RESEARCH REPORT

ADDICTION   SSA

Socio-economic inequalities in smoking and drinking in adolescence: Assessment of social network dynamics

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Abstract

Aims: We investigated whether (1) adolescents selected friends with a similar socio-economic status (SES), (2) smoking and alcohol consumption spread in networks and (3) the exclusion of non-smokers or non-drinkers differed between SES groups.

Design: This was a longitudinal study using stochastic actor-oriented models to analyze complete social network data over three waves.

Setting: Eight Hungarian secondary schools with socio-economically diverse classes took part.

Participants: This study comprised 232 adolescents aged between 14 and 15 years in the first wave.

Measurements: Self-reported smoking behavior, alcohol consumption behavior and friendship ties were measured. SES was measured based upon entitlement to an income-tested regular child protection benefit.

Findings: Non-low-SES adolescents were most likely to form friendships with peers from their own SES group [odds ratio (OR) = 1.07, 95% confidence interval (CI) = 1.02–1.11]. Adolescents adjusted their smoking behavior (OR = 24.05, 95% CI = 1.27–454.86) but not their alcohol consumption (OR = 1.65, 95% CI = 0.62–4.39) to follow the behavior of their friends. Smokers did not differ from non-smokers in the likelihood of receiving a friendship nomination (OR = 0.98, 95% CI = 0.87–1.10), regardless of their SES. Alcohol consumers received significantly more friendship nominations than non-consumers (OR = 1.16, 95% CI = 1.01–1.33), but this association was not significantly different according to SES.

Conclusions: Hungarian adolescents appear to prefer friendships within their own socio-economic status group, and smoking and alcohol consumption spread within those friendship networks. Socio-economic groups do not differ in the extent to which they encourage smoking or alcohol consumption.

KEYWORDS
Adolescents, alcohol, health inequalities, peers, smoking, social influence, social network, social selection, stochastic actor-oriented models

INTRODUCTION

Tobacco smoking and alcohol consumption are the leading preventable causes of premature mortality and morbidity, killing 11 million people annually and causing an additional 250 million disability-adjusted life-years world-wide [1–3]. They are also substantial contributors to health inequalities: smoking contributes up to 32% to the socio-economic gradient in all-cause mortality, and alcohol contributes up to 17% [4, 5]. Although population-level interventions are effective in reducing smoking and alcohol consumption prevalence [6–11], inequalities in these behaviors across socio-economic status (SES) persist or have widened in most high-income countries [12–15]. As such, preventing the development of socio-economic inequalities in smoking and alcohol consumption in adolescence is crucially important, given that these behaviors develop during this period of life [16, 17]. We refer to the inequalities in the adoption of health-related behaviors (such as smoking and alcohol consumption) based on individuals' SES as socio-economic inequalities in health behaviors throughout this study.

Social network theories can explain the existence of any group-level inequalities in two ways and, as such, they can also be applied to understand inequalities in health behaviors. One way that social networks can contribute to inequalities in health behaviors is when peers tend to choose friends from similar SES backgrounds, known as homophilous peer selection, and harmful behaviors spread among friends. As a result, inequalities in health behaviors worsen as low-SES adolescents are more likely to be exposed to higher levels of harmful behavior from their friends, leading to their adoption of smoking or alcohol consumption [18, 19]. Despite the spread of health behavior in the network and homophilous peer selection based on SES often being studied independently, only a few longitudinal studies for smoking [20, 21] and alcohol consumption [22–24] investigated these mechanisms simultaneously [25]. Most studies supported that friendship selection is homophilous based on SES [26–28]. Additionally, most previous studies found that smoking and alcohol consumption spread in networks as adolescents tended to be influenced by their peers to adopt their smoking and alcohol consumption and to select friends who smoke or consume alcohol [29]. Some studies, however, found that smoking and drinking are associated with isolation or having fewer friends [17, 18] or reported no evidence of peer influence [19, 20].

Based on social network theories, another less frequently discussed possible way in which inequalities in health behaviors could emerge is that an oppositional culture may exist whereby low-SES peers encourage each other more than non-low-SES groups to smoke or drink alcohol. Research on oppositional culture focused upon academic achievement differences throughout ethnic groups [30–34]. These studies found that African Americans consider high academic achievement as a characteristic of White Americans and thus exclude their members who study well to protect their identity, contributing to academic inequalities. Similar analytical strategies have also been applied to understand inequalities [32–35] in other behaviors than school performance [31, 36]. One study investigated whether adolescents from different SES groups rate the popularity of smoking and alcohol-consuming peers differently [37]. This study, however, did not use complete social network data, which is necessary for controlling network processes, such as homophilous friendship selection (the other possible reason for rising inequalities) [38].

A comprehensive analysis of the social network determinants of persistent inequalities in health behaviors would allow the development of an effective network-based intervention which recognizes that tackling inequalities due to homophilous friendship selection or to oppositional culture requires different strategies [39, 40]. With unique data on complete social networks in socio-economically diverse classes we were able to test the presence of these mechanisms in a single study simultaneously, allowing us to assess the importance of key social network mechanisms: social influence on health behaviors, selection of friends based on health behaviors, socio-economically homophilous friendship selection and oppositional culture in contributing to inequalities in health behaviors. Data were collected in Hungary, where large health inequalities in smoking and alcohol consumption can be found despite relatively low-income inequalities [41, 42].

METHODS

Sample

We used data from the 'Wired into Each Other' longitudinal social network survey [43]. Data collection was carried out in four waves during the period of 2010–13 (wave 1 in November 2010, wave 2 in April 2011, wave 3 in April 2012 and wave 4 in April 2013) in 44 high school classes from central Hungarian towns and the capital city (Supporting information, Appendix S1). Participants were aged between 14 and 15 years in wave 1. Sampling was designed to ensure high variance in the socio-economic compositions of the selected schools. Thus, schools with a high share of disadvantaged adolescents compared to the Hungarian average have been over-represented (sample prevalence of low SES adolescents = 32.20%, general population prevalence of low-SES adolescents = 10.40%). Survey data collection was conducted using a self-administered paper-and-pencil questionnaire (approximately 30–40 min long) during regular school lessons. Trained research assistants supervised the data collection on-site. Participation was voluntary, parental consent was required to be included in the analysis and participants were assured that their answers would remain anonymous and only be used for academic research. Almost everybody (99.30% of the eligible adolescents) provided parental consent. This study was approved by the Corvinus University of Budapest (Institute of Sociology and Social Policy) and Oxford University (Social Sciences and Humanities) institutional review boards (approval number: SSD/CUREC1A/12-130).

Of the 44 classes and four waves of observations, the current analysis focuses upon eight classes among three data collection waves (see differences in composition in Supporting information, Figure S1). The fourth wave was excluded because of high attrition (63.32%),

which was due to students switching between training programs, moving to another class or school or completely leaving the education system (attrition was 16.60% between the first and second and 48.29% between the first and third waves). As suggested in the social network literature, we included only classes with at least an 80% response rate to the network questions (thus, 26 classes were excluded) [44]. To be able to model socio-economic inequalities in health behaviors, we included only classes with at least three low-SES adolescents (thus, five classes were excluded). Finally, one class was excluded due to no change in self-reported smoking over time.

Measures

Smoking

Smoking was assessed with the question: 'Some students have already tried cigarettes. Do you smoke?', asked to all respondents in each wave. Response options were 'No, never', 'No, but I've already tried it', 'Yes, but only together with others' and 'Yes, regularly'. Adolescents were defined as smokers when they answered 'Yes, but only together with others' or 'Yes, regularly' and non-smokers otherwise.

Alcohol consumption

For alcohol consumption, we asked 'Some students have already tried alcohol. Do you consume alcohol?' question (response options: 'No, never', 'No, but I've already tried it', 'Yes, but only together with others' and 'Yes, at least once a week') at every wave of data collection. We considered someone an alcohol consumer when they answered either 'Yes, but only together with others' or 'Yes, at least once a week'.

Friendship network

In each wave, every participant was asked to assess their relationship with all their classmates as 'I hate him/her' (−2), 'I dislike him/her' (−1), 'He/she is neutral to me' (0), 'I like him/her' (+1) or 'He/she is a good friend' (+2). A binary friendship variable was created based on whether a friendship tie, +2 value of the scale, was present or absent between any two adolescents.

Gender and SES

Gender and SES were assessed as binary variables. We identified adolescents from low-SES backgrounds based on whether their family received an income-tested targeted regular child protection benefit (information taken from official classroom books). SES was treated as a binary and time-invariant variable in our analysis, where individuals who received a benefit in at least one wave were classified as low SES.

Analytical strategy

We analyzed the coevolution of friendship networks and health behaviors using stochastic actor-oriented models (SAOMs) implemented in the RSiena package in R (Supporting information, Appendix S2) [45]. This method reconstructs the temporal processes that are most likely to create the observed social network processes. SAOMs allow the simultaneous modeling of friendship changes and changes in health behavior, taking into account the mutual feedback processes between these two dynamics. Thus, we can disentangle social selection and social influence effects [38].
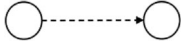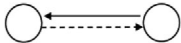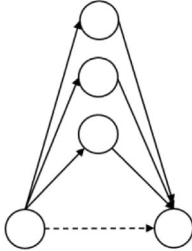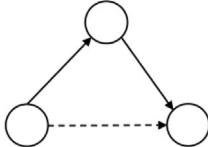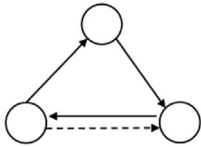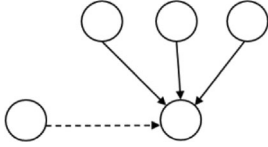
SAOMs require complete social network data; that is, each member of a class needs to evaluate their relationship with all other members. Being absent due to changing classes or dropping out between waves was treated as structurally missing in our analysis [46]. Missing data for individual characteristics were treated as non-informative in the estimation process [47].

We simultaneously modeled the changes in friendship networks (including structural effects, health behavior effects, covariate effects and the interaction of health behavior and SES) and health behavior dynamics (including social influence effect), as defined in Table 1 (Supporting information, Figure S2 and S3). To understand inequalities in health behaviors, our primary interests were to simultaneously assess (1) whether friendship nominations were socio-economically homophilous (i.e. SES ego × SES alter variable), (2) whether smokers/alcohol consumers were more/less likely to receive a friendship nomination than non-smokers/non-alcohol consumers (i.e. health behavior alter variable), (3) whether low-SES smokers/alcohol consumers were more/less likely to receive a friendship nomination than other smokers/alcohol consumers (i.e. SES alter × health behavior alter variable), (4) whether low-SES smokers/alcohol consumers were more/less likely to receive a friendship nomination from low SES peers than from other peers (i.e. SES ego × SES alter × health behavior alter variable) ('oppositional cult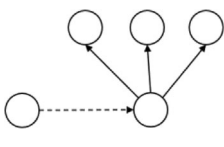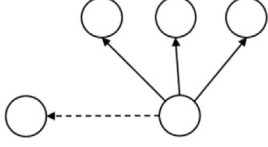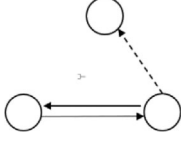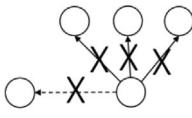ure') and (5) whether adolescents were influenced by their friends' smoking/alcohol consumption behavior (i.e. health behavior average similarity variable).

Parameter estimations were translated into odds ratios (ORs) for ease of interpretation. In the network dynamic sections of our model, we estimated the odds of the creation/maintenance of a friendship tie (versus no tie) conditional on various structural characteristics of the network (Table 1). In the health behavior dynamics section, we estimated the odds of becoming a smoker/alcohol consumer versus not becoming one, given the structural characteristics of the network. We calculated selection tables for same-SES and cross-SES friendship formation (Supporting information, Appendix S3).

To explore the robustness of our findings, we (1) included more classes (12 classes) than in the main analysis, even with suboptimal goodness-of-fit (Supporting information, Appendix S2), (2) we defined smokers and alcohol consumers more broadly, including those also who answered 'No, but I've already tried it' for questions on their substance use, (3) considered less strong network ties than in the

TABLE 1 Description and graphical representation of the included model parameters.

Model parameter	Description	Graphical representation
Friendship network dynamics		
Structural effects		
Out-degree (density)	Overall tendency to nominate friends	
Reciprocity	The tendency to reciprocate friendship nomination	
Transitive triplets	The tendency for friends of a friend to become friends (the more common friends they have the more likely they will become friends)	
Transitive ties	The tendency for friends of a friend to become friends (given that one common friend exists, extra common friends will not further contribute to the tendency to become friends)	
Transitive reciprocal triplets	The tendency to have reciprocated friendship ties to friends of friends	
In-degree—popularity (square root)	The tendency to nominate as a friend those peers who are popular (i.e. have higher in-degree)	
Out-degree—popularity (square root)	The tendency of those with higher out-degree to be popular (i.e. have higher in-degree)	
Out-degree—activity (square root)	The tendency of those with higher out-degree to nominate more peers as a friend	
Reciprocal degree—activity	The tendency for those with many reciprocal friendships to nominate more peers as a friend	
Out-isolate	The tendency of those who do not send any friendship nominations to anyone to keep not sending any nominations	

(Continues)

TABLE 1 (Continued)

Model parameter	Description	Graphical representation
Smoking and covariate effects		
Health behavior[a] alter	Smokers/alcohol consumers are more or less likely than non-smokers/non-alcohol consumers to be nominated as friends by other peers	○ ----▶ ●
Health behavior[a] ego	Smokers/alcohol consumers are more or less likely than non-smokers/non-alcohol consumers to nominate friends	● ----▶ ○
Health behavior[a] ego × health behavior[a] alter	Adolescents with the same health behavior are more or less likely to nominate each other as friends	● ----▶ ●
Girl alter	Girls are more or less likely than boys to be nominated as friends by other peers	○ ----▶ △
Girl ego	Girls are more or less likely than boys to nominate friends	△ ----▶ ○
Girl ego × girl alter	Adolescents of the same gender are more or less likely to nominate each other as friends	△ ----▶ △
Low-SES alter	Low-SES adolescents are more or less likely than non-low-SES adolescents to be nominated as friends by other peers	○ ----▶ □
Low-SES ego	Low-SES adolescents are more or less likely than non-low-SES adolescents to nominate friends	□ ----▶ ○
Low-SES ego × low-SES alter	Adolescents with the same SES were more or less likely to nominate each other as friends	□ ----▶ □
Low-SES ego × health behavior[a] alter	Low-SES adolescents are more or less likely than non-low-SES adolescents to nominate smokers/alcohol consumers as friends	□ ----▶ ●
Low-SES alter × health behavior[a] alter	Smokers/alcohol consumers who are also low SES are more or less likely to be nominated as friends by other peers	○ ----▶ ■
Low-SES ego × low-SES alter × health behavior[a] alter	Low-SES adolescents are more or less likely to nominate low-SES adolescents if they smoke/consume alcohol as a friend	□ ----▶ ■
Smoking dynamics		
Smoking linear shape		○ ◍ ●
Health behavior[a] average similarity	The tendency that adolescents adjust their smoking/alcohol consumption behavior to that of their friends to become more or less similar	● ● ○ ↘↓↙ ◍

Note: The nodes are adolescents, the black nodes represent smokers/alcohol consumers, the dashed nodes represent soon-to-be smokers/alcohol consumers, the squares are low-SES adolescents and the triangles are females. The arrows represent friendship nominations, the solid arrows represent existing nominations and the dashed arrows represent nominations that will occur in the future.

Abbreviations: CI = confidence interval; OR = odds ratio; SES = socio-economic status; Sig. = significance level.

[a]Health behavior indicates smoking in the smoking model and alcohol consumption in the alcohol model.

main analysis; that is, not only the +2 value of the initial relationship networks but also the +1 value, (4) a model in which we explored whether boy smokers/alcohol consumers were more/less likely to receive a friendship nomination than girl smokers/alcohol consumers (gender alter × health behavior alter and gender ego × gender alter × health behavior alter variable) and (5) a random effect model for the classes in the main analysis and all classes from our sample. The analysis was not pre-registered, and the results should be considered as exploratory.

RESULTS

Descriptive statistics

Adolescents' characteristics

Our analysis is based on data regarding 232 adolescents and 4607 friendship nominations among the three data collection waves in eight classes. Table 2 shows the characteristics of our subsample used in our

TABLE 2 Descriptive statistics of the sample and the main variables.

	Total		Low SES		Non-low SES		
	Mean	SD	Mean	SD	Mean	SD	P-value
Number of observations	232		72		160		
Outcomes							
Smokers in wave 1 (%)	16.82	37.49	27.69	45.10	12.08	32.70	< 0.01
Smokers in wave 2 (%)	23.29	42.36	32.84	47.31	19.08	39.42	0.03
Smokers in wave 3 (%)	29.65	45.77	42.86	49.84	23.72	42.67	< 0.01
Alcohol consumers in wave 1 (%)	38.03	48.66	49.23	50.38	33.11	47.22	0.03
Alcohol consumers in wave 2 (%)	57.60	49.53	56.72	49.92	58.00	49.52	0.86
Alcohol consumers in wave 3 (%)	60.89	48.91	71.01	45.70	56.41	49.75	0.04
Covariates							
Low SES (%)	31.03	46.36	–	–	–	–	–
Girl (%)	65.09	47.77	69.44	46.4	63.12	48.40	0.35
Social network position							
In-degree in wave 1	6.98	4.23	6.01	3.31	7.41	4.52	0.02
In-degree in wave 2	6.47	3.97	5.24	3.20	7.02	4.17	< 0.01
In-degree in wave 3	6.23	3.99	4.69	2.78	6.91	4.25	< 0.01
In-degree from low-SES peers in wave 1	2.05	1.96	2.65	2.05	1.78	1.86	< 0.01
In-degree from low-SES peers in wave 2	1.65	1.52	2.26	1.53	1.37	1.44	< 0.01
In-degree from low-SES peers in wave 3	1.60	1.41	1.92	1.43	1.46	1.39	0.02

Note: In-degree is the number of received friendship nominations for each individual.

Abbreviations: SD = standard deviation; SES = socio-economic status.

analysis. In total, 65.09% of the adolescents were girls and 31.03% of them were low SES. On average, 16.82% of the adolescents smoked in wave 1, which increased to 29.65% in wave 3. The prevalence of alcohol consumption rose from 38.03% in wave 1 to 60.89% in wave 3. Smoking prevalence in each wave and alcohol consumption prevalence in waves 1 and 3 were significantly higher among low-SES adolescents than among non-low-SES adolescents.

Network characteristics

On average, adolescents received 6.98, 6.47 and 6.23 friendship nominations (i.e. in-degree) in waves 1, 2 and 3, respectively (Table 2). In all waves, low-SES adolescents received fewer friendship nominations (6.01, 5.24 and 4.69 received friendship nominations in waves 1, 2 and 3, respectively) than non-low-SES adolescents (7.41, 7.02 and 6.91, respectively). Further, both low- and non-low-SES adolescents received fewer friendship nominations from low-SES peers than from non-low-SES peers (Table 2).

SAOM results for friendship network and smoking initiation dynamics

In the coevolution model of smoking dynamics and friendship formation (Table 3), low-SES adolescents nominated significantly fewer

friends than other adolescents [OR = 0.90; 95% confidence interval (CI) = 0.84–0.98]. Based on the selection table for friendship formation (Table 4), the odds for having non-low SES–non-low-SES friendships over not having these friendships (OR = 1.07; 95% CI = 1.02–1.11) was larger than the odds for low-SES–low-SES friendships (OR = 0.93; 95% CI = 0.84–1.04) or cross-SES friendships [OR of low SES mentioning non-low SES = 0.93 (95% CI = 0.86–1.01); OR of non-low SES mentioning low SES = 0.96 (95% CI = 0.89–1.04)].

Smokers did not differ from non-smokers in the likelihood of receiving a friendship nomination (OR = 0.98; 95% CI = 0.87–1.10; Table 3), irrespective of SES. The likelihood of smokers receiving a friendship nomination from their own SES group was not significantly different for low-SES as compared to non-low-SES smokers (OR = 0.85; 95% CI = 0.47–1.52). Smokers also did not differ from non-smokers in the likelihood of nominating other smokers (OR = 1.36; 95% CI = 1.00–1.87). Adolescents adjusted their smoking behavior to that of their friends (OR = 24.05; 95% CI = 1.27–454.86), controlling for friendship formation dynamics.

SAOM results for friendship network and alcohol consumption dynamics

In the model on the coevolution of alcohol consumption dynamics and friendship formation, low-SES adolescents nominated fewer friends than did other adolescents (OR = 0.90; 95% CI = 0.84–

TABLE 3 Stochastic actor-oriented model for the coevolution of friendship formation and health behaviors (odds ratio, 95% confidence interval and significance level).

Effects	Smoking OR (95% CI)	Sig.	Alcohol consumption OR (95% CI)	Sig.
Friendship network dynamics				
Structural effects				
Out-degree (density)	0.24 (0.17–0.33)	***	0.25 (0.17–0.36)	***
Reciprocity	10.49 (8.45–13.01)	***	10.49 (8.29–13.27)	***
Transitive triplets	1.27 (1.22–1.32)	***	1.27 (1.22–1.32)	***
Transitive reciprocal triplets	0.95 (0.91–0.99)	*	0.95 (0.91–0.99)	*
Transitive ties	2.16 (1.81–2.58)	***	2.18 (1.83–2.60)	***
In-degree popularity (square root)	1.03 (0.93–1.14)		1.02 (0.92–1.13)	
Out-degree popularity (square root)	0.51 (0.47–0.55)	***	0.51 (0.47–0.55)	***
Out-degree activity (square root)	1.12 (1.03–1.21)	*	1.11 (1.02–1.20)	*
Reciprocal degree—activity	0.90 (0.89–0.92)	***	0.90 (0.87–0.94)	***
Out-isolate	5.31 (2.95–9.56)	***	5.05 (2.75–9.28)	***
Health behavior[a] and covariate effects				
Health behavior[a] alter	0.98 (0.87–1.10)		1.16 (1.01–1.33)	*
Health behavior[a] ego	0.98 (0.87–1.10)		1.08 (0.96–1.22)	
Health behavior[a] ego × health behavior[a] alter	1.36 (1.00–1.87)		0.79 (0.56–1.10)	
Girl alter	1.02 (0.94–1.10)		1.02 (0.94–1.10)	
Girl ego	1.03 (0.93–1.14)		1.04 (0.96–1.13)	
Girl ego × girl alter	1.49 (1.25–1.78)	***	1.51 (1.29–1.76)	***
Low-SES alter	0.93 (0.86–1.01)		0.93 (0.86–1.01)	
Low-SES ego	0.90 (0.84–0.98)	*	0.90 (0.84–0.98)	*
Low-SES ego × low-SES alter	1.12 (0.94–1.33)		1.11 (0.93–1.32)	
Low-SES ego × health behavior[a] alter	1.14 (0.85–1.53)		1.02 (0.76–1.37)	
Low-SES alter × health behavior[a] alter	0.99 (0.77–1.28)		0.81 (0.62–1.07)	
Low-SES ego × low-SES alter × health behavior[a] alter	0.85 (0.47–1.52)		0.98 (0.52–1.89)	
Health behavior[a] dynamics				
Health behavior[a] linear shape	2.86 (0.57–14.26)		2.03 (1.35–3.07)	**
Health behavior[a] average similarity	24.05 (1.27–454.86)	*	1.65 (0.62–4.39)	

Note: See the effect definitions in Table 1. Number of cases: 232 adolescents, 4607 friendship nominations, eight classes. Convergence for smoking model: all convergence t ratios < 0.08; overall maximum convergence ratio 0.25. Convergence for alcohol model: all convergence t ratios < 0.06; overall maximum convergence ratio 0.23.

Abbreviations: CI = confidence interval; OR = odds ratio; SES = socio-economic status; Sig. = significance level.

[a]Health behavior indicates smoking in the smoking model and alcohol consumption in the alcohol model.

*$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$.

TABLE 4 Homophilous friendship selection effects for same- and cross-SES friendships in the smoking and alcohol models (odds ratio and 95% confidence interval).

		Alter			
		Smoking		Alcohol	
		Low SES	Non-low SES	Low SES	Non-low SES
Ego	Low SES	0.93 (0.84–1.04)	0.93 (0.86–1.01)	0.93 (0.83–1.03)	0.93 (0.86–1.01)
	Non-low SES	0.96 (0.89–1.04)	1.07 (1.02–1.11)*	0.96 (0.89–1.04)	1.07 (1.02–1.11)*

Abbreviations: OR = odds ratio; SES = socio-economic status.

*$P < 0.05$.

0.98). The selection table for friendship formation in same- and cross-SES friendships was similar in the alcohol and smoking model (Table 4); non-low SES–non-low-SES friendships (OR = 1.07; 95% CI = 1.02–1.11) were more likely than low SES–low-SES friendships (OR = 0.93; 95% CI = 0.83–1.03) or cross-socio-economic friendships [OR of low SES mentioning non-low SES = 0.93 (95% CI = 0.86–1.01); OR of non-low SES mentioning low SES = 0.96 (95% CI = 0.89–1.04)].

Alcohol consumers received more friendship nominations than non-alcohol consumers (OR = 1.16; 95% CI = 1.01–1.33). This pattern was not significantly different by the SES of the person who received the friendship nomination (OR = 0.81; 95% CI = 0.62–1.07), that of the person who sent the friendship nomination (OR = 1.02; 95% CI = 0.76–1.37) or by having same-SES friendships (OR = 0.98; 95% CI = 0.52–1.89). Alcohol consumers did not differ from non-alcohol consumers in the likelihood of nominating alcohol consumers (OR = 0.79; 95% CI = 0.56–1.10). Adolescents' drinking behavior was not significantly influenced by their friends' alcohol consumption (OR = 1.65; 95% CI = 0.62–4.39), controlling for friendship formation dynamics.

Findings were robust in sensitivity analyses (Supporting information, Tables S5–S9). A random-effects panel regression model without controlling for network effects found that health behavior was not associated with the number of received friendship nominations (in-degree), neither in the classes from the main model nor in the whole sample (Supporting information, Table S10). Goodness of Fit statistics are displayed in Supporting Information Table S11 and Supporting Information Figure S4-S5.

DISCUSSION

Analyzing longitudinal social network data of socio-economically diverse school classes, we tested for several possible network mechanisms that can contribute to inequalities in health behaviors. We found that adolescents with non-low SES were more likely to select same-SES friends, adolescents influenced each other's smoking behavior and alcohol consumers were popular for friendship choices, supporting the existence of homophilous friendship selection and spreading of health behaviors. But we found that low-SES adolescents did not select friends based on their smoking and alcohol consumption to a different extent than high-SES adolescents did, rejecting the existence of the oppositional culture hypothesis for health behaviors. Our findings suggest that inequalities arise primarily due to homophilous friendship selection, peer influence effects on smoking and attractiveness of alcohol consumption for friendship selection, but not because of oppositional culture.

To our knowledge, our study is the most comprehensive assessment of how social network dynamics contribute to inequalities in smoking/alcohol consumption. Based on sociological theories [18, 31], socio-economic inequalities in health behaviors can arise due to (1) the coexistence of social influence/selection with homophilous friendship selection based on SES or (2) due to socio-economic inequalities in social selection/social influence. Our study is consistent with a few existing pieces of evidence investigating the co-existence of social influence/selection with homophilous friendship selection based on SES [20–23]. Additionally, our finding about the association between popularity and health behaviors were irrespective of SES confirms results of a previous study on the topic [37]. Unlike this previous study, however, we used a complete social network, allowing us to control for network processes such as homophilous friendship selection and social influence to rule out alternative explanations [38]. Moreover, our study furthers the existing literature by examining whether oppositional culture exists in terms of health behavior (operationalized as whether low-SES adolescents exclude low-SES peers if they do not smoke/drink).

The main strength of our study is its ability to highlight the coevolution of social networks and health behaviors in different SES groups using longitudinal social network data [48]. Using a socio-economically diverse sample, we went beyond disentangling social influence and selection effects and also investigated the selection effects separately for different SES groups. Additionally, including a set of network and individual control variables helped to rule out alternative explanations for our findings. Our findings were robust in various model specifications strengthening confidence in the results.

Our study has limitations that should be borne in mind when interpreting these results. Both smoking and alcohol consumption were self-reported, and thus could be biased. Previous cohort studies with biomarker data, however, found self-reports to be reasonably reliable [49, 50]. Our longitudinal data analysis controlled for both observed and unobserved time-invariant heterogeneity, and additionally controlled for the most important time-varying variables. However, we cannot rule out the effects of other potentially relevant time-varying individual attributes (e.g. parental health behavior) [51, 52]. Similar to most school-based network data, we did not collect information about social contacts outside the classroom, limiting our ability to consider all potentially influential social ties [29]. In our model, the friendship dynamics section analyzed friendship nominations (n = 4607), while the health behavior dynamic section utilized individual analysis (n = 232). Consequently, the latter part may exhibit increased imprecision and heterogeneity in estimated influence effects. The sample size did not allow us to stratify the social influence effect according to SES or to control for individual attributes in the smoking dynamics estimation. The number of friendship nominations was nevertheless sufficiently large to investigate whether the selection effect differed among SES groups and to control for important network structural effects. Another limitation of the data is its inability to effectively distinguish adolescents who occasionally and solitarily consume alcohol/smoke, potentially leading to an underestimation of prevalence rates [53–55]. The prevalence of adolescents engaging exclusively in solitary drinking and smoking, however, is relatively low (e.g. life-time solitary drinking was 14% among adolescents in a systematic review) [56], and our study focuses primarily upon social network mechanisms, which are less impacted by solitary behavior [53, 54]. Finally, due to the exclusion of classes with fewer than three low-SES adolescents and no change in smoking/alcohol consumption status over time, which was needed to estimate the intra-SES effects and dynamic effects, the generalizability

of our findings to classrooms characterized by more homogeneity in SES or stability in smoking patterns may be limited.

Future research should focus upon the role of contextual factors such as school SES or culture or national-level tobacco control measures, which may moderate the link between individual-level SES and the spread of health behaviors [25, 57, 58]. Ethnic and gender inequalities have not been the focus of this study but should be further explored, as they probably play a crucial role in the segregation of social networks and could be the basis of oppositional culture [59, 60]. Another avenue for future research is investigating how the use of novel tobacco products (e.g. e-cigarettes) and the growing importance of on-line contacts change the role of social networks in forming the health behaviors of adolescents [61–64]. Our research may be replicated in other settings, given that the local context (Supporting information, Appendix S1) investigated in this study may not be generalizable to other contexts that have different track systems, different ratios of smokers/alcohol consumers or with different levels of segregation [19]. Future studies with larger sample sizes should distinguish a more detailed SES variable, as inequalities may exist across other strata and permanent and temporary financial difficulties might have different impacts.

CONCLUSION

Although population-level interventions have improved adolescents' health behaviors over the past decades, relative inequalities in health behaviors persist [6, 12–15]. Our findings indicate that the reason for this partially lies in socio-economically segregated social networks. Promoting more contact between socio-economic groups may bring about clinically relevant changes for low-SES adolescents. Although opportunities to intervene in friendship formation are limited, interventions could promote more opportunities for different SES to meet and interact, for example, by assigning seating arrangements, groups in introductory meetings and dormitory roommates, or providing out-of-school-context meeting opportunities (e.g. summer camps) [65–69]. Future interventions should consider socio-economic differences in social network processes to address not only the overall prevalence of smoking and alcohol consumption but also to close the gap in these respects between affluent and poor adolescents.

AUTHOR CONTRIBUTIONS

Márta K. Radó: Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); visualization (lead); writing—original draft (lead). **Dorottya Kisfalusi:** Conceptualization (supporting); formal analysis (supporting); investigation (supporting); methodology (supporting); supervision (supporting); writing—review and editing (supporting). **Anthony A. Laverty:** Conceptualization (supporting); investigation (supporting); writing—review and editing (supporting). **Frank J. van Lenthe:** Conceptualization (supporting); investigation (supporting); writing—review and editing (supporting). **Jasper V. Been:** Conceptualization (supporting); investigation (supporting);
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DECLARATION OF INTERESTS

None to declare.

DATA AVAILABILITY STATEMENT

De-identified individual participant data (including data dictionaries, protocol and consent forms) are available [43].

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.