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Differential effects of adolescent health behaviours on adult cardiometabolic health by parental and neighbourhood socioeconomic background

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Abstract

Adolescent healthy behaviours may improve cardiometabolic health in adulthood differently across socioeconomic groups. We aimed to quantify the effects of adolescent healthy behaviours on multiple biomarkers of adult cardiometabolic health by socioeconomic backgrounds. We used a population-based cohort of Finnish adolescents from the Young Finns Study (1980–89, $n = 2984$) followed into adulthood (2001–11). Healthy behaviours (no smoking, no alcohol consumption, sufficient physical activity, daily fruit and vegetable consumption) and socioeconomic backgrounds (parental- and neighbourhood-related) were measured in adolescence (12–18 years). Biomarkers of adiposity [waist circumference, body mass index (BMI)], cardiovascular [blood pressure (BP), cholesterol, apolipoprotein B], and metabolic [plasma glucose, insulin resistance] outcomes were measured in adulthood (33–40 years). We estimated conditional average effects of healthy behaviours via inverse-probability-weighted marginal structural models. Sufficient physical activity lowered adiposity biomarkers to a greater extent among adolescents from disadvantaged neighbourhood, with additional decreases of 2.2 cm [95% confidence interval (CI): −0.1 to 4.7] in waist circumference and 1 kg/m^2 (95% CI: 0.2 to 1.9) in BMI. In contrast, daily fruit and vegetable consumption lowered BP with additional 2.0–3.6 mmHg (95% CI: 0.3 to 6.1) among adolescents with advantaged either parental or neighbourhood socioeconomic backgrounds. There was little evidence for differential effects on other outcomes and for no smoking and alcohol. Socioeconomic backgrounds modified the effects of adolescent physical activity and fruit and vegetable consumption on adult cardiometabolic health. These findings indicate that population-wide interventions promoting healthy behaviours during adolescence have the potential to either mitigate or exacerbate long-term socioeconomic inequalities in cardiometabolic health.

Introduction

Cardiometabolic diseases, such as diabetes and cardiovascular disease, are major contributors to disease burden and mortality in high-income countries [1]. Prevention of cardiometabolic diseases should begin early, taking socioeconomic determinants into account [2, 3], because risk factors accumulate over decades before cardiometabolic diseases are diagnosed. Even before disease is manifest, cardiometabolic health can be objectively measured via biomarkers, including waist circumference, blood pressure (BP), and blood glucose [4].

Key modifiable behaviours influencing cardiometabolic health include physical activity, diet, smoking, and alcohol use [5]. These health behaviours also contribute to socioeconomic disparities in adult cardiometabolic health outcomes via two mechanisms: differential exposure and differential susceptibility [6, 7]. Differential exposure occurs when healthy behaviours are more common among socioeconomically advantaged groups. Differential susceptibility refers to heterogenous effects of healthy behaviours, where advantaged groups may experience greater protective effects due to more biological, material or psychosocial reserves, or fewer co-occurring risk factors. While there is extensive research on differential exposure to health behaviours, the evidence on differential susceptibility is notably scarce, especially on adolescents [6, 8, 9].

Adolescence is a sensitive period for socioeconomic influences and establishing health behaviours, due to biological changes, attainment of education, increasing autonomy in decision-making, and social role transitions [10]. The limited research on differential susceptibility is a major gap because socioeconomic-patterned effects of health behaviours may have important implications for interventions and health policy. If disadvantaged adolescents benefit more from behavioural changes, then population-wide interventions that achieve the same relative reduction of health risk behaviours across socioeconomic groups may reduce social inequalities in cardiometabolic health. Conversely, if adolescents from advantaged socioeconomic backgrounds benefit more, increased inequalities are a likely outcome.

This study examined whether parental and neighbourhood indicators of socioeconomic background modified the effects of healthy behaviours in adolescence on adult cardiometabolic health.

Methods

This study followed a pre-published protocol [11]. Deviations from the protocol are reported in Supplementary S1.

Study design, setting, and participants

We used data from the longitudinal Young Finns cohort study, which recruited 3596 children and adolescents in 1980 (83.2% response rate from a random sample of the Finnish population aged 3, 6, 9, 12, 15, and 18) and followed them up in 1986, 2001, and 2011 [12]. We included participants when they were adolescents aged 12–18, corresponding to baselines in 1980 and 1989. Socioeconomic backgrounds, health behaviours, and other covariates were self-reported at these baselines. Cardiometabolic health biomarkers were measured after 21 or 22 years of follow-up in 2001 and 2011 (ages 33–40).

We excluded individuals with missing baseline information—those aged 3–9 at recruitment but lost-to-follow-up in their respective baseline of 1989 ($n = 356$); those with missing information on health behaviours ($n = 204$), or parental smoking, history of disability, adversity, and chronic disease ($n = 52$). The final analytic sample included 2984 adolescents (Supplementary Fig. S1). We accounted for differential death ($n = 82$) or loss to follow-up ($n = 852$) after the baseline through inverse-probability-censoring-weights.

The Young Finns study was conducted according to the guidelines of the Declaration of Helsinki, and the protocol was approved by ethics committees of University of Helsinki, Kuopio, Oulu, Tampere and Turku.

Causal model and measures

We followed a causal inference approach based on the development of a causal model informing the minimally sufficient subset of confounding factors for the causal analysis (Supplementary S3, and Supplementary Figs S2 and S3) [11]. To avoid over adjustment, we did not include mediating factors during follow-up (e.g. adult behaviours, income etc.).

Exposures: health behaviours in adolescence

We assessed physical activity, diet, alcohol use, and smoking using self-administered questionnaires. Physical activity was measured with three items: frequency of physical exercise (>30 minutes outside of school per week), participation in sport clubs, and intensity of normal exercise. We classified physical activity as *sufficient* (daily exercise or 2–6 times weekly at high intensity), *moderate* (regular exercise or weekly vigorous activity/sports club), and *low* (exercise less than once per week outside school).

Fruit and vegetable consumption was measured via food frequency questionnaires. We classified consumption as *sufficient* (fruit and vegetables daily), and *insufficient* (less than daily consumption, or daily consumption of only fruits or only vegetables).

Alcohol consumption was measured through the frequency of drinking beer, strong beer, wine, hard liqueurs, or spirits and the number of past year heavy alcohol intoxications. We classified alcohol use as *abstinence* (no drinking and never intoxicated), *moderate* (neither abstainers nor hazardous users), and *hazardous* (drinking alcohol daily, or strong alcohol at least weekly, or over 10 occasions of intoxications in the past year). Smoking included information on habitual and current smoking and the lifetime number of cigarettes, pipefuls, cigars, or snus. We classified smoking as *never*, *past*, and *current* smoking.

We used these 2- or 3-level exposures for latent class analyses, and dichotomized all exposures into healthy or health risk behaviour for causal analyses. Those behaviours closest to following WHO guidelines were assigned to healthy [13, 14], namely *sufficient* physical activity, *sufficient* fruit and vegetables, and alcohol *abstinence*. For smoking, we classified *never* or *past* smoking as healthy, as most adolescent past smoking is due to experimentation and many interventions target both prevention and cessation [5].

Effect modifiers: socioeconomic background in adolescence

As adolescents have not yet established their own socioeconomic position, we assessed family-level socioeconomic background through parental education and occupational status in our data (income was not consistently measured across the two baselines) [15]. Parental education was classified as *low* if both parents had <9 years of schooling (compulsory school) and *high* otherwise. Occupational class was *manual* if both parents had manual occupations and *non-manual* otherwise.

Neighbourhood-level deprivation can significantly impact adolescents' future health [16]. We used a neighbourhood deprivation score described in detail elsewhere [16]. The score is a mean value across three Z-scores derived from the proportion of adults with only primary education, unemployment rate, and proportion of people living in rented housing weighted by the time lived in the neighbourhood between ages 6 and 21. Neighbourhood deprivation was dichotomized (yes/no) with those having above average deprivation (Z-score >0) as deprived compared to those with average or below-average deprivation.

Outcomes: cardiometabolic health in adulthood

We examined eight biomarkers measured during a clinical examination using standard procedures and state-of-the-art measurements at ages 33–40 [12]. Adiposity biomarkers were (i) waist circumference (waist, in cm) [17], and (ii) body mass index [18] (BMI, in kg/m^2). Cardiovascular biomarkers were resting (iii) systolic and (iv) diastolic BP [19], (v) low-density lipoprotein cholesterol (LDLc) [20], and (vi) fasting apolipoprotein B (ApoB) from venous blood samples [21]. Diabetes-related biomarkers were (vii) fasting plasma glucose (glucose) and (viii) the homeostasis model of insulin sensitivity (HOMA) [22]. For the interpretation of findings, we considered only results that were consistent across closely related biomarkers within each of the three groups (i.e. BMI and waist, or systolic and diastolic BP, or glucose and HOMA).

Confounding factors

Confounding factors at baseline were biological sex assigned at birth (male/female), age at baseline (12 and 15/18 years), birth period (1960s/1970s), adverse birth outcome (preterm or small for gestational age at birth, no/yes), parental smoking (no/yes), history of disability (no/yes), history of chronic disease diagnosis in childhood (diagnosis of heart disease, diabetes, asthma or any other chronic disease, no/yes), and history of social adversity (none/one/two or more of: parental separation, living outside parental care, parental mental disorder, parental alcohol misuse, death of a partner, and death of a parent before baseline).

Unmeasured confounders were childhood overweight, adolescent mental health, and adolescent peer position.

Statistical analysis

We conducted a descriptive and a causal analysis. For the descriptive analysis, we ran a latent class analysis (LCA) to examine if behaviours among the participating adolescents co-occurred forming specific clusters of people with typical combinations of behaviours (Supplementary S4.2). The identified behaviour clusters subsequently informed the choice of exposures in the causal analysis as single or joint behaviours [23].

For the causal analysis, we quantified the effect of health behaviours on the population-average value of cardiometabolic biomarkers conditional on socioeconomic backgrounds separately for each socioeconomic indicator. Our estimand was the difference in the conditional average causal effects (cACEs) between the two levels of socioeconomic background variables. The cACE was estimated through inverse-probability-weighted marginal structural models (with an interaction term between exposure and socioeconomic background). We calculated stabilized inverse-probability-weights for standardizing cACE by the measured confounding factors (Supplementary S5.1) and accounting for potential non-random loss to follow-up (Supplementary S5.3). The final inverse-probability-weights were the product of these two sets of weights. Confidence intervals (CIs) were generated via 95% percentiles of 1000 bootstrap draws with replacement.

All analyses were conducted using R 4.3.2.

Internal validity of the estimates requires various assumptions: no residual confounding, consistency, positivity, no measurement error, correct specification of estimation models and no selection bias from potential losses during follow-up [24]. We strengthened the tenability of the positivity assumption by computing stabilized inverse probability weights and by truncating the weights at 99%.

Sensitivity analyses

We ran sensitivity analyses to assess potential bias from unmeasured confounding, measurement error, and model misspecification (Supplementary S6).

Additionally, as the chosen dichotomization of socioeconomic backgrounds might conceal inequalities in more dissimilar groups, we estimated differential effects when contrasting the lowest and highest groups of three-level socioeconomic backgrounds (Supplementary S6.5). As alcohol and smoking was infrequent at age 12, we repeated the analysis in a reduced sample excluding 12-year old participants (Supplementary S6.6). Lastly, we also estimated the cACE of alcohol and smoking as single behaviours (Supplementary S6.7).

Results

Characteristics of the analytic sample

As displayed in Table 1, more than half of the adolescents reported to be sufficiently physically active (57%), to eat fruit and vegetables daily (58%), and to not smoke currently (72%), while slightly less than half reported to have never drunk alcohol (47%). More than half of participants were from more advantaged socioeconomic backgrounds (64% from highly educated parents, 75% from parents having non-manual occupations, and 56% from non-deprived neighbourhoods). The median values of the cardiometabolic biomarkers at ages 33–40 were within the normal ranges. Those having healthy behaviours were more commonly socioeconomically advantaged and socioeconomic differences were evident in some outcomes (Supplementary S4.1).

Clustering of health behaviours

Results from the LCA revealed that smoking and alcohol use clustered. Whereas various levels of physical activity and fruit and vegetable consumption co-occurred with both healthy and risky levels of smoking and drinking. A three-class model had the best model-fit

Table 1. Summary of analytic sample characteristics

	Total $n = 2984$, n (%)
Exposures	
Physical activity	
Sufficient	1708 (57.2)
Moderate	672 (22.5)
Low	604 (20.2)
Fruit and vegetable consumption	
Sufficient (daily)	1724 (57.8)
Not sufficient	1260 (42.2)
Smoking	
Never	1381 (46.3)
Past	770 (25.8)
Current	833 (27.9)
Alcohol consumption	
Abstinence	1413 (47.4)
Moderate	1303 (43.7)
Hazardous	268 (9.0)
Effect modifiers	
Parental education	
High	1886 (63.2)
Low	1082 (36.3)
Missing	16 (0.5)
Parental occupational status	
Non-manual	2208 (74.0)
Manual	720 (24.1)
Missing	56 (1.9)
Neighbourhood deprivation	
No	1425 (47.8)
Yes	1113 (37.3)
Missing	446 (14.9)
Confounding factors	
Sex	
Female	1565 (52.4)
Male	1419 (47.6)
Age at baseline	
12 and 15	2037 (68.3)
18	947 (31.7)
Birth period	
1960s	1667 (55.9)
1970s	1317 (44.1)
Parental smoking	
No	907 (30.4)
Yes	2077 (69.6)
Adverse birth outcomes	
No	2030 (68.0)
Yes	486 (16.3)
Missing	468 (15.7)
History of disability	
No	2895 (97.0)
Yes	89 (3.0)
History of chronic diseases	
No	2831 (94.9)
Yes	153 (5.1)
Adverse experiences	
None	1443 (48.4)
1	1109 (37.2)
2 or more	432 (14.5)
Outcomes	Total $n = 2050$, median (interquartile range)
Waist (cm)	86.00 (77.50–95.30)
Missing	24 (1.2)
BMI (kg/m^2)	24.97 (22.43–27.98)
Missing	16 (0.8)
Systolic BP (mmHg)	115.00 (107.00–124.00)
Missing	21 (1.0)
Diastolic BP (mmHg)	75.00 (68.38–83.00)
Missing	367 (17.9)
LDLc (mmol/L)	3.21 (2.70–3.80)
Missing	42 (2.0)
ApoB (g/L)	5.10 (4.80–5.40)
Missing	9 (0.4)
Glucose (mmol/L)	1.47 (0.95–2.29)
Missing	9 (0.4)
HOMA	1.03 (0.86–1.23)
Missing	10 (0.5)

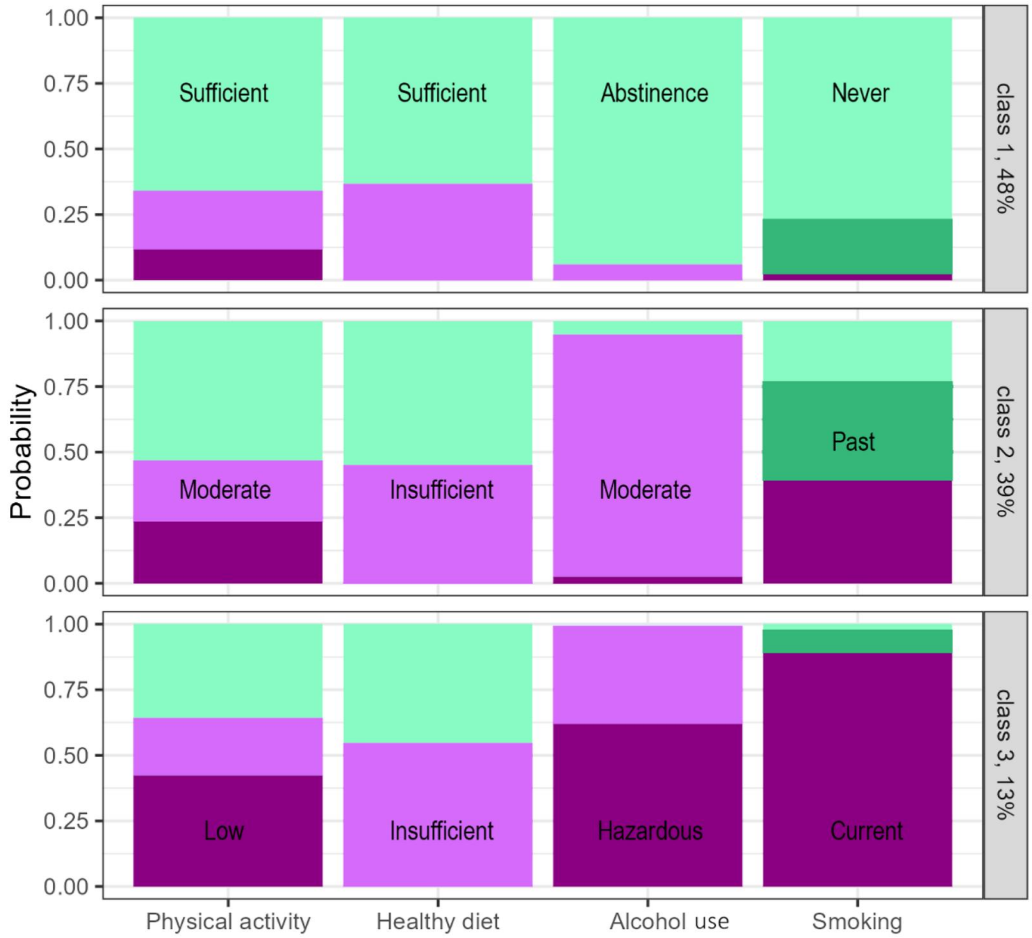

Figure 1. Conditional probabilities of health behaviours within three latent classes. Green (the lighter colours on the top) indicates healthy and purple (the darker shades on the bottom) health risk behaviours in the causal analysis.

(Fig. 1 and Supplementary S4.2). Class 1 represented 48% of the participants and displayed a co-occurrence of healthy behaviours, characterized by high probabilities of not currently smoking (0.98), alcohol abstinence (0.94), and average probabilities of sufficient physical activity (0.66) and sufficient fruit and vegetable consumption (0.63). Class 2 (39% of adolescents) was characterized by high probability of moderate drinking (0.92) and average probability of current smoking (0.39) combined with varied levels of physical activity and diet. In Class 3 (13%) health-risk behaviours co-occurred, specifically high probabilities of current smoking (0.89) and of moderate or hazardous alcohol consumption (0.99). As we observed co-occurrence of smoking and alcohol use, we considered smoking and alcohol as joint exposures in the causal analysis. Physical activity and fruit and vegetable consumption were considered as single exposures in the causal analysis as they did not clearly cluster here or in higher class models (Supplementary S4.2).

Differential effects of health behaviours on cardiometabolic health

Figure 2 displays the estimated effects of adopting healthy behaviours (vs. health risk) conditional on each socioeconomic background. Notwithstanding some heterogeneity across biomarkers and socioeconomic indicators, sufficient fruit and vegetable consumption and physical activity during adolescence were overall associated with lower mean values of cardiometabolic biomarkers in adulthood. Abstaining from alcohol and smoking was associated with uncertain changes in the mean values of biomarkers.

Some healthy behaviours had differential effects on adiposity and cardiovascular outcomes albeit in different directions (Fig. 3; values above zero indicate a more protective effect of healthy behaviour in the socioeconomically advantaged groups compared to the disadvantaged groups). Specifically, sufficient fruit and vegetable consumption was associated with lower average BP among adolescents from socioeconomically advantaged backgrounds to a greater extent compared to those from disadvantaged backgrounds. The average systolic BP was lowered by an additional 3.6 mmHg (95% CI: 1.0–6.1) among those with highly educated parents; by an additional 3.0 mmHg (95% CI: 0.3–5.7) among those with parents in non-manual occupations; and by an additional 2.3 mmHg (95% CI: 0.2–4.5) among those from non-deprived neighbourhoods. Similar differential decreases were observed for diastolic BP.

In contrast, sufficient physical activity was associated with lower adiposity biomarkers among the socioeconomically disadvantaged to a greater extent compared to the socioeconomically advantaged (Fig. 3). The additional decrease was 1.0 kg/m^2 (95% CI: 0.2–1.9) in average BMI and 2.2 cm (95% CI: -0.1–4.3) in average waist circumference among adolescents from deprived compared to non-deprived neighbourhoods.

Sensitivity analyses

The negative control exposure analysis indicated that residual confounding might be present for LDLc and ApoB but negligible for the other outcomes (Supplementary S6.1). When correcting for misclassification of physical activity and fruit and vegetable consumption, the estimated cACE remained similar to those reported in main analyses (Supplementary S6.2), indicating negligible bias from measurement error of these behaviours. The differential effect of sufficient fruit and vegetable consumption on hypertension, including antihypertensive medication, ranged between 61 and 82 fewer cases

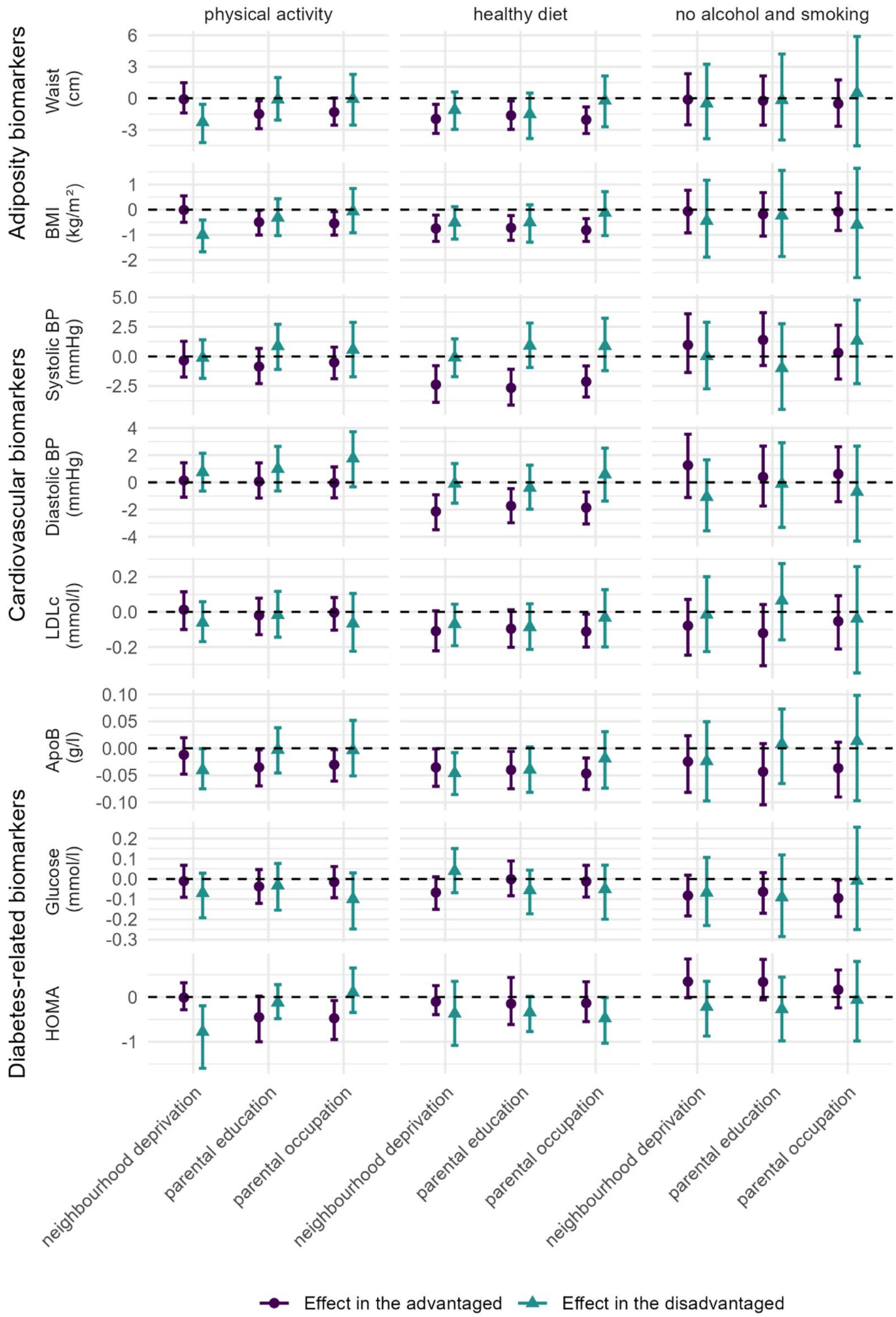

Figure 2. Average causal effects of healthy behaviours on cardiometabolic health conditional on socioeconomic background. Biomarkers are arranged as adiposity, cardiovascular, and diabetes related. Waist: waist circumference; BMI: body mass index; BP: blood pressure; LDLc: low-density lipoprotein cholesterol; ApoB: apolipoprotein B; HOMA: homeostasis model of insulin sensitivity. For the interpretation of findings, we considered only results that were consistent across closely related biomarkers within each of the three groups (i.e. BMI and waist, or systolic and diastolic BP, or glucose and HOMA).

per 1000 population (95% CI: −20 to 169) among the advantaged. Thereby, antihypertensive medication is not driving the effect modification observed in the main analyses (Supplementary S6.3). The double robust estimation of the differential effects aligned with those reported in the main analyses, thus indicating negligible bias from misspecification of statistical model to estimate the cACE (Supplementary S6.4). Differential effects of fruit and vegetable consumption were also observed when comparing the most advantaged to more disadvantaged groups using three-level operationalizations of the effect modifiers. For neighbourhood deprivation and physical activity, the CIs of the effect modification widened (Supplementary S6.5). The lack of evidence of effect modification by socioeconomic backgrounds for no smoking and alcohol use persisted when excluding those who were 12 years old at baseline,

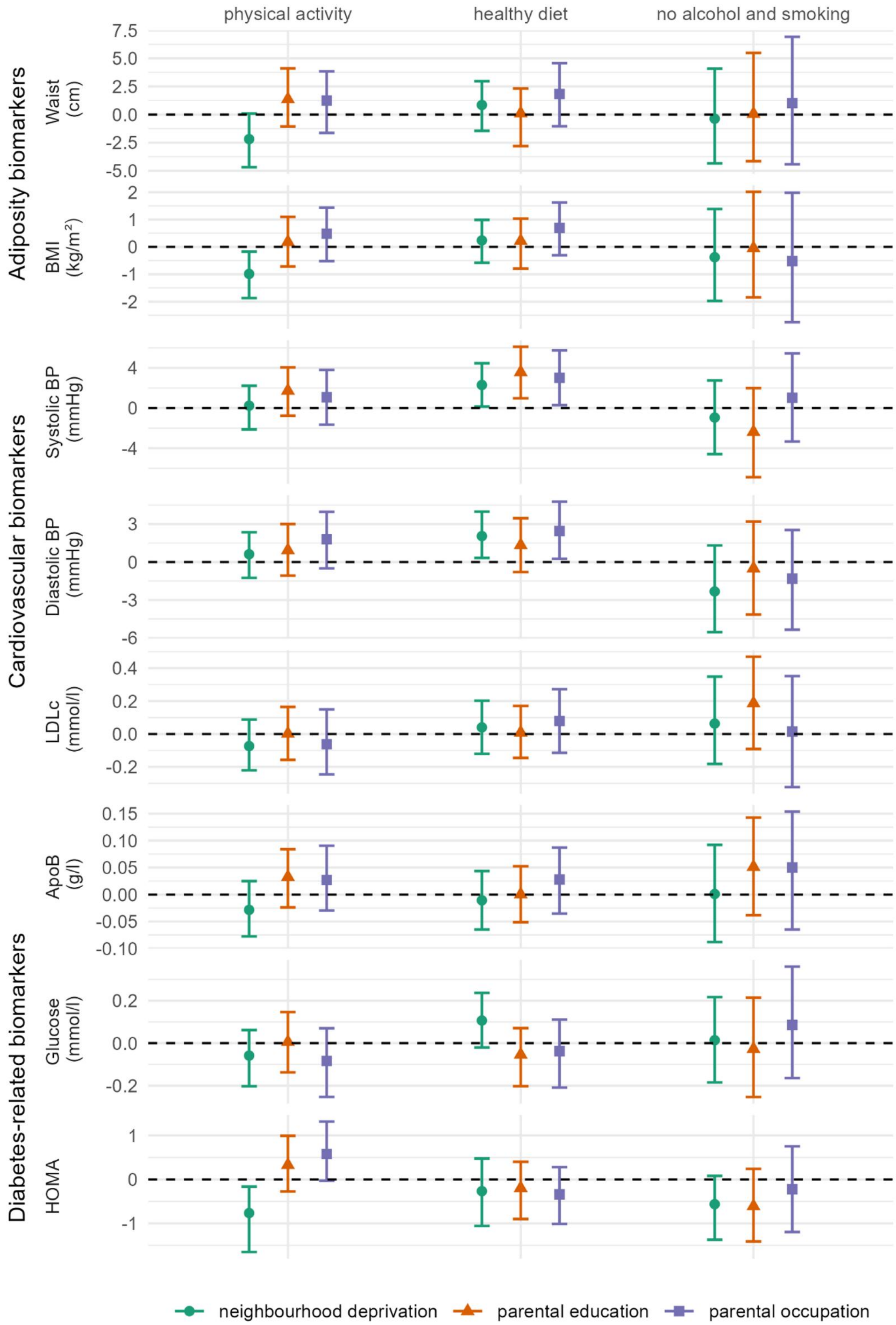

Figure 3. Differential effects by socioeconomic backgrounds, calculated as the difference between effects among the advantaged minus the disadvantaged social groups. Values above zero indicate a more protective effect of the healthy behaviour in the advantaged social group compared to the disadvantaged group. Waist: waist circumference; BMI: body mass index; BP: blood pressure; LDLc: low-density lipoprotein cholesterol; ApoB: apolipoprotein B; HOMA: homeostasis model of insulin sensitivity.

or when examining differential effects of the single behaviours (Supplementary S6.6 and S6.7).

Discussion

We investigated the co-occurrence of adolescent health behaviours and the differential susceptibility to adolescent health behaviours on adult cardiometabolic health across parental and neighbourhood socioeconomic backgrounds using longitudinal data of 2984 Finnish adolescents. Smoking and alcohol use co-occurred. Socioeconomic backgrounds did not modify effects of adolescent smoking and alcohol use on adult cardiometabolic health. In contrast, sufficient fruit and vegetable consumption lowered adult BP more among individuals from advantaged compared to disadvantaged backgrounds.

Additionally, adolescent physical activity lowered adult waist circumference and BMI more among individuals from disadvantaged neighbourhoods. Investments into adolescents' healthy behaviours have long been proposed [25–27]. Yet, disregarding the heterogeneity in the protective effects of healthy behaviours could lead to widening socioeconomic inequalities in cardiometabolic health. Differential susceptibility to health behaviours might be an understudied mechanism contributing to social inequalities in cardiometabolic health.

The protective effect of daily fruit and vegetable consumption on BP was limited to adolescents from socioeconomically advantaged families and neighbourhoods. Effect sizes of 2–3.6 mmHg lower average BP in the advantaged groups are substantive and in line with effects of reduced sodium intake among adults [28]. The finding of differential effects aligns with that from an Italian cohort study, where adhering to a Mediterranean diet reduced cardiovascular diseases only among adults with high education or income [29]. Our results complement this study by providing evidence of a cardiovascular-protective effect of adhering to daily consumption of fruits and vegetables during adolescence among those from socioeconomically advantaged families and neighbourhoods. Overall, this finding points to the potential roles of socioeconomically patterned parental dietary practices, food knowledge [30], and food environments (e.g. availability of fast-food) [31] as underlying factors in the observed differential effects.

The protective effect of physical activity on adult waist circumference and BMI was limited to adolescents from deprived neighbourhoods. While an additional reduction of 1 kg/m^2 may appear small, it might be clinically relevant as even small reductions in weight can lead to sizable reductions in diabetes risks [32]. Our results align with a UK trial reporting more favourable effects of school-based intervention to promote physical activity on BMI in disadvantaged adolescents [33]. Differential susceptibility to physical activity was also found in adults participating to the UK biobank study, whereby those who were more physically active in deprived socioeconomic areas had fewer cardiovascular diseases [34]. Finally, since the differential effect in our study was observed only across neighbourhood socioeconomic backgrounds but not parental socioeconomic backgrounds, this might highlight the importance of physical activity in buffering against environmental disadvantages such as higher density of fast-food outlets, fewer green spaces [35], or higher exposure to air pollution [36].

Cigarette and alcohol use co-occurred among adolescents in our study, consistent with observations from other samples [37, 38], and with underlying common sociocultural drivers and peer/family influences [39]. In contrast, we found no substantive evidence of protective or differential effects associated with abstaining from alcohol and smoking. This does not imply these adolescent behaviours have no impact on adult cardiometabolic health, but rather that measurement error may have biased our estimates, that large uncertainties in these estimates limited our interpretation, or that these behaviours changed later in adulthood. Additional studies are needed, particularly given that a meta-analysis demonstrated differential effects of multiple ($\geq$3) health behaviours, which reduced cardiovascular risks more significantly among socioeconomically disadvantaged adults [9].

This study has limitations. All behaviours are self-reported and might not reflect truly sufficient physical activity or fruit and vegetable intake. Other aspects of healthy diets should be investigated in future studies. Moreover, we examined socioeconomic backgrounds and health behaviours at a single time point during adolescence. Given that behaviours can evolve both during adolescence and into adulthood, our approach may have limitations. For smoking and alcohol use in particular, our findings of limited effects may reflect temporary experimentation rather than established habits. Understanding how health inequalities emerge may therefore require examining differential health behaviour trajectories from adolescence to adulthood [16], representing an important direction for future research. Due to data limitations, we did not assess effect modification by parental income. The consistency assumption might be violated as we are not measuring the effect of a specific intervention but rather a potential weighted mean effect of interventions that would achieve a healthy behaviour. Study participants were ethnically homogenous, potentially not reflecting the multilayered vulnerabilities of adolescents in multicultural societies today. Studies from different geographical contexts and periods will be needed to assess whether our findings are generalizable to other countries and generations.

Strengths of our study are the longitudinal design with long follow-up from adolescence to mid-life and population-based measurements of biomarkers. The causal framework involved identification of prior assumptions and using inverse-probability-weighted marginal structural models to estimate effect modification. Moreover, we conducted a range of sensitivity analyses to quantitatively assess potential biases in the estimates. These analyses strengthened confidence in the validity of our estimates.

Our findings of unequal benefits of adolescent fruit and vegetable consumption and physical activity for cardiometabolic health have important implications for prevention and policy. Since adolescent fruit and vegetable consumption may disproportionately benefit adolescents from more advantaged socioeconomic backgrounds, dietary interventions aiming to avoid widening socioeconomic inequalities could be tailored to disadvantaged adolescents. Conversely, population-wide interventions promoting physical activity could mitigate socioeconomic inequalities in adiposity, as they may have greater benefits for socioeconomically disadvantaged adolescents [40]. The actual impact of these interventions on health disparities requires further study, as intervention effects depend not only on differential susceptibility but also on differences in implementation, effectiveness, and access.

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Author contributions

Josephine Jackisch and Cristian Carmeli conceived the study and developed the analytic plan. Josephine Jackisch and Cristian Carmeli did the statistical analyses, wrote, and reviewed the statistical codes underpinning the results of the study. Josephine Jackisch drafted the first draft of the manuscript and lead the revision. Cristian Carmeli critically revised successive drafts of the manuscript and provided important intellectual input. Olli T. Raitakari, Terho Lehtimäki, and Mika Kähönen curated the data. Nazihah Noor, Olli T. Raitakari, Terho Lehtimäki, Mika Kähönen, Stéphane Cullati, Cyrille Delpierre, and Mika Kivimäki gave critical feedback on study design and revised the manuscript. Nazihah Noor, Stéphane Cullati, and Cristian Carmeli contributed to interpreting the results. All authors approved the final version to be published. Josephine Jackisch and Cristian Carmeli are the guarantor.

Supplementary data

Supplementary data are available at *EURPUB* online.

Conflict of interest: None declared.

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Data availability

Technical details or statistical code are available from the corresponding author upon request. Data access may be permitted on a case-by-case basis on request only. Data sharing outside the group is done in collaboration with the Young Finns Study group and requires a data-sharing agreement. Investigators can submit an expression of interest to the chair of the Young Finns Study steering group (Professor Olli T. Raitakari, University of Turku, Turku, Finland).

Key points

- By estimating whether adolescent healthy behaviours are unequally beneficial for adult cardiometabolic health across socioeconomic backgrounds, this longitudinal cohort study sheds light on differential susceptibility as a mechanism contributing to long-term health inequalities.
- There was evidence for differential effects of physical activity in reducing adiposity more among adolescents from deprived neighbourhoods, while fruit and vegetable consumption lowered blood pressure more among those from advantaged parental and neighbourhood socioeconomic backgrounds.
- Interventions to promote fruit and vegetable consumption and physical activity in adolescence should consider their effects on long-term health inequalities as they may yield unequal benefits for cardiometabolic health depending on socioeconomic background.

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