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Dynamics of adolescent friendship networks and smoking behavior

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ABSTRACT

The mutual influence of smoking behavior and friendships in adolescence is studied. It is attempted to disentangle influence and selection processes in reciprocal and non-reciprocal friendships. An actor-based model is described for the co-evolution of friendship networks and smoking behavior. This model considers alternative selection and influence mechanisms, and models continuous-time changes in network and behavior. The data consists of a longitudinal sample of 1326 Finnish adolescents in 11 high schools. Findings suggest that selection as well as influence processes play an important role in adolescent smoking behavior. Selection had a relatively stronger role than influence, in particular when selecting non-reciprocal friends. The strength of both influence and selection processes decreased over time.
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1. Introduction

One of the main preventable causes of cancer, heart disease, and premature death is cigarette smoking (Ezzati and Lopez, 2003; Office for National Statistics, 1997; US Department of Health and Human Services, 1994; Warren et al., 2006). Many youngsters experiment with smoking, which often results in becoming a regular smoker in adulthood (Chassin et al., 1996). During adolescence, smoking behavior tends to be similar among friends (Bauman et al., 1984; Eiser et al., 1991; Ennett et al., 1994; Sussman et al., 1990). This similarity in smoking behavior, which can be regarded as network autocorrelation (Doreian, 1989), could be caused by selection of similar others as friends as well as by influence processes where friends adjust their smoking behavior to each other, or by a combination of these. This article will demonstrate the use of stochastic actor-based models (Snijders et al., 2007a; Steglich et al., submitted for publication) capable of disentangling influence and selection processes by simultaneously representing changes in friendship network structure and changes in smoking behavior among adolescents. In particular, the impact of friendship reciprocity on selection and influence processes will be explored. Reciprocal friendships may offer higher friendship quality, which in turn could result in more opportunities for influence processes leading to smoking behavior similarities among friends (Parker and Asher, 1993; Urberg et al., 2003). Pearson and Michell (2000) examined non-reciprocal and reciprocal friendships and concluded that adolescents in the periphery of peer groups were the most important targets of influence.

Several studies attempted to disentangle selection and influence processes in the context of smoking behavior and suggested that selection of friends based on smoking behavior may be just as important as influence processes to explain similarity among friends, or even more important (Cohen, 1977; De Vries et al., 2006a; Ennett and Bauman, 1994; Fisher and Bauman, 1988; Kandel et al., 1978; Mercken et al., 2007). Studies that considered friendship reciprocity showed mixed results. Several studies found stronger support for influence within reciprocal compared to non-reciprocal friendships (Mercken et al., 2007; Parker and Asher, 1993; Urberg et al., 2003), other researchers did find strong support for influence of non-reciprocal or desired friends (Aloise-Young et al., 1994).

Disentangling selection and influence processes, as well as the role of friendship reciprocity in these processes, is difficult, due to the dynamic interdependent nature of friendship networks and smoking behavior. Previous studies have three main shortcomings. First, although most previous studies did include important alternative influence processes such as the influence of parental and sibling smoking (Avenevoli and Merikangas, 2003), they did not control adequately for alternative explanatory selection mechanisms. A smoking adolescent, for example, might choose a smoker as a friend because this individual already indicated the adolescent as his friend (reciprocity) or because this particular person was already a friend of the adolescent's other friends (transitivity). Further, the selection of this smoking friend might be based not on similarities in smoking behavior but on similarities in age,

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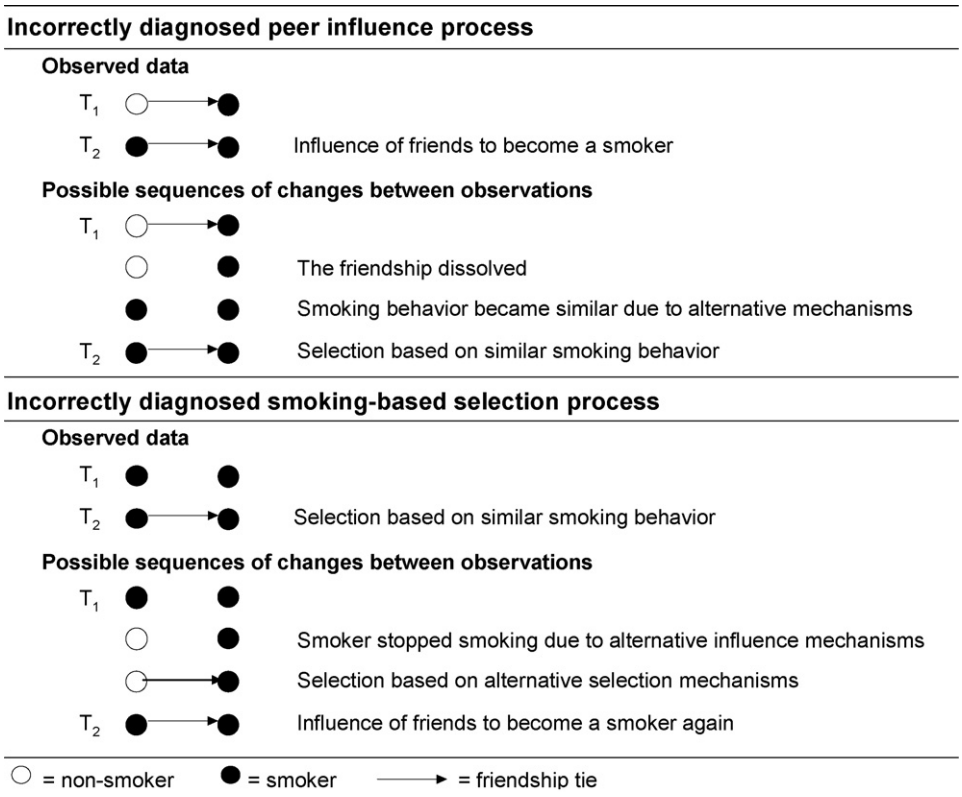

Fig. 1. Possible changes between behavior and network observations.

gender, alcohol consumption, school achievement, etc. Support for these alternative causes of tie formation was found by previous researchers (Burk et al., 2007; McPherson et al., 2001; Snijders and Baerveldt, 2003). Failing to control for alternative mechanisms might result in an overestimation of the strength of smoking-based selection processes. Second, researchers did not consider the continuous changes of network structure and smoking behavior over time happening between observations. Longitudinal data is mostly gathered at only a few discrete moments, which makes it impossible to unequivocally identify the processes responsible for a network or behavioral change. In between two observation moments, changes will occur in friendships and smoking behavior, and a change may even be followed by a change back to the original value before the next observation moment. Fig. 1 demonstrates influence and smoking-based selection processes that are likely to be diagnosed incorrectly on the basis of discrete observations if change between the observations is not accounted for. Consecutive observations are denoted here by T1 and T2, and some sequences of changes that may have occurred between observations are also indicated. Analysis techniques that are based on classifying observed changes as being due to influence or selection without accounting for the possibility of other intervening changes (De Vries et al., 2006a; Ennett and Bauman, 1994; Mercken et al., 2009) may be misleading, and it is preferable to use a technique that does take this possibility into account.

Finally, independence assumptions that underlie the employed statistical methods are violated. Even more advanced statistical techniques such as structural equation modeling used for this type of data (De Vries et al., 2006a; Mercken et al., 2009) assume incorrectly that there are no dependencies caused by the network structure of an adolescent. For example, a given individual's value on smoking behavior could appear within more than one observation, e.g., as the smoking behavior dependent variable for one case, and as smoking behavior of one of the friends supplying data for the independent variables in other cases.

New social network analysis methods have recently been developed which are able to consider alternative explanatory selection mechanisms, to model continuous-time changes in smoking behavior and friendship networks, and to take dependencies into account caused by the network structure. Stochastic actor-based models (Snijders, 2001, 2005) have been developed to include network and behavior co-evolution (Snijders et al., 2007a; Steglich et al., submitted for publication). The following section will describe such an actor-based model for network–behavior co-evolution in the context of adolescent friendship networks and smoking behavior. A more extensive introduction is given in Snijders et al. (this issue).

1.1. An actor-based model for friendship network–smoking behavior co-evolution

Actor-based models for network–behavior co-evolution assume that at two or more observation moments, a directed network and one or more behavioral variables are observed for a finite set of social actors. In our study, the actors are adolescents in a school. The network is a dichotomous relational variable, in our case indicating who directs friendship ties to whom. The behavior is assumed to be a dichotomous or discrete ordinal variable, in our case smoking behavior. Adolescents can change their smoking behavior, and also their friendship ties, in response to the current friendship network structure and the smoking behavior of the other adolescents in the network. It is assumed that all actors are fully informed about the state of the network, covariates and smoking behavior of all other actors in the network. Actors are only allowed to change their own outgoing ties and their own smoking behavior; they cannot make changes in outgoing ties or smoking behavior of other actors. Each adolescent is furthermore assumed to make decisions to change friendship ties or smoking behavior by probabilistic rules depending on the current configuration of network and behavior. The functions that determine the probabilities of change are

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called the objective functions, and there are separate objective functions for network change and for behavior change. Probabilities of change to a particular network or behavior state are higher accordingly as the objective function is higher; see Snijders et al. (2007a, this issue). One interpretation is that the changes are the result of choices to optimize the actor's position in the network according to short-term preferences and constraints combined with random disturbances, and the objective function represents these short-term preferences and constraints. Finally, all actors consider and execute network and smoking behavior changes independently, given the current state of the network and everybody's behavior. Actors may change only one friendship tie or one level of smoking behavior at any moment in time. This implies that actors may react to each other's changes in friendship ties and smoking behavior, but do not negotiate or otherwise make joint changes based on a prior agreement. Therefore a negotiation like 'when you start smoking, I'll become your friend' would need to be represented as the result of two smaller changes, between which the causal link cannot be enforced: 'you may start smoking, but whether I will become your friend remains to be seen'. Note that while an actor cannot be certain that starting to smoke will result in a friendship, if smoking similarity has a positive effect on friendship selection then the actor does know that starting to smoke will increase the probability of being considered as a friend by smoking schoolmates.

The actor-based models for co-evolving networks are modeled according to a continuous-time Markov process in which likely developmental trajectories between observation moments are imputed (continuous-time property), and changes adolescents make are assumed to depend only on the current state of affairs (Markov property).

To model the co-evolution of friendship and smoking two models are created, one for friendship network change and one for smoking behavior change. The network evolution and behavior evolution models are integrated as one internally dependent process. In this manner, the current state of the continuously changing friendship network can be a dynamic constraint for changes in smoking behavior, while simultaneously the current state of smoking behavior can act as a dynamic constraint for changes in the friendship network.

Using this approach, four main research questions are addressed in this study:

1. Do adolescents select friends based on similar smoking behavior?
2. Are adolescents influenced by friends to adjust to their smoking behavior?
3. Does the strength of these selection and influence processes differ for non-reciprocated and reciprocated friendships?
4. What is the relative contribution of selection and influence processes over time?

2. Methods

2.1. Participants

The sample consists of 11 Finnish schools containing 1326 adolescents that participated as a control group in the ESFA study (De Vries et al., 2006b, 2003), which was an intervention study with interventions taking place at the community level. The participating Finnish organization demanded that participating schools be located exclusively in Helsinki. In this research region, communities/neighborhoods were randomly selected. High schools within the target communities were asked to participate, indicating that they would have a 50% chance of becoming an experimental school. Experimental schools were excluded in this study since the intervention may have changed the relationship between variables of interest. The present study included all control schools that participated at each of the four measurement times, resulting in 11 schools with in total 1326 participating adolescents.

2.2. Procedure

Self-administered questionnaires were distributed in schools among seventh graders during autumn 1998, since smoking onset is most likely to occur among this age group. Follow-up was conducted respectively 12, 24, and 30 months later (De Vries et al., 2006b, 2003). On the days of data collection, present students were asked to complete the questionnaire. It was explained to the adolescents that responses would be treated confidentially and they could refuse to participate. Questionnaires were returned in sealed envelopes to guarantee their anonymity. In Finland, the overall rate of refusals to participate was 3%.

2.3. Questionnaire

Friendship ties were assessed by one question in which adolescents could name up to five best friends inside and/or outside school (McCallister and Fisher, 1978). Only best friends inside school in the same grade are included here, to have complete networks as data material.

Smoking behavior of adolescents was assessed by one question: 'On average, how many cigarettes do you smoke during a week (also count the weekend)?' (0 = 0, 1 = between 0 and 1, 2 = 2–10, 3 = 11–30, 4 = more than 30).

Parental smoking behavior was measured by two questions: 'Does your father (male caregiver) smoke?' and 'Does your mother (female caregiver) smoke?', and was recoded into one variable (0 = neither smokes, 1 = at least one parent (caregiver) smokes).

Sibling smoking behavior was measured by two questions: 'Do one or more of your brother(s) smoke?' and 'Do one or more of your sister(s) smoke?', and was recoded into one variable (0 = no siblings smoke, 1 = at least one sibling smokes).

Alcohol consumption (0 = 0 glasses of alcoholic drinks per week, 1 = 1 or 2 glasses, 2 = 3–5 glasses, 3 = more than 5 glasses), age (in years), gender (0 = boy, 1 = girl), and self-reported school achievement (1 = lower third of the class, 2 = middle third, 3 = highest third) were also recorded.

2.4. Plan of analysis

2.4.1. Model development

An actor-based model was constructed which consisted of two models: one model simulates the evolution of the friendship network (which allows the study of selection processes), and the other model simulates the evolution of smoking behavior (for studying influence processes). The combined model simulates selection and influence processes simultaneously while controlling either process for the other one. Four observations were available for each school. None of the respondents were excluded from the network. Even those respondents who entered the study at a later time point or left the study before the end of the study were included in the model for the duration of their membership of the school (Huisman and Snijders, 2003). The detailed mathematical specification of actor-based models is given by Snijders et al. (2007a, this issue). Table 1 presents a list of descriptions and mathematical specifications of all the included effects and a sketch of the model is as follows.

The friendship network evolution part of the model specifies the preferred direction of network change by a list of functions of net-

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Table 1
Mathematical formula and descriptions of the included effects, as components of objective functions, for modeling selection and influence processes simultaneously.

	SIENA formula	Description
Network decision: selection processes		
Smoking behavior adolescent	$\sum_j x_{ij} z_i$	Main effect of own smoking behavior on own number of friends
Smoking behavior potential friend	$\sum_j x_{ij} z_j$	Main effect of potential friend's smoking behavior on selection
Smoking behavior adolescent × potential friend	$\sum_j x_{ij} z_i z_j$	Tendency to select based on similar smoking behavior
Smoking behavior squared potential friend	$\sum_j x_{ij} z_j^2$	Effect of potential friend's squared smoking behavior on selection
Outgoing friendship ties	$\sum_j x_{ij}$	General tendency to choose friends
Reciprocal outgoing friendship ties	$\sum_j x_{ij} x_{ji}$	Tendency to reciprocate friendships
Transitivity	$\sum_{j,h} x_{ij} x_{jh} x_{ih}$	Tendency to being a friend of a friend's friend
Alcohol consumption adolescent	$\sum_j x_{ij} v_{1i}$	Main effect of own alcohol consumption on own number of friends
Alcohol consumption potential friend	$\sum_j x_{ij} v_{1j}$	Main effect of potential friend's alcohol consumption on selection
Alcohol consumption adolescent × potential friend	$\sum_j x_{ij} v_{1i} v_{1j}$	Tendency to choose a friend based on similar alcohol consumption
Alcohol consumption squared potential friend	$\sum_j x_{ij} v_{1j}^2$	Effect of potential friend's squared alcohol consumption on selection
Age adolescent	$\sum_j x_{ij} v_{2i}$	Main effect of own age on own number of friends
Age potential friend	$\sum_j x_{ij} v_{2j}$	Main effect of potential friend's age on selection of friends
Age adolescent × potential friend	$\sum_j x_{ij} v_{2i} v_{2j}$	Tendency to choose a friend based on similar age
Gender adolescent	$\sum_j x_{ij} v_{3i}$	Main effect of own gender on own number of friends
Gender potential friend	$\sum_j x_{ij} v_{3j}$	Main effect of potential friend's gender on selection
Gender adolescent × potential friend	$\sum_j x_{ij} v_{3i} v_{3j}$	Tendency to choose a friend based on similar gender
School achievement adolescent	$\sum_j x_{ij} v_{4i}$	Main effect of own school achievement on own number of friends
School achievement potential friend	$\sum_j x_{ij} v_{4j}$	Main effect of potential friend's school achievement on selection
School achievement adolescent × potential friend	$\sum_j x_{ij} v_{4i} v_{4j}$	Tendency to choose a friend based on similar school achievement
Smoking behavior similarity × reciprocity[a]	$\sum_j x_{ij} x_{ji} z_i z_j$	Interaction between reciprocity of friendship and tendency to choose a friend based on similar smoking behavior
Behavior decision: influence processes		
Average smoking behavior friends	$\left(\sum_j x_{ij} z_j\right) / \left(\sum_j x_{ij}\right)$	Main effect of friend's smoking behavior on his own smoking behavior
Tendency to smoke	z_i	Linear component in basic preference function for smoking
Tendency to smoke: squared component	z_i^2	Squared component in basic preference function for smoking, representing feedback effect of own smoking behavior
Smoking behavior parents	$z_i v_{5i}$	Main effect of parental smoking behavior on his own smoking behavior
Smoking behavior siblings	$z_i v_{6i}$	Main effect of siblings' smoking behavior on own smoking behavior
Alcohol consumption adolescent	$z_i v_{1i}$	Main effect of own alcohol consumption on own smoking behavior
Age adolescent	$z_i v_{2i}$	Main effect of own age on own smoking behavior
Gender adolescent	$z_i v_{3i}$	Main effect of own gender on his own smoking behavior
School achievement adolescent	$z_i v_{4i}$	Main effect of own school achievement on his own smoking behavior
Number of outgoing friendships[a]	$z_i \sum_j x_{ij}$	Main effect of own number of nominated friends on own smoking behavior
Number of incoming friendship nominations[a]	$z_i \sum_j x_{ji}$	Main effect of number nomination by others on own smoking behavior
Smoking behavior of friends × reciprocity[a]	$\left(\sum_j x_{ij} x_{ji} z_j\right) / \left(\sum_j x_{ij} x_{ji}\right)$	Effect expressing influence from reciprocal friends on smoking behavior, additional to influence from all friends.

[a] Denotes effects tested by means of a score test. Formulae: i = adolescent; j, h = peers; x_j indicates presence of a friendship from i to j; x_{ji}, indicates presence of a friendship tie from j to i. Description: "own" refers to the adolescent him/herself; "selection" refers to selection as a friend. All variables are grand mean centred; z_i = smoking behavior of i, v_{2i} =alcohol consumption, v_{3i} =age, etc.

work 'effects', depending on current network structure as well as on attributes of adolescents. Friendship choice probabilities depend on these effects. This list contains four smoking-related friendship selection components: the effect of adolescent's smoking behavior on number of friends chosen (smoking adolescent), the effects of smoking behavior of potential friends and its square on choosing them (smoking potential friend, squared smoking potential friend), and an interaction effect between smoking adolescent and smoking potential friend, which is used to test that adolescents who smoke more also tend to select friends who smoke more (smoking behavior adolescent × potential friend). The reason for including both the raw and the squared value of the behavior of friends is to control for possible nonlinearities and to have a more robust assessment of the influence of friends on the respondent (Snijders et al., this issue). As network dynamics have major endogenous components (McPherson et al., 2001; Snijders, 2001; Van de Bunt et al., 1999), several characteristics of the current network and various individual attributes were included as control variables. These were: number of friends chosen (outgoing friendships), number of reciprocal friends chosen (reciprocity), and the number of friends who are also a friend-of-a-friend (transitivity[1]). Furthermore, as control effects, similarity on alcohol consumption, age, gender, and school achievement were included, as well as the effects of these attributes on the number of friends chosen (e.g., age adolescent) and on the propensity to be chosen as a friend (e.g., age potential friend). The friendship network evolution part of the combined model is summarized in the upper part of Table 1. The rather large number of control effects is necessary because friendship selection is a multidimensional process and smoking behavior may correlate with many other attributes as well as with network position, so that the failure to control adequately for such characteristics could lead to misleading inferences.

The smoking behavior evolution part of the model likewise specifies preferred directions of changes in smoking status. It encompasses a list of functions of network, smoking behavior, and other attributes on which probabilities of changes in smoking

[1] Transitive ties.

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Table 2
Descriptive statistics of school network structure and individual characteristics.

	Wave 1	Wave 2	Wave3	Wave 4
Average number of outgoing ties	1.67	2.02	1.75	1.77
Average smoking behavior adolescent	0.46	0.90	1.36	1.38
Average observed network autocorrelation (Moran's I)	0.42	0.42	0.41	0.39
	Period 1	Period 2		Period 3
Average number of adolescents joining a school network	8	9		2
Average number of adolescents leaving a school network	8	10		20
				Mean
Number of adolescents in school				121
Alcohol consumption adolescent				0.3
Percentage at least one smoking parent				49.9
Percentage at least one smoking sibling				23.0
Age (in years) at baseline				13.4
Percentage females				47.0
School achievement				2.0

Smoking behavior is coded: 0 = 0 cigarettes each week; 1 = between 0 and 1; 2 = 2–10; 3 = 11–30; 4 = >30; alcohol consumption is coded: 0 = 0 glasses alcohol each week; 1 = 1–2; 2 = 3–5; 3 = >5; school achievement is coded: 1 = among the lower third of the class; 2 = middle third; 3 = best third.

behavior may depend. This list contained one main friendship-related influence component: the effect of smoking behavior of friends[2] on adolescent smoking behavior. Included control effects were the basic tendency to smoke expressed as a quadratic function of smoking behavior and therefore represented by two parameters, one for the linear and one for the quadratic term; smoking behavior of parents and siblings; and own alcohol consumption, age, gender, and school achievement. This list is given as the lower part of Table 1.

Since previous social network analyses within six European countries (Mercken et al., submitted for publication) did not find evidence for the effects of number of received and outgoing friendship nominations on smoking behavior, these extra effects on which smoking behavior changes might depend were only tested by means of score tests (Schweinberger, submitted for publication). Similarly, two interaction effects of smoking-based selection and influence of friends with reciprocity were tested by score tests to examine whether the strength of smoking-based selection and influence of friends differs between non-reciprocated and reciprocated friendships. Because of collinearity considerations, this score test procedure for identifying additional effects to include in a model is generally preferable to attempts of direct estimation of the effects in question. The latter procedure runs the risk of not obtaining convergence in the estimation algorithm, and not being able to identify the newly included effect, and possibly others.

2.4.2. Statistical analysis

For each school separately, the combined model, including the four score tests, was analyzed using the Unconditional Method of Moments (Snijders, 2001; Snijders et al., 2007a) in SIENA version 3.14 (Simulation Investigation for Empirical Network Analysis) (Snijders et al., 2007b). The included effects were tested on the basis of *t*-ratios defined as estimate divided by standard error, with an approximate standard normal null distribution (Snijders, 2001). Subsequently, the results of all separate school network analyses were combined in a meta-analysis. The *t*-ratios were combined separately for each of the effects in Table 1. It was desired to use a combination method with a good power to detect various patterns of non-zero parameter values across the 11 schools and with a minimum of assumptions. For each effect, the overall null hypothesis that the corresponding parameter is 0 in all schools was tested by using Fisher's combination procedure (Hedges and Olkin, 1985) twice, once for a right-sided and once for a left-sided test. In the right-sided test the null hypotheses is that in all schools the coefficient of this effect is non-positive, and the alternative hypothesis is that in at least one school the coefficient is positive. In the left-sided test, the same is done with interchanged roles of 'positive' and 'negative'. The test statistic in Fisher's procedure is minus twice the sum of the natural logarithms of the *p*-values of the one-sided tests for the individual schools, with under the combined null hypothesis a chi-squared distribution having, for 11 schools, 22 degrees of freedom. To control for multiple (right and left) testing, there was deemed to be significant support for an effect if either of these combination tests was significant at level 0.025 (Bonferroni correction). In addition, the null hypothesis that effect parameters are constant across schools was tested by the method of Cochran (1954) adapted for network dynamics by Snijders and Baerveldt (Cochran, 1954; Snijders and Baerveldt, 2003). Depending on the results of the score tests, the final model for analysis was extended by the effects for which the score test produced evidence.

Additional models will be estimated to explore whether smoking-based selection and influence effects differ between the three separate data waves. Network autocorrelations will be examined to explore the relative contribution of selection, influence, and alternative mechanisms to observed smoking behavior similarities among friends.

3. Results

3.1. Descriptive statistics

Table 2 demonstrates the average number of friends per adolescent, smoking behavior of adolescents, and observed network autocorrelations for each wave, and baseline demographic characteristics. The average numbers of friends generally increased between subsequent waves, with one exception (slight decrease after wave 2), while smoking behavior increased over time. The observed network autocorrelation slightly decreased from 0.42 in the first wave to 0.39 in the last wave.

3.2. Friendship network evolution

The score test for interaction between friendship reciprocation and selection based on similar smoking behavior was significant (left one-sided Fisher's combination, chi-square = 39.6, df = 20,

[2] Average smoking behavior of friends.

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Table 3
Results meta analysis Finland.

	Snijders–Baerveldt method		Fisher's combination test			
	b	S.E.	Left one-sided		Right one-sided	
			Chi-square	*p*-Value	Chi-square	*p*-Value
Network decision: selection processes						
Smoking behavior adolescent	−0.035	0.029	30.8	0.10	13.2	0.93
Smoking behavior potential friend	−0.106	0.197	18.6	0.67	16.0	0.82
Smoking behavior adolescent × potential friend	**0.093*****	**0.016**	**3.7**	**1.00**	**70.8**	**<0.001**
Smoking behavior adolescent × potential friend × reciprocity	**−0.126****	**0.040**	**40.3**	**0.002**	**5.4**	**1.00**
Smoking behavior squared potential friend	0.049	0.102	16.6	0.79	18.2	0.70
Outgoing friendship ties	**−3.356*****	**0.224**	**276.2**	**<0.001**	**0.6**	**1.00**
Reciprocal outgoing friendship ties	**1.763**^{***,a}	**0.088**	**0.9**	**1.00**	**3031.9**	**<0.001**
Transitivity	**1.175*****	**0.052**	0.1	**1.00**	**3104.0**	**<0.001**
Alcohol consumption adolescent	−0.023	0.047	24.1	0.34	14.5	0.88
Alcohol consumption potential friend	**0.189***	**0.081**	**10.5**	**0.98**	**40.0**	**0.01**
Alcohol consumption adolescent × potential friend	**0.092***	**0.048**	9.4	0.99	34.6	0.04
Alcohol consumption squared potential friend	**−0.100***	**0.040**	**38.3**	**0.02**	**9.4**	**0.99**
Age adolescent	−0.148	0.080	30.5	0.11	10.8	0.98
Age potential friend	−0.037	0.052	30.4	0.11	12.7	0.94
Age adolescent × potential friend	0.063	0.133	14.0	0.83	19.5	0.49
Gender adolescent	0.019	0.130	21.2	0.51	26.9	0.22
Gender potential friend	−0.117	0.088	31.1	0.09	13.0	0.94
Gender adolescent × potential friend	**3.188**^{***,a}	**0.231**	0.0	1.00	**382.9**	**<0.001**
School achievement adolescent	0.018	0.033	14.8	0.87	22.5	0.43
School achievement potential friend	−0.034	0.031	31.4	0.09	19.0	0.64
School achievement adolescent × potential friend	0.023	0.036	17.0	0.77	23.4	0.38
Behavior decision: influence processes						
Average smoking behavior friend	**0.221****	**0.069**	**7.6**	**1.00**	**42.7**	**0.005**
Tendency to smoke	**−0.922**^{***,a}	**0.081**	**8477.3**	**<0.001**	**0.0**	**1.00**
Tendency to smoke: squared component	**0.484*****	**0.022**	**0.1**	**1.00**	**3112.4**	**<0.001**
Smoking behavior parents	**0.232*****	**0.047**	**2.2**	**1.00**	**67.2**	**<0.001**
Smoking behavior siblings	0.125*	**0.054**	11.4	0.97	34.4	0.04
Alcohol consumption adolescent	0.009	0.053	24.0	0.35	22.0	0.46
Age adolescent	0.029	0.064	21.9	0.47	21.8	0.47
Gender adolescent	0.056	0.049	15.9	0.82	28.4	0.16
School achievement adolescent	−0.023	0.041	28.6	0.16	19.9	0.59

b = unstandardized coefficients according to the Snijders–Baerveldt method (2003); S.E. = standard error; bold values represent significant results. All chi-squared values have 22 df except for alcohol consumption adolescent × potential friend (df = 18) and age adolescent × potential friend (df = 20).

[a] Significant differences found between schools according to the Snijders–Baerveldt method (2003).

* Two-sided $p < 0.05$.

** Two-sided $p < 0.01$.

*** Two-sided $p < 0.001$.

$p = 0.006$) and therefore this effect was included in the final model.

Results for the friendship network evolution part of the model are reported in the upper part of Table 3. In discussing these we focus on the effects linking friendship and smoking. Adolescents who smoked more had a greater tendency to choose friends who likewise scored high on smoking behavior as indicated by the significant interaction smoking ego by smoking alter effect (chi-square = 70.8, df = 22, $p < 0.001$). There were no significant main effects of the smoking behavior of the adolescent or the potential friend on friendship selection.

The additionally included significant interaction effect with reciprocity furthermore indicated that the tendency to choose similar smoking friends (interaction smoking ego by smoking alter) was significantly higher when selecting non-reciprocated friends as compared to reciprocal friends. The remaining effect of selection of reciprocated friends based on similar smoking behavior was calculated by combining the results of the interaction smoking ego by alter effect and the three way interaction of smoking ego by alter by reciprocity effect for each school separately. The results for all schools were then examined using the Fisher's combination of one-sided tests (left-sided chi-square = 24.94, df = 18, $p = 0.13$; right-sided chi-square = 13.20, df = 18, $p = 0.78$). These results imply that similarity of smoking behavior played a significant role in friendship selection only when there was not already a tie in the reciprocal direction.

Results for other effects included in the friendship dynamics model and considered here as control effects, are in line with what has been found more often in research on friendship dynamics and are not specifically discussed here. To have a more detailed representation of the contributions of smoking of the adolescent and the potential friend on tie formation and dissolution, the upper part of Table 4 gives the total contribution of all smoking-related effects to the objective function for network change, as defined on the basis of estimated average parameters. This technique, explained in Section 16 of Snijders et al. (2007b), represents numerically the attractiveness of friends with specific smoking behavior values to be chosen as a friend by the adolescent. The most attractive potential friends for adolescents that smoke less than one cigarette each week are the classmates who do not smoke at all. For adolescents who smoke one or more cigarettes each week, the most attractive friends are those who smoke at the highest rate. Furthermore, smoking behavior of potential friends mattered most in friendship selection for adolescents who smoked at the highest rate.

3.3. Smoking behavior evolution

The score tests for the interaction between friendship reciprocation and influence of friends' smoking behavior, the number of outgoing friendship nominations and the number of received friendship nominations, all turned out not to be significant and were therefore not included in the final model.

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Table 4
The attractiveness of smoking behavior.

	Adolescent	Friend				
		0	1	2	3	4
Selection	0	**0.288**	0.038	−0.114	−0.169	−0.125
	1	**0.159**	0.002	−0.058	−0.019	0.118
	2	0.030	−0.034	−0.001	0.131	**0.361**
	3	−0.099	−0.070	0.056	0.281	**0.604**
	4	−0.228	−0.107	0.113	0.431	**0.847**
Influence	0	**1.654**	1.430	1.207	0.983	0.760
	1	0.013	0.011	0.008	0.006	0.003
	2	−0.659	−0.441	−0.222	−0.004	0.214
	3	−0.364	0.075	0.515	0.954	1.394
	4	0.899	**1.560**	**2.220**	**2.881**	**3.541**

Contributions of smoking behavior of adolescent and potential friend to the objective function for friendship (top panel) and for smoking (bottom panel). Smoking behavior is coded: 0 = 0 cigarettes each week; 1 = between 0 and 1; 2 = 2–10; 3 = 11–30; 4 = >30. Bold values represent the most attractive potential friend for adolescents in each smoking behavior category (top panel), and the most attractive smoking behavior for adolescents with friends in each smoking behavior category (bottom panel).

The results of the smoking behavior evolution part of the social network analysis, which specifies the preferred direction of change in smoking behavior, are reported in the lower part of Table 3. Adolescent's smoking behavior was influenced by the smoking behavior of their friends. Adolescents adjusted their smoking behavior to the smoking behavior of their friends (chi-square = 42.7, df = 22, $p = 0.005$). The lower panel of Table 4 gives the combined contribution of the smoking behavior of the adolescent and that of his/her friends' to the objective function for smoking. This represents the attractiveness of different values of smoking behavior, depending on the behavior of the friends. The most attractive smoking behaviors for adolescents lie on both ends of the spectrum (the highest and lowest scores). Smoking in-between the highest and lowest rate, for example score 2, is very volatile and will be absorbed to one of the ends of the spectrum. The most attractive smoking behavior for adolescents with friends that do not smoke is non-smoking. For adolescents whose friends do smoke, the most attractive behavior seemed to be smoking at the highest rate.

With regard to the other included effects, the significant squared component of the smoking tendency expresses the positive feedback effect of current smoking, confirming the addictive nature of smoking. Further, adolescents having at least one smoking parent or sibling had a higher tendency to smoke.

The results of the additional analyses indicated no differences in the main included smoking-based selection and influence effects between the three separate waves. Adolescents selected friends based on similarities in smoking behavior during each wave. The score test included to test for differences in selection based on similar smoking behavior between non-reciprocal and reciprocal friends, was significant in the second wave (left-sided chi-square = 37.99, df = 22, $p = 0.02$; right-sided chi-square = 8.18, df = 22, $p = 1.00$) implying that the tendency to choose similar smoking friends was significantly higher when selecting non-reciprocated friends as compared to reciprocal friends. This significant result was not found in the first (left-sided chi-square = 31.86, df = 20, $p = 0.05$; right-sided chi-square = 15.13, df = 20, $p = 0.77$) and third wave (left-sided chi-square = 17.07, df = 22, $p = 0.76$; right-sided chi-square = 20.76, df = 22, $p = 0.54$). In none of the three separate waves, a significant effect of average smoking behavior of friends was found, although a trend was visible.

3.4. Network autocorrelations

A descriptive statistic measuring the similarity of individuals linked in a network is Moran's I, a spatial autocorrelation coefficient (Cliff and Ord, 1981) applied to adjacency in the network rather than in space. By calculating the average network autocorrelation in simulated models with coefficients estimated under various model specifications, it is possible to express the contributions of each of these specifications to observed smoking similarity between friends. For this purpose we follow the approach explained more fully in Steglich et al. (submitted for publication). Five model specifications were used. The first is a baseline model expressing only the effects of the initial smoking distribution within the initial network, the time trends in number of friends and in smoking. This is a straw man model which serves only as a baseline. The second is a model including all control effects but excluding smoking-based friendship selection and excluding influence between friends. In this model the network dynamics and the smoking dynamics are modeled in a realistic way, but these two processes are assumed not to influence one another. The third model differs from the second by the inclusion of smoking-based selection effects, while the fourth differs from the second by including influence by the smoking behavior of friends. These two models, therefore, represent friendship–smoking co-evolution with only smoking-based friendship selection, and only

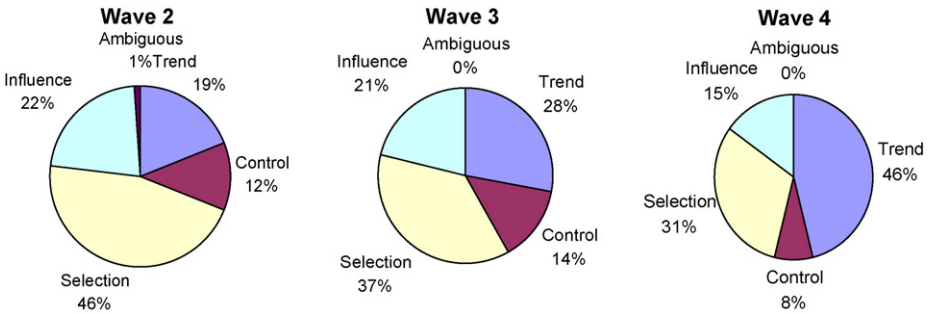

Fig. 2. The relative contribution of selection and influence processes to smoking behavior similarities.

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influence from friends on smoking behavior, linking the two subprocesses. The fifth model, finally, was obtained as the end result of the analysis presented in Table 3, assuming smoking-based selection as well as influence by friends. Network autocorrelation as expressed by the average Moran's I in a large number of simulations is expected to be lowest in the first and second models, intermediate in the third and fourth, and highest in the fifth model. The relative increase when going from the second to the third or from the second to the fourth model, compared with the increase from the second to the fifth, indicates the proportion of network autocorrelation that can be attributed to selection or to influence, respectively. Network autocorrelations were averaged across schools to obtain an overall picture for each of the three waves.

Fig. 2 presents the allocation of network autocorrelation as observed in waves 2–4 to diverse mechanisms generating similarity of friends, estimated by comparing the average values of Moran's I obtained under the five presented models. The slices labeled 'selection' cover the five included effects of adolescent's smoking behavior on network change (adolescent's own smoking behavior, effect of smoking behavior of potential friends, squared smoking behavior of adolescent, interaction between smoking behavior of adolescents and potential friends, and interaction of the latter effect with reciprocity), and the slices labeled 'influence' the single included effect of an adolescent's network on his own smoking behavior (smoking behavior of nominated friends). The slices labeled 'trend' cover the consequences of the network autocorrelation observed in the preceding wave, such as would be generated by a very simple model including only basic trends and the tendency to select arbitrary friends. The other alternative explanatory mechanisms, such as reciprocity, transitivity and influences of covariates, are represented by the slices labeled 'control'. The small 'ambiguous' slice is the proportion of network autocorrelation that could be allocated either to influence or to selection, depending on the order in which these components are included in the model.

The proportion of network autocorrelation allocated to smoking-based friendship selection was higher than the proportion allocated to influence processes in each of the three waves. The mean proportion allocated to selection decreased from 46% during the first wave to 31% during the third wave. The mean proportions allocated to influence decreased from 22% during the first wave to 15% during the last wave.

The increasing proportion allocated to trend effects reflects that patterns of smoking behavior and friendships crystallize over the years of adolescence: the effect of the preceding wave becomes more and more important. Other selection processes, such as selecting friends who are friends of friends or selection based on gender, and other influence processes, such as from parents and siblings, also play an important role to explain the observed network autocorrelations.

4. Discussion

The main goal of the present study was to test social influence and social selection processes in the interdependent dynamics of adolescent friendship networks and smoking behavior, while controlling the test of each of these processes for the other process and for other processes in the dynamics of friendship and of smoking. This was studied on the basis of a 4-wave panel study of smoking dynamics among adolescents (age 13–16 years) in 11 schools in Finland. Due to the dynamic and interdependent nature of friendship network ties and adolescent smoking behavior, a recently developed social network analysis method was employed: an actor-based model for friendship network and smoking behavior co-evolution. This method can account for alternative mechanisms explaining selection, as well as dependencies caused by network structure, and is capable of modeling continuous-time changes in smoking behavior and friendship networks.

Our findings demonstrate that selection and influence processes both played an important role in creating and maintaining smoking behavior similarity within friendships. In line with previous research that already acknowledged the importance of selection processes (Cohen, 1977; De Vries et al., 2006a; Ennett and Bauman, 1994; Fisher and Bauman, 1988; Kandel et al., 1978), adolescents preferred to select friends with similar smoking behavior. Nonsmokers were the most attractive for those smoking less than once a week, whereas those smoking on average more than one cigarette per week preferred to choose friends that smoked at the highest rate.

Support for peer influence within friendships, which is often suggested in the literature (Aloise-Young et al., 1994; Kandel et al., 1978; Sussman et al., 1990), was also found. The results of this analysis differ from the results of a previous study on the Finnish ESFA data (De Vries et al., 2006a), in which no support was found for influence among friends. However, in this previous study (De Vries et al., 2006a) only data of the first two observations were included and other statistical methods were used which do not fully account for the dependencies caused by the network structure, potentially leading to biased estimations of peer influence.

We furthermore found that the strength of influence processes did not differ between non-reciprocated and reciprocated friendships, implying that adolescents were influenced equally by their non-reciprocal and reciprocal friends. This contradicts previous studies that argue that reciprocal friendships encompass more opportunities for influence processes to cause smoking behavior similarities among friends due to higher friendship quality (Parker and Asher, 1993; Urberg et al., 2003).

The importance of smoking for selection of friends did differ between reciprocated and non-reciprocated friendships. Results indicated that similarity of smoking behavior played a role in friendship selection mainly for the selection of non-reciprocated friends. Furthermore, this effect was mainly found to be significant in the second data wave according to the results of additional analyses in the three separate data waves. Selection of non-reciprocated friends might be regarded as an initial phase of friendship formation, while returning a friendship might be regarded as a later phase of the friendship formation process. Previous research already demonstrated that similarity appeared to be relatively more important during the initial phases of friendship formation, when individuals choose potential friends. In later phases, when they establish long-lasting friendships, the provision of social and emotional resources such as companionship, emotional support, help and self-validation, becomes more important (Aboud and Mendelson, 1996), and may allow for more dissimilarity in smoking behavior. Another explanation might be the social position of the non-reciprocal friends in a larger friendship group. Previous studies have demonstrated that adolescents in the periphery of their peer group were the most important targets for selection (Pearson and Michell, 2000). Future research should examine selection and influence processes considering friendship reciprocity, in the context of larger friendship groups.

The present study included a number of alternative explaining mechanisms to counter biased estimations of influence and selection processes. In line with previous studies, this showed that adolescents highly preferred to reciprocate friendships and to become friends with friends of their friends (Burk et al., 2007; Snijders and Baerveldt, 2003), and to select friends based on gender and alcohol consumption similarities (McPherson et al., 2001; Steglich et al., 2006). This also yielded support for the feedback

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effect of current smoking behavior, which reflects the addictive nature of smoking. In line with previous studies (Avenevoli and Merikangas, 2003; McAlister et al., 1984; West et al., 1999), adolescents were furthermore influenced by the smoking behavior of their parents and siblings.

Smoking-based selection explained a larger proportion of smoking behavior similarity between friends, compared to influence of friends during each of the three successive waves. The contributions of both of these processes to similarity between friends of smoking behavior decreased over time while the contribution of the previous wave increased, reflecting that the friendship network and the smoking patterns become less fluid as adolescents age from 13 to 16.

The following limitations of this study may be mentioned. First, self-reported smoking behavior was not validated by biochemical measures. However, self-reports have been shown to be reliable and to correspond well with biological indicators when measurements are done under optimized measurement conditions, assuring anonymity (Dolcini et al., 1996). During the ESFA project, measurement conditions were optimized by guaranteeing strict confidentiality of adolescent responses (De Vries et al., 2003). Second, the use of a name generator limited to a maximum of five friends might have limited adolescents' possibilities to nominate all their best friends. However, previous research, allowing 7th graders to nominate any number of friends, showed that on average only 4.09 friends were nominated (Cairns et al., 2003). Allowing to nominate more than five best friends might provoke adolescents to nominate peers who are not 'best' friends. Third, we focused on friendships within schools in the same grade. Although for adolescents, these specific friends form an important social environment, they do not represent their entire social network of peers. Future social network studies should aim to include all friends outside and inside school. Fourth, standardized effect sizes are very hard to define and therefore not yet provided for complex models such as actor-based models which makes it difficult to compare our findings with results of previous studies. However, allocation of network autocorrelation to diverse processes (Fig. 2) and calculating the attractiveness of friends (Table 4) is a good alternative way to demonstrate the strength of selection and influence processes. Fifth, in the present study, we controlled for alternative selection and influence mechanisms involving observed and reported variables, although there could be selection and influence mechanisms involving unobserved covariates too. Finally, the conclusions obtained here are based on the specification of the actor-based model described above, and it is possible that other specifications, e.g., controlling for other processes by including other characteristics of adolescents or different specifications of the influence mechanism, would yield different results.

This study has several practical implications. First, smoking prevention programs should not solely focus on social influence processes, but also consider peer selection processes. Previous research already emphasized that peer network structure needs more attention within prevention programs besides the promotion of social influence skills (Dishion and Owen, 2002; Pearson and West, 2003; Valente et al., 2003). Second, the actor-based model for network and behavior co-evolution presented in the present study might be used also in different research fields to address a variety of interesting research questions. This model provides a tool to disentangle selection and influence mechanisms in numerous social network configurations and behaviors. Third, adolescents in the present study significantly selected friends based on similar gender, which indicates that there are gender segregated social networks of boys and girls. Future research might examine differences in selection and influence processes between boy and girl friendship networks.

Conflict of interest

The authors have no conflict of interest to declare.

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