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 FFQ, respectively. We estimated the likelihood of a 1-year reduction in BMI z-score (BMIz) and population risk difference (PRD) under hypothetical DI and PA levels and socio-economic 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 WHO, the prevalence of overweight and obesity among children and adolescents aged 5–19 years was 18 % in 2016 *v.* 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 there is a 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 socio-economic 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 has not been studied. The assessment of

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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 randomised 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 randomisation 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 the 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: 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 randomised 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). Randomisation 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 the parents of all adolescents. The trial was registered in ClinicalTrials.gov (NCT01688453) in September 2012. We included 1130 adolescents who had weight status (BMI z-score (BMIz)) data available at T0 and T1. Adolescents with missing data on BMIz at T1 were 'non-completers'.

Measurements

A FFQ 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 d. According to the WHO guidelines[6], adolescents with at least 1 h of moderate to vigorous PA per d and at least 3 d of vigorous PA per week were considered to achieve PA guidelines. Moreover, a daily screen time more than 2-h 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 metres. 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 centimetres 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 and 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 and full-boarding), number of parents responsible (zero, one and two), social and professional class of the family (executives, farmers, craftsmen, intermediate jobs, employees, workers and other), adolescents' perceived income level of the family (low, average and high), intervention group (less advantaged with standard care, less advantaged with standard and strengthened care, and 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

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*
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 v. 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 v. 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 v. 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 v. 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 v. 1)

DI, dietary intake (fruit and vegetable + sugar foods/drinks); PA, physical activity; T0, baseline; T1, 1-year follow-up.
* Scenarios 2–6 were compared with scenario 1 as a reference on the likelihood of a 1-year reduction in BMIz.

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's *t* test was used for analysing continuous variables and χ^2 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, w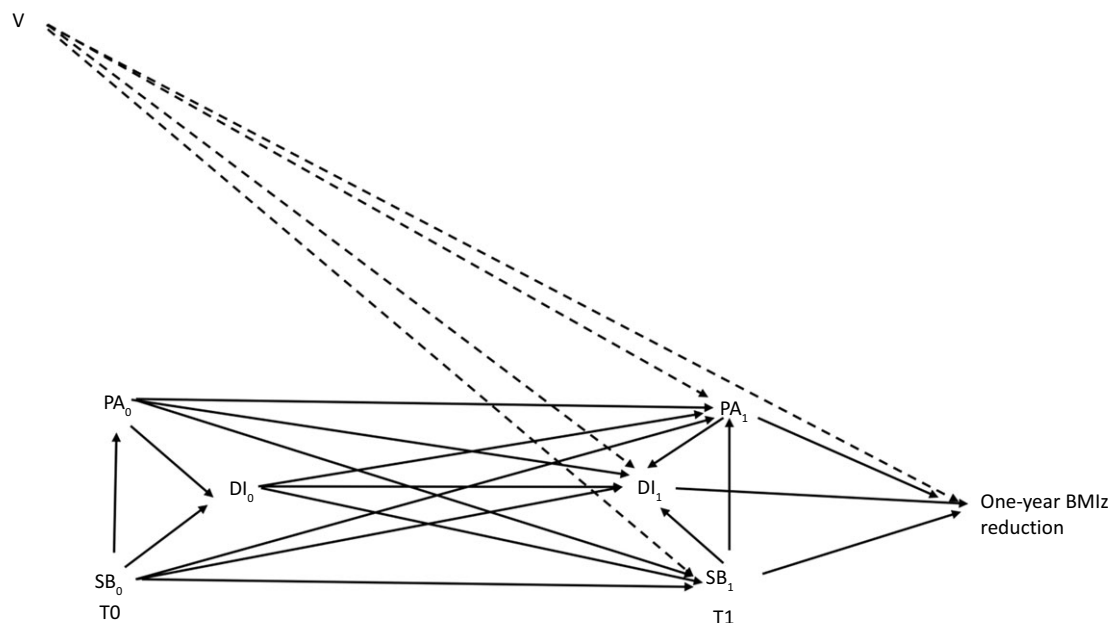e chose time-varying covariates (FAV, SFD, PA and SB guidelines achievement) and fixed baseline covariates (age, sex, school type and grade, school boarding status, number of parents responsible, social and professional class of the family, perceived income level of the family, intervention group and BMIz at baseline). SES (advantaged/less advantaged) was used as a conditional variable in the scenarios. The steps were as follows (Fig. 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 d and a logistic regression model for PA guidelines achievement (yes/no). SB was used as a 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 minimise simulation error[28]. For everyone, the values of baseline covariates (T0) were randomly sampled with replacement from the individual's 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 1–6) 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

Fig. 1. Directed acyclic graph showing hypothesised 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 and intervention group) used to adjust models. Time-varying covariates: DI, dietary intake; PA, physical activity; SB, sedentary behaviour; BMIz, BMI z-score.

(population risk), the population risk differences (PRD) (differences between less advantaged and advantaged adolescents in the likelihood of a 1-year reduction in BMIz) 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 % 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 CI 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.

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 % CI were calculated by using scenario 1 as a reference.

Data were analysed with SAS 9.4 (SAS Institute) 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 *v.* 15.5 ± 0.7 years, $P < 0.001$) and had more boys (45.7 % *v.* 37.4 %). Completers were also more enrolled in middle school 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 % *v.* 26.3 %; $P < 0.001$) and PA (20.9 % *v.* 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

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

	Total			Non-completers			Study sample			
	n 1419			*n* 289			*n* 1130			
				(20·4 %)			(79·6 %)			
	n	%/mean	SD*	*n*	%/mean	SD*	*n*	%/mean	SD*	*P*†
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		108	37·4		516	45·7		
Girl	795	56		181	62·6		614	54·3		
School type (grade)										< **0·001**
General high school (10)	621	43·8		133	46		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		
School boarding status										0·07
Non-boarding	278	19·9		60	21·1		218	19·6		
Half-boarding	769	55		140	49·3		629	56·5		
Full-boarding	350	25·1		84	29·6		266	23·9		
Missing	22			5			17			
Number of parents responsible										**0·04**
0	39	2·7		9	3·1		30	2·7		
1	193	13·6		52	18		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		
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		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		
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 care	196	13·8		39	13·5		157	13·9		
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/m^2)	1419	26·6	4	289	26·6	3·8	1130	26·6	4	0·8
BMI categories										0·68
No excess body weight‡	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/d										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/d										0·25
No	1144	80·7		240	83		904	80·1		
Yes	274	19·3		49	17		225	19·9		
Missing	1			0			1			
More than 1 h of MVPA and VPA ≥ 3/week										0·25
No	930	75·1		191	78		739	74·4		
Yes	308	24·9		54	22		254	25·6		
Missing	181			44			137			

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

No.	Scenarios*	Likelihood of BMIz reduction† (ΔBMIz$_{T1-T0}$ < 0)		Population risk ratio†		Population risk difference†		Number needed to treat§	
		%	95 % CI	Ratio	95 % CI	%	95 % CI		95 % CI
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‡	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	–	

BMIz, BMI z-score; DI, dietary intake (fruit and vegetable + sugar foods/drinks); PA, physical activity; T0, baseline; T1, 1-year follow-up.
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.
* Simulated scenarios under parametric G-formula modelling based on observed data.
† 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, socio-economic status and BMIz at baseline).
‡ Reference category.
§ Number needed to treat is given only when the population risk difference reaches statistical significance.

(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 a continuous variable. Online Supplementary 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 (online Supplementary 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 a 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 would be 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 healthcare, and protection from stressors) that results 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 is 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 v. 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

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

No.	Scenarios*	Means of BMIz difference†	SD	Percentile 2·5 of BMIz difference†	Percentile 97·5 of BMIz difference†	Ratio of means of BMIz difference†	95 % CI	Difference in means of BMIz difference†	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‡	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

BMIz, BMI z-score; DI, dietary intake (fruit and vegetable + sugar foods/drinks); PA, physical activity; T0, baseline; T1, 1-year follow-up.
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.
* Simulated scenarios under parametric G-formula modelling based on observed data.
† 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, socio-economic status and BMIz at baseline).
‡ Reference category.

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 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 randomised 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 UK, 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 authors suggested that reducing 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

the 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 *v.* continuous variable could be explained by the limitations of this weight status indicator with variability due to the 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 energy content 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 the 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 generalisation of our findings. However, this context was taken into account by considering another hypothetical intervention

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(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, the measurement of PA, DI and SB involved self-reporting questionnaires (FFQ 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 the 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 in 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 generalisation 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 the advantaged group as a 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.

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Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114524001090

References

1. World Health Organization (2021) Obesity and Overweight. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight (accessed June 2023).
2. Angelantonio ED, Bhupathiraju SN, Wormser D, et al. (2016) Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. Lancet 388, 776–786. Elsevier.
3. Chung A, Backholer K, Wong E, et al. (2016) Trends in child and adolescent obesity prevalence in economically advanced countries according to socioeconomic position: a systematic review. Obes Rev 17, 276–295.
4. Sares-Jäske L, Grönqvist A, Mäki P, et al. (2022) Family socioeconomic status and childhood adiposity in Europe - a scoping review. Prev Med 160, 107095.
5. Ding C, Fan J, Yuan F, et al. (2021) Association between physical activity, sedentary behaviors, sleep, diet, and adiposity among children and adolescents in China. Obes Facts 15, 26–35.
6. Chaput J-P, Willumsen J, Bull F, et al. (2020) 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence. Int J Behav Nutr Phys Act 17, 141.
7. Bambra C (2011) Health inequalities and welfare state regimes: theoretical insights on a public health 'puzzle'. J Epidemiol Community Health 65, 740–745. BMJ Publishing Group Ltd.
8. Inchley J, Currie D, Jewell J, et al. (2017) Adolescent Obesity and Related Behaviours: Trends and Inequalities in the WHO European Region, 2002–2014: Observations from the Health Behaviour in School-aged Children (HBSC) WHO Collaborative Cross-National Study. World Health Organization. Regional Office for Europe [Internet]. [cited 2023 Oct]. Available from: https://iris.who.int/handle/10665/329417.
9. Akkoyun-Farinez J, Omorou AY, Langlois J, et al. (2018) Measuring adolescents' weight socioeconomic gradient using parental socioeconomic position. Eur J Public Health 28, 1097–1102.
10. Hillier-Brown FC, Bambra CL, Cairns J-M, et al. (2014) A systematic review of the effectiveness of individual, community and societal level interventions at reducing socioeconomic

inequalities in obesity amongst children. *BMC Public Health* **14**, 834.

11. Freudenberg N (2013) Commentary: reducing inequalities in child obesity in developed nations: what do we know? What can we do? *Rev Port Saúde Pública* **31**, 115–122. Elsevier.

12. Brown T, Moore TH, Hooper L, *et al.* (2019) Interventions for preventing obesity in children. *Cochrane Database Syst Rev 2019*, issue 7, CD001871. John Wiley & Sons, Ltd.

13. Jebeile H, Kelly AS, O'Malley G, *et al.* (2022) Obesity in children and adolescents: epidemiology, causes, assessment, and management. *Lancet Diabetes Endocrinol* **10**, 351–365.

14. Taubman SL, Robins JM, Mittleman MA, *et al.* (2009) Intervening on risk factors for coronary heart disease: an application of the parametric g-formula. *Int J Epidemiol* **38**, 1599–1611.

15. Legrand K, Lecomte E, Langlois J, *et al.* (2017) Reducing social inequalities in access to overweight and obesity care management for adolescents: the PRALIMAP-INÈS trial protocol and inclusion data analysis. *Contemp Clin Trials Commun* **7**, 141–157.

16. Briançon S, Legrand K, Muller L, *et al.* (2020) Effectiveness of a socially adapted intervention in reducing social inequalities in adolescence weight. The PRALIMAP-INÈS school-based mixed trial. *Int J Obes* **44**, 895–907. Nature Publishing Group.

17. Cole TJ, Bellizzi MC, Flegal KM, *et al.* (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* **320**, 1240–1243.

18. McCarthy HD, Jarrett KV & Crawley HF (2001) The development of waist circumference percentiles in British children aged 5·0–16·9 years. *Eur J Clin Nutr* **55**, 902–907.

19. Currie C, Molcho M, Boyce W, *et al.* (2008) Researching health inequalities in adolescents: the development of the Health Behaviour in School-Aged Children (HBSC) family affluence scale. *Soc Sci Med* **66**, 1429–1436.

20. Boyce W, Torsheim T, Currie C, *et al.* (2006) The family affluence scale as a measure of national wealth: validation of an adolescent self-report measure. *Soc Indic Res* **78**, 473–487.

21. Fédération nationale des observatoires régionaux de la santé (2009) Harmoniser les études en nutrition un guide de bonnes pratiques pour les études régionales et locales. 79p. France [Internet]. [cited 2023 Oct]. Available from: https://sante.gouv.fr/IMG/pdf/guide_fnors_nutrition.pdf

22. Ministère des Solidarités et de la Santé (2018) Programme National Nutrition Santé 2019–2023. 93p. France [Internet]. [cited 2023 Oct]. Available from: https://pedagogie.ac-strasbourg.fr/fileadmin/pedagogie/nutrition/Textes_officiels/pnns4_2019-2023.pdf

23. Craig CL, Marshall AL, Sjöström M, *et al.* (2003) International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* **35**, 1381–1395.

24. Hagströmer M, Bergman P, De Bourdeaudhuij I, *et al.* (2008) Concurrent validity of a modified version of the International Physical Activity Questionnaire (IPAQ-A) in European adolescents: the HELENA Study. *Int J Obes* **32**, S42–S48. Nature Publishing Group.

25. de Onis M, Onyango AW, Borghi E, *et al.* (2007) Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* **85**, 660–667.

26. Kolsgaard MLP, Joner G, Brunborg C, *et al.* (2011) Reduction in BMI z-score and improvement in cardiometabolic risk factors in obese children and adolescents. The Oslo Adiposity Intervention Study - a hospital/public health nurse combined treatment. *BMC Pediatr* **11**, 47.

27. World Health Organization (2018) *Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World*. Geneva: World Health Organization.

28. Thoemmes F, MacKinnon DP & Reiser MR (2010) Power analysis for complex mediational designs using Monte Carlo methods. *Struct Equ Model* **17**, 510–534.

29. Manneville F, Omorou AY, Legrand K, *et al.* (2019) Universal school-based intervention does not reduce socioeconomic inequalities in weight status among adolescents. *Childhood Obes* **15**, 532–540. Mary Ann Liebert, Inc., publishers.

30. Beauchamp A, Backholer K, Magliano D, *et al.* (2014) The effect of obesity prevention interventions according to socioeconomic position: a systematic review. *Obes Rev* **15**, 541–554.

31. Peeters A & Backholer K (2014) Prioritising and tackling socioeconomic inequalities in obesity. *BMC Obes* **1**, 16.

32. de Mestral C, Chatelan A, Marques-Vidal P, *et al.* (2019) The contribution of diet quality to socioeconomic inequalities in obesity: a population-based study of Swiss adults. *Nutrients* **11**, 1573.

33. Andrade S, Lachat C, Ochoa-Aviles A, *et al.* (2014) A school-based intervention improves physical fitness in Ecuadorian adolescents: a cluster-randomized controlled trial. *Int J Behav Nutr Phys Act* **11**, 153.

34. Hollis JL, Sutherland R, Campbell L, *et al.* (2016) Effects of a 'school-based' physical activity intervention on adiposity in adolescents from economically disadvantaged communities: secondary outcomes of the 'Physical Activity 4 Everyone' RCT. *Int J Obes* **40**, 1486–1493. Nature Publishing Group.

35. Pfeiffer KA, Robbins LB, Ling J, *et al.* (2019) Effects of the Girls on the Move randomized trial on adiposity and aerobic performance (secondary outcomes) in low-income adolescent girls. *Pediatr Obes* **14**, e12559.

36. Pearce A, Hope S, Griffiths L, *et al.* (2019) What if all children achieved WHO recommendations on physical activity? Estimating the impact on socioeconomic inequalities in childhood overweight in the UK Millennium Cohort Study. *Int J Epidemiol* **48**, 134–147.

37. Svendsen MT, Bak CK, Sørensen K, *et al.* (2020) Associations of health literacy with socioeconomic position, health risk behavior, and health status: a large national population-based survey among Danish adults. *BMC Public Health* **20**, 565.

38. Setiono FJ, Guerra LA, Leung C, *et al.* (2021) Sociodemographic characteristics are associated with prevalence of high-risk waist circumference and high-risk waist-to-height ratio in U.S. adolescents. *BMC Pediatr* **21**, 215.

39. Leme ACB, Lubans DR, Guerra PH, *et al.* (2016) Preventing obesity among Brazilian adolescent girls: six-month outcomes of the Healthy Habits, Healthy Girls–Brazil school-based randomized controlled trial. *Prev Med* **86**, 77–83.

40. Moore SM, Borawski EA, Love TE, *et al.* (2019) Two family interventions to reduce BMI in low-income urban youth: a randomized trial. *Pediatrics* **143**, e20182185.

41. Lee S, Kim Y & Han M (2022) Influence of waist circumference measurement site on visceral fat and metabolic risk in youth. *J Obes Metab Syndr* **31**, 296–302.

42. Omorou AY, Manneville F, Langlois J, *et al.* (2020) Physical activity rather than sedentary behaviour is socially determined in French adolescents with overweight and obesity. *Prev Med* **134**, 106043.

43. Wasserstein RL & Lazar NA (2016) The ASA statement on *P*-values: context, process, and purpose. *Am Statistician* **70**, 129–133. Taylor & Francis.

44. Graham H & Kelly M (2004) *Health Inequalities: Concepts, Frameworks and Policy*. London: Health Development Agency.

45. Prado G, Fernandez A, St. George SM, *et al.* (2020) Results of a family-based intervention promoting healthy weight strategies in overweight Hispanic adolescents and parents: an RCT. *Am J Prev Med* **59**, 658–668.