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Role of dietary intake and physical activity in reducing weight social inequalities among adolescents: an application of G-formula to PRALIMAP-INÈS trial

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Abstract

Interventions aiming to reduce social inequalities of weight status in adolescents usually focus on lifestyle behaviours, but their effectiveness is limited. This study analysed the effect of achieving levels of dietary intake (DI) and/or physical activity (PA) guidelines on reducing social inequalities in weight status among adolescents. We included adolescents from the PRomotion de l'ALIMentation et de l'Activité Physique – INÉgalité de Santé (PRALIMAP-INÈS) trial with weight status data available at baseline and 1-year follow-up (n=1130). PA and DI were measured using the International Physical Activity Questionnaire and a validated food frequency questionnaire, respectively. We estimated the likelihood of a 1-year reduction in body mass index z-score (BMIz) and population risk difference (PRD) under hypothetical DI and PA levels and socioeconomic status using the parametric G-formula. When advantaged and less advantaged adolescents maintained their baseline DI and PA, we found social inequalities in weight status, with a PRD of a 1-year reduction in BMIz of -1.6% (-3.0%; -0.5%). These inequalities were not observed when less advantaged adolescents increased their proportion of achieving DI guidelines by 30% (PRD=2.2% [-0.5%; 5.0%]) unlike the same increase in PA (PRD= -3.9% [-6.8%; -1.3%]). Finally, social inequalities of weight status were not observed when levels of achievement of both PA and DI guidelines increased by 30% (PRD= 2.2% [-0.5%; 4.0%]). Enhancing DI rather than PA could be effective in reducing social inequalities in weight status among adolescents. Future interventions aiming to reduce these inequalities should mostly target DI to be effective.

Keywords: Dietary intake, Physical activity, Social inequalities, Weight status, adolescents, G-formula

Introduction

According to the World Health Organization (WHO), the prevalence of overweight and obesity among children and adolescents aged 5 to 19 years was 18% in 2016 versus 4% in 1975 [(1)]. This situation leads to several short- and long-term undesirable health consequences [(2)]. Moreover, there are social inequalities in overweight and obesity in adolescents [(3)]. The inequalities are characterized by high levels of adiposity among less socially advantaged groups in high-income countries and low levels in developing and medium- to low-income countries [(4)].

The literature shows that most adolescents do not achieve physical activity (PA), dietary intake (DI) and sedentary behaviour (SB) guidelines, although the demonstrated relation (negative for PA and positive for high energy-dense DI and SB) between these factors and weight status [(5,6)]. Theorical frameworks were developed to explain the link between lifestyle behaviours and social inequalities of weight status. According to the cultural-behavioural approach, the link between socioeconomic status (SES) and health is a result of differences between SES in terms of health-related behaviours [(7)]. This framework exhibits how inequalities in DI, PA, and SB [(8)] lead to a weight social gradient [(9)] whose reduction is the purpose of most public health interventions [(10,11)]. Nutrition public health interventions are then implemented and mainly focus on lifestyle behaviours to overcome inequalities of weight status [(12)]. However, the effect of levels of achieving lifestyle guidelines (DI and PA) on the reduction in inequalities have not been studied. The assessment of single or combined lifestyle behaviours that have a positive effect on reducing social inequalities of weight status and their required levels could be helpful for the development of effective interventions. These components could be combined in a randomized controlled trial but is difficult first because of the need for many arms of lifestyle behaviours with a large sample size; second because of additional difficulties of randomization on SES (advantaged group and less advantaged group); and third because lifestyle behaviours change across time in adolescents (time-varying covariates) [(13)].

Also, there is a need for statistical approaches that consider these changes. The parametric G-formula [(14)] is used to estimate the effect of hypothetical interventions with repeated measurements for each individual in a context of time-varying covariates [(14)]. This study used the G-formula with data from the PRomotion de l’ALIMentation et de l’Activité Physique – INÉgalité de Santé (PRALIMAP-INÈS) trial to analyse the effect of achieving levels of DI and/or PA guidelines on reducing social inequalities in weight status among adolescents.

Methods

Study sample

Data were from the PRALIMAP-INÈS trial [15,16] that included adolescents from September 2012 to September 2015 who had excess weight: body mass index (BMI) greater than the International Obesity Task Force (IOTF) [17] cut-off and/or waist circumference greater than the McCarthy cut-off values for age and sex [18]. Eligible adolescents were divided into two groups according to SES measured by the Family Affluence Scale (FAS) [19]. The FAS score (from 0 to 9 [20]) is based on four simple questions exploring the availability of a personal bedroom, family cars and computers and opportunities for family holidays. Advantaged adolescents (FAS score ≥5) received the standard intervention and constituted the "advantaged with standard care" group. Less advantaged adolescents (FAS score <5) were randomized to two subgroups: one third received standard care (less advantaged with standard care) and two-thirds received standard and adapted care (less advantaged with standard and strengthened care). Randomization was at the individual level [15]. The interventions were implemented during one academic year, with follow-up at baseline (T0) and at the end of the intervention (T1). The PRALIMAP-INÈS trial protocol has been published elsewhere [15]. This study was conducted according to the guidelines in the Declaration of Helsinki, and all procedures involving human subjects/patients were approved by the French consultative committee for the treatment of information in health research (no. 12.299), the French National Commission for Data Protection and Liberties (no. 912372) and the French Person Protection Committee (no. 2012/15). Written informed consent was obtained from parents of all adolescents. The trial was registered in ClinicalTrials.gov (NCT01688453) in September 2012. We included 1130 adolescents who had weight status (body mass index z-score[BMIz]) data available at T0 and T1. Adolescents with missing data on BMIz at T1 were “non-completers”.

Measurements

A food frequency questionnaire was used to assess the number of portions of fruits and vegetables (FAV) and sugar foods and drinks (SFD) consumed by adolescents each day [21]. The cut-off for DI guidelines were “at least five parts of FAV a day” (yes/no) and “at most one a day for SFD” (yes/no) in accordance with WHO guidelines and the French Programme National Nutrition Santé [22].

PA and SB were measured with the International Physical Activity Questionnaire (IPAQ) [23], a valid and reliable questionnaire for adolescents in France [23,24]. The IPAQ assesses the frequency (days per week) and duration (minutes) of sitting, walking, moderate and vigorous PA during the previous 7 days. According to the WHO guidelines [6], adolescents with at least 1 hr of moderate to vigorous PA per day and at least 3 days of vigorous PA per week were considered to achieve PA guidelines. Moreover, a daily screen time more than 2-hr cut-off defined SB (yes/no) [6].

Weight status was measured by trained school nurses/clinical research nurses as well as physicians by use of the BMI, the ratio of weight to height squared. Weight was expressed in kilograms and height in meters. We also calculated BMIz as the distance between the measured BMI and the mean BMI of a WHO age- and sex-specific reference population [25]. Other measurements were the waist circumference (WC) in centimeters and the prevalence of overweight or obesity according to the IOTF age- and sex-specific cut-off values for BMI [17].

Baseline sociodemographic characteristics included age (year), sex (boy/girl), and school type (general high school, vocational high school, middle school). Students in general and vocational high schools were in grade 10, whereas those in middle schools were in grade 9. The other sociodemographic characteristics were related to school boarding status (non-boarding, half-boarding, full-boarding), number of parents responsible (zero, one, two), social and professional class of the family (executives; farmers, craftsmen; intermediate jobs; employees; workers; other), adolescents' perceived income level of the family (low, average, high), intervention group (less advantaged with standard care; less advantaged with standard and strengthened care; advantaged with standard care) and SES measured by FAS score.

The main outcome of the study was the likelihood of a 1-year reduction in BMIz defined as $\Delta BMIz_{T1-T0} < 0$. This cut-off was used given that a modest reduction in BMIz (i.e., >0) after a 1-year intervention in adolescents was found associated with improvement in several cardiovascular risk factors [26]. The secondary outcomes were differences in BMIz and WC from T0 to T1 (T0-T1).

Interventions were developed based on achieving DI and PA guidelines and baseline SES (advantaged and less advantaged). We considered six hypothetical interventions for 1 year (T0 and T1) as shown in **Table 1**. The interventions were based on a counterfactual hypothesis: What would happen if:

- *Socially advantaged adolescents maintained their lifestyle behaviours? (scenario 1).* This means that adolescents were socially advantaged and maintained their baseline DI and PA.

- *Socially less advantaged adolescents maintained their lifestyle behaviours? (scenario 2).* This means that adolescents were socially less advantaged and maintained their baseline DI and PA.
- *Socially less advantaged adolescents behaved like socially advantaged ones? (scenario 3).* In this scenario, socially less advantaged adolescents have lifestyle behaviours (DI and PA) at T1 corresponding to those of socially advantaged ones at baseline.
- *Socially less advantaged adolescents improved their DI? (scenario 4).* In this scenario, adolescents are socially less advantaged and the proportion of those achieving DI (both FAV and SFD) guidelines increases by 30% between T0 and T1.
- *Socially less advantaged adolescents improved their PA? (scenario 5).* In this scenario, adolescents are socially less advantaged and the proportion of those achieving PA guidelines increases by 30% between T0 and T1. Given that we were in an interventional context and had less advantaged adolescents, we doubled the new target of the WHO's Global Action Plan on Physical Activity 2018–2030, which consists of a 15% relative reduction in physical inactivity globally by 2030 [27].
- *Socially less advantaged adolescents improved both DI and PA? (scenario 6).* In this scenario, adolescents are socially less advantaged and the proportion of those achieving DI (both FAV and SFD) and PA guidelines increases by 30% between T0 and T1.

By using *scenario 1* as a reference for all comparisons between scenarios, their meanings are reported in **Table 1**.

Statistical analysis

First, Student *t* test was used for analysing continuous variables and chi-squared test for categorical variables. Then, the likelihood of a 1-year reduction in BMIz under the different hypothetical interventions was investigated with the parametric G-formula [14]. For this, we chose time-varying covariates (FAV, SFD, PA and SB guidelines achievement) and fixed baseline covariates (age, sex, school type and grade, school boarding status, number of parents responsible, social and professional class of the family, perceived income level of the family, intervention group and BMIz at baseline). SES (advantaged/less advantaged) was used as a conditional variable in the scenarios. The steps were as follows **(Figure 1)**:

Step 1: We fitted parametric regression models for the time-varying covariates at T1 as a function of T1 and T0 covariate history (baseline sociodemographic characteristics). Therefore, we developed linear regression models to estimate number of parts of FAV, SFD and duration of screen time (SB) per day and a logistic regression model for PA guidelines achievement (yes/no). SB was used as time-varying covariate to adjust our models as baseline covariates.

Step 2: We fitted a logistic regression model for the likelihood of a 1-year reduction in BMIz as a function of hypothetical intervention and covariates history (baseline sociodemographic characteristics and time-varying covariates) among individuals under follow-up.

Step 3: We used a Monte Carlo simulation to generate a 10,000-individual population based on original data from PRALIMAP-INÈS and under each of the hypothetical interventions to minimize simulation error [28]. For everyone, the values of baseline covariates (T0) were randomly sampled with replacement from the individuals PRALIMAP-INÈS trial data. Then, time-varying covariates were generated at T1 by using the equation of the parametric regression models of step 1. After the values were generated at T1, values of covariates that were to undergo hypothetical interventions (scenarios 1 to 6) were then changed according to the specified scenario rule. The likelihood of a 1-year reduction in BMIz was finally estimated for each of the 10,000 histories under each hypothetical intervention based on the logistic regression models in step 2.

Step 4: We computed the likelihood of a 1-year reduction in BMIz in the population under each hypothetical intervention (population risk), the population risk differences (differences between less advantaged and advantaged adolescents in likelihood of a 1-year reduction in BMIz [PRD]) and the population risk ratio (ratio of likelihood of a 1-year reduction in BMIz) between hypothetical interventions by using scenario 1 as the reference for each comparison. A significant PRD reflected inequalities in the likelihood of a 1-year reduction in BMIz (positive values in favour of less advantaged adolescents and negative values in favour of advantaged ones), whereas a non-significant PRD means that inequalities were not shown.

Step 5: We repeated the previous steps in 100 bootstraps to obtain 95% confidence intervals (CI) of the different estimators. The algorithm also calculated the likelihood of a reduction in BMIz under a natural course (no change in any of the time-varying covariates estimated in step 3 at T1). The goodness of fit of the model was appreciated by the observed likelihood of the reduction in BMIz (likelihood of a 1-year reduction in BMIz based on PRALIMAP-INÈS data and without any simulation), which must be included in the confidence interval of the same reduction under the natural course for a good model fit. The natural course represents a simulation of 10,000 adolescents based on the PRALIMAP-INÈS trial without any change in levels of achieving DI and PA guidelines.

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Sensitivity analysis

The same analyses were performed for secondary outcomes (BMIz and WC difference from T0 to T1). The model estimated the means of differences and standard errors under each hypothetical intervention. Finally, ratios of means, differences of means and their corresponding 95% CIs were calculated by using scenario 1 as a reference.

Data were analysed with SAS 9.4 (SAS Institute, Cary, NC, USA) with an implementation of the macro G-formula 3 [(14)]. The macro is available at http://www.hsph.harvard.edu/causal/software. P<0.05 was considered statistically significant.

Results

Baseline sociodemographic, anthropometric characteristics and achievement of lifestyle guidelines for the study sample and the non-completers (BMIz data not available at T1) are in **Table 2**. As compared with non-completers, the study sample was younger (mean age 15.2± 0.7 vs 15.5± 0.7 years, p<0.001) and had more boys (45.7% vs 37.4%). Completers were also more enrolled in middle schools and less in high school. Adolescents with at least one parent responsible and high prevalence of SB were more able to attend the follow-up. Additionally, non-completers and the study sample significantly differed in the social and professional class of their family (p=0.02). Moreover, the study sample and non-completers did not differ in the most relevant baseline variables such as SES (family affluent scale score, perceived income level of the family), anthropometric characteristics and lifestyle guidelines except screen time.

Adolescents in the PRALIMAP-INÈS trial had low levels of achieving lifestyle guidelines at baseline regardless of their SES (22.1% and 25.6% achieved FAV and PA guidelines, respectively) (**Table 3)**. We found social inequalities in achieving FAV (16.7% vs 26.3%; p<0.001) and PA (20.9% vs 29.1%; p=0.003) guidelines in favour of advantaged adolescents at baseline. Overall, 56% of adolescents reduced their BMIz at 1 year, with no difference by SES. There was also no difference in WC reduction by SES.

Table 4 shows the likelihood of a 1-year reduction in BMIz under different hypothetical interventions. Under the natural course (simulation of 10,000 adolescents based on the PRALIMAP-INÈS trial without any change in levels of achieving DI and PA guidelines), the likelihood of a 1-year reduction in BMIz was 51.2% (95%CI=[45.2; 56.6]), which included the observed likelihood (likelihood of a 1-year reduction in BMIz based on PRALIMAP-INÈS data and without any simulation: 56.0%), and suggests a good model fit. Under scenario 1 (i.e., advantaged adolescents maintaining their baseline achievement of DI [FAV:

26.3%; SFD: 20.6%] and PA [29.1%] guidelines), the likelihood of adolescents reducing the 1-year BMIz was 54.9% (95% CI 48.5%; 60.5%). Additionally, when less advantaged adolescents maintained their baseline achievement of lifestyle guidelines (scenario 2: FAV [16.7%]; SFD [19.1%] and PA [20.9%]), 53.3% (46.6%; 58.6%) were able to reduce their BMIz. As compared with scenario 1 (reference), the PRD was -1.6% (-3.0%; -0.5%) and confirms the social inequalities of weight status among adolescents. Moreover, the number needed to treat (NNT) was 62, so for 62 less advantaged adolescents under this hypothetical intervention, one adolescent increased or maintained the BMIz after 1 year as compared with advantaged adolescents (scenario 1). These inequalities were not observed when less advantaged adolescents behaved like advantaged ones (scenario 3: FAV [16.7% to 26.3%]; SFD [19.1% to 20.6%] and PA [20.9% to 29.1%]) with a PRD of -0.2% (-1.6%; 0.5%). Similar results were observed when less advantaged adolescents increased the proportion of those achieving DI guidelines by 30% (scenario 4: FAV [16.7% to 46.7%] and SFD [19.1% to 49.1%]) with a PRD of 2.2% (-0.5%; 5.0%). Unlike when less advantaged adolescents increased the proportion of only those achieving PA guidelines by 30% (scenario 5: PA [20.9% to 50.9%]), inequalities persisted with a PRD of -3.9% (-6.8%; -1.3%). Finally, we found no inequalities of weight status when less advantaged adolescents increased the proportion of those achieving DI and PA guidelines by 30% (scenario 6: FAV [16.7% to 46.7%]; SFD [19.1% to 49.1%] and PA [20.9% to 50.9%]) with a PRD of 2.2% (-0.5%; 4.0%). Results in **Table 5** confirm our findings when BMIz reduction was used as continuous variable. **Table S1** shows that social inequalities were not observed for the likelihood of a 1-year reduction in WC when scenarios involved DI or PA or both. However, with WC used as a continuous variable, we did not find social inequalities in the evolution of WC from T0 to T1 (**Table S2**).

Discussion

The results of this study confirm low levels of achieving lifestyle guidelines in adolescents regardless of SES with social inequalities in weight status (likelihood of a 1-year reduction in BMIz under each scenario). Differences by SES in obesity-related behaviours with a high prevalence of unhealthy lifestyle behaviours in adolescents with low SES result in social gradient of lifestyle behaviours [8] and weight status [29].

In this work, we developed scenarios targeting mainly less advantaged adolescents. If adolescents achieved the same levels of lifestyle guidelines as advantaged ones, there were no social inequalities of weight status. This result suggests that social inequalities of weight status are mostly mediated by differences in lifestyle behaviours due to differences in SES, as supported by the cultural-behavioural theory of health inequalities [7]. An unequal distribution of resources and environments prevents excess weight gain for height (healthy food, opportunities for PA, primary and preventive health care, and protection from stressors) that result in inequalities of weight status [11]. Future interventions should actively target a balanced distribution of lifestyle behaviours across different levels of the social hierarchy. In a systematic review, Beauchamp et al. showed that unlike studies targeting individual-level behaviour, those that primarily included community-based strategies or policies and aiming at structural changes to the environment were effective for low-SES participants [30]. Such strategies include restrictions in marketing unhealthy food and drink and pricing measures. However, their implementation are politically difficult [31].

When less advantaged adolescents achieved both FAV and SFD (DI guidelines) rather than PA guidelines by 30%, social inequalities of weight status were not observed. Moreover, we showed that interventions targeting PA in order to reduce social inequalities of weight status must be combined with improvements in diet to be effective (scenario 6 vs 1). The contribution of diet quality to social inequalities of weight status was reported in an adult population-based study in Switzerland [32]: the proportion of the association between educational level and obesity that was mediated by diet quality was 22.1% when using BMI. The authors suggested that focusing efforts on improving the diet quality of less advantaged groups could help reduce social inequalities in obesity.

When the proportion of less advantaged adolescents who achieved PA guidelines increased by 30%, inequalities persisted. Studies examining PA by SES showed mixed results [33,34], potentially due to differences in the how PA was measured. Previous interventions aiming to increase the proportion of less advantaged adolescents that achieved PA guidelines had no effect on mean BMIz or prevalence of overweight and obesity [33,35]. In a randomized controlled trial that assessed the impact of a school-based PA intervention on adiposity of less advantaged adolescents, the authors found no effect on BMIz after 1 year, but a significant reduction after 2 years of the intervention [34]. The short duration of interventions (1 year in our scenarios) could underestimate the impact of PA on inequalities of weight status. However, using retrospective cohort data for children in the United Kingdom, Pearse et al. [36] simulated various interventions on the achievement of the WHO PA guidelines. The authors showed that universal achievement of the WHO's PA guidelines, if attainable, would reduce the prevalence of childhood overweight and obesity but not inequalities. The same result was reported when the authors targeted less advantaged groups. As shown in our study, these

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authors suggested that to reduce inequalities in overweight/obesity should involve examining policy scenarios that also focus on the upstream influences on diets. Nevertheless, given that inadequate health literacy is strongly associated with low SES [37], the difference in effectiveness of DI and PA interventions on social inequalities of weight status raises the question of bias related to how the messages were transmitted and the ability of adolescents to understand.

Social inequalities in WC among adolescents have been reported [38] with controversial results of interventions [39,40]. The discrepancy in the results when the difference in WC was used as binary versus continuous variable could be explained by the limitations of this weight status indicator with variability due to measurement site [41].

In this study, we only reported short-term results, but the sustainability of healthy behaviours is required. According to authors who advocate incremental changes, only modest change is politically feasible [11]. They argue that reducing DI by 50-100 calories a day or increasing daily PA by 10 min is sufficient, if sustained to bring about measurable declines in obesity.

Limitations and strengths

The first limitation is that scenarios were simulated by using data from an intervention that was effective in reducing social inequalities [16] in weight status among adolescents with overweight and obesity (no difference in proportion of a 1-year reduction in BMIz between advantaged and less advantaged adolescents). This leads to a natural course, which was the context of PRALIMAP-INÈS trial and could limit the generalization of our findings. However, this context was taken into account by considering another hypothetical intervention (scenario 1) as a reference category, and all simulations were adjusted on intervention groups of the PRALIMAP-INÈS trial as a fixed baseline covariate. Second, measurement of PA, DI and SB involved self-reporting questionnaires (food frequency questionnaire and IPAQ). However, these questionnaires are valid and reliable [21,23,24]. Third, SB was not included in the scenarios given that a recent paper on PRALIMAP-INÈS baseline data demonstrated that PA rather than SB was socially determined in French adolescents with overweight and obesity [42]. Nevertheless, it was used as a time-varying covariate to adjust our models. Fourth, the result about the effectiveness of interventions aiming to improve PA on social inequalities of weight status (BMIz) should be taken with caution because absence of evidence is not evidence of absence [43].

Despite these limitations, this study has several strengths. First, this is the only study that investigated the effect of different levels of lifestyle guidelines achievement on social inequalities of weight status with a longitudinal design and a large sample size (1130 participants). Second, the target of 30% improvement in proportion of adolescents achieving lifestyle guidelines in the scenarios is reasonable. For example, the WHO's target is an increase of 15% in PA globally by 2030 [27]. We doubled this target, given that less advantaged adolescents with lower levels of achievement of recommendations were interested by our strategies. This is the principle of targeted interventions in order to narrow the health gap [44]. Third, the absence of significant differences in relevant variables between the study sample and non-completers suggests a limitation of the risk of selection bias and could increase the generalization of our results. Finally, this study shows the real effect of several interventions targeting less advantaged groups on the reduction in social inequalities of weight status by considering the natural course in advantaged group as reference. It offers more robust conclusions on social inequalities of weight status than most interventions considering the natural course of less advantaged adolescents as a reference and did not allow for conclusions on reducing inequalities but only on changes in weight status indicators [35,45].

Conclusion

This study confirms social inequalities of a 1-year reduction in BMIz. By increasing the proportion of adolescents achieving DI guidelines by 30%, these inequalities were no longer observed. Policies that address inequalities of weight status among adolescents could focus on and improve levels of achievement of DI guidelines. Additionally, interventions aiming at improving PA could be associated with DI to be more effective on inequalities of weight status. Most efforts are required to allow less advantaged adolescents to access healthy foods in order to achieve DI guidelines.

Declarations

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Table 1. Description of hypothetical interventions (scenarios) and meanings of comparisons simulated

Scenarios (number)	Counterfactual questions: what happen if?	Definitions of the scenarios	Interpretation of comparisons[a]
1	Socially advantaged adolescents maintained their lifestyle behaviours?	Adolescents are socially advantaged and do not change their baseline DI and PA from T0 to T1	Reference
2	Socially less advantaged adolescents maintained their lifestyle behaviours?	Adolescents are socially less advantaged and do not change their baseline DI and PA from T0 to T1	Explore social inequalities in weight status (scenario 2 versus 1)
3	Socially less advantaged adolescents behave like socially advantaged ones?	There is no behavioural difference (DI and PA) between less advantaged and advantaged adolescents	Explore whether social inequalities in weight status are due to other factors than lifestyle behaviours (DI and PA) (scenario 3 versus 1)
4	Socially less advantaged adolescents improved their DI?	The proportion of socially less advantaged adolescents achieving DI guidelines increased by 30% between T0 and T1	Effectiveness of improving less advantaged adolescents DI on social inequalities in weight status (scenario 4 versus 1)
5	Socially less advantaged adolescents improved their PA?	The proportion of socially less advantaged adolescents achieving PA guidelines increased by 30% between T0 and T1	Effectiveness of improving less advantaged adolescents PA on social inequalities in weight status (scenario 5 versus 1)
6	Socially less advantaged adolescents improved both DI and PA?	The proportion of socially less advantaged adolescents achieving DI and PA guidelines increased by 30% between T0 and T1	Effectiveness of improving less advantaged adolescents DI and PA on social inequalities in weight status (scenario 6 versus 1)

Abbreviations: DI, dietary intake (fruit and vegetable + sugar foods/drinks); PA, physical activity; T0, baseline; T1, 1-year follow-up.

[a] *Scenarios 2 to 6 were compared to scenario 1 as a reference on the likelihood of a 1-year reduction in BMIz.*

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Table 2. Comparison of baseline sociodemographic, anthropometric characteristics and lifestyle guidelines achievement between the study sample and non-completers

	Total N= 1419			**Non-completers N=289 (20.4%)**			**Study sample N=1130 (79.6%)**			
	N	**%/mean**	**SD[a]**	**N**	**%/mean**	**SD[a]**	**N**	**%/mean**	**SD[a]**	**p[b]**
Sociodemographic characteristics										
Age (years)	1419	15.3	0.7	289	15.5	0.7	1130	15.2	0.7	**<0.001**
Sex										**0.01**
Boy	624	44.0		108	37.4		516	45.7		
Girl	795	56.0		181	62.6		614	54.3		
School type (grade)										**<0.001**
General high school (10)	621	43.8		133	46.0		488	43.2		
Vocational high school (10)	540	38.1		135	46.7		405	35.8		
Middle school (9)	258	18.2		21	7.3		237	21.0		
School boarding status										0.07
Non-boarding	278	19.9		60	21.1		218	19.6		
Half-boarding	769	55.0		140	49.3		629	56.5		
Full-boarding	350	25.1		84	29.6		266	23.9		
Missing	22			5			17			
Number of parental responsible										**0.04**
0	39	2.7		9	3.1		30	2.7		
1	193	13.6		52	18.0		141	12.5		
2	1187	83.7		228	78.9		959	84.9		
Social and professional class of the family										**0.02**
Executives	157	11.1		27	9.3		130	11.6		
Farmers, craftsmen	174	12.3		28	9.7		146	13.0		
Intermediate jobs	247	17.5		48	16.6		199	17.7		
Employees	317	22.4		63	21.8		254	22.6		
Workers	376	26.6		78	27.0		298	26.5		
Other	143	10.1		45	15.6		98	8.7		
Missing	5			0			5			
Perceived income level of the family										0.06
Low	136	9.6		34	11.8		102	9.0		
Average	647	45.6		115	39.8		532	47.1		
High	635	44.8		140	48.4		495	43.8		
Missing	1			0			1			
FAS Score	1419	5.7	1.8	289	5.8	1.8	1130	5.7	1.8	0.82
PRALIMAP-INES Intervention group										0.76
Less advantaged with standard	196	13.8		39	13.5		157	13.9		

care										
Less advantaged with standard and strengthened care	415	29.2		80	27.7		335	29.6		
Advantaged with standard care	808	56.9		170	58.8		638	56.5		
Anthropometric characteristics										
BMIz	1419	1.6	0.7	289	1.6	0.7	1130	1.7	0.7	0.33
BMI (kg/m²)	1419	26.6	4.0	289	26.6	3.8	1130	26.6	4.0	0.80
BMI categories										0.68
No excess body weight [c]	302	21.3		56	19.4		246	21.8		
Overweight	810	57.1		169	58.5		641	56.7		
Obese	307	21.6		64	22.1		243	21.5		
Waist circumference (cm)	1418	87.8	11.1	289	88.5	10.8	1129	87.7	11.1	0.24
Obesity										0.81
No	1112	78.4		225	77.9		887	78.5		
Yes	307	21.6		64	22.1		243	21.5		
Lifestyle guidelines										
Fruits and vegetables ≥ 5/day										0.67
No	1100	77.7		221	76.7		879	77.9		
Yes	316	22.3		67	23.3		249	22.1		
Missing	3			1			2			
Sugar foods and drinks ≤ 1/day										0.25
No	1144	80.7		240	83.0		904	80.1		
Yes	274	19.3		49	17.0		225	19.9		
Missing	1			0			1			
More than 1 hr of MVPA and VPA ≥ 3/week										0.25
No	930	75.1		191	78.0		739	74.4		
Yes	308	24.9		54	22.0		254	25.6		
Missing	181			44			137			
Screen time < 2 hr/day										**0.02**
No	996	79.1		185	73.7		811	80.5		
Yes	263	20.9		66	26.3		197	19.5		
Missing	160			38			122			

Abbreviations: BMI, body mass index; BMIz, body mass index z-score; FAS, Family Affluence Scale; MVPA, middle to vigorous physical activity; VPA, vigorous physical activity.
[a] *Standard deviation*
[b] *p-value for chi-square test for categorical variables, Student t test for quantitative variables*
[c] *Close to overweight (International Obesity Task Force 25 percentile minus 1 kg/m2) associated with waist circumference greater than the McCarthy cut-off values for age and sex or eating disorders.*
All percentages were calculated with the denominator as the total number (N in the column head) minus the number of missing data. Bold values are used for statistical significance (p<0.05)

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Table 3. Comparison of baseline lifestyle guidelines achievement and weight status change between T0 and T1 according to socioeconomic status

	Total N= 1130			**Less advantaged N=492 (43.5%)**			**Advantaged N=638 (56.5%)**			
	N	**%/mean**	**SD[a]**	**N**	**%/mean**	**SD[a]**	**N**	**%/mean**	**SD[a]**	**p[*]**
Fruits and vegetables ≥ 5/day										**<0.001**
No	879	77.9		410	83.3		469	73.7		
Yes	249	22.1		82	16.7		167	26.3		
Missing	2			0			2			
Sugar foods and drinks ≤ 1/day										0.54
No	904	80.1		398	80.9		506	79.4		
Yes	225	19.9		94	19.1		131	20.6		
Missing	1			0			1			
More than 1 hr of MVPA and VPA ≥ 3/week										**0.003**
No	739	74.4		337	79.1		402	70.9		
Yes	254	25.6		89	20.9		165	29.1		
Missing	137			66			71			
BMIz reduction between T0 and T1										0.51
No	497	44.0		211	42.9		286	44.8		
Yes	633	56.0		281	57.1		352	55.2		
WC reduction between T0 and T1										0.41
No	669	61.3		282	59.9		387	62.4		
Yes	422	38.7		189	40.1		233	37.6		
Missing	39			21			18			
BMIz difference (units) [b]	1130	0.08	0.29	492	0.09	0.31	638	0.07	0.28	0.14
WC difference (cm) [c]	1091	-1.13	5.85	471	-0.81	5.94	620	-1.37	5.77	0.11

Abbreviations: BMIz, body mass index z-score; MVPA, middle to vigorous physical activity; VPA, vigorous physical activity; T0, baseline; T1, 1-year follow-up; WC, waist circumference

[a] *Standard deviation*

[b] *BMIz difference = BMIz at T0 minus BMIz at T1*

[c] *WC difference = WC at T0 minus WC at T1*

[*] *p-value for chi-square test for categorical variables*

All percentages were calculated with the denominator as the total number (N in the column head) minus the number of missing data. Bold values are used for statistical significance (p<0.05)

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Table 4. Probabilities of a 1-year reduction in BMIz under various achievements of DI and PA guidelines

No.	Scenarios[a]	Likelihood of BMIz reduction[b] ($\Delta BMIz_{T1-T0}$ <0) % [95%CI]	Population risk ratio[b] Ratio [95%CI]	Population risk difference[b] % [95%CI]	Number needed to treat[d]
0	Natural course	51.2 [45.2; 56.6]	0.93 [0.89; 0.99]	-3.7 [-6.2; -0.5]	-27 [-134; -15]
	Adolescents socially advantaged				
1[c]	No change in baseline DI and PA from T0 to T1	54.9 [48.5; 60.5]	1.00	1.0	-
	Adolescents socially less advantaged				
2	No change in baseline DI and PA from T0 to T1	53.3 [46.6; 58.6]	0.97 [0.95; 0.99]	-1.6 [-3.0; -0.5]	-62 [-198; -33]
3	With baseline DI and PA of advantaged adolescents at T1	54.7 [48.2; 59.5]	1.00 [0.97; 1.01]	-0.2 [-1.6; 0.5]	-
4	With increase in proportion of achievement of baseline DI guidelines by 30% at T1	57.1 [51.0; 63.2]	1.04 [0.99; 1.09]	2.2 [-0.5; 5.0]	-
5	With increase in proportion of achievement of baseline PA guidelines by 30% at T1	50.9 [44.0; 56.9]	0.93 [0.87; 0.98]	-3.9 [-6.8; -1.3]	-25 [-67; -13]
6	With increase in the proportion of adolescents achieving baseline DI and PA guidelines by 30% at T1	57.1 [50.2; 62.9]	1.04 [0.99; 1.07]	2.2 [-0.5; 4.0]	-

Abbreviations: BMIz, body mass index z-score; DI, dietary intake (fruit and vegetable + sugar foods/drinks); PA, physical activity; T0, baseline; T1, 1-year follow-up; 95%CI, 95% confidence interval

Observed likelihood of a 1-year reduction in BMIz was 56.0%

Population risk differences: differences between less advantaged and advantaged adolescents (reference) in likelihood of a 1-year reduction in BMIz

Population risk ratio: ratio of likelihood of a 1-year reduction in BMIz between hypothetical interventions by using scenario 1 as a reference category for each comparison

[a] *simulated scenarios under parametric G-formula modelling based on observed data*

[b] *All models included lagged values of time-varying covariates (fruits and vegetables, sugar foods and drinks, PA and sedentary behaviour guidelines achievement) and baseline fixed covariates (age, sex, school type and grade, school boarding status, number of parents responsible, social and professional class of the family, perceived income level of the family, intervention group, socioeconomic status and BMIz at baseline)*

[c] *Reference category*

[d] *Number needed to treat is given only when the population risk difference reaches statistical significance*

Table 5. Means of a 1-year difference in BMIz under various levels of achievement of DI and PA guidelines

No.	Scenarios[a]	Means of BMIz difference ± SD[b]	Percentile 2.5 of BMIz difference[b]	Percentile 97.5 of BMIz difference[b]	Ratio of means of BMIz difference[b] [95%CI]	Difference in means of BMIz difference[b] [95%CI]
0	Natural course	0.03±0.01	0.01	0.09	0.52 [0.17; 1.21]	-0.04 [-0.07; 0.00]
	Adolescents socially advantaged					
1[c]	No change in baseline DI and PA from T0 to T1	0.07±0.02	0.01	0.11	1.00	1.0
	Adolescents socially less advantaged					
2	No change in baseline DI and PA from T0 to T1	0.06±0.02	0.01	0.09	0.84 [0.66; 0.99]	-0.01 [-0.03; 0.00]
3	With baseline DI and PA of advantaged adolescents at T1	0.07±0.02	0.01	0.10	0.99 [0.85; 1.09]	0.00 [-0.01; 0.01]
4	With increase in proportion of achievement of baseline DI guidelines by 30% at T1	0.10±0.04	0.03	0.17	1.47 [0.99; 1.96]	0.03 [0.00; 0.07]
5	With increase in proportion of achievement of baseline PA guidelines by 30% at T1	0.03±0.02	0.00	0.05	0.43 [0.11; 0.85]	-0.04 [-0.07; -0.01]
6	With increase in the proportion of adolescents achieving baseline DI and PA guidelines by 30% at T1	0.09±0.04	0.01	0.16	1.38 [0.89; 1.69]	0.02 [0.00; 0.06]

Abbreviations: BMIz, body mass index z-score; DI, dietary intake (fruit and vegetable + sugar foods/drinks); PA, physical activity; T0, baseline; T1, 1-year follow-up; 95%CI, 95% confidence interval
BMIz difference = BMIz at T0 minus BMIz at T1
Observed mean of a 1-year difference in BMIz was 0.8 units
Ratio of means: ratio of means of BMIz difference between hypothetical interventions by using scenario 1 as the reference category for each comparison
Population risk differences: differences between less advantaged and advantaged adolescents (reference) in means of BMIz differences
[a] *simulated scenarios under parametric G-formula modelling based on observed data*
[b] *All models included lagged values of time-varying covariates (fruits and vegetables, sugar foods and drinks, PA and sedentary behaviour guidelines achievement) and baseline fixed covariates (age, sex, school type and grade, school boarding status, number of parents responsible, social and professional class of the family, perceived income level of the family, intervention group, socioeconomic status and BMIz at baseline)*
[c] *Reference category*

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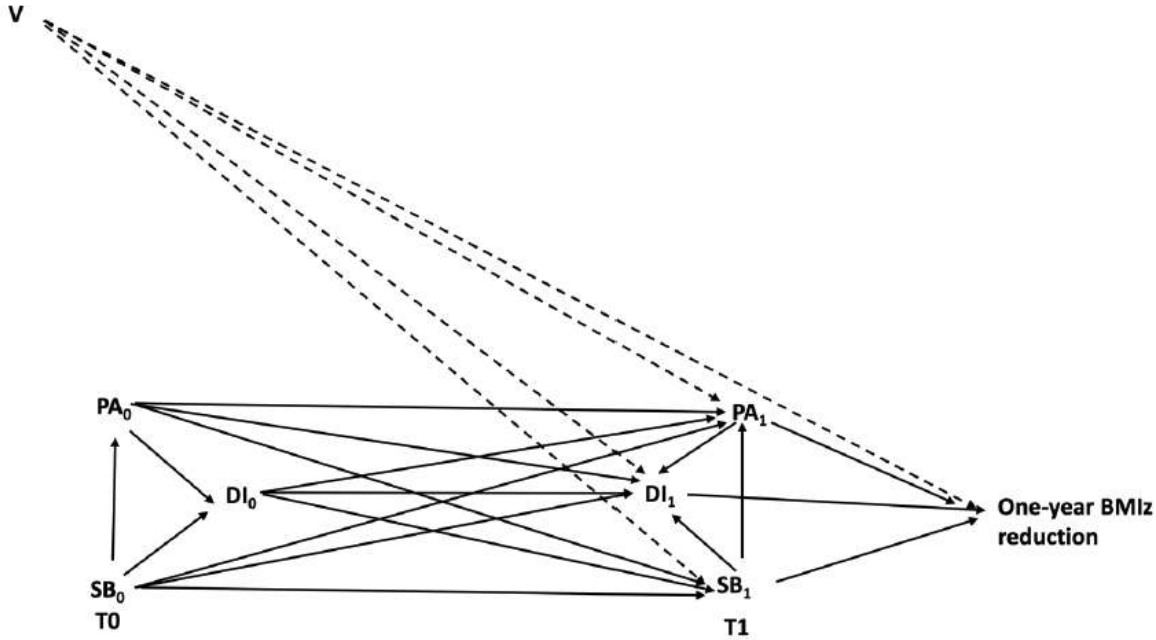

Figure 1. Directed acyclic graph showing hypothesized causal relations among study fixed (V) and time-varying (DI, PA, and SB) covariates used in scenarios at baseline (T0) and 1-year follow-up (T1)

Abbreviations:

V= fixed covariates (age, sex, school type and grade, school boarding status, number of parents responsible, social, and professional class of the family, perceived income level of the family, intervention group) used to adjust models

Time-varying covariates (DI, dietary intake; PA= physical activity; SB, sedentary behaviour)

BMI, body mass index z-score

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