Cross-Dimensional Selection and the Co-evolution of Adolescent Social Networks and Substance Use[1]

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[1] Presented at the 2011 annual meeting of the Population Association of America. This research was supported by a grant from the Eunice Kennedy Shriver National Institute of Child Health and Human Development R21HD060927. Do not cite or distribute without permission from the authors.

INTRODUCTION

Researchers have long been interested in the role of peers and social influence processes in determining health related behaviors such as smoking, drinking and other substance use. More recently this has included the study of social network processes. A consistent finding from that work has been homophily on health-related behaviors such as smoking and other substance use (Ennett and Bauman 1994). Traditionally, this approach has tended to view network ties as fixed and exogenous to social influence and behaviors. This has led researchers to focus on the psychosocial pathways by which individuals *influence* the behavior of their peers. Thus the existence of social relationships were often taken as a given without much regard for the notion that substance use may influence the creation and maintenance of ties as substance use may impact one's relative desirability as a peer. More recently, research has acknowledged that individuals play a role in determining who their friends are. Thus, homophily on health behaviors may be due to not only influence, but also friend selection mechanisms. Thus, any investigation of homophily must examine both selection into similar relationships and influence on the behavior (Steglich, Snijders and Pearson 2010a).

This creates a paradoxical situation. On the one hand social relationships largely form on the basis of homophily. However, in order for peer influence (behavioral socialization) to occur there must be imperfect homophily on the behaviors in question. In other words, peer influence can only occur in the absence of homophily. Thus, the question remains, what mechanisms operate to inhibit homophily?

One explanation for this paradox centers on the multidimensional nature of friend selection. That is, multiple dimensions (i.e., age, sex, SES) operate simultaneously to draw individuals together. Despite the extensive amount of research on homophily, few

researchers have considered how dimensions of homophily may operate in conjunction. An exception is prior work on consolidation (Blau 1977). Blau argued that when dimensions are positively correlated within populations, homophily on one dimension can contribute to homophily on the other. For example, when income and education are positively correlated, homophilous selections on education create homophily on income as well. Alternatively, when dimensions are negatively correlated, selection on one can create heterophily on the other.

We propose an alternative mechanism that works against selection homophily. We propose that multiple dimensions not only work simultaneously, but have complex interactions in the form of *cross-dimensional selection.* Cross-dimensional selection occurs when an individual's attribute A affects one's choice of partners on another attribute B. For example, students with low school attachment may be more likely to select peers involved in substance use than students with high schoo attachment. This process can bring students with low school attachment together with students who engage in substance use, which creates the opportunity for influence on substance use to occur.

To better understand the role of social influence on substance use we attempt to separate out its effects from those associated with the peer selection process. In doing so we seek to provide a more detailed picture of the selection process that puts people at risk for peer influence. Specifically we test the cross-dimensional selection mechanism by modeling who selects substance users as friends and who do substance users select as friends?

BACKGROUND

Numerous social psychological theories have been suggested to understand illicit substance use among adolescents. For many of these theories, peers are seen as central to the process. For example, according to social learning theory, peers can influence both use-efficacy by modeling substance use and thus providing knowledge and information necessary for use, and refusal self-efficacy by modeling successful avoidance strategies (Bandura 1982). Similarly, peer's perception that their close friends approve of substance use is critical in understanding alcohol and marijuana use (Akers et al. 1979). Fisher and Bauman (1988) go as far as to suggest that high level of similarity in substance use that social learning theory attributes to peer influence actually reflects the tendency for adolescents who experiment with illicit substance to choose as peers those who similar experiment. However, other than the vague notion that experimenters choose each other, social learning theory provides little guidance as to why some adolescents choose peers who use illicit substances while others do not.

Social control theory (SCT) (Elliot et al. 1989) and the social development model (SDM) (Hawkins & Weis 1985), provide rationales for why adolescents may form relationships with substance users. Though they propose somewhat different mechanisms both SCT and SDM posit that adolescents turn to deviant others as a result of weak attachment to conventional social norms such as academic achievement, and institutions such as schools, churches, and family. This social disconnectedness can result from low social and academic skills, which are necessary to facilitate positive interactions with traditional peers and institutions and opportunities to reinforce pro-social norms. Thus adolescents with weak attachment to traditional influences are more likely to form attachments to similarly disconnected others who use substances. Empirical analysis

indeed suggests that rebellious, alienated, non-conforming youth, and those who feel detached from family, school, and religion are more like to use substances (Jessor, Donovan and Costa 1991) and to form ties with deviant peers (Elliot et al. 1985; Jessor et al. 1991).

Recently there have been calls to study the process of peer influence as a two-stage process which first models the selection into networks and then the influence of peers conditional on friendship formation (Urberg, Luo, Pilgrim, & Degirmencioglu 2003; Arnett 2006). Selection refers to the processes by which relationships form between individuals – why individuals choose the friends they do. Individuals select their friends for several reasons, including (1) others' characteristics (as in status seeking), (2) joint characteristics (i.e., homophily), and (3) endogenous network processes (such as transitivity, whereby friends of friends are more likely to become friends). Most research examining peers, health behaviors, and psychological characteristics has not considered selection, instead treating the network of relationships as exogenous (Bauman and Ennett 1996). The limited research that exists on selection has been interested in its role in producing homophily and differentiating its effect on dyadic similarity from that of influence (e.g., Cohen 1977; Hoffman et al. 2007; Kandel 1978; Simons-Morton and Chen 2006). Accordingly, recent studies have utilized advancements in dynamic social network models to estimate the impact of substance on peer selection process and the subsequent influence of peers.

Dynamics of Substance Use and Friendship Networks

Advances in social network modeling now allow researchers to simultaneously consider changes in behavior due to social influence as well as the role of the behavior in

driving network change. Specifically, the Stochastic Actor-Based model allows one to simultaneously model changes networks and individuals behavior over time (Snijders 2001; Steglich et al., 2010a). Much research on health-related behavior following the SAB approach has demonstrated that similarity in substance use significantly predict the formation of friendship ties (Mercken, Snijders, Steglich, & de Vries, 2009; Mercken, Snijders, Steglich, Vartiainen, & Vries, 2010 a, b; Pearson, Steglich, & Snijders, 2006; Steglich, Snijders, & Pearson, 2010). This effect has been consistently observed in adolescent friendship networks in Europe (i.e., Scotland, UK, Finland, Denmark, Netherlands, Spain, and Poland). It is noteworthy that two of these studies demonstrated that similarity on smoking behaviors positively contributes to the likelihood of friendship formation regardless of the frequency of this behavior (Pearson et al., 2006; Steglich et al. 2010b). The other three revealed the effects of homophily on smoking are contingent of the magnitude of that behavior suggesting that adolescents who smoked more frequently were more likely to select friends with similarly high levels of smoking (Mercken et al., 2009; 2010a, 2010b).

Most recent work has been directed to providing a multidimensional account of how smoking affects friendship formation by focusing on interaction of this behavior with various network processes (Mercken et al., 2010a, 2010b; 2009). For instance, Mercken and colleagues (2010a) considered the role of reciprocity of friendship nominations in order to describe smoking effects on network formation. They found a significant negative three-way interaction of effects of smoking behavior on outgoing and incoming friendship nominations and reciprocity suggesting that the noted similarity on smoking behavior operated only among friendship ties that were not already reciprocated.

Such a pattern is likely to emerge when the adolescent who nominated the friend, who does not reciprocate, is using smoking as a friendship formation basis/peer group entry. This pattern is especially troubling because smoking is used as an activity through which the nominator "attempts" to form a relationship, which does not happen. But what happens is that nominator picks "friends" who are likely to smoke as much as he does. This results in adolescents who smoke together a lot, but without benefits of being friends.

In another study of nine friendship networks of Finnish teenagers focusing on gender dynamics implicated in smoking and network co-evolution, Mercken and colleagues (2010b) reported no gender differences in the role of homophily on smoking behaviors for friendship tie formation. This study showed that both males and females selected friends who reported to smoke more frequently if they likewise were frequent smokers. No gender differences were reported in the tendency to select reciprocate or nonreciprocated friends who are similar in smoking behavior. Overall, they did not observe any significant gender differences in network formation processes related to smoking.

All of these studies estimate two additional effects of the effects of smoking behavior on network evolution. The first one is the effect of smoking on the number of outgoing nominations that an adolescent sends out in his or her network, and the second estimates the role of smoking for the number of incoming friendship nominations, thus, describing the attractiveness of a smoker as a potential friend. Only two studies reported that smokers were significantly more attractive as potential friends among adolescents from Scotland, Denmark, and Spain (Mercken et al., 2009; Pearson et al., 2006). Only

Mercken and colleagues (2009) found a negative association between smoking behavior and the number of outgoing friendship ties among Dutch students. Finally, three studies reported no significant effects of smoking on the outgoing, incoming friendship nominations, and incoming nominations squared term, which emphasizes the effects of smoking behavior for highly popular and unpopular adolescents (Mercken et al., 2010a, 2010b; Snijders et al., 2010). Thus, existing evidence is rather mixed about whether smokers are different from nonsmokers in (a) the number of friends that they nominate and (b) the degree of their attractiveness as potential friends.

Finally, Mercken et al. (2010a) examined the contributions of all of the smoking-related effects to the objective network function in order to describe the attractiveness of adolescents as potential friends based on their degree of smoking. They observed that focal adolescents who did not smoke at all were mostly attracted to nonsmokers as friends; those who smoked 0-1 cigarettes per week preferred to be friends with others who smoked at the same rate, and those who smoked more than 30 cigarettes per week preferred peers with the same levels of smoking. Interestingly, focal adolescents who smoked 2-10 and 11-30 cigarettes per week were mostly attracted to peers who smoked at much higher levels than they did, more than 30 cigarettes per week. Thus, it appears that intermediate smokers were more attracted to peers with higher level of tobacco consumption, which is likely to lead to escalation of their own smoking.

Selection across Multiple Dimensions

This paper explores how individual dimensions such as those implicated by SCT and SDM interact to select individuals into social relationship with substance users and thus put them at risk for social influence. Beyond interactions that produce homophily,

we propose *cross-dimensional selection*, which occurs when one's value on a particular dimension facilitates a tie to someone with a particular value on a second dimension. Cross-dimensional selection may help explain the peer selection process by which adolescents are placed at risk for social influence. For example, adolescents with low levels of school attachment may be more like to form ties with those with high levels of substance use. An important consequence of cross-dimensional selection is the lack of perfect homophily on the two cross-dimensions. Cross-dimensional selection would allow an adolescent who has low school attachment, but doesn't engage in substance use, to form a friendship with a peer who does engage in substance use. This provides the first adolescent with exposure to substance use behavior, thereby increasing his or her risk. This type of process has not been investigated previously, but is an important complement to research on homophily. Strong tendencies toward homophily act to prevent behavioral differences between individuals. Cross-dimensional selection is a process that can act as a counterbalance to the force of homophily. It can thus help explain the paradoxical simultaneous presence of wide spread homophily and social influence.

Several researchers have recognized the multidimensional nature of relationships, that individuals are simultaneously drawn together or repelled from one another based upon a range of characteristics (Blau 1977; Burt 1990; Huckfeldt 1983; Laumann 1973; Popielarz and McPherson 1995; Skvoretz 1983). Research has detailed the gradations of homophily, the relation between social position and homophily, and how some dimensions are more salient than others (Marsden 1987). Yet, the majority of research on homophily has examined a single dimension (Feld 1982; Hallinan and Williams 1989;

Robins, Elliott and Pattison 2001) or multiple dimensions sequentially rather than simultaneously (Blau et al 1984; Burt 1990; McPherson and Smith-Lovin 1987; Marsden 1987; Skvoretz 1990).[2] Recent work in network modeling has begun to consider dimensions simultaneously (Goodreau, Kitts and Morris 2009), though the emphasis has remained on treating dimensions independently.

Although dimensions may have interactive effects on friendship in many ways, we focus specifically on cross-dimensional selection. Cross-dimensional selection occurs when an individual's value on one dimension is associated with a friend's value on another dimension. For example, cross-dimensional selection would exist if males have a greater preference than females to associate with sensation-seekers. To be classified as cross-dimensional selection, the rate of association between males and sensation seeking would need to be net of homophily on sex and sensation seeking. Established social psychological theory implicitly hypothesizes a form of cross-dimensional selection as a key mechanism leading to adolescent substance use. To be more specific, extant theory hypothesizes that adolescent's value on one dimension (weak attachment to conventional social norms and institutions) increases their odds of forming ties with others with particular values on a second dimension (deviancy/substance use). In the analysis below we investigate cross-dimensional selection along characteristics that social psychological theories suggest place adolescents at risk for affiliation with substance using peers. These include low socioeconomic status, low academic achievement, low levels of school

[2] An exception to the uni-dimensional approach to homophily is the work of Fararo and Skvoretz in their development of two-dimensional biased-net models, which capture levels of homophily under a given population distribution (Fararo and Skvoretz 1984, 1989; Skvoretz 1983; Skvoretz and Fararo 1986). These models do not include interactions between dimensions, implicitly assuming that biases toward homophily are independent.

belonging, depression, low self-esteem, and non-intact families. We do this within a model that estimates the simultaneous co-evolution of networks and substance use.

METHOD

The analysis below utilizes the wave 1 in-school (time 1), wave 2 in-home (time 2), and wave 3 in-home (time 3) interviews from the National Longitudinal Study of Adolescent Health (Add Health). Time 1, time 2, and time 3 interviews were conducted between September 1994 to April 1995, April 1995 to December 1995, and April 1996 to August 1996, respectively. The SIENA framework is used to model peer selection and behavioral dynamics in complete social networks. For that reason we restricted our analysis of Add Health to network and survey data from 2 large schools (school 77, n = 2,062; school 58, n = 924) from which complete networks can be constructed.

Network and Dependent Variables

Friendship networks. Students were asked to nominate up to 5 male and 5 female friends. These nominations were used to construct directed networks at each time. At the initial interview, approximately 5% of students were only allowed to name 1 male and 1 female friend. To control for this anomaly, our models include a dummy variable indicating whether or not the adolescent received the truncated friendship roster (0 = full friendship roster; 1 = truncated friendship roster).

Substance use behavior. The outcome variables used in analyses were frequency of tobacco use, marijuana use, and alcohol use. Each of the behavioral outcome variables was assessed at both time points. Students were asked how many days they had smoked cigarettes in the past 30 days. Adolescents were classified as non-smokers, light smokers,

or regular smokers (0 = never, 1 = smoked 1 to 11 days in the past 30 days, 2 = smoked 12 or more days in the last 30 days).

For marijuana use, students were asked how many times in the past 30 days they had used marijuana. Marijuana use was coded as an ordinal variable, indicating whether the student did not use marijuana, used marijuana infrequently, or used marijuana frequently (0 = no marijuana use in past 30 days, 1 = used marijuana 1 to 4 times in the past 30 days, 2 = used marijuana 5 or more times in the past 30 days).

Regarding alcohol use, students were asked how many days they had drank alcohol in the 12 months prior to interview. Alcohol use frequency was coded as an ordinal variable indicating whether the adolescent did not use alcohol, used alcohol infrequently, or used alcohol regularly (0 = no alcohol use, 1 = used alcohol once or twice a week or less, 2 = used alcohol more than twice a week).

Cross-Dimensional Selection Factors

We measured six individual attributes that place adolescents at risk for selecting substance-using peers. *Parent education* was coded as an ordinal measure indicating the highest level of education reached by either parent (0 = no school, 1 = less than HS degree, 2 = high school degree or GED, 3 = some post-secondary school, 4 = college graduate, 5 = beyond 4-year degree). *Grade point average* (GPA) was included as the average of the student's grades in math, science, history, and English was taken with scores ranging from 4 = A, 3 = B, 2 = C, 1 = D or lower. Grades from each course were averaged with low scores indicating poor academic performance. *Self-esteem* was assessed using the average value of each adolescent's response to six questions ("You have a lot of good qualities", "You have a lot to be proud of", "You like yourself just the

way you are", "You feel like you are doing everything just about right", "You feel socially accepted", "You feel loved and wanted"; 1 = strongly disagree, 5 = strongly agree). This measure exhibited good reliability (α = .87). *School belonging* was measured as the average response to 6 questions ("You feel close to people at your school", "You feel like you are part of your school", "Students at your school are prejudiced" (reverse coded), "You are happy to be at your school", "The teachers at your school treat students fairly", and "You feel safe in your school"; 1 = strongly disagree, 5 = strongly agree), and this measure had adequate reliability (α = .67). *Depression* was coded as a dichotomous variable indicating whether the student exhibited signs of depression. Each students was asked 19 questions regarding depression taken from the Center for Epidemiological Studies Depression Scale (CES-D), with each response ranging from 0 (never or rarely) to 3 (most of the time or all of the time). Males with a score of 21 or higher, and females with a score of 23 or higher, were coded as depressed (0 = not depressed, 1 = depressed).

Parent marital status was used indicate if the student was residing in a single parent household (0 = parent reports being married, 1 = parent reports being single, widowed, divorced, or separated).

Controls

The adolescent's sex, age, and race/ethnicity were included to control for selective affiliation and behavior dynamics associated with these characteristics. Parental tobacco use was included to control for the adolescent's home environment. Parent smoking was a dichotomous measure indicating whether either the mother or father were smokers (0 = neither parent smoker, 1 = one or both parents are smokers). Lastly, to

control for structural factors that promote friendship, we measured extracurricular activity participation. For each pair of adolescents in the network, we calculated the number of activities (out of 30 possible activities) in which both adolescent participated.

Analysis

The co-evolution of adolescent social networks and smoking behavior was assessed with a Stochastic Actor-Based (SAB) model using the Simulation Investigation for Empirical Network Analysis (SIENA) package in the R statistical program (Ripley and Snijders 2010). The SAB model is developed around a multinomial probability model focusing on the creation and dissolution of network ties, with an objective function specifying the structural aspects of the network and individual attributes that are hypothesized to affect change in the network. The SAB model provides each actor opportunities to make changes to their outgoing ties within the context of constraints and opportunities determined by the structural aspects of the social network and the individual's personal attributes. SAB models are estimated using a continuous-time Markov process where the trajectories between observations are imputed and changes to the network are assumed to be dependent only on the current state of the network. Snijders and colleagues (2010) give a detailed explanation of the SAB modeling framework.

Model Specification

Numerous effects can be included to control for the influence of network structure and individual attributes on friendship dynamics, and the estimates taken from these effects can be interpreted as the level of "preference" of the average network member for

forming and preserving friendship ties based on the given effect. Thus, larger parameter values reflect that the friendship ties producing the effect are more likely to exist.

Friendship selection processes. The friendship selection side of the model focuses on determining predictors of network formation. A rate parameter was included in all models to control for the observed level of change in the friendship network. The probability of making a friendship choice was conditioned by characteristics of the network structure as well as adolescents' characteristics. Current network structure influences possible friendship choices (McPherson et al. 2001, Snijders 2001; Van de Bunt, van Duijn, and Snijders 1999), thus controls were included for the number of friends chosen (out-degree), number of reciprocated friendship nominations (reciprocity), and the number of friends named who were also friends of a friend (transitivity). Also, the square root of the number of incoming friendship nominations was included as a control for the adolescent's popularity.

In addition to the selection processes influenced by structural effects, friendships may be developed selectively with individual characteristics being the basis of friendship ties. For example, adolescents' smoking behavior may influence the number of incoming friendship nominations (in-degree), outgoing friendship nominations (out-degree), as well as the likelihood of forming a friendship with another student who has similar smoking behaviors (similarity). In addition to friendship selection based on tobacco and alcohol use behavior, we included tests of individual effects for gender, age, parents' smoking behavior, and GPA. In the model exploring tobacco use we included controls for adolescents' alcohol use frequency, and in the model exploring alcohol use frequency we included controls for adolescents' tobacco use frequency. We also controlled for the

increased likelihood of nominating friends who participate in similar extra-curricular activities. Finally, we included a control for friendship selection based on race/ethnicity. School 77 was the only school in our sample with adequate amounts of racial heterogeneity for use of this effect, so our meta-analysis presents this estimate for school 77 only.

We included two effects for each of the six cross-dimensional selection factors hypothesized to place adolescents at-risk for selecting substance-using peers. The first effect tests how an at-risk factor (i.e., depression) affected the likelihood of selecting a peer with a higher level of substance use. Second, we also included a control for how substance use behavior affected the likelihood of selecting a peer who was more at risk (i.e., more depressed).

Behavior influence processes. With controls for friendship selection in place, estimates of tobacco and alcohol use behavior change were specified. A rate effect was included in all models to control for the level of observed change in the behavior across the two waves. A linear behavior change shape effect was included for both the tobacco use and alcohol use models, and the effect of the behavior on itself (quadratic shape effect) was included for alcohol use (our use of a dichotomous measure of smoking disallowed the use of the quadratic behavior effect). Individual characteristics included in the behavior portion of the model tested the effect of gender, age, parent's smoking, and GPA on the likelihood of increasing or decreasing tobacco and alcohol use. In the tobacco use model, alcohol use was included as a behavior effect, and in the alcohol use model, tobacco use was included as a behavior effect. Also, an effect was included to assess the likelihood of the respondent's behavior change based on the average similarity

between the respondent's tobacco or alcohol use and the tobacco or alcohol use of their peer group. Finally, we control for the possible influence of the average age of the respondent's peer group on the respondent's smoking and drinking behavior.

RESULTS

Baseline Models

We first present baseline models that demonstrate the role of smoking, alcohol use, and marijuana in the friend selection process. These models do not include cross-dimensional selection effects. Table 2 presents estimates from the base model of smoking. The top half of the table provides estimates from the peer selection part of the model. As expected there are strong and significant homophily effects by gender, age, race, and smoking behavior (similarity effects). Over time adolescent's networks are more likely to select friends who are similar to themselves on sex, race, age, and smoking behavior. Girls are also less likely to be nominated by their peers as friends (female alter). The smoking alter effect suggests that smokers are more likely to be nominated than are non-smokers. However, smokers nominate fewer friends than non-smokers.

The bottom of table 2 presents estimates of the behavior function. The smoking average similarity effect detects the impact of social influence. There is a significant positive effect of smoking average similarity. Thus, over time adolescents are altering their smoking behavior in ways that make them more similar to the behavior of their peers. Girls are slightly more likely to increase their smoking over time as are older adolescents, those with lower academic achievement, from non-intact families, and those with less attachment to school. We find no significant impact of self-esteem or depressive symptoms on the rate of smoking over time.

Estimates for the baseline model of alcohol use are presented in table 3. In addition to the homophily on age, gender, race, and activities, we find a significant positive effect of alcohol similarity on the probability of ties existing over time. Thus, adolescents are more likely to select friends with similar levels of alcohol use. There is also a marginally significant effect of alcohol use alter, suggesting that peers who use more alcohol are more to be nominated as friends than are non-drinkers. The bottom of table 3 provides estimates of the alcohol behavior function. There is a marginally significant positive effect of average similarity. This suggests that kids are altering their alcohol consumption in ways that make them similar to their peers. We also find that girls, those with greater degree of school belong, and those from single-parent households drink less alcohol over time than other adolescents. Kids whose parents smoke are more likely to drink alcohol than those whose parents do not. We find no effect of GPA, self-esteem, or depressive symptoms on alcohol consumption.

Table 4 provides estimates of marijuana use. As with smoking and alcohol use we find homophily on marijuana use within friendship networks. We also find that adolescents who use marijuana are significantly more likely to be selected as friends than are non-users. In the behavioral function we find a significant positive effect of average similarity on marijuana use. Therefore adolescent's behavior regarding marijuana use is becoming increasingly more like that of their friends over time. This suggests a significant role for social influence on marijuana use. In addition, the baseline model reveals that kids with higher GPAs and self-esteem are less likely to use marijuana. However, those with greater depressive symptoms and those from single-parent homes are more like to use marijuana.

Cross-Dimensional Selection

Having examined whether substance use influences one's relative desirability as a peer we then tested for cross-dimensional selection to see if the selection of substance using peers is more common among those predicted by substance use theory. We estimated a separate model for selection on each combination of the six at-risk factors and three substance-use behaviors. Table 5 provides estimates of the eighteen cross-dimensional selection models. Though not shown, each model controls for the main ego, alter, and similarity selection effects for the substance-use modeled and the at-risk factor.

Among the factors examined here we find significant evidence of cross-dimensional selection for four of the six at-risk behaviors (no evidence was found for parent education or GPA). Beginning with self-esteem, we expected that adolescents with lower self-esteem would be more likely to choose substance-using peers, which would be a negative cross-dimensional selection effect. As shown in Table 5, this is the case for alcohol use and marijuana use, where the cross-dimensional selection effects are negative. Adolescents with greater self-esteem are less likely to select friends who use alcohol (μ_θ = -.17, $p < .001$) and less likely to select friends who use marijuana (μ_θ = -.06, $p < .001$). We expected the same pattern of negative effects for school belonging. Results again provide support for the hypothesized effects of school belonging on selecting substance-using peers. Adolescents with greater school belonging were less likely to select friends who smoked (μ_θ = -.09, $p < .001$), used alcohol (μ_θ = -.19, $p < .001$), or used marijuana (μ_θ = -.11, $p < .001$).

We expected depressed adolescents to be more likely to select substance-using peers, which would produce a positive cross-dimensional selection effect. As shown in

Table 5, more depressed adolescents were more likely to select friends who smoked tobacco ($\mu_\theta = .06$, $p < .001$) or marijuana ($\mu_\theta = .29$, $p < .001$). We had the same expectation for adolescents living with a single parent. Results indicate that adolescents living with one parent were more likely to select friends who drank alcohol ($\mu_\theta = .17$, $p < .001$).

In combination, these results provide strong evidence for the presence of cross-dimensional selection. We found at-risk adolescents were more likely to select friends who smoked, drank alcohol, and used marijuana. Importantly, these cross-dimensional selection effects were observed net of the main effects and homophily. For example, the observed effect that adolescents with lower self-esteem were more likely to select friends who drank alcohol is net of the tendency for adolescents to select friends with similar levels of self-esteem and alcohol use.

DISCUSSION

This study uses a dynamic actor-based model to investigate the co-evolution of friendship networks and substance use overtime among US adolescents. In particular the study investigates the process of cross-dimensional selection by which one's value on a particular dimension facilitates a tie to someone with a particular value on another dimension. Established theory of adolescent substance use predicts cross-dimensional selection will occur as adolescents who lack secure attachment to traditional norms and institutions as evidenced by characteristics such as low GPA, low self-esteem, depression, and low attachment to school will be more likely to form ties with deviant peers and those who use illicit substances. Our analysis provides evidence that cross-dimensional selection operates to structure friendships within adolescent friendship

networks and place individuals at risk for social influence for substance use. The results shed light on the underlying social dynamics by which various social psychological factors long known to be risk factors for adolescent substance use may be operating. Risk factors such as low SES, non-intact families, low academic and personal skills, depression, and low attachment to traditional institutions like schools operate in part by influencing the peer selection process. While their effects are heterogeneous across substances, these factors increased the likelihood of forming and maintaining ties with peers engaging in illicit substance use. The results thus provide empirical support for both social control and the social development model. Unlike previous research we have analyzed these processes within a dynamic framework that models simultaneous change in both the structure and composition of social networks as well as their behavior over multiple time points.

Interestingly we also find that smoking, alcohol, and marijuana use increases one social desirability within the network as those who use substances are more likely than their non-using peers to be nominated as friends. To the extent that adolescents themselves are cognitively aware of the larger social network it may thus also be the case that adolescent view the use of these substances as gateways to increased social status, popularity and social connectedness. Adolescents are actively involved in seeking status or approval from their peers, which comes from associating with high-status friends. Strategies to associate with high-status peers may involve adopting behaviors that make one more attractive to high-status others. There are several correlates of high status; common examples include school grade, family background, and sports participation. These behaviors differ in their ability to be adopted with some, such as family

background, impossible for an adolescent to change. Athletics participation can change, however that option is limited to adolescents with greater athletic capabilities. School grade changes as adolescents get older, but cannot be manipulated by them. In general, behaviors that convey maturity are status conveying; however, there are constraints on the behavior-change strategies adolescents can pursue. A strategy that is open to all adolescents is the adoption of taboo behaviors that signal maturity. For example, research has documented that one reason adolescent girls begin smoking is to enhance their prestige (Michell and Amos 1997). If such a strategy is successful, and smoking conveys maturity, then we would expect adolescents who smoke to have more ties to older peers. This may also be the case for additional behaviors that are considered risky for adolescents, including alcohol use, sexual activity, and illicit drug use.

Most of the at-risk measures we identified are not only risk factors for selecting substance-using friends, but are also risk factors for one's own substance use. The logical next step is to investigate how these risk factors operate to encourage substance use, with particular attention to the role of peers. The cross-dimensional selection model proposes that these at-risk factors operate by promoting friendships with peers who already engage in substance use and are likely to serve as a negative influence. Thus, we would expect cross-dimensional selection behavior to be followed by increases in substance use behavior. Our ongoing research is currently addressing these processes.

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Table 1: Descriptive Statistics

	School 58			School 77		
	Mean	SD	%	Mean	SD	%
Smoke period 1	0.84	0.88		0.26	0.59	
Smoke period 2	0.93	0.89		0.35	0.66	
Marijuana period 1	0.36	0.66		0.25	0.58	
Marijuana period 2	0.42	0.75		0.27	0.61	
Alcohol period 1	1.05	0.76		0.67	0.77	
Alcohol period 2	0.97	0.88		0.63	0.87	
Female	0.47	0.50		0.51	0.50	
Age	15.39	0.99		15.69	0.76	
Parent smoke	0.78	0.41		0.58	0.49	
Flag for presence of 2 or 10 nominations	0.04	0.20		0.04	0.19	
Parent education	2.90	1.08		2.82	1.31	
Average GPA	2.64	0.75		2.62	0.79	
Self-esteem	3.71	0.83		3.83	0.72	
Depression	0.08	0.28		0.12	0.32	
School belonging	3.42	0.63		3.52	0.63	
Single Parent	0.21	0.41		0.21	0.41	
Number of extra-curricular activities	1.58	1.94		1.01	1.53	
White			97.18			2.84
Black			0.00			20.82
Hispanic			1.28			40.85
Asian			0.51			32.97
Indian			0.77			1.10
Other race/ethnicity			0.26			1.42
Similarity on Attribute						
Female	0.50			0.50		
Age	0.73			0.84		
Similarity race	0.98			0.70		
Parent smoke	0.66			0.51		
Flag for presence of 2 or 10 nominations	0.92			0.93		
Parent education	0.76			0.71		
Average GPA	0.72			0.70		
Self-esteem	0.77			0.80		
Depression	0.85			0.79		
School belonging	0.83			0.80		
Single parent	0.67			0.66		
Alcohol use	0.73			0.74		
Marijuana use	0.71			0.79		
Smoking	0.53			0.78		
Network Descriptives						
Jaccard Index	0.24			0.28		
Average degree period 1	3.53			2.09		
Average degree period 2	2.82			1.76		

Note: School 58 N = 509, School 77 N = 645

Table 2: Baseline SAB model for smoking

Network Function Estimates	μ_θ	se
Basic rate parameter friendship	7.91***	2.30
Effect presence of 2/10 nom. on rate	-1.00***	0.18
Out-degree (density)	-4.49***	0.61
Reciprocity	2.15***	0.22
Transitive triplets	0.50***	0.01
In-degree (sqrt.)	0.36***	0.08
Activities	0.35***	0.10
Female alter	-0.08***	0.00
Female ego	0.00	0.04
Female similarity	0.37***	0.13
Age alter	0.08	0.09
Age ego	-0.03	0.02
Age similarity	1.03***	0.02
Same race	1.02***	0.07
Smoke alter	0.14***	0.01
Smoke ego	-0.03*	0.01
Smoke similarity	0.71***	0.14
Behavior Function Estimates		
Rate smoke period 1	1.97***	0.06
Smoke linear shape	-1.03	0.84
Smoke quadratic shape	1.22***	0.06
Smoke average similarity	2.61***	0.36
Smoke effect from female	0.01***	0.00
Smoke effect from age	-0.08†	0.05
Smoke effect from parent smoke	0.25	0.20
Smoke effect from parent education	0.01	0.03
Smoke effect from GPA	-0.14***	0.02
Smoke effect from self-esteem	-0.03	0.06
Smoke effect from depression	-0.03	0.19
Smoke effect from school belonging	-0.31***	0.06
Smoke effect from single parent	-0.31***	0.05

Note: $\mu\theta$ = estimated average effect size † p< .10; * p< .05; ** p< .01; *** p<.001, School 58 N = 509, School 77 N = 645

Table 3: Baseline SAB model for alcohol use

Network Function Estimates	μ_θ	se
Basic rate parameter friendship	7.81***	2.39
Effect presence of 2/10 nom. on rate	-0.99***	0.22
Out-degree (density)	-4.50***	0.72
Reciprocity	2.16***	0.20
Transitive triplets	0.51***	0.01
In-degree (sqrt.)	0.36***	0.09
Activities	0.36***	0.10
Female alter	-0.09***	0.00
Female ego	-0.01	0.05
Female similarity	0.37***	0.14
Age alter	0.09	0.09
Age ego	-0.02	0.02
Age similarity	1.00***	0.01
Same race	1.03***	0.07
Alcohol alter	0.10†	0.06
Alcohol ego	0.05	0.08
Alcohol similarity	1.52***	0.45
Behavior Function Estimates		
Rate alcohol period 1	2.12***	0.17
Alcohol linear shape	-0.54**	0.23
Alcohol quadratic shape	0.13	0.20
Alcohol average similarity	1.34†	0.75
Alcohol effect from female	-0.20***	0.06
Alcohol effect from age	0.02	0.08
Alcohol effect from parent smoke	0.19***	0.02
Alcohol effect from parent education	0.02	0.06
Alcohol effect from GPA	-0.07	0.12
Alcohol effect from self-esteem	0.02	0.06
Alcohol effect from depression	0.08	0.12
Alcohol effect from school belonging	-0.21***	0.02
Alcohol effect from single parent	-0.14***	0.03

Note: $\mu\theta$ = estimated average effect size † p< .10; * p< .05; ** p< .01; *** p<.001, School 58 N = 509, School 77 N = 645

Table 4: Baseline SAB model for marijuana use

Network Function Estimates	μ_θ	se
Basic rate parameter friendship	7.96***	2.36
Effect presence of 2/10 nom. on rate	-0.98***	0.19
Out-degree (density)	-4.45***	0.66
Reciprocity	2.17***	0.20
Transitive triplets	0.51***	0.01
In-degree (sqrt.)	0.36***	0.09
Activities	0.35***	0.10
Female alter	-0.09***	0.00
Female ego	0.00	0.04
Female similarity	0.36***	0.13
Age alter	0.08	0.09
Age ego	-0.03†	0.02
Age similarity	1.01***	0.01
Same race	1.02***	0.07
Marijuana alter	0.23***	0.00
Marijuana ego	0.06	0.04
Marijuana similarity	0.63***	0.06
Behavior Function Estimates		
Rate marijuana period 1	2.87***	0.21
Marijuana linear shape	-2.69***	0.24
Marijuana quadratic shape	1.77***	0.13
Marijuana average similarity	0.88***	0.04
Marijuana effect from female	0.11	0.09
Marijuana effect from age	-0.07***	0.01
Marijuana effect from parent smoke	0.07	0.08
Marijuana effect from parent education	0.04†	0.02
Marijuana effect from GPA	-0.22*	0.09
Marijuana effect from self-esteem	-0.05**	0.02
Marijuana effect from depression	0.25**	0.10
Marijuana effect from school belonging	-0.04	0.03
Marijuana effect from single parent	0.29***	0.03

Note: $\mu\theta$ = estimated average effect size † p< .10; * p< .05; ** p< .01; *** p<.001, School 58 N = 509, School 77 N = 645

Table 5: Results of Cross-Dimensional Selection SAB Models for Tobacco Use, Alcohol Use, Marijuana Use

	Tobacco Use		Alcohol Use		Marijuana Use	
	μ_θ	se	μ_θ	se	μ_θ	se
Parent education ego x Behavior alter	0.05***	0.00	0.06	0.06	0.04***	0.01
Behavior ego x Parent education alter	-0.03	0.03	0.00	0.01	-0.01	0.01
GPA ego x Behavior alter	-0.06	0.07	-0.03	0.16	-0.01	0.05
Behavior ego X GPA alter	-0.05	0.05	-0.04*	0.02	-0.09	0.09
Self-esteem ego x Behavior alter	-0.07	0.10	-0.17***	0.00	-0.06***	0.01
Behavior ego x Self-esteem alter	-0.04	0.05	0.10	0.07	-0.10	0.10
School belonging alter x Behavior alter	-0.09***	0.01	-0.19***	0.03	-0.11***	0.01
Behavior ego x School belonging alter	-0.03	0.05	-0.01	0.03	-0.07	0.06
Depression ego x Behavior alter	0.06***	0.01	0.18	0.14	0.29***	0.00
Behavior ego x Depression alter	0.16*	0.07	0.02	0.19	-0.12	0.10
Single parent ego x Behavior alter	0.01	0.05	0.17***	0.01	0.05	0.11
Behavior ego x Single parent alter	-0.14***	0.02	-0.06	0.06	-0.02	0.06

Note: $\mu\theta$ = estimated average effect size † p< .10; * p< .05; ** p< .01; *** p<.001, School 58 N = 509, School 77 N = 645