





Mediators and moderators of the effects of a school-based intervention on adolescents' fruit and vegetable consumption: the HEIA study

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Abstract

Objective: To examine whether targeted determinants mediated the effects of the HEalth In Adolescents (HEIA) intervention on fruit and vegetable (FV) consumption and explore if these mediating effects were moderated by sex, parental education or weight status.

Design: Cluster-randomised controlled trial.

Setting: The HEIA study (2007–2009) was a Norwegian 20-month multi-component school-based intervention to promote healthy weight development. FV consumption and targeted determinants were self-reported at baseline, mid-way (8 months) and post-intervention (20 months).

Participants: Adolescents (11–13-year-old) in twenty-five control schools (*n* 746) and twelve intervention schools (*n* 375).

Results: At post-intervention, more adolescents in the intervention group compared with the control group had knowledge of the FV recommendations (OR: 1.4, 95% CI 1.1, 1.9) and reported a decreased availability of vegetables at home (β : -0.1, 95% CI -0.2, 0.0). Availability/accessibility of FV at home, availability of vegetables at dinner, taste preferences for different types of FV and knowledge of the FV recommendations were positively associated with the consumption of FV. However, none of the post-intervention determinants significantly mediated the intervention effects on FV consumption. Although no moderating influences by sex, parental education or weights status were observed on the mediating effects, exploratory analyses revealed significant moderations in the b-paths.

Conclusions: Since none of the targeted determinants could explain the increase in FV consumption, it remains unclear why the intervention was effective. Reporting on a wide range of mediators and moderators in school-based interventions is needed to reveal the pathways through which intervention effects are achieved.

Keywords

School-based intervention
Fruit and vegetables
Determinants
Mediation
Moderation

The promotion of fruit and vegetable (FV) consumption among children and adolescents is of great importance in preventing childhood obesity and reducing the risk of chronic diseases in adulthood^(1–3). In Western countries, most children and adolescents consume insufficient

amounts of FV⁽⁴⁾. A previous European study reported that only 25% of school-aged children met the WHO's recommendation of at least 400 grams of FV per d⁽⁵⁾. Children's FV consumption has been shown to track into adulthood, which indicates the importance of

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establishing healthy dietary habits early in life⁽⁶⁾. Therefore, effective interventions aimed at increasing FV consumption in children and adolescents are needed^(1,3).

Evidence demonstrates that schools are an ideal setting for tackling energy balance-related behaviour because of their potential to reach almost all children in the population, irrespective of socio-economic position^(7,8). The school curricula, infrastructure and policies provide opportunities for health education, supplying meals and creating a health-promoting environment⁽⁸⁾. Recent reviews of school-based interventions for preventing obesity in children or adolescents have shown some short-term success in increasing the consumption of FV^(9–11). However, achieving long-term changes in dietary habits and clinically relevant reductions in BMI remains difficult^(12,13).

To facilitate improvement of school-based interventions targeting FV consumption, an understanding of the underlying mechanisms through which these interventions operate is needed^(14,15). The examination of mediators and moderators can help in identifying which specific intervention strategies work (i.e. mediators) and for whom and under what circumstances these strategies achieve the greatest effects (i.e. moderators)^(14–16). Mediators are defined as third variables that are intermediate in the causal pathway between an independent and a dependent variable, whereas moderators are third variables that alter the relationship between an independent and a dependent variable⁽¹⁷⁾. Few studies have explored mediators and moderators of FV consumption in school-based interventions^(14,16,18–20). Three reviews on mediators included only nine studies and found indications for attitude, knowledge of recommendations, self-efficacy and planning as potential mediators of school-based intervention effects on FV consumption^(14,18,19). A review on moderators reported moderations by sex and to a lesser extent age, baseline levels of outcomes and family involvement⁽²⁰⁾, whereas an earlier review could not draw any conclusions due to the lack of published studies⁽¹⁶⁾. It thus remains important to investigate and report information on mediators and moderators in intervention studies, since this can be used to clarify the processes of behaviour change and as such contribute to future intervention design and implementation^(14–16).

In Norway, the promotion of FV consumption has been an important part of the national public health policy, particularly aimed to reduce health-related social inequalities⁽²¹⁾. Norwegian children and adolescents consume only half of the recommended daily FV intake, which has shown a decreasing trend among children of lower socio-economic status^(22,23). Numerous efforts have been made by health authorities and organisations to improve FV consumption and stimulate healthier behaviours within school settings. One of these initiatives was the HEalth in Adolescents (HEIA) study: a Norwegian comprehensive,

multi-component school-based intervention designed to promote healthy weight development among adolescent schoolchildren (11–13-year-old)⁽²⁴⁾. The HEIA intervention targeted five energy balance-related behaviours, including the consumption of FV, as well as important determinants of these behaviours. These determinants were availability/accessibility of FV at home, availability of vegetables at dinner, taste preferences for different types of FV, parental encouragement of vegetable consumption and knowledge of the FV recommendations⁽²⁴⁾. An earlier study reported a significant increase in the consumption of fruit and positive change in the consumption of vegetables in the intervention group compared with the control group after 20 months⁽²⁵⁾. However, which of the targeted determinants mediated these effects was not investigated, and whether these associations may be moderated by adolescents' characteristics has not been explored. The latter is particularly of importance for identifying health inequalities in achieving intervention effects⁽²⁶⁾.

Given the scarce number of studies on mediators and moderators in school-based interventions specifically focused on increasing FV consumption, the present study aimed to clarify the underlying mechanisms of increased FV consumption in the HEIA intervention by conducting secondary analyses. The objectives of this study were twofold: (1) to examine whether targeted determinants (availability/accessibility at home, availability at dinner, taste preferences, parental encouragement and knowledge of recommendations) of FV consumption mediated the intervention effects, and (2) to explore if these mediating effects were moderated by sex, parental education or weight status.

Methods

Study design and population

Data were obtained from the HEIA study of which a detailed description of the development, design and methodology can be found elsewhere⁽²⁴⁾. Participants were recruited from schools with more than forty pupils in the sixth grade located in towns/municipalities in seven counties in the south-eastern part of Norway. A total of thirty-seven schools out of the 177 invited schools accepted the invitation (response rate: 21 %), and all the sixth graders (*n* 2165) in the attending schools and their parents/legal guardians were invited to participate (Fig. 1). Of them, 1580 returned a parent-signed informed consent form (response rate: 73 %).

A cluster-randomised controlled study design was used to evaluate the effectiveness of the intervention; twenty-five schools were randomly assigned by simple drawing to the control group and twelve schools to the intervention group (Fig. 1). The intervention was conducted during the school years 2007–2009 and lasted for 20 months. Data

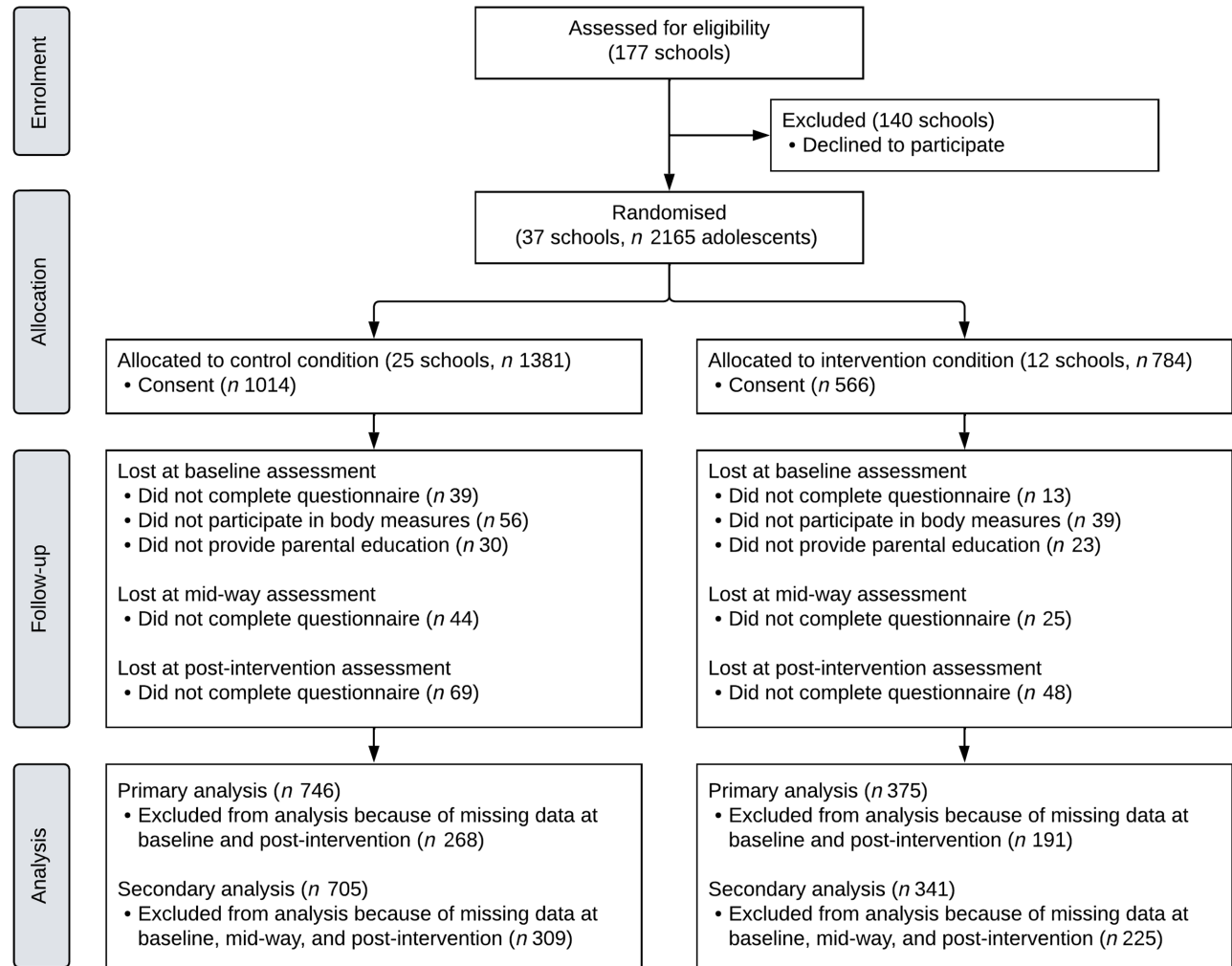


Fig. 1 Flow diagram of enrolment, allocation, follow-up and analysis of adolescents in the HEIA study. HEIA, HEalth In Adolescents ⁽²⁴⁾

were collected at baseline in September 2007 (in the beginning of the sixth grade), at mid-way in May 2008 (in the end of the sixth grade; 8 months past baseline) and at post-intervention in May 2009 (in the end of the seventh grade; 20 months past baseline). All assessments were administered over approximately 4 weeks, with parallel assessments in the intervention and control group. In total, 1121 (*n* 746 control; *n* 375 intervention) adolescents who participated in the baseline and post-intervention data collections were included in the primary analysis in the current study, whereas 1046 (*n* 705 control; *n* 341 intervention) adolescents who additionally participated in the mid-way data collection were included in the secondary analysis (Fig. 1).

Intervention

The HEIA study comprised a multi-component intervention aimed to promote healthy weight development among young adolescents in collaboration with school principals,

teachers, school health services and parent committees. The intervention consisted of a mix of individual, group and environmental strategies and components targeting energy balance-related behaviours, and was implemented in the last 2 years of primary school. It was designed to generate synergic effects on the targeted behaviours and their determinants, which has been described in more detail previously⁽²⁴⁾. Intervention delivery was at school class level to all eligible pupils and their parents irrespective of whether adolescents participated in the data collection. The team of teachers at the concerning grade level led the implementation.

At the start of each school year, the intervention was initiated by a kick-off meeting to ensure all involved implementers knew the rationale, were familiar with the various intervention elements and were motivated to implement these. The kick-off meeting comprised a 20 min project presentation for all pedagogic personnel at the school and a session based on the teacher's manual for the sixth- and seventh-grade teachers. To facilitate



smooth implementation, teachers received monthly emails with brief reminders, all materials were ready to be handed out to pupils/parents and equipment for the activities was provided.

The first year (sixth grade) of the intervention primarily targeted dietary behaviours and physical activity, whereas in the second year (seventh grade) additional components targeting screen time behaviours were included. Three intervention components, including five lessons with student booklets on diet and physical activity (first year), monthly posters in classrooms (first and second year) and five computer tailoring programmes on diet, physical activity and screen time (second year), were aimed to increase the adolescents' knowledge of the FV recommendations. Taste preferences for different types of FV were targeted with a weekly FV break with inspirational sheets for teachers (first and second year). Finally, monthly fact sheets for parents (first year) with additional child-parent homework assignments (second year) were aimed to increase the availability/accessibility of FV at home, availability of vegetables at dinner and parental encouragement of vegetable consumption.

Measurements

At all assessment points, adolescents filled in an Internet-based questionnaire during school hours that consisted of mostly pre-coded answer categories and took about 45 min to complete. The questionnaire included questions on demographic characteristics, dietary behaviours, physical activity, sedentary behaviours and potential determinants. The mid-way and post-intervention questionnaires additionally included questions on process evaluation, dose received and usefulness of each intervention component. To prevent the questionnaires from getting too long, a few questions on determinants were excluded from the mid-way questionnaire. Trained staff visited the schools and collected all data. A detailed description of all measurements that were included in the analysis is provided in online Supplementary Table S1.

Fruit and vegetable consumption

The consumption of FV was assessed by frequency with one question for fruit and two questions for vegetables (raw and cooked vegetables). Frequencies were measured using the following answer categories: never/seldom (0), less than once a week (0.5), once a week (1), 1–2 times per week (1.5), 3–4 times per week (3.5), 5–6 times per week (5.5), once per d (7), twice per d (14) and 3 times or more per d (21). The answers for the consumption frequency were adjusted to correspond to the adolescents' eating frequency per week (in parentheses above). A test–retest study of the questionnaire among 114 adolescents, from the same sampling area as the main study population, was conducted before baseline⁽²⁴⁾. The self-reported measures

of FV consumption had acceptable to good reliability, with Pearson's correlation coefficients of 0.75 and ≥ 0.60 , respectively.

Determinants of fruit and vegetable consumption

The determinants were adopted from previous studies and included availability/accessibility of FV at home, availability of vegetables at dinner, parental encouragement of vegetable consumption, taste preferences for different types of FV and knowledge of the FV recommendations^(27,28). All determinants, except for knowledge of the FV recommendations, should be interpreted as perceived determinants as these were obtained by self-report from the adolescents. Availability and accessibility at home were measured using separate questions for FV consumption: 'How often are fruit/vegetables that you like available at home?' (five categories: from always to never) and 'When there are fruit/vegetables that you like at home, can you eat whenever you want?' (six categories: from always to no fruit/vegetables in my house). For both determinants, answer categories were recoded in an ascending five-point Likert scale. The answer categories 'never' and 'no fruit/vegetables in my house' were merged into one answer category. Availability at dinner was measured only for vegetables using the following statement: 'At home we usually have vegetables for dinner every day' (five categories: from completely disagree to totally agree). Parental encouragement was measured only for vegetables with the following statement: 'My mom and/or dad encourages me to taste the vegetables we have for dinner' (six categories: from completely disagree to no encouragement needed). The answer category 'no encouragement needed' was considered as neutral and therefore merged with the answer category 'neither agree nor disagree'. Taste preferences for different types of FV were derived from answers on eleven common or trending FV, respectively (five categories: from like very much to have not tasted). FV that were ranked as 'like a bit' and 'like very much' were considered as tasty, and these were summed to generate a possible range of 0–11 for fruit and 0–11 for vegetables. Knowledge of recommendations was measured for FV consumption combined: 'How many servings of FV are recommended that someone your age should eat every day?' (seven categories: from none to more than five). It was included in the analysis as both a continuous and dichotomous variable. The continuous variable resembled a range of the original answer categories. To create the dichotomous variable, the answer was split into the categories 'less than five servings/d' and 'five servings/d or more' to reflect the knowledge of the five-a-day recommendation for FV. Since the mid-way questionnaire was shorter than the baseline and post-intervention questionnaires, mid-way variables were only available for availability at home/dinner, parental encouragement and knowledge of recommendations.



Demographic and anthropometric characteristics

Information on the educational level of both parents was obtained from the parents through the informed consent form for their child. Parental education – of the parent with the highest level of education or else the one available – was categorised into three levels: low (≤ 12 years), medium (13–16 years) and high (> 16 years). Anthropometric measurements were taken of the pupils by trained staff at baseline and post-intervention⁽²⁴⁾. Age- and sex-specific BMI cut-off values proposed by the International Obesity Task Force were used to categorise the adolescents as normal weight (including underweight) and overweight (including obese)⁽²⁹⁾.

Power calculation

Power calculations were made based on changes in primary outcomes, including BMI, physical activity measured by accelerometers and consumption of fruit, vegetables and soft drinks. Taking the cluster effect of randomly assigning schools to the control and intervention group into account, assuming that 80% of the pupils would participate and that the attrition rate would not exceed 15% per year, we aimed for forty schools (thirty control and ten intervention) with an average of forty-five pupils participating from each school. This sample size would provide more than 80% power to detect a 1.2 times/week difference in fruit consumption and 1.0 times/week difference in vegetable consumption between the control and intervention group after 2 years. The study was not powered to conduct moderation analyses; thus these are exploratory.

Statistical analysis

Data were analysed using IBM SPSS Statistics version 26.0. A two-sided P -value of < 0.05 was considered statistically significant for all analyses, except for the interaction tests where a two-sided P -value of < 0.10 was applied.

Demographic and anthropometric characteristics, FV consumption and the determinants at baseline are presented for the study population as percentages and means with standard deviations. Independent t tests and χ^2 tests were performed to test differences between the control and intervention group. The possible clustering by schools was tested with the linear mixed model procedure. As only 0–2% of the unexplained variance of adolescents' FV consumption was found at the school level, all analyses were conducted without adjusting for clustering at the school level.

To assess whether the determinants mediated the intervention effects on FV consumption, mediation analysis was used based on the script of MacKinnon⁽¹⁷⁾. Mediation analysis quantifies the extent to which one or more proposed intervening variable(s) transmit(s) the effect of an independent variable on a dependent variable⁽¹⁷⁾. The conceptual mediation models (Fig. 2) were examined using the PROCESS macro version 4.1 for continuous mediators and by hand for dichotomous mediators.

Unstandardised β coefficients with 95% CI were obtained with linear regression for continuous mediators. For dichotomous mediators, both logistic and linear regression were used to generate OR and unstandardised β coefficients with 95% CI. Primary analyses were based on post-intervention variables of FV consumption and the determinants, adjusted for baseline values. In secondary analyses, we included mid-way variables of the determinants in the models. Age, sex, parental education and weight status were examined as potential confounders but did not influence the associations. Assumptions of the regression and mediation analyses – homoscedasticity, independence and normality of the residuals, multicollinearity, linearity of the association and no interaction between the independent variable and mediator – were tested and met in all models.

Single mediation models (Fig. 2(a)) were calculated in five steps: (1) estimating the total effect of the intervention on FV consumption (c-path); (2) estimating the effect of the intervention on the determinants (a-path); (3) estimating the independent effect of the determinants on FV consumption adjusted for the intervention condition (b-path); (4) estimating the direct effect of the intervention on FV consumption adjusted for the determinants (c'-path); and (5) computing the mediated effect ($a \times b$). The mediated effect was tested by calculating 95% CI using bootstrapping with 1000 resamples of the data (continuous mediators)⁽³⁰⁾ or the Sobel method (dichotomous mediators)⁽³¹⁾.

Next, moderating influences on the mediating effects (a-path and b-path) were explored for baseline values of sex, parental education and weight status in separate models (Fig. 2(b)). This selection was based on previous studies^(16,20) and availability of data. Moderators were analysed by including interaction terms in the single mediation models, performing subgroup analyses for the mediated effects and calculating the moderated mediation index⁽³²⁾. For cases in which significant moderations were revealed, graphs were generated to assess differences between the control and intervention group for each subgroup.

Results

Baseline characteristics

Table 1 shows the baseline characteristics of the total study population as well as stratified by intervention condition. Of the 1121 participants included in the primary analyses, 50.3% were girls, 28.9% had parents with a low education and 12.3% had overweight/obesity. The mean age was 11.2 years. No significant differences between the control and intervention group were found for the demographic and anthropometric variables. Attrition analyses revealed that participants who were lost to follow-up more often had overweight/obesity, were a boy or assigned to the intervention group (online Supplementary Table S2). FV

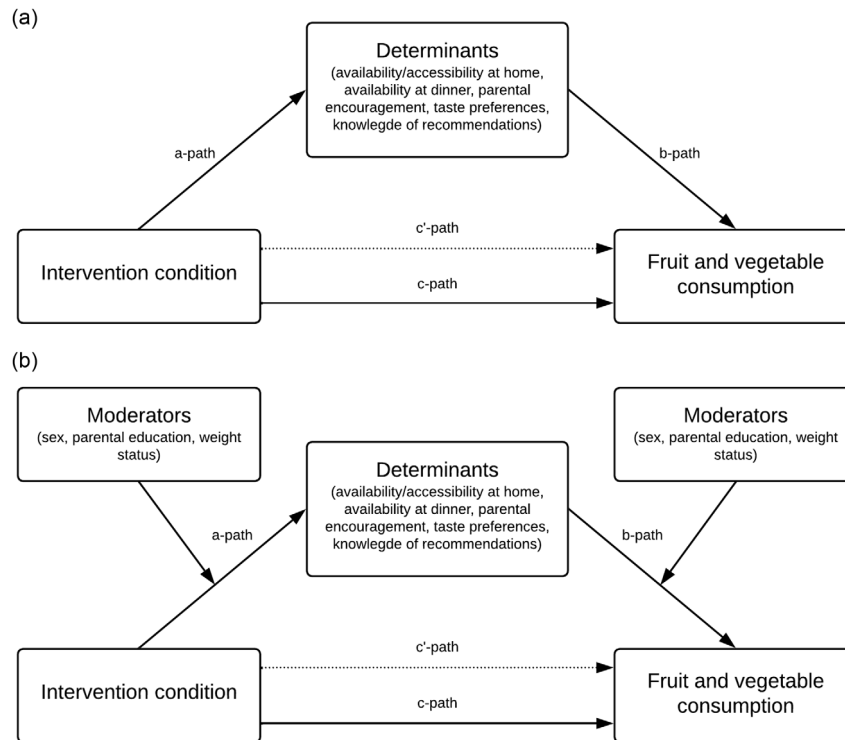


Fig. 2 (a) Conceptual mediation models for the mediation of the mid-way and post-intervention determinants in the associations between the intervention condition and fruit and vegetable (FV) consumption in the HEIA study. Path c represents the total effect of the intervention on FV consumption. Path a represents the effect of the intervention on the determinants. Path b represents the associations between the determinants and FV consumption adjusted for the intervention condition. Path c' represents the direct effect of the intervention on FV consumption adjusted for the determinants. (b) Conceptual moderated mediation models for the moderation by baseline values of sex, parental education and weight status of the mediating effects (a-path and b-path). HEIA, HEalth In Adolescents

Table 1 Baseline demographic and anthropometric characteristics of the total study population and stratified by intervention condition in the HEIA study

	Total (n 1121)			Control (n 746)			Intervention (n 375)			P-value*
	%	Mean	SD	%	Mean	SD	%	Mean	SD	
Age (years)		11.2	0.3		11.2	0.3		11.2	0.3	0.59
Sex										
Girl	50.3			50.1			50.7			0.87
Boy	49.7			49.9			49.3			
Parental education†										
Low	28.9			30.2			26.4			0.37
Medium	36.0			35.8			36.3			
High	35.1			34.0			37.3			
Weight status‡										
Normal weight	87.7			86.5			90.1			0.08
Overweight	12.3			13.5			9.9			

HEIA, HEalth In Adolescents.

*Independent *t* test (age) and χ^2 test between control and intervention group.

†Based on the parent with the highest level of education or else the one available: low (≤ 12 years), medium (13–16 years) and high (> 16 years).

‡Based on age- and sex-specific BMI cut-off values proposed by the International Obesity Task Force: normal weight (including underweight) and overweight (including obese)⁽²⁹⁾.

consumption and their determinants at baseline, mid-way and post-intervention are presented in Table 2. There were no significant differences between the control and intervention group at baseline.

Mediation analysis

Table 3 shows the mediation of the post-intervention determinants between the intervention condition and FV consumption. A significant total effect was found of

**Table 2** Baseline, mid-way and post-intervention fruit and vegetable (FV) consumption and their determinants of the control and intervention group in the HEIA study

	Baseline				<i>P</i> -value*	Mid-way				Post-intervention			
	Control (n 746)		Intervention (n 375)			Control (n 705)		Intervention (n 341)		Control (n 746)		Intervention (n 375)	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	Mean	SD
	%		%		%		%		%		%		%
Dietary behaviours													
Fruit consumption (times/week)	10.0	6.9	9.9	7.0	0.72	10.0	6.9	11.4	7.2	9.6	6.8	11.1	7.2
Vegetable consumption (times/week)	11.2	9.8	10.9	8.6	0.65	11.2	9.5	12.9	9.9	10.4	8.6	11.4	9.4
Determinants fruit consumption													
Availability at home†	4.4	0.8	4.4	0.7	0.77	4.4	0.8	4.5	0.8	4.5	0.7	4.5	0.8
Accessibility at home†	4.5	0.7	4.5	0.7	0.50					4.7	0.6	4.7	0.7
Taste preferences‡	9.6	2.2	9.5	2.3	0.94					9.7	2.0	9.6	2.5
Determinants vegetable consumption													
Availability at home†	4.1	0.9	4.2	0.9	0.36	4.3	0.9	4.4	0.8	4.3	0.8	4.2	1.0
Availability at dinner†	3.6	1.2	3.8	1.2	0.08	3.7	1.4	3.8	1.3	3.8	1.2	3.9	1.3
Accessibility at home†	4.3	0.9	4.4	0.9	0.70					4.6	0.8	4.5	0.9
Taste preferences‡	7.6	2.7	7.8	2.7	0.27					7.7	2.6	7.7	2.8
Parental encouragement†	2.6	1.2	2.5	1.1	0.50	2.5	1.2	2.5	1.1	2.5	1.2	2.5	1.2
Determinants FV consumption													
Knowledge – continuous§	4.6	1.5	4.6	1.4	0.72	5.0	1.4	5.3	1.2	5.2	1.3	5.3	1.3
Knowledge – dichotomous		36.1		35.2	0.78		53.2		63.0		59.9		67.2

HEIA, HHealth In Adolescents.

*Independent *t* test and χ^2 test (knowledge – dichotomous) between control and intervention group.

†Range 1–5 (lowest to highest with a neutral midpoint).

‡Range 0–11 (number of tasty fruit/vegetables).

§Range 1–7 (no servings/d to more than five servings/d).

||Percentage of adolescents that have knowledge of the recommendations (five servings/d or more).

Table 3 Mediation of the post-intervention determinants in the associations between the intervention condition and fruit and vegetable consumption in the HEIA study (*n* 1121)

	c-path†		a-path‡		b-path†		c'-path†		Mediated effect		Proportion mediated (a × b)/c
	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI	a × b	95 % CI§	
Fruit consumption											
Availability at home	1.5*	0.7, 2.3	0.0	-0.1, 0.1	2.1*	1.6, 2.6	1.5*	0.7, 2.2	0.0	-0.2, 0.2	–
Accessibility at home			0.0	-0.1, 0.1	1.8*	1.2, 2.4	1.5*	0.8, 2.3	0.0	-0.1, 0.1	–
Taste preferences			-0.1	-0.3, 0.1	0.7*	0.4, 0.9	1.6*	0.9, 2.4	0.0	0.0, 0.0	–
Knowledge – continuous			0.2	0.0, 0.3	0.6*	0.3, 0.9	1.4*	0.7, 2.2	0.1	0.0, 0.2	–
Knowledge – dichotomous			0.4*	0.1, 0.6	1.0*	0.3, 1.8	1.4*	0.7, 2.2	0.4	0.0, 0.8	–
Vegetable consumption											
Availability at home	1.1*	0.0, 2.1	-0.1*	-0.2, 0.0	2.3*	1.7, 2.9	1.2*	0.2, 2.2	-0.2	-0.5, 0.0	–
Availability at dinner			0.0	-0.1, 0.2	1.8*	1.4, 2.1	0.9	-0.1, 1.9	0.1	-0.2, 0.3	–
Accessibility at home			0.0	-0.1, 0.1	1.0*	0.4, 1.6	1.1*	0.1, 2.1	0.0	-0.2, 0.0	–
Taste preferences			-0.1	-0.4, 0.1	0.8*	0.6, 1.1	1.0*	0.0, 2.0	-0.1	-0.4, 0.1	–
Parental encouragement			0.0	-0.1, 0.2	0.2	-0.2, 0.6	1.1*	0.0, 2.1	0.0	0.0, 0.1	–
Knowledge – continuous			0.2	0.0, 0.3	0.6*	0.3, 1.0	1.0	-0.1, 2.0	0.1	0.0, 0.2	–
Knowledge – dichotomous			0.4*	0.1, 0.6	1.2*	0.1, 2.2	1.0	-0.1, 2.0	0.4	-0.1;0.9	–

HEIA, HHealth In Adolescents.

**P* < 0.05.

†Linear regression.

‡Linear regression (continuous mediators) or logistic regression (dichotomous mediators).

§Bootstrapping with 1000 resamples of the data (continuous mediators) or Sobel test (dichotomous mediators).

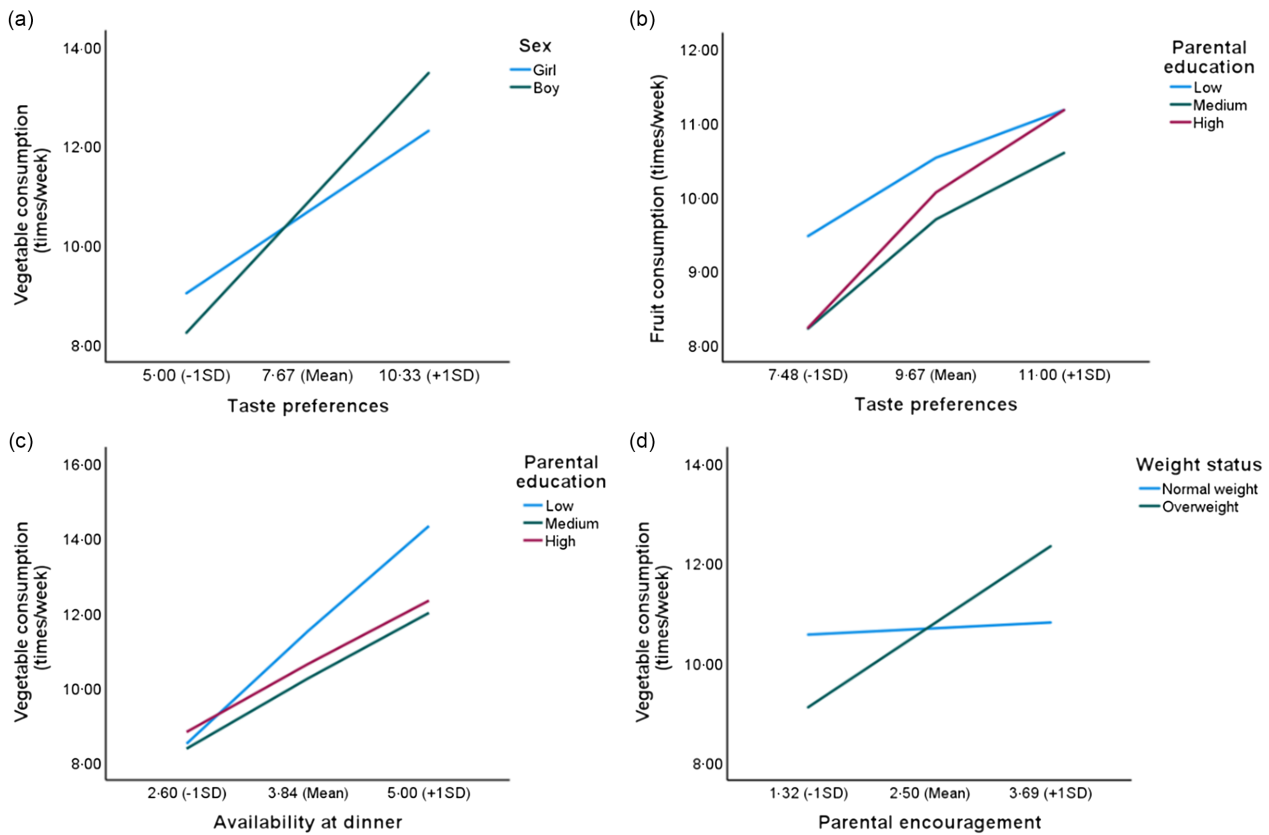


Fig. 3 Moderation by baseline values of (a) sex, (b), (c) parental education, and (d) weight status of the associations between the post-intervention determinants and fruit and vegetable consumption in the HEIA study. HEIA, HHealth In Adolescents

the intervention on FV consumption after 20 months. Adolescents in the intervention group consumed on average 1.5 times (95 % CI 0.7, 2.3) more fruit per week and 1.1 times (95 % CI 0.0, 2.1) more vegetables per week than adolescents in the control group at post-intervention. None of the post-intervention determinants significantly mediated these associations.

At post-intervention, more adolescents in the intervention group compared with the control group had knowledge of the FV recommendations (OR: 1.4, 95 % CI 1.1, 1.9), but they reported a decreased availability of vegetables at home (β : -0.1, 95 % CI -0.2, 0.0). In addition, all determinants were positively associated with fruit consumption, with the strongest association for availability at home (β : 2.1, 95 % CI 1.6, 2.6), followed by accessibility at home (β : 1.8, 95 % CI 1.2, 2.4), knowledge of recommendations (dichotomous) (β : 1.0, 95 % CI 0.3, 1.8), taste preferences (β : 0.7, 95 % CI 0.4, 0.9) and knowledge of recommendations (continuous) (β : 0.6, 95 % CI 0.3, 0.9). Similar associations for vegetable consumption were found, with the following descending associations from strong to weak: availability at home (β : 2.3, 95 % CI 1.7, 2.9), availability at dinner (β : 1.8, 95 % CI 1.4, 2.1), knowledge of recommendations (dichotomous) (β : 1.2, 95 % CI 0.1, 2.2), accessibility at home (β : 1.0, 95 % CI 0.4, 1.6), taste preferences (β : 0.8, 95 % CI 0.6, 1.1) and knowledge of recommendations (continuous) (β : 0.6, 95 % CI

0.3, 1.0). The associations with parental encouragement were not significant.

In secondary analyses with mid-way determinants, we found that the intervention effect on fruit consumption was 9 % mediated by knowledge of recommendations (continuous) (online Supplementary Table S3). Besides, the post-intervention determinants knowledge of recommendations (continuous) (7 %) and knowledge of recommendations (dichotomous) (32 %) significantly mediated the intervention effect on FV consumption and fruit consumption, respectively, in this slightly smaller study population.

Moderated mediation analysis

Sex, parental education and weight status did not moderate the mediating effects of the post-intervention determinants between the intervention condition and FV consumption (online Supplementary Table S4). Despite this, significant moderations in the b-paths were observed in exploratory analyses. Sex significantly moderated the association between taste preferences and vegetable consumption ($P=0.05$). Taste preferences were stronger associated with vegetable consumption for boys compared with girls (Fig. 3(a)). Furthermore, parental education significantly moderated the association between taste preferences and fruit consumption ($P=0.09$), as well as the association



between availability at dinner and vegetable consumption ($P=0.04$ – 0.06). Taste preferences were stronger associated with fruit consumption for adolescents with high-educated parents compared with adolescents with low- and medium-educated parents (Fig. 3(b)). Besides, availability at dinner was stronger associated with vegetable consumption for adolescents with low-educated parents compared with adolescents with medium- and high-educated parents (Fig. 3(c)). Finally, weight status significantly moderated the association between parental encouragement and vegetable consumption ($P=0.07$). Parental encouragement was stronger associated with vegetable consumption for adolescents with overweight compared with adolescents with normal weight (Fig. 3(d)).

Discussion

The present study first examined whether post-intervention values of availability/accessibility at home, availability at dinner, taste preferences, parental encouragement and knowledge of recommendations mediated the effects of the HEIA intervention on FV consumption. Second, it was explored if sex, parental education and weight status moderated these mediation effects. Although more adolescents in the intervention group compared with the control group had knowledge of the FV recommendations and reported a decreased availability of vegetables at home, none of the post-intervention determinants (20 months) significantly mediated the associations. Besides, no moderating influences by sex, parental education or weights status were observed on the mediating effects. However, exploratory analyses indicated moderations by sex, parental education and weight status of the associations of taste preferences, availability of vegetables at dinner and parental encouragement with the consumption of fruit and/or vegetables.

Previous school-based intervention studies exploring knowledge of recommendations as a mediator of intervention effects on FV consumption show mixed results; two studies reported significant mediations by knowledge of recommendations^(33,34), whereas two other studies did not find a mediating effect^(35,36). Post-intervention values of knowledge of recommendations did not act as mediator in the HEIA intervention. Although knowledge of recommendations satisfied the conditions for mediation analysis (the intervention was associated with a change in the mediator, which in turn was associated with a change in FV consumption), no significant mediation effect was found. This finding is likely due to the use of the Sobel test for dichotomous mediators, which may have resulted in a lack of power to detect mediating effects⁽¹⁷⁾. Our results indicate a clear difference between analysing knowledge of recommendations as a continuous or dichotomous variable; the continuous variable did not differ between the control and intervention group over time, whereas the

dichotomous variable increased more for adolescents in the intervention group compared with the control group (Table 2). Since the dichotomous variable better reflects the actual knowledge of the five-a-day recommendation for FV consumption, future studies should make efforts for the use of more powerful techniques (e.g. bootstrapping), so dichotomous mediators can be correctly investigated^(17,37).

Despite that observational studies have consistently identified availability/accessibility at home, parental influences and taste preferences of different types of FV as potential determinants of adolescents' FV consumption^(38–40), there is a lack of evidence for mediation of these determinants in school-based interventions^(33,34,36,41). Similar to these findings, we report significant b-paths for almost all determinants (the determinants were positively associated with FV consumption), but the intervention had no effect on these determinants. Considering that only two out of five intervention components were targeted at availability/accessibility at home, availability at dinner, taste preferences and parental encouragement (and three out of five intervention components targeted knowledge of recommendations), the delivered activities have probably been insufficient and/or were not implemented as expected to change the hypothesised determinants. For instance, a weekly FV break where adolescents had to bring their own food was aimed to increase the taste preferences of different types of FV, but perhaps specific taste lessons with a diversity of FV as included in a Finnish school-based intervention study⁽³⁴⁾ may be more effective. Careful evaluation of the logic model of the HEIA intervention is needed to clarify this. Another explanation could be that the intervention effect on FV consumption was mediated via other determinants which were not measured in this study. Earlier school-based intervention studies tested mediators more related to the individual level and reported significant mediations by attitude, self-efficacy, planning and overall liking of FV in the associations with FV consumption^(34,36,42). In our study, both the lessons with student booklets and computer tailoring programmes contained specific components to increase awareness of one's own behaviour and support self-efficacy and action planning, which may have contributed to the observed positive effect on FV consumption. Nonetheless, eating behaviour is complex resulting from a myriad of individual, social, economic and political factors^(43,44), which we were unable to capture with the determinants included in the current study. Measuring a wide range of determinants related to the intervention activities and surrounding systems is thus essential for clarifying and understanding the mechanisms of behaviour change in these interventions⁽⁴⁵⁾.

Unique about the present study is that both mid-way and post-intervention values of mediators were analysed. Most mediation studies evaluating school-based dietary



behaviour interventions only used pre- and post-intervention measures^(33–36,41,46) and therefore do not fulfil the temporal precedence assumption of the mediation model. This assumption requires that changes in the mediating variable should follow implementation of the intervention and should precede changes in the intervention outcome^(17,47). Results of the secondary analyses, which were performed in a smaller study population due to missing values of mid-way determinants, show almost no differences for including mid-way or post-intervention determinants in the mediation analyses. Knowledge of recommendations significantly mediated the intervention effect on fruit consumption for both time points, whereas the mediation of all other determinants remained non-significant. Since the secondary analyses were based on a smaller study population and no substantial differences were found between mid-way and post-intervention determinants, the primary analyses were interpreted as the main results. Nevertheless, it remains important to include multiple assessment points in future study design and examine mid-way mediators to be able to conclude on causality^(17,47).

Few studies have investigated moderating influences on mediators in school-based interventions targeting FV consumption. Only Lubans *et al.*⁽⁴¹⁾ reported on moderation by sex in the intervention effect on FV consumption and hypothesised mediators (availability at home and self-efficacy). Changes observed in FV consumption among females were larger over the study period, but the researchers did not elaborate on differences in effects on mediators that could explain this⁽⁴¹⁾. Our study showed moderating influences by sex, parental education and weight status on the associations of taste preferences, availability of vegetables at dinner and parental encouragement with the consumption of fruit and/or vegetables. These findings suggest that interventions to change dietary behaviour in adolescents may require different strategies for various population subgroups. For instance, targeting taste preferences might be more effective for boys and adolescents with medium- to high-educated parents. Adolescents with low-educated parents may benefit more from increasing the availability of vegetables at dinner, and adolescents with overweight/obesity could be more sensitive to parental encouragement for increasing their FV consumption. Indeed, previous research points out that children with low-educated parents appear more susceptible to environmental changes in food availability, probably due to the lower availability of healthy foods (e.g. FV) at home compared with high-educated households, which leaves room for improvement⁽⁴⁸⁾. As such, in high-educated households where FV availability is generally higher, taste preferences may become a more important driver for increasing FV consumption⁽²³⁾. Distinct approaches for adolescents with low- or high-educated parents are thus needed to reduce social disparities in FV consumption⁽⁴⁹⁾. However, it should be

noted that our analyses are exploratory as we performed numerous of statistical tests which may have led to false-positive results⁽⁵⁰⁾. More mediation studies investigating moderating influences with sufficient power are needed to confirm our findings, as well as qualitative studies to generate a more thorough understanding of why these interactions occur.

Strengths and limitations

The strengths of the current study include the large sample size and high participation rate, long duration of the intervention (20 months) and three measurement points. Effects on FV consumption and their determinants were examined and reported separately as they follow different consumption patterns⁽⁵¹⁾. Furthermore, the analyses of mediating and moderating effects provided insights about both underlying mechanisms and intervention effectiveness in subgroups.

Nonetheless, the study had some limitations. First, dietary behaviour and their determinants were assessed using self-reported measures which are prone to measurement errors, particularly among youth⁽⁵²⁾. For instance, the intervention activities could have affected how adolescents perceive their own behaviour and environment. Besides, the precision of the measures may be limited as single items were used to measure them, although this is common in research with children to limit the length of the questionnaires. The use of more objective measures, such as photographic tools to capture dietary behaviour or combining perceptions from multiple actors (e.g. adolescents, parents, teachers and school principals) could enhance the validity and reliability of the collected data. Second, the study population was recruited from a limited geographical area in south-eastern Norway and included a low number of adolescents with overweight/obesity, compared with nationwide population-based studies in Norway⁽⁵³⁾. Since we also aimed for complete case analysis, a considerable part of the study population had to be excluded due to missing values in the broad number of variables included. Attrition analyses showed significant differences in sex, weight status and intervention condition between those included and excluded from the analyses. In fact, in our study population, we observed a significant increase in vegetable consumption among adolescents in the intervention group, whereas an earlier report on the HEIA study that included a larger number of participants did not find a significant effect on vegetable consumption at post-intervention⁽²⁵⁾. Thus, we probably analysed a more selected sample which may limit the generalisation of our findings to a broader population. Third, power calculations were made based on anthropometric measures and changes in energy balance-related behaviours but not on their determinants. As such, the sample size may have been too small to detect differences in effects on the determinants between the control and intervention group.





A lack of power could also have been a problem in the moderation analyses. Small effect sizes and low statistical power of tests for interaction effects make it difficult to find existing moderating influences^(54,55), especially in case of moderation by weight status, as our study population included a small proportion of adolescents with overweight/obesity (12.3%). To overcome the lack of power, we applied a two-sided *P*-value of <0.10 for interaction effects and created figures to illustrate the nature of the moderations^(54,56).

Conclusions

While the HEIA intervention significantly increased adolescents' fruit consumption and had a positive influence on the consumption of vegetables over the 20-month study period⁽²⁵⁾, none of the targeted determinants could explain this behaviour change. This indicates either a poor delivery or lack of effective intervention components targeting the hypothesised determinants. Nonetheless, availability/accessibility of FV at home, availability of vegetables at dinner, taste preferences for different types of FV and knowledge of the FV recommendations were positively associated with the consumption of fruit and/or vegetables among all participants. This creates opportunities for future school-based dietary interventions to achieve even larger effects when well designed and implemented. Sex, parental education and weight status moderated the associations between multiple determinants and the consumption of fruit and/or vegetables, suggesting that interventions may require specific strategies for different subgroups of adolescents. Reporting on a wide range of mediators and moderators in school-based interventions more often is needed to identify these distinct mechanisms and reveal the pathways through which intervention effects are achieved.

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Conflict of interest

There are no conflicts of interest.

Authorship

M.C.D., M.K.G., N.L. and M.P.P. conceived the study. M.C.D. performed the data analysis and wrote the draft and final manuscript. N.L., L.F.A., K.I.K. and M.B. are main investigators in the HEIA study, who participated in the study design, project planning and data collection. All authors provided feedback on different versions of the manuscript and approved the final version submitted for publication.

Ethics of human subject participation

The HEIA study complies with the guidelines described in the Declaration of Helsinki, and all procedures were approved by the Regional Committee for Medical Research Ethics (S-07119b) and the Norwegian Social Science Data Service (16434). Written informed consent was obtained from all school administrators and parents of participating adolescents. The study was reported following the Consolidated Standards of Reporting Trials (CONSORT) and the Template for Intervention Description and Replication (TIDieR) checklist and guide.

Supplementary material

For supplementary material accompanying this paper visit <https://doi.org/10.1017/S1368980024000260>

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