eating together | Reynolds et al. | 50 | NS | NS:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 50 | NS | N/S:NS | NS:NS | FV intake elementary school children |
| Parent consumption | Reynolds et al. | 50 | NS | NS:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 50 | + | N/S:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 89 | NS | N/S:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 89 | NS | N/S:NS | NS:NS | FV intake elementary school children |
| Availability | Lubans et al. | 89 | NS | + | NS | FV intake |
| | Reynolds et al. | 50 | NS | N/S:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 50 | NS | N/S:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 89 | NS | N/S:NS | NS:NS | FV intake elementary school children |
| | Reynolds et al. | 89 | NS | N/S:NS | NS:NS | FV intake elementary school children |
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, availability, and self-efficacy) 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 influences, 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. Abraham and Michie55 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 Araujo-Soares et al.36 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.57,58 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.\footnote{59}

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\footnote{31,37} or mediator.\footnote{33,42,46,48,52} 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.\footnote{24} and Cerin et al.,\footnote{25} 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.\footnote{24} 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.,\footnote{25} 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\footnote{60} and by sex.\footnote{60,61} 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\footnote{27} calculated that when applying the Baron and Kenny causal-step test, about 21000 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.\footnote{22,27} 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.\footnote{27} 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.\textsuperscript{21,22,62}

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).\textsuperscript{22,63} 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 variability 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.

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**References**

1 Visscher TL, Seidell JC. The public health impact of obesity. *Am J Prev Med* 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 Maffeis 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 Maffeis C. Aetiology of overweight and obesity in children and adolescents. *Eur J Pediatr* 2000; 159(Suppl 1): 535–544.
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.
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 MJM. 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 mediation 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 trails or observational studies. *Ann 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, Hoffmann 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: Leinfardt S (ed). *Sociological Methodology*. American Sociological Association: Washington, DC, 1982. pp 290–312.

69 Mackinnon DP, Fritz MS, Williams J, Woodlock CM. Distribution of the product confidence limits for the indirect effect: program PRODCLIN. *Behav Res Methods* 2007; 39: 384–389.

70 Efron B, Tibshirani RJ. *An Introduction to the Bootstrap*. Chapman & Hall: New York, 1993.

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