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Dynamic associations of network isolation and smoking behavior

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Abstract

Prevailing social network frameworks examine the association between peer ties and behaviors, such as smoking, but the role of social isolates is poorly understood. Some theories predict isolated adolescents are protected from peer influence that increases smoking, while others suggest isolates are more likely to initiate smoking because they lack the social control provided by peer friendships. Building on a growing literature that seeks to explain these contradictions by moving beyond a homogeneous understanding of isolation, we identify the relationship between smoking and three distinct dimensions of isolation: avoided (adolescents who do not receive ties), withdrawn (adolescents who do not send ties), and externally oriented (adolescents who claim close out-of-grade friends). We examine the co-evolutionary effects of these dimensions and cigarette smoking using an autoregressive latent trajectory model with PROSPER Peers, a unique, longitudinal network dataset. These data include students (47% male and 86% white) from rural Iowa and Pennsylvania, ranging successively from grades 6–12 in eight waves of data. We find avoided isolation is associated with decreased subsequent smoking in high school. Smoking increases subsequent avoided and withdrawn isolation, but decreases external orientation.

Keywords: *social networks, social isolation, substance use, smoking, SEM, adolescence*

1 Introduction

Social isolation is often associated with a variety of negative health outcomes in adolescence. A range of studies find isolates are at greater risk for depression (Hall-Lande et al., 2007), suicidality (Bearman & Moody, 2004), and substance use, including smoking (Ennett & Bauman, 1993). However, several studies have found isolated teens both smoke more (Ennett & Bauman, 1993; Osgood et al., 2014) and less than socially connected teens (Henry & Kobus, 2007; Kobus & Henry, 2010). Discrepant findings for isolates may stem, in part, from the varied definitions of isolation used, including a feeling of lacking friendships (Tani et al., 2001), having one or zero ties (Fujimoto & Valente, 2012; Osgood et al., 2014), or having any number of ties with others on the fringe of a network (Ennett & Bauman, 1993). A nascent literature seeks to clarify isolation by separating conceptually distinct isolation types and isolating processes (Copeland et al., 2015; Niño et al., 2016; Schaefer et al., 2011).

We extend the isolation literature by examining the co-evolutionary relationship between isolation and smoking. We also consider three constituent dimensions of

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isolation: avoided, withdrawn, and externally oriented, which indicate fundamentally different positions in the social space of the school and orientations toward school peers. Using a unique, longitudinal dataset that follows adolescents' social networks and smoking behavior through middle and high school, we construct an autoregressive latent trajectory model (ALT) to examine complete network effects (withdrawn and avoided) and ego-network effects (externally oriented) simultaneously. The ALT measures within person change over time to provide an innovative tool for network analysts that can transparently model the co-evolution of behavior and isolation, including conceptually distinct types of isolates, who are rare in a given network and are not captured with existing measures typically used to estimate stochastic actor-oriented models.

2 Theoretical background

2.1 Dimensions of isolation

Most theories considering substance use and adolescent networks examine how behaviors spread through ties via peer influence or structure friendships through selection, implicitly assuming individuals are linked to others (Kirke, 2004; Mercken et al., 2010; Schaefer et al., 2012). This focus means the risks of substance use for isolated adolescents, who are relatively disconnected from peer networks, remain understudied. This gap is exacerbated because many studies focused on integrated adolescents often use very different definitions for isolates, a residual classification in these studies.

To address the conceptual ambiguity surrounding social isolation in adolescent networks, several recent studies distinguish theoretically meaningful isolation types and processes. Niño and co-authors (2016) describe three categories of isolated students: socially avoidant, socially disinterested, and actively isolated. This conception of isolation relates to the classification presented here, but relies heavily on adolescents' social skills to differentiate isolation types. These types also conflate the conceptually distinct dimensions we outline here by combining patterns of sent and received nominations in each type. Copeland et al. (2015) present three dimensions of isolation based on individuals' sent, received, and out-of-grade ties, while additionally considering each of the mutually exclusive subtypes generated by the interaction of the three isolation dimensions. Schaefer et al. (2011) distinguish two conceptually distinct network mechanisms that can lead to reduced network ties over time: avoidance, meaning a decrease in the number of ties received, and withdrawal, meaning a decrease in the number of ties sent. The authors find each mechanism contributes differently to depression homophily, as only withdrawal remains significant after controls, but the study does not go on to address isolation as the result of avoidance and withdrawal processes at their limit.

We further build upon the concepts of avoidance and withdrawal by considering the impact of friendships beyond the typical network boundary, by examining a health behavior rather than homophily, and by analyzing the co-evolution of smoking and social isolation over seven years of adolescence. The resulting framework captures how isolated adolescents hold different positions in the social space of the school, each with distinct orientations toward same-age peers and

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the school environment. These positions can be differentiated according to three conceptual dimensions.

We extend the distinction between avoidance and withdrawal mechanisms by considering the logical extreme of each process as two separate types of isolation: avoided and withdrawn. *Avoided* adolescents do not receive friendship nominations from other students, resulting in an in-degree of zero.[1] *Withdrawn* adolescents do not send friendship nominations to their peers, meaning they have zero out-degrees. We additionally consider *externally oriented* adolescents, who have ties with out-of-grade friends they consider as close or closer than in-grade peers. While an adolescent may experience multiple dimensions of isolation simultaneously (akin to the traditional definition of a complete isolate, who lacks both in- and out-degrees), here we examine these dimensions separately to outline the distinct co-evolutionary relationship of each dimension with smoking behavior.

Before hypothesizing associations between each isolation dimension and smoking, we briefly review why isolates may experience qualitatively different risks for substance use compared to socially connected peers. First, isolated teens may be particularly at risk for unhealthy or maladaptive behaviors because ties to school peers play a critical role in supporting healthy social development in adolescence. Same-age peers in school contexts provide critical reference points for learning social norms and developing a sense of identity (Cairns & Cairns, 1994). Having same-age (and therefore generally same-grade) friends in school is typical, prosocial adolescent behavior (Cotterell, 2007; McFarland et al., 2014). Isolation from in-grade friendships may exacerbate a sense of normlessness or lack of social control associated with increased antisocial attitudes and deviant behaviors like substance use (Ennett & Bauman, 1993; Hirschi, 1969; Rubin & Mills, 1988; Wentzel et al., 2004).

Second, smoking cigarettes is considered an illicit, adult-like activity associated with signaling deviant identity (DeLay et al., 2013) and other antisocial behaviors, including low school attachment, poor academic performance, and delinquency (Choi & Smith, 2013; Dishion et al., 1995; Urberg et al., 2003). While several studies examine variation in the perceived popularity of smoking across school contexts with different cultures and rates of cigarette use[2] (Alexander et al., 2001; Valente et al., 2005), smoking cigarettes can still be considered a more antisocial behavior compared to using other types of substances, like drinking alcohol, which are consistently associated with socializing and "party" atmospheres (Maxwell, 2002; Osgood et al., 2014).

[1] Consistent with previous networks literature, these dimensions refer to sent/received ties, not the qualitative or affective nature of relationships. The terms avoided, withdrawn, and externally oriented are concise short-hands referencing patterns of ties and conceptual orientations. For example, peers may feel indifference or active dislike for avoided isolates, as avoided isolation refers only to zero in-degrees. Accordingly, these dimensions are effectively captured with the name generator used in this study measuring close friendships, rather than negative ties.

[2] While the normativity of cigarette use may vary across school contexts, smoking is always a rare behavior in schools in our sample (no school reaches 40% or higher smokers). The deviance of smoking is heightened by the illegality of purchasing cigarettes under age 18, while smoking under 18 is also illegal in about half of our sample. Additionally, analyses account for the impact of different school cultures regarding smoking by using robust standard errors and controlling for average smoking behaviors.

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The antisocial orientations of both isolation and smoking suggest isolates may smoke more than connected peers if they turn to smoking to signal deviance or to cope with the stress of lacking typical in-grade friendships (DeLay et al., 2013; Ennett & Bauman, 1994; Osgood et al., 2014). In addition to isolation shaping smoking behavior, the antisocial nature of smoking in adolescence means cigarettes may affect isolation. Prosocial in-grade peers, who refrain from cigarette use may be more likely to terminate or avoid ties with peers who smoke, such that avoidance leads to reduced popularity of smokers over time (Schaefer et al., 2011), which may eventually lead to isolation. Similarly, smokers may withdraw from friendships with non-smoking peers (DeLay et al., 2013; Schaefer et al., 2011). These complex reciprocal processes between smoking and isolation highlight the necessity of disentangling isolation types to examine connections to smoking behavior in greater detail.

2.2 Hypotheses

We present hypotheses for each isolation dimension and smoking in turn below.

Avoided isolates receive zero friendship nominations from in-grade peers, suggesting exclusion from typical socializing. Received friendship nominations reflect how other students view the target adolescent in the social environment of the school. In-degrees reflect both observable friendships and aspirational friendships with high-status individuals, due to the tendency of youth with low social status to systematically send ties to high-status peers (Ball & Newman, 2013; Gould, 2002). Avoided students with an in-degree of zero are, therefore, not considered part of the peer social structure or have insufficient status to receive aspirational ties. Yet not receiving ties in itself does not suggest the target adolescent holds an antisocial orientation, since avoided adolescents may still be sending prosocial, unreciprocated friendship overtures to in-grade peers. We expect these adolescents are, therefore, no more likely than their socially integrated peers to use antisocial-signaling substances like cigarettes. Additionally, avoided isolates' relative lack of connections means we expect these teens to be less able to access cigarettes overall. Accordingly, we expect:

Hypothesis 1: Avoided isolation is associated with decreased subsequent smoking.

Withdrawn isolates do not nominate any classmates as friends. Sent ties, or out-degrees, are completely under an individual's control, meaning out-degrees reflect how an adolescent views their own position in the social ecology of the school. Adolescents with zero out-degrees to in-grade peers do not consider themselves part of the typical in-grade social network or seek prosocial connections with classmates, demonstrating an orientation away from in-grade peers and the school environment. Given this orientation away from in-grade peers, we expect withdrawn adolescents will be more likely to demonstrate behaviors signaling antisociality, including cigarette smoking. Thus, we predict:

Hypothesis 2: Withdrawn isolation is associated with increased subsequent smoking.

The third dimension of isolation, external orientation, refers to students who are focused toward peers outside of the grade, school, or grade and school boundaries.

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We combine these groups under the umbrella of out-of-grade friends to highlight their distinction from the reference category of in-grade same-school peers, who provide socially integrative friendships that foster well-being (Goodreau et al., 2009; McFarland et al., 2014). Several studies measuring networks and substance use find youth who lack in-grade friends are more likely to both claim higher numbers of out-of-grade friends and smoke cigarettes (Ennett et al., 2006; Ennett & Bauman, 1993). Externally oriented students focus their social energy on close ties with out-of-grade peers. While friends outside of a students' grade and school are not inherently deviant, research suggests these youth are more likely to socialize in unsupervised areas outside of the school setting that provide opportunities to engage in deviant behaviors like smoking, and are more likely to provide access to substances, like cigarettes (Ennett et al., 2008; Haynie & Osgood, 2005; Hoffman et al., 2006; Mahoney & Stattin, 2000).

We expect adolescents oriented away from in-grade peers toward out-of-grade peers, who provide greater opportunities to obtain and use cigarettes will be more likely to smoke:

Hypothesis 3: External orientation is associated with increased subsequent smoking.

In addition to isolation affecting smoking behaviors, we expect smoking behaviors affect isolation. As smoking is a deviant behavior signaling antisocial identity (DeLay et al., 2013; Kreager, 2004) and lacks the social connotations of other substances (Maxwell, 2002), smokers may be less likely to be nominated as a friend by in-grade peers in the future, leading to increased avoidance and ultimately avoided isolation of smokers over time. Smoking, as a behavior signaling deviance, is often mirrored by increases in other antisocial behaviors (Dishion et al., 1995), including friendship behaviors like eschewing ties with in-grade peers (Ennett & Bauman, 1994). Smoking would then lead to subsequent increases in withdrawn isolation and external orientation. Accordingly, we predict smoking behaviors will be associated with subsequent increases in all three types of isolation:

Hypothesis 4: Smoking increases avoided, withdrawn, and externally oriented isolation.

Finally, it is important to note that isolation and smoking behavior in adolescence are both subject to developmental processes. Developmental changes may affect the association between smoking and isolation by shaping a variety of social and behavioral processes. Development in adolescence is associated with changes in the extent of reciprocity or cross-gender ties (McFarland et al., 2014; Molloy et al., 2014), the degree to which isolation indicates antisociality or inner turmoil (Wentzel et al., 2004), and changes in the social motivations and prevalence of substance use into emerging adulthood (Arnett, 2000, 2004). Additionally, most adolescents experience puberty, prompting a range of physical, psychological, and social changes as teens mature (Hamilton et al., 2014; Poulin & Pedersen, 2007). We expect these developmental processes will lead to independent increases in both smoking behavior and isolation from in-grade peers over time, and accordingly consider time trends in our analysis, but make no specific predictions about

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how developmental changes might moderate the association between smoking and isolation.

3 Data

The data for this project come from the PROSPER (Promoting School-community-university Partnerships to Enhance Resilience) Peers project, which studies adolescent social networks and behaviors (Spoth et al., 2004, 2011). This survey sampled two cohorts of students from every school with a 6th grade in 28 selected school districts located in rural Iowa and Pennsylvania. Sampled schools come from districts with enrollments ranging from 1,300 to 5,200, with predominantly white student populations (ranging from 61% to 97%) where at least 15% of families are eligible for free or reduced school lunch. The survey was first administered in the fall of 2002, when the first cohort was in 6th grade, then repeated every Spring for each cohort, resulting in eight waves of data covering grades 6–12. Thus, wave 1 data include when students are in the fall of 6th grade, wave 2 from the spring of 6th grade, and the waves 3–8 from each subsequent Spring of grades 7–12. Schools were randomly assigned to receive a school-based intervention program targeting resilience against substance use, and a subset of adolescents within treatment schools participated in a similar family-based intervention program.

Network data were collected using an open name generator at each wave of the survey. Students listed up to seven peers in response to the question "Who are your best and closest friends in your grade?" These names were matched to the roster of students to form 271 in-grade networks, where one student is a vertex, and a friendship nomination is a directed edge. Students also answered "How many friends do you have who go to other schools who are AS CLOSE or CLOSER to you than the friends you listed above?" and a similar question about friends in other grades. Note that like many surveys of adolescent networks, these questions capture close ties, meaning weak ties are not considered in the present study. Taken together, these questions provide a measure of the complete, in-grade network in which a student is embedded, and an ego-centric measure of the number of connections that he or she has outside of the grade.

Our primary variables will be binary variables indicating past month *cigarette use*, *avoided*, *withdrawn*, and *externally oriented*. *Cigarette use* indicates whether the student self-reported smoking in the previous month. *Avoided isolation* is measured as an indicator of whether the student was not listed as a friend by any other students in their network. *Withdrawn isolation* is measured as an indicator of whether the student did not list any other people in their network as friends on the survey. *External orientation* is a dummy variable indicating whether the student identified that he or she had more than one friend outside of his/her grade or outside of his/her school as close or closer than any in-grade peers listed. In network terms, avoided isolation is a dummy variable indicating that the student's in-degree is 0, withdrawn isolation is a dummy variable indicating that the student's out-degree is 0, and external orientation indicates that a respondent has more than one close out-of-network tie. Like most school-based surveys, the PROSPER dataset does not collect information about the out-of-network alters. Accordingly—regardless of the method employed—researchers do not have a lever to analyze

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Table 1. Summary statistics of selected variables for grades 6–12 by smoking status.

Variable	Proportion or mean (SD)		Range	Proportion missing
	No cigarette use	Cigarette use		
Isolation				
Avoided isolate	0.155	0.108***	0–1	0.061
Withdrawn isolate	0.227	0.126***	0–1	0.061
External orientation	0.381	0.421***	0–1	0.298
Controls				
Observation (in grade 9–12)	0.755	0.505***	0–1	0.00
White	0.869	0.852***	0–1	0.025
Male	0.469	0.491***	0–1	0.001
Treatment group	0.483	0.489	0–1	0.00
Grade	0.675	1.790***		
(Centered on 8th grade)	(1.931)	(1.752)	−2 to 4	0.00
Waves observed	6.481	5.999***	2–8	0.00
	(1.624)	(1.770)		
Observations	53092	10076		

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, or difference in proportion mean by smoking status.

the influence or selective effect of these ties. Instead, we must look to whether the existence of such close ties, i.e. an external orientation, has an effect on smoking behavior.

In our modeling strategy, we control for gender (*male* = 1, female = 0) and race (*white*=1, non-white = 0) using dummy variables. We also include a fixed effect for the year the student started 6th grade with a dummy variable (*cohort*), and whether the individual was in a treatment school by dummy variable (*treatment group* = 1, untreated group = 0). We also include a dummy variable for *high school* (grades 9–12) and a continuous measure of *grade*, centered on 8th grade. We center on 8th grade for two reasons. First, this centering moves the overall mean grade close to 0 (as shown in Table 1). Second, it provides a sensible reference category to interpret differences between middle and high school, with intercept terms centered on the transitional grade (Raudenbush, 2002). By interacting *high school* and *grade* and the *high school* dummy variable, the model freely estimates two piecewise constant slopes: one slope for middle school (baseline) and one for high school (adjusted). This allows direct comparison of developmental trajectories in addition to between- and within-person differences.

In our analytic sample, we remove individuals who were held back ($n = 116$), moved between different treatment group schools ($n = 156$), or are observed only once in the survey period ($n = 2{,}068$). Our final analytic sample includes 14,481 individuals and 64,246 person-waves for these students. As external orientation was only measured in grades 8–12, analyses including this dimension are limited to those grades, using 11,802 individuals and 33,352 person-waves.

4 Methods

We develop a series of ALT models (Bollen & Curran, 2006, p. 218) to test the inter-relationships among smoking behavior and three dimensions of social isolation,

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measuring simultaneous change across these four endogenous dependent variables over seven periods of observation. The ALT developed by Bollen and Curran (2004; 2006) flexibly combines an autoregressive (cross-lagged) design with a latent trajectory, which, unlike a simple cross-lagged design, adjusts for dependence across individual observations with fixed or random effects (Bollen & Curran, 2004). By design, the ALT controls for important blind spots in simple cross-lagged models, which are biased by both individual-specific effects at the observation level and developmental trajectories at the population level (Curran, 2000). The fundamental model assumes an ongoing, endogenous process that occurs at the individual level, or that an individual's observed state at time $t+1$ is conditional on the observed state at time t. We use a modified version of Woolridge's "auxiliary working model" for the endogenous, dichotomous outcomes to condition subsequent observations on the initial observations, which are treated as exogenous (Wooldridge, 2005).

Observations of the outcome, y, across the four dimensions noted above, d, are written as a two-level model, for individuals, i, and observations t as follows:

Level 1 (within-person equation):

$$g\left(y_{it}^{(d)}\right) = \alpha_i^{(d)} + \gamma^{(d)} x_{it} + \rho_t^{(j)} y_{it-1}^{(j)};\ t = 1, 2, 3...$$

Level 2 (between-person equation):

$$\alpha_i^{(d)} = \lambda_0^{(d)} + \lambda_y^{(d)} y_{i0}^{(d)} + \lambda_z^{(d)} z_i + \lambda_x^{(d)} x_{i0} + \lambda_{\bar{x}}^{(d)} \bar{x}_{i\cdot} + \omega^{(d)}.$$

This provides a classic longitudinal specification as a hierarchical model, where individuals are nested in time: level 1 provides estimates relative to cross-dimensional changes within individuals, and level 2 provides estimates relative to the average differences between individuals. Our model is estimated with a logit specification in the level 1 equation. As a multivariate model, there are coefficients for each dimension of smoking and isolation (d) as well as coefficients for cross-dimensional effects (j). γ represents the conditional effects of time-varying covariates (x), and ρ indicates the stability coefficient when lagged across the same dimension (when $j = d$), and the net cross-dimensional effect with respect to the other dimensions (when $j \neq d$). α represents an individual, randomly distributed effect. The random effects of each dimension ($\omega^{(d)}$) are jointly distributed with a stochastic disturbance of mean 0, and a covariance matrix that allows for correlation between random effects. First observations y_{i0} are modeled as exogenous variables, which affect outcomes by adjusting the conditional mean of the random effect, and through the stability coefficient ρ when $t = 1$. We interact the lagged observation of each dimension ($y_{it-1}^{(j)}$) with a dummy indicator for high school to provide a straightforward test of differences in associations among isolation types and cigarette use between high school and middle school.

In the level 2 equation, we also condition the randomly distributed individual effect on all observed fixed individual characteristics (z) like race and gender; on the first observations of each dependent dimension ($y_{i0}^{(d)}$), the first observation of each time-varying control (x_{i0}), like grade level, and each individual's mean of the time-varying controls ($\bar{x}_{i\cdot}$). These adjustments allow for accurate estimation of the cross-dimensional effects (ρ), even when the time-varying control is endogenous (Skrondal & Rabe-Hesketh, 2014). In other words, if the effect of an isolation type

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is conditional on grade level, controlling for the individual's mean observed grade minimizes bias from the association.

To test the dynamic interplay across the dimensions of smoking and isolation, we estimate four models. Models 1–3 include estimates with cross lags (ρ) for cigarette use and each dimension of isolation separately. These models do not allow for cross-influence among isolation types. Moreover, Models 1 and 2 (for avoided and withdrawn isolation) include the dummy variable and interaction for high school, freely estimating different associations between these isolation types and smoking based upon whether the respondent is in grades 6–8 or grades 9–12. Since external orientation is not measured in middle school, Model 3 includes only high school grades.

Model 4 loosens the assumption that isolation types are independent by modeling all dimensions simultaneously. This means that all isolation types are allowed to cross-influence each other (as well as smoking status). This model allows for a propensity *toward* or *away* from isolation. For example, if an avoided isolate is more likely to become a withdrawn isolate, Models 1–3 do not measure the association, and correlation with smoking may be spurious for any particular isolation type. Model 4 avoids this potential spuriousness by directly testing the independence of the isolation types and modeling all of the isolation types together.

We estimate all models with a logit link using Mplus 7 with a full information maximum likelihood estimator, adjusted for correlation of individuals residing in the same school district (*community*) by using robust standard errors.

We use the ALT for several key reasons. First, this model avoids bias from spuriousness with time. Second, the ALT allows us to distinguish within- from between-person change to examine within-person associations between isolation dimensions and smoking over time. As part of this strategy, the ALT centers on individual-level means to reduce risks of bias from omitted, time-invariant individual characteristics, much like individual fixed effects (difference) models (Allison, 2009). Similarly, the robust standard errors also account for differences across school and community contexts (e.g. prevalence of smoking in a given school). Third, the ALT, like other models with a logit link function, generates parameters that are relatively simple to interpret, which allows us to consider different trajectories in middle and high school with relative ease. Fourth, the ALT allows us to examine the relationship between smoking and the dimensions of isolation separately as well as allowing each dimension of isolation to co-vary, to provide a more accurate and realistic picture of how these dimensions may associate with smoking.[3]

5 Results

5.1 Descriptive statistics for ALT

Table 1 includes selected descriptive statistics for the full analytic sample covering grades 6–12 and provides preliminary evidence for a relationship between isolation

[3] While stochastic actor-oriented models (SAOM's) can also examine co-evolutionary relationships between networks and behavior, the dimensions of isolation cannot be measured separately by the current version (1.1.294) of the most popular software tool for estimating these models, RSiena, particularly in relation to behavioral outcomes as we explain further in Section 6.

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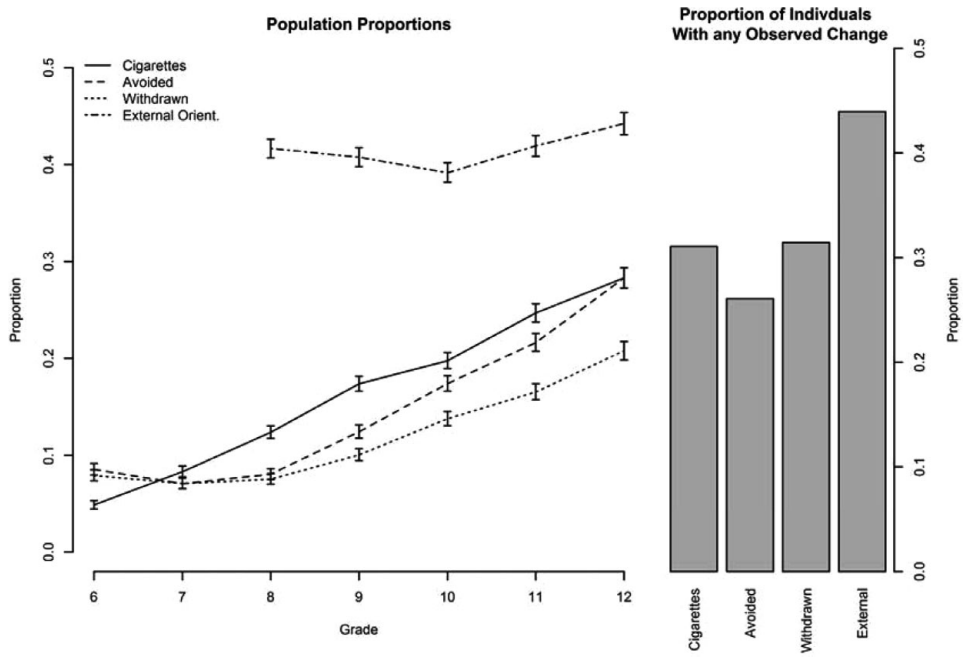


Fig. 1. Proportion of population across waves and proportion of individuals changing, for each dimension of isolation and smoking status.
Note: Error bars indicate 95% confidence intervals. Right panel reports proportion of individuals with any change on a dimension at any wave in any direction.

types and smoking. However, the association between these statuses is complicated by time and individual variability.

The left panel of Figure 1 graphs changes in proportions of smoking and isolation dimensions over grades 6–12. The proportions of cigarette use, avoided isolation, and withdrawn isolation increase fairly steeply (from under 10% to over 20%), while external orientation increases modestly between grades 10 and 12. These patterns suggest developmental trajectories for isolation types and smoking behavior across adolescence.

Additionally, the dependent variables show significant variation across individuals. The right panel of Figure 1 identifies the proportion of individuals in the sample, who change at any point for each variable. The final bar in this panel shows that despite the fairly stable population levels of external orientation, 44% of individuals have at least one observed change in external orientation status. Similarly, while there are larger population changes for avoided isolation, there are a smaller proportion of individuals with observed changes (26%), suggesting avoided isolation is more persistent once acquired. The changing population trajectories and importance of accounting for individual change shown by the descriptive statistics strongly suggest both individual variation and time must be considered to accurately estimate these dynamic associations, as the ALT is designed to do.

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5.2 Cross-influence of smoking and independent isolation types with the ALT

Figure 2 summarizes the results of three ALT models for each separate isolation dimension (Models 1–3), which show avoided isolation is associated with decreased cigarette use (Hypothesis 1), smoking is associated with increased withdrawn isolation and decreased external orientation (Hypothesis 4), and the relationship between smoking and isolation differs between middle school and high school. Full results of the models summarized in Figure 2 are included in the supplemental Table S1. Each model adjusts for the grade of the observation to control for population-level trends, and includes an individual, random intercept to control for fixed individual characteristics. This random intercept is adjusted for controls at the initial observation for respondent gender, race, and treatment group status and includes robust standard errors with adjustments for the respondents' school district to control for school contextual effects.[4] In terms of the ALT equation outlined above, Figure 2 reports the effects designated as ρ.

Only significant effects ($p < 0.05$) are shown in Figure 2, with solid lines representing positive associations (odds ratio greater than 1), dashed lines representing negative associations (odds ratio less than 1), and arrow size proportional to the odds ratio. Standard errors for the p values of high school effects were estimated using the delta method.

The top panels in Figure 2 show that avoided isolation is negatively associated with subsequent smoking (consistent with Hypothesis 1). This association is marginally negative in middle school with an odds ratio of 0.771 (0.61–1.01, 95% C.I.), and does not significantly differ between middle and high school. The middle and bottom panels of Figure 2 (Models 2 and 3 in Table S1) provide partial support for Hypothesis 4 with smoking influencing withdrawn isolation. Although the baseline influence of smoking on withdrawn isolation is marginally significant ($p < 0.1$; row 1 column 4 of Table S1), the effect increases in high school, reaching classical levels of significance with an odds ratio of 1.364 (1.301–1.431, 95% C.I.). Counter to Hypothesis 4, smoking is associated with decreased subsequent external orientation with an odds ratio of 0.880 (0.795–0.973, 95% C.I.; row 1, column 6 of Table S1). As neither withdrawn isolation or external orientation increases subsequent smoking, these models do not support Hypotheses 2 or 3. Overall, these results suggest that smoking increases subsequent withdrawn isolation and decreases external orientation in high school, while only avoided isolation has an effect on subsequent smoking behavior.

These findings indicate the constituent dimensions of isolation are differentially associated with smoking. However, Models 1–3 implicitly assume that each dimension of isolation operates independently on cigarette use, when in reality, isolation types

[4] We have also run models separately between treatment and non-treatment schools, and results show substantially similar associations between the treatment and non-treatment groups with respect to the cross-association of isolation types and smoking, with only minor differences in magnitude. Accordingly, there is no difference across treatment groups for the key findings of the study. There are statistically significant differences in the association between isolation types, however. As shown in Table 2, withdrawn isolation and external orientation are both inversely associated, though the effect of withdrawn isolation on subsequent external orientation is only marginally significant. For treatment schools, these effects are in the same direction, but much stronger and highly statistically significant. In non-treatment schools the effects are non-significant.

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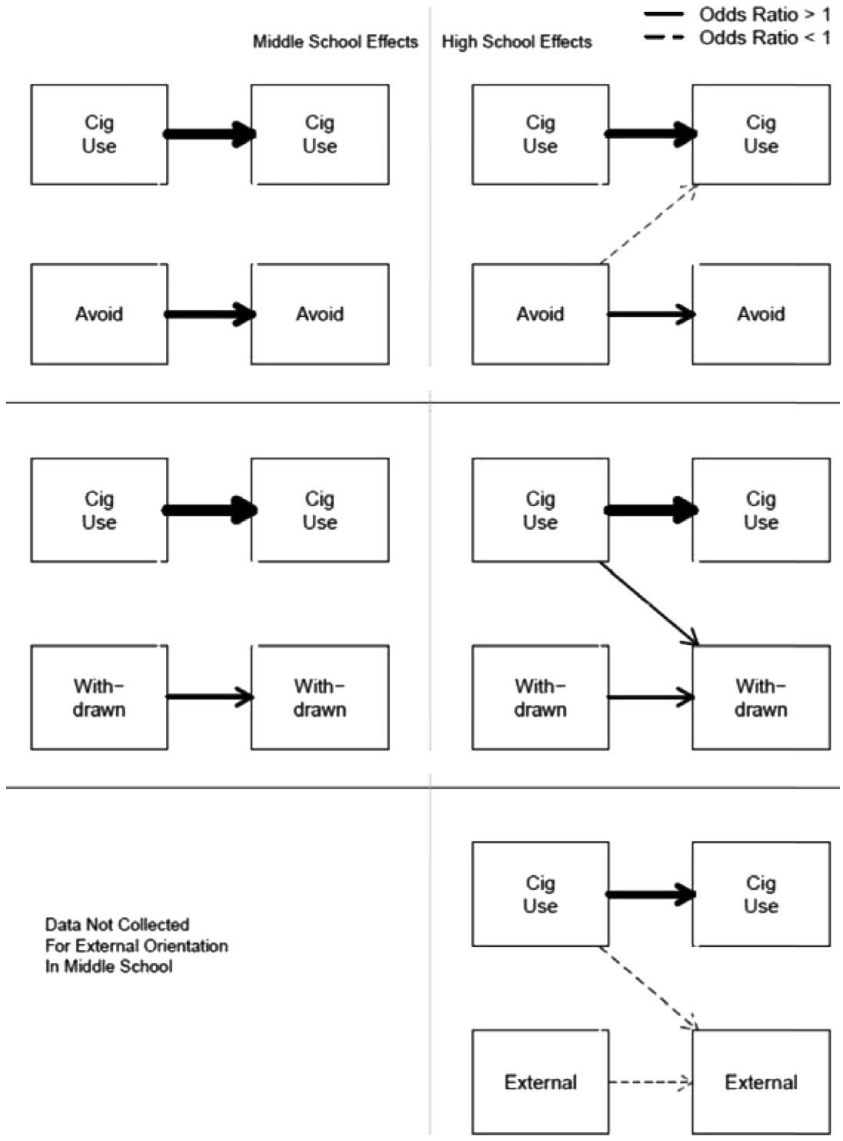


Fig. 2. Path diagram for Models 1–3 showing cross-evolution of cigarette use with isolation types.
Note: Size of arrow is proportional to odds ratio; only significant effects ($p < 0.05$) are pictured. Diagram adjusts for individual random effects and all controls (not pictured). Diagram reports results in Models 1–3 of Table S1.

likely co-vary at times. Model 4 builds upon Models 1–3, relaxing this assumption of independence by allowing cross-associations among the isolation dimensions as well as cigarette use.

5.3 Considering isolation types dynamically with the ALT

Model 4 reports results of a four dimensional dynamic logistic regression in Table 2. Model 4 is limited to high school outcomes (grades 9–12 with a baseline measure

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Table 2. Results of multivariate logistic regression (Model 4).

Variables	Cigarette	Avoided	Withdrawn	External
Within person				
Cigarette $_{t-1}(\rho)$	1.282***	0.352***	0.383***	−0.128*
	(0.072)	(0.070)	(0.068)	(0.051)
Avoided $_{t-1}(\rho)$	−0.083	0.607***	0.041	−0.068
	(0.078)	(0.075)	(0.070)	(0.056)
Withdrawn $_{t-1}(\rho)$	0.036	0.119†	0.355***	0.145**
	(0.077)	(0.069)	(0.076)	(0.053)
External $_{t-1}(\rho)$	−0.092†	−0.067	−0.188***	−0.458***
	(0.053)	(0.052)	(0.050)	(0.041)
Between person intercepts				
	$\alpha_{\text{cigarettes}}$	α_{avoided}	$\alpha_{\text{withdrawn}}$	α_{external}
Intercept	2.181***	−0.288**	2.415***	1.893***
	(0.116)	(0.090)	(0.112)	(0.126)
Initial obs Cigarette $_{t=0}$	2.887***			
	(0.105)			
Initial obs Avoided $_{t=0}$		1.661***		
		(0.081)		
Initial obs Withdrawn $_{t=0}$			1.536***	
			(0.083)	
Initial obs External $_{t=0}$				1.176***
				(0.045)

Note: N = 33,353; BIC = 459,724. Limited to parameters of interest; full table included in supplement. Gray shading indicates parameters not estimated in Models 1–3.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, $^{\dagger}p < 0.1$.

at grade 8) when external orientation data are available. In some respects, Model 4 results are consistent with those from Models 1–3. First, the results of Model 4 remain consistent with Hypothesis 1 that avoided isolation is negatively associated with subsequent smoking (Table 2, row 2 column 1), although the effect is not statistically significant.

Second, like Models 2 and 3, Model 4 reports positive associations between smoking and subsequent withdrawn and avoided isolation (row 1 columns 2–3, Table 2). However, the effect is negative for external orientation. While data on external orientation is not available in middle school, Model 3 shows that there is an increase in external orientation across grades in high school. It may well be that having close out-of-grade friends is increasingly typical or prosocial in high school as teens develop increasing friendships with peers of varying ages while entering emerging adulthood.

Because the effects of Model 4 are fully conditional on the both the within-person dynamic associations among isolation types (highlighted gray in Table 2) and between-person covariances across isolation types and smoking (last 4 rows at the bottom of Table S2), these patterns show that the dimensions are not independent. Rather, external orientation is associated with decreasing withdrawn isolation (row 4, column 3). Additionally, individual, between-person propensities to withdrawn and avoided isolation are negatively correlated with external orientation (rows 17–

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18, column 4), meaning the association observed between smoking and subsequent external isolation is also conditional on the cross-influence of external orientation and withdrawn or avoided isolation, as both avoided and withdrawn isolation are positively associated with smoking. In other words, Model 4 suggests that isolation dimensions have complicated associations with each other over time, as well as with smoking.

Sensitivity analyses indicate ALT estimates for the co-evolution of isolation types and smoking is consistent across a number of specifications. Estimates are similar with models including additional time-varying covariates, such as free school lunch (a proxy for socioeconomic status), or whether the respondents live with both parents (a measure often correlated with adolescent substance use and sociality) (Osgood et al., 2014). The model is also consistent with or without community-level robust standard errors, and estimates are generally consistent when estimated separately for treatment groups. Finally, unlike overly-simplistic cross-lagged models, the estimated ALT effects explicitly include endogenous effects, such as isolation.

6 Discussion and conclusion

The relationship between social isolation and substance use presents an interesting case that challenges expectations for typical network processes like peer influence or selection, while at the same time isolated adolescents may face greater risks of adopting deviant behaviors with negative health consequences like smoking. We provide the first steps toward disentangling the complicated co-evolutionary relationship between smoking and dimensions of isolation by building upon a nascent literature that differentiates isolation types and processes. We identify three conceptually distinct dimensions of isolation: avoided, withdrawn, and externally oriented. Each dimension suggests separate positions in the social space of the school, orientations toward and recognition from in-grade peers, and potential associations with substance use. We use an ALT model to distinguish the association between each isolation dimension and smoking net of individual time-invariant characteristics and contextual factors.

Results illustrate three key findings. First, avoided isolation is negatively associated with subsequent smoking in high school (supporting Hypothesis 1). Second, smoking increases subsequent avoided and withdrawn isolation, but not external orientation (partially supporting Hypothesis 4). Finally, the dynamic associations between isolation and smoking are mainly operative in high school rather than middle school. Results did not show a significant association between withdrawn isolation or external orientation and subsequent smoking (failing to support Hypotheses 2 and 3).

These findings are consistent with theories regarding peers as pathways for accessing cigarettes in adolescence (Dishion & Owen, 2002; Haas & Schaefer, 2014; Kobus, 2003), as isolated adolescents are less likely to subsequently use cigarettes than non-isolates. ALT results distinguishing isolation dimensions indicate smoking may be particularly subject to avoidance and withdrawal processes as found with depressed youth (Schaefer et al., 2011; Van Zalk et al., 2010). External orientation is also associated with lower relative odds of subsequent withdrawn isolation, meaning that individuals with out-of-grade ties are likely to maintain in-grade ties, while

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the positive association from withdrawn to external orientation suggests withdrawn isolates are more likely to develop out-of-grade ties compared to peers who are not withdrawn.

The differential cross-influence of these isolation types suggests traditional conceptions of isolation as homogeneous lack critical information for understanding the relationship between isolation and smoking. Additionally, the link between smoking and increased subsequent isolation suggests adolescent smokers not only face the physical risks of addiction and compromised health, but may be increasingly exposed to risks associated with social isolation. Policy makers should consider how distinct types of isolation indicate teens who face different risks for substance use. For example, avoided adolescents may be protected from subsequent smoking behavior, while smoking increases avoided and withdrawn isolation, which may carry further risks of increased detachment from peer contexts critical to healthy adolescent development.

In this study, we have proposed a new modeling approach for social isolation, an ALT model. The model that we use has two advantages over simple, population-level cross-lagged structural equation models that have historically been used to investigate network processes (Curran & Hussong, 2003; Snijders et al., 2010). First, it controls effects that are spurious because of a shared relationship with time. For example, both withdrawn isolation and smoking increase over time, as shown in Figure 1. The ALT provides a test for whether these increases are independent, which is especially necessary as adolescents are experiencing developmental changes. Second, the ALT includes individual fixed effects, which allow us to estimate within-person effects. These within-person estimates effectively control for *any* time-invariant characteristics of a person, including unobserved characteristics.

The key disadvantage of the approach we propose is its inability to explicitly model higher-order network dependencies. Although an SAOM can model network dependencies, at the time of writing, the current version of the most common SAOM software, RSiena (version 1.1-294), cannot model the effect of distinct dimensions of isolation on behavioral outcomes like smoking. Table S3 contrasts the estimates that the ALT produces with the estimates available from an SAOM. As the table indicates, the current software for SAOM's cannot distinguish the effects of avoided or withdrawn isolation on a behavioral outcome, while external orientation can only be modeled as an individual covariate or dependent behavior.[5]

To test our hypotheses, RSiena would need to include parameters for the effects of each isolation dimension on behavior and allow these separate isolation types to interact with behaviors to predict subsequent network changes. External orientation presents a challenging case as a SAOM can measure the effect of having out-of-network friends on sending or receiving in-network ties, but it is not possible to

[5] Specifically, RSiena has structural network parameters that separate out-degrees and in-degrees for isolation, such as those for an in-degree isolate to send outgoing ties, for the inverse tendency of ego to have zero out-degrees, and for ego to send ties to an alter who otherwise might be in-degree isolated (the in-isolate out-degree, truncated out-degree, and anti in-isolates effects, respectively). However, the only behavioral effect related to isolation considers total isolates, meaning the effects of each separate type of isolation on the differential attractiveness of smoking cannot be distinguished (Ripley et al., 2016). While the isolation dimensions can be included as time-varying individual covariates, this can create discrepancies between isolation covariate status and the network ties predicted in the micro-steps of the model.

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examine structural network parameters like transitivity with out-of-network ties. While this is a fundamental boundary limitation of any network data collection, RSiena currently does not provide a way to address these missing data.

The ALT additionally estimates some quantities that SAOM's would have difficulty estimating in theory. In particular, SAOM's are ill-equipped to handle within-person estimates (Steglich et al., 2010). While the SAOM may be able to theoretically adjust for within-person differences by including a dummy variable for each person in the sample, such a strategy is often computationally infeasible. The ability to estimate within-person effects, controlling for any time-invariant characteristics of an individual, is a key advantage of the ALT as compared to an SAOM.

A further advantage of the ALT model that we propose vis-à-vis SAOM's is its parsimony, which allows us to make use of data from all of the schools. SAOM's require fitting the parameters of an agent-based model to each school network separately. For example, in Model 4, the ALT requires fitting 73 parameters to the observed data. By contrast, a comparable SAOM fit on the same sample would require thousands of parameters (e.g. estimating only 10 parameters per model, times the number of independent high school networks (52), plus $1-n$ (11,801) individual dummy variables for individual fixed effects requires estimating a total of 12,321 parameters). By taking advantage of the partial pooling across school networks by using random effects in the ALT (Gelman & Hill, 2006), we are able to estimate the model even for cases that are statistically rare in a given school, like isolated smokers. In an SAOM, the rarity of these cases in smaller schools may have caused estimates to not converge, leading to an analyst throwing away data in non-convergent schools. While the SAOM does allow pooling using Bayesian statistics, both computational time and weak theoretical development on appropriate prior elicitation make this pooling impractical (Ripley et al., 2016, pp. 101–104). The ALT allows us to parsimoniously use data from all of the schools in a well-studied Frequentist framework, which we consider a significant benefit.

The accuracy of the ALT in a network setting, particularly with respect to an SAOM, depends on the extent to which isolation is driven by higher-order network effects for which the ALT cannot control. If the association between isolation and smoking is driven by reciprocity or transitivity, for example, the ALT would likely estimate an effect of isolation when no such effect should be found. By explicitly modeling the network processes that could jointly change isolation and smoking, the SAOM could, in principle, identify how isolation and smoking coevolve more accurately. If, on the other hand, isolation is largely orthogonal to local network effects, then we expect that the ALT will be unbiased, and in certain cases, less biased than an SAOM. For example, if an unobserved, time-constant personality trait causes both social isolation and smoking, an SAOM would erroneously identify an association between social isolation and smoking, while the ALT, by controlling for time-invariant individual characteristics, would correctly identify no association between social isolation and smoking.

For the specific case of social isolation, the difference between the SAOM and ALT may not be as large as it seems. Both fundamentally assume there is something about social isolates that causes other students to avoid them, or that causes them to withdraw from peers. In the SAOM, this is most clearly demonstrated by the

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parameter used by the current version of the RSiena software to estimate the effect of in-degree isolation, the anti in-isolates effect, which estimates the effect of a student wanting to send a tie to a peer who would be isolated otherwise. For this parameter to be sensible, adolescents must know a given classmate is unlikely to receive ties from anyone. Conceptually, this measure is similar to saying that there is some effect of being a student others want to avoid, which is the effect that the ALT estimates.

As guidance for future researchers, we suggest three possible frameworks for considering the isolation–smoking relationship, and whether the ALT or an SAOM—with appropriately modified software—would be preferable. First, if the isolation–smoking association is driven by isolation dimensions representing enduring and distinct positions in the underlying social space of the school, the ALT and SAOM models should be comparable. Second, if the isolation–smoking relationship is driven by—or is confounded by—local network effects, then the SAOM should be more accurate. Finally, if the smoking–isolation relationship is spurious on developmental trajectories or time-invariant individual characteristics that are not easily quantified then we would expect the ALT to be more accurate. Using their *a priori* beliefs about which process is primarily driving the results, future researchers can use this heuristic to choose the best modeling approach. Ultimately, however, we encourage the further development of the measurement of the effect of isolation dimensions on behavior in the RSiena software so that the differences between these approaches can be tested explicitly.

This study has several limitations beyond the inability of the ALT to model local network effects. First, data were not collected on external orientation in middle school, which limits our examination of the effect of external orientation over time. Second, the sample is limited to students in rural communities in Iowa and Pennsylvania. The results may not extend to other contexts, such as urban settings, or outside of the United States. Additionally, deviant or antisocial students might be less likely to thoroughly complete the survey, which would result in exclusion from our sample or observation as withdrawn isolation. Finally, while the ALT measures within-person change, there could still be unobserved factors correlated with either smoking or isolation, such as other delinquent behaviors, creating a spurious relationship between isolation and cigarette use.

Our findings suggest future research should consider isolation a multi-dimensional concept, as lacking in-degrees or out-degrees are not socially equivalent processes for substance use. Further research is needed on the role of close ties beyond school network boundaries, particularly for students who otherwise appear isolated. Because we find dynamic effects between isolation dimensions and smoking, at least some of the dynamics of smoking behavior appear to operate separately from direct influence of friends. In addition, these co-evolutionary trajectories are not stationary, but change as students move from middle to high school as predicted by developmental literature. The interplay across these dimensions illustrates the importance of long-term data collection projects like PROSPER Peers for disentangling adolescent smoking behaviors. Such projects are important for understanding adolescent development and social processes, and guiding policies aiming for reduced adolescent substance use. Such policies can benefit from considering the social differences of

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smoking in middle versus high school, the role of isolation dimensions for smoking, and the increased social costs of cigarette use.

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Supplementary materials

To view supplementary material for this article, please visit https://doi.org/10.1017/nws.2017.9.

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