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The Social Context of Adolescent Smoking: A Systems Perspective

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Abstract

Objectives: We examined the context of adolescent cigarette smoking as a system of contextual structures including youths' personal and school networks, and neighborhoods, which, via flows of emotional support and influence from friends' smoking behavior, affect past month smoking at two time points.

Methods: Using public use data (N=6,504) from wave one, and one measure of past month smoking from wave two, of the National Longitudinal Study of Adolescent Health, a nationally representative sample of students in grades 7 through 12, we employ Structural Equation Modeling to test relationships.

Results: Personal network properties affected past month smoking at time two via the flow of emotional support. Friends smoking had an effect on past month smoking at both time points. We found evidence of a partial feedback loop, from personal network properties to emotional support and then to past month smoking at time two. Past month smoking at time one fed back to positively affect in-degree centrality.

Conclusions: Findings suggest that personal and school networks and neighborhoods were important structures in the system, via flows of emotional support, in positively affecting past month smoking.

Adolescent smoking remains a complex Public Health problem in the United States. Although lifetime and current frequency of cigarette smoking among adolescents decreased from the late 1990's to 2003, the prevalence remained unchanged during the period of 2003 until 2005 [1]. Current estimates of smoking among adolescents rest around 23% [1], posing ongoing challenges for tobacco control efforts.

The Social Context of Adolescent Smoking

Cross-cutting literatures suggest that adolescent smoking is inextricably connected to the social context in which it occurs. Literature shows that adolescents and their peers display similar smoking behavior [2-6]. Why this similarity occurs is a longstanding debate; some studies suggest that this is due to peer influence on adolescent smoking [7, 8], while others suggest it is due to the selection of smoking peers [8], and yet others consider both influence and selection [2]. Other literature implicating adolescents' social context in their own smoking behavior examines youths' social networks of friends and peers from a structural perspective. Such studies focus on how structural and positional characteristics of these networks relate to adolescent smoking. The former reflects information about linkages among individuals while the latter indicates the significance of occupying different network positions. In general, studies find that isolated youth are likely to smoke, although some studies have found that popular youth are likely to smoke [3-5, 9-12]. Implicit in each literature is that youths' social context of friends and peers plays a critical role in their own smoking behavior.

Conceptualizing the Social Context of Adolescent Smoking

The relevance of the social context in adolescent smoking necessitates understanding of how to conceptualize and measure it. Past research has utilized ecological models to inform the theoretical specification of the context of adolescent smoking and other substance use [13].

Ecological models allow for theoretically partitioning the context into levels of influence. While there are valuable insights yet to be gained from such models, more theoretically informed research is necessary to more fully elaborate the complexity of the social context of adolescent smoking. Moreover, because theories are often integrated at different levels in such models, whether conceptual coherence is achieved across and within levels is unclear given the possibility of incongruous assumptions of theories applied at each level. Lastly, such models do not provide specific guidance about mechanisms through which levels of influence relate to outcomes such as adolescent smoking. Theoretical models which more specifically and holistically elaborate features of the social context of adolescent smoking and how they act in concert are necessary.

A Systems Model of the Context of Adolescent Smoking

The present study incorporates valuable insights from ecological models which theoretically partition the environment into levels of influence in framing the social context of youth smoking as a complex social system. We employ a *Systems Science* [14] approach in conceptualizing the social context of adolescent smoking, which emphasizes interdependence in complex relationships among people or organizations [15]. Defining features of systems include 1) parts or *components* yielding a whole that is greater than the sum of the parts, 2) system inputs and *flows*, and 3) *feedback loops* linking parts of a system. Such system features hold promise for informing theoretical models elaborating adolescents' social networks, the dimensionality of their relationships , and interdependence in levels of influence within their context.

We focus on three key structures in the social environment of adolescent smoking as *structural components* defining the system under study, including youths': 1) personal networks

of friends, 2) school networks, and 3) neighborhoods. School networks are *whole networks of* all students in a school and the social ties among them.These networks are constructed from adolescents' nominations of up to ten friends from a roster listing all names of adolescents in their own high school and a geographically proximal "sister" junior or senior high school. Adolescents' personal networks are subsets of whole school networks, and are comprised of friends nominated within their schools and their friends' ties. The neighborhoods under study are the physical area where adolescents live. We investigate how characteristics of these three structural components influence adolescent smoking via flows of two social processes: social support and peer influence (see Figure 1). We suggest that these social processes are mechanisms through which the structural components influence smoking.

In this introduction, we focus on the paths of main theoretical interest depicted in this model. We refer to the other constructs in the Data and Methods section only. Throughout this manuscript, we describe the model, findings, and discussion of results in terms of the causal directionality assumed in our model for ease of exposition only, and not due to any causal claims.

<<<Figure 1 about here>>>

Structural Components and Adolescent Smoking: Personal Networks, School Networks and Neighborhoods

The present study focuses on properties of personal and school networks which are salient to the flow of the content of network ties throughout the larger system under study and which have been related to adolescent smoking. Network ties carry resources which flow through a network and are exchanged by network members, including social influence and social support. At the personal network level, conceptualized at the level of the adolescent, we focus on

adolescents' 1) *in-degree centrality* or popularity; 2) whether their friendships are mutually *reciprocated;* 3) the *density* of their network ties or the extent to which those named in adolescents' networks know one another; 4) the social *distance between adolescents in their networks* or the number of *path lengths* between them, which are relationship ties linking individuals in a network [16]and 5) the number of *people they nominated as friends outside of their schools*.

At the school network level, we focused on the network properties of size, density, and the mutuality of ties, all of which may affect smoking behavior [17]. *Size* refers to the number of students in a school, *density* is the extent to which students know one another in a school, and *mutuality* is the extent to which youths' relationships are mutually reciprocated within the broader school context. School level network characteristics may affect the structure and positional attributes of personal networks as larger scale versions of these constructs.

The theoretical intuition underlying each of the above network properties is what makes them salient to adolescent smoking from a systems perspective. Popular youth are directly connected to many others and can quickly and disproportionately transmit and receive network resources such as support. Being central in networks is positively related to smoking among youth [11, 12]. Having *reciprocated* friendships may facilitate the flow of network resources throughout a network, as resources are likely exchanged in mutual friendships, both in personal and school networks. One study found that adolescents with reciprocated ties with a best friend were less likely to smoke at ages 11 and 13 than those without such ties [4]. *Personal network density* reflects the extent to which those in an adolescent's personal network know one another. The density of ties, either in personal or whole networks, likely plays a role in the flow of resources throughout a network by binding people together and strengthening adherence to

pervasive norms and beliefs. Dense ties can also limit the inflow of resources from outside a network. One study found that adolescents at age 15 with dense local networks had lower odds of recent smoking [4]. If adolescents are close to one another in a network--i.e., *path length* is low--then social influences and network resources may be easily transmitted as the probability of transmitting network resources decreases over longer path lengths [18]. Previous research indicates that adolescents who were socially proximal to a smoker had increased odds of smoking [4]. Lastly, the number of friendship nominations youth made *outside of their schools* capture relationships that either reinforce or attenuate the effect of social influences from in-school friends, depending on the types of influences exerted by each of these friends. There is evidence that having ties to friends from outside youths' schools is positively related to adolescent smoking [4].

Although past research offers insight into how each of these network properties relates to adolescent smoking, smoking behavior, via network processes such as influence, social support, and selection, may impact the structure and position of individuals in a network. This notion is explored in the present study by positing feedback pathways from smoking to the network characteristics under study.

Finally, we take into account adolescents' neighborhoods, utilizing insights from Social Disorganization Theory [19, 20]. Specifically, this ecological theory posits that the key structural characteristics of economic disadvantage, racial/ethnic heterogeneity, and residential instability lead to an overall milieu of social disorganization within certain neighborhoods that gives rise to higher levels of delinquency. In such neighborhoods, this disorganization limits residents' ability to provide the informal social control that would otherwise reduce adolescents' delinquent behavior. Although the bulk of research using this theory has focused on the generation of

criminal forms of delinquency [21-23], recent research has tested whether these structural characteristics also increase the delinquent behavior of cigarette smoking [24-26].

Social Processes as System Flows: Emotional Support and Peer Influence

To study how the structural components of interest exert influence on adolescent smoking, we suggest that two social processes--emotional support and peer influence--may be *mechanisms* through which properties of these structural components influence adolescent smoking. Emotional support relates to health through direct and buffering effects [29]. Social support may be a pathway linking social networks and health indicators, as past work has related structural network characteristics to health via emotional support and social influence processes [30]. Prior research highlights the notion that research should focus on how social influence mechanisms potentially mediate the relationship between social networks and health [28, 30 27] particularly addressing why certain types of supportive networks are associated with health-compromising behavior [31]. Therefore, we focus on emotional support, which generally extends to feelings of closeness, encouragement, and belongingness [32], and peer influence, narrowly defined as the influence exerted from adolescents' friends who smoke, as mechanisms linking social network ties and adolescent smoking**.** While more inclusive conceptualizations of peer influence exist, we focus only on the influence derived from adolescents' friends who smoke, as they may be particularly proximal to adolescents' smoking behavior.

Studies have found that emotional support is positively associated with smoking [33]. Perhaps the closeness generated from an emotionally supportive tie reinforces social bonding as friends smoke together. An analogous argument comes from the injection drug use literature, showing that the provision of emotional support in relationships mediated the relationship

between network characteristic of the closeness of ties and needle sharing [34]. Among injection drug users, needle sharing behavior was likely a symbolic act of solidarity, exclusivity, and bonding. For adolescents, smoking behavior may carry a similar symbolic meaning relating to social bonding, especially in the context of emotionally supportive and valued friendships. Moreover, receipt of emotional support may be contingent upon engaging in a delinquent behavior in some friendships, as failure to smoke and being different from a friend on this dimension might be perceived as a strike against the friendship. That emotional support has potential for being health compromising is not surprising, as prior research indicates that social support can reinforce delinquent behaviors among youth and their network members via modeling processes [35, 36].

Beyond the effect of emotional support on smoking behavior, there is reason to expect that the network characteristics under study increase emotional support. It is likely that more central individuals are in a position to provide support to others or may be connected to others who could also provide support [37]. Likewise, mutually reciprocated ties, as well as the density of ties [38], likely increase emotional support through increased closeness. Also, shorter path lengths in networks likely increase emotional support, as being proximal to others may lead to the provision or receipt of more emotional support.

The second mechanism under study potentially mediating the effect of properties of the structural components on smoking is peer influence. In the present study, peer influence is the influence exerted by adolescents' friends' smoking behavior on adolescents own smoking behavior. The positive relationship between peer influence and smoking is well documented [39] [40]. Peer influence processes have been measured in numerous ways in relation to smoking, including as the number of friends who smoke [41, 42]. Furthermore, studies have found that

network characteristics affect the number of friends who smoke. For example, studies have found that reciprocity [43] and the density of network ties are associated with more peer influence, arguably through tightly binding people together in a network and amplifying social influence behavior [44, 45]. Peer influence is also likely positively related to being central in networks, as highly central individuals can quickly receive and transmit influence, and to path length in networks, as social influences may be quickly transmitted if individuals are close to one another in a network.

Although there is likely an influence effect of friends' smoking behavior on adolescent smoking, there is also likely a selection effect in which persons who smoke are more likely to choose friends who also smoke. To the extent that having friends who smoke then affects one's position in the network, we suggest that there will be a feedback loop (see Figure 1) from personal network characteristics, to friends' smoking behavior, to smoking at wave 1.

In sum, this study examines direct, mediated, and feedback pathways through which these structural components influenced smoking at two time points via flows of emotional support and peer influence. Given the systems nature of the study, a number of pathways were examined, including: 1) direct pathways indicating how properties of personal and school networks and neighborhoods influenced smoking; 2) indirect pathways through which properties of networks and neighborhoods influenced smoking via emotional support and peer influence exerted by friends' smoking behavior. Lastly, we investigate two feedback loops: 1) from the network properties to emotional support, then to smoking and back to the network variables; 2) from personal network characteristics to past month smoking via friends' smoking.

Data and Methods

Study design

The data for this study come from the first wave of the National Longitudinal Study of Adolescent Health (Add Health), a school based longitudinal study, though we also include a measure of smoking from the second wave which occurred one year later. This nationally representative sample was conducted in 1994 of students in grades 7 through 12. We use the public-use data, which are a random sample of 6,504 individuals from the complete study. Our sample responded both to an in-home survey as well as an in-school survey. The social network measures are based on a network elicitation item asking a respondent to nominate up to five male friends and five female friends. Respondents could name persons outside of their school. We also utilized contextual data from the 1990 U.S. Census based on the 2,407 block groups of residence in the sample (block groups had an average population of about 1,100 persons in 1990). The design sampled first on schools, and then on students within schools; the neighborhoods under study simply arose as a byproduct of this sample design, as they are defined by where adolescents in the sample live.

Measures

The measures used in the analyses are described in Table 1, along with their summary statistics, and the level at which they are measured. To aid in identifying the model (described below), we also included four measures of smoking risk (measured at the individual level) that likely affect smoking behavior, but not network characteristics. We included demographic characteristics that are likely related to our endogenous variables. We measured racial/ethnic heterogeneity based on a dispersion formula:

$$D = \frac{K(N^2 - \sum f_k{}^2)}{N^2(K-1)}$$

where K is the number of groups, N^2 is the number of persons squared, and f_k is the frequency of group k (D ranges from 0 to 1).

<<<Table 1 about here>>>

Methods

We specify the ten equations in our system as a series of simultaneous equations using Structural Equation Modeling (SEM). SEM is ideal for our approach as it allows estimating the equations simultaneously with a maximum likelihood estimator, and allows for specifying reciprocal effects and feedback loops while appropriately accounting for possible endogeneity. We account for the clustering within schools by computing robust standard errors. Although hierarchical linear models handle clustering, they cannot handle reciprocal relationships and feedback loops given current software constraints. We will estimate the model displayed in Figure 1. Note that the exogenous variables are depicted on the left hand side of the Figure and are not predicted by any other variables. The other variables displayed in this figure are endogenous variables in our system (each is predicted by some other variables). Each of these endogenous variables is represented by an equation based on our theoretical discussion above. For instance, in-degree centrality is a function of the following equation:

in-degree centrality = β_1 friends'_smoking_behavior + β_2 past month smoking (wave1) + Γ_1 nghbrhood + Γ_2 demographics + Γ_3 school_network + ζ_1

where β_1 shows the effect of friends' smoking behavior on the in-degree centrality of the respondent, β_2 shows the effect of the respondent's past month smoking on their own popularity, Γ_1 is a vector capturing the effects of the neighborhood variables on respondent popularity, Γ_2 is a vector capturing the effects of the respondent's demographic on their own popularity, Γ_3 is a vector capturing the effects of the school network variables on respondent popularity, and ζ_1 is an error term. Analogous equations can be written for the other endogenous variables. We allowed for correlated errors among the personal network variables, and between emotional support and friends' smoking behavior. We used various techniques to assess that our model is identified, including estimating models with varying starting values [42]. We also assessed that our instrumental variables (IV's) are appropriate: the non-significant results of the Sargan test confirmed that these IV's are indeed independent of the error term in these equations, as hypothesized. These IV's explained a reasonable amount of the partial variance in the first stage equation, which is an important indicator of their strength.

Note that one reciprocal effect that we cannot estimate because we do not have any plausible instrumental variables to estimate both of these paths is the selection/influence relationship between friends' smoking behavior and adolescent's past month smoking. Thus, having friends who smoke likely increases an adolescent's past month smoking, but those who smoke are more likely to associate with friends who also smoke. Rather than simply assuming that the degree of association between these two constructs is entirely due to an influence effect, we adopted a novel technique to test the robustness of our system assuming various values for the relative proportion of this relationship due to the selection effect [46]. We estimated models in which we fixed the selection effect to various values: 1) zero selection effect; 2) selection effect 1/3 the size of the influence effect; 3) equal selection and influence effects; and 4) selection

effect three times the size of the influence effect. This technique has only occasionally been employed [46].

Another advantage of SEM is that it allows us to test the overall fit of the model. SEM allows the specification of a causal model, and then can test how well the model represents the observed data as one test of causality, as has been described in other work [47-49]. This tests the similarity of the model implied covariance matrix to the sample covariance matrix. Although a good model fit would be consistent with our theorized model, it is possible that other theories that might be specified could fit these data equally well. Therefore, the causal conclusions must necessarily be tempered despite the fact that the *specified* model is inherently a causal one. The approximate fit indices of CFI = .998, TLI = .991 and RMSEA =.008 suggest an excellent fit for our model [49]

Results

The summary statistics for the variables used in the analyses are shown in Table 1. At wave 1, 70.5% had not smoked, whereas this figure was 67% by wave 2 among all adolescents in the sample. The mean days smoking per month for the entire sample increased from 4.9 to 5.2 over the two waves. Performing bivariate analyses on our key outcome measures, we found that Whites smoke significantly more than other groups (5.65 days per month), whereas Blacks and Latinos smoke significantly less (1.81 and 3.97 days per month, respectively) (all *p*-values in this paragraph < .01). We also found that females (4.16 vs. 5.39 for males) and those whose mothers have higher levels of education (3.11) smoke less days per month. The pattern is similar for friends' smoking behavior, as Whites have friends who smoke more (.87 friends who smoke), whereas Blacks (.53), females (.74) and those with more educated mothers (.62) have friends who smoke less. For emotional support, we find that Whites (38% of their friends provide

emotional support) and females (44%) have more, on average, whereas Latinos (30%) and Blacks (31.5%) have less. Finally, Whites (named by 5.95 ties), and females (5.73 vs. 5.35 for males) have higher in-degree centrality, whereas Blacks (5.06) and Latinos (4.77) have fewer social ties.

The results for our full simultaneous equations model are displayed in Table 2. Given the complexity of the results, we focus on key findings based on our theoretical discussion.

We begin with the system component of school network measures. School networks with greater density and mutuality increase the likelihood that the respondents' personal network will have greater density and reciprocity ($p < .01$) (equations 1 through 3)**.** And respondents in school networks with more density (b=.289, $p < .01$) and mutuality (b=.714, $p < .10$) will have greater in-degree centrality. We see in equation 6 that adolescents in the largest and smallest schools receive the fewest nominations. Taking the first derivative and setting it equal to zero, we see that students in schools with about 1,580 students have the largest in-degree centrality (size=-(.766/(-.243*2)) = 1.576), whereas students in smaller and larger schools have fewer nominations. Although there was no evidence that these school network measures directly affected adolescents' past month smoking (in ancillary models not presented in which we added these variables to equations 9 and 10), we do see that adolescents in larger school networks have fewer friends who smoke (b=-.251, p < .01, in equation 7).

<<<Table 2 about here>>>

For the structural component of neighborhood properties, adolescents from block groups with more economic resources have more ties outside the school (equation 5) and higher mean distance to reachable people (equation 4). Neighborhood economic resources have a curvilinear

relationship with the density of personal networks and friends' smoking behavior: the peak density of personal networks occurs in neighborhoods with somewhat above average median home values of about $151,000 (value = -(.106 / (-.035*2))=1.514). In contrast, the number of smokers in adolescents' networks is lowest in middle class neighborhoods. Residential stability has a direct negative effect on in-degree centrality (b=-.081, $p < .01$) and increases past month smoking (b=.120, $p < .05$, in equation 9).

Turning to the role emotional support plays in the system, we see in equation 8 that several personal network characteristics affect the amount of emotional support. A 10 % increase in in-degree centrality leads to a .087 proportionate increase in persons providing emotional support. Likewise, those with more ties outside the school, and reciprocation from the best friend (especially females), increases the amount of emotional support received. Only personal network density shows a negative effect on emotional support.

There is also evidence that adolescents with more emotional support engage in more past month smoking. This effect was positive (.381) in the equation predicting past month smoking at the same time point (equation 9), and in equation 10 for past month smoking at the next time point (.66), even controlling for past month smoking at the previous time point. This implies that emotional support plays a long-term role in mediating the relationship between the various personal network measures and smoking the following year. For example, those with more social ties inside and outside the school, and those with reciprocated ties with their best friend, have more emotional support which leads to more smoking one year later.

We see little evidence that friends' smoking behavior mediates the relationship between the personal network measures and past month smoking. On the one hand, friends' smoking

behavior increases past month smoking (in equation 9) and past month smoking at the next wave controlling for time one smoking (equation 10). Each additional friend who smokes increases the number of days smoked per month 77%. On the other hand, there is evidence in equation 7 that those who are more popular (high in-degree centrality) have more friends who smoke. The other network measures have no effect on friends' smoking behavior.

Although we see little evidence that these personal network measures increase friends' smoking behavior, we do see evidence in equation 6 that the popularity of adolescents (in-degree centrality) is affected both by their own past month smoking as well as their friends' smoking behavior. A one percent increase in past month smoking increases in-degree centrality 2.3% (b=.023, $p < .01$). However, there is a countervailing effect if one has friends who smoke: each additional friend who smokes reduces in-degree centrality by 15.3% (b=.153, $p < .01$). There is little evidence that past month smoking or friends' smoking behavior affects the other personal network measures (equations 1 through 5).

Sensitivity checks

We performed sensitivity tests of our model. As described above, we set the parameter for the effect of adolescents' past month smoking on friends' smoking behavior to various values and assessed the robustness of the system. In short, the system appears relatively robust regardless of the ratio of influence to selection. For example, the effect of adolescent past month smoking on in-degree centrality ranges from .014 if we assume no selection effect, to .018 if 25% of the relationship is due to selection, to .023 if 50% is due to selection, to .030 if 75% is due to selection (all effects are $p < .05$). Likewise, the effect of friends' smoking behavior on in-degree centrality ranges from -.128 to -.171 (all effects are $p < .05$). The other parameters in the

model show even more stability over these various parameterizations, indicating that our results are robust regardless how much of this relationship is selection and how much is influence.

We also assessed whether emotional support and friends' smoking work multiplicatively at the level of social ties. We tested this by constructing a measure that multiplied the emotional support score and the smoking behavior for each of an individual's friendship ties, and then computed the average of these values among the ties of an individual. In ancillary models not presented including personal and school network measures and demographics, we tested the effect of this variable on past month smoking behavior at time one and time two and found no significant effects (results available upon request) . Finally, we estimated a school-level fixed effects model to control for unobserved differences across schools, and the substantive results were very similar to those presented in the text (results available upon request).

Discussion

Our findings indicate that when a system of pathways between characteristics of personal networks, school networks, and neighborhoods are taken into account, via flows of emotional support and the influence exerted through friends' smoking behavior, we gain important insights into the complexity of the social context of adolescent smoking. Personal network characteristics—being central, having ties outside of the school, having a best female friend reciprocate, and the density of ties—influenced the flow of emotional support, which in turn influenced past month smoking at the second time point. We found that although the flow of influence from friends' smoking behavior is not impacted by personal or school level network characteristics, it did affect past month smoking. Findings pertaining to the school component indicated that school level density and size affected personal network characteristics, density,

reciprocation of ties from best female friend, mean distance to reachable people, in-degree centrality, and the number of nominations sent outside of youths' schools. Findings relating to the neighborhood component of the system indicated that median home value negatively affected past month smoking at time one. The neighborhood characteristics also affected network characteristics, including density, reciprocation and ties outside of the school. Findings are suggestive of a partial feedback loop from personal network characteristics to emotional support to past month smoking at time one then back to personal network characteristics, including the provocative finding that past month smoking at time one affects in-degree centrality.

Our finding that personal network characteristics increased emotional support, which then increased past month smoking, supports past research identifying emotional support as a mechanism through which networks relate to health and to risk behavior [28 34]. These findings were not surprising as being central in a network likely affords opportunities for giving and receiving emotional support. Secondly, having friendships outside of school may increase the number of friends youth have, thus increasing the probability of receiving support from any one friend, and may also suggest that friends outside of school are close ties which provide emotional support. Third, having a female friend reciprocate may increase the emotional support exchanged in a mutually reciprocated friendship tie, given that females may often be sources of emotional support. Lastly, the negative effect of density on emotional support may be explained by the numerous relationship obligations and constraint which densely connected ties can impose, constituting a great demand on one's personal resources. Moreover, if density of ties limits the resources entering from outside the network, this can further limit the amount and diversity of personal resources to expend as emotional support to others.

It is notable that the only school level characteristic to increase emotional support was the mutuality index. Perhaps a whole network structure with a large proportion of mutually reciprocated ties increases the possibility that emotional support will be exchanged in any one of these close ties. We observe that neither school level density nor size had an effect on the flow of emotional support, and the former finding is consistent with the idea that density may limit support in a network. The latter may reflect that larger schools promote anonymity and consequently less support resources, leading to more diffuse networks and fewer close and supportive ties.

Our finding that emotional support influences past month smoking at both time points is consistent with past work showing that emotional support positively relates to smoking [33]. Perhaps the effect between emotional support and smoking is more likely to occur between close friends in emotionally supportive relationships. That this relationship persisted at the second time point may indicate its strength and that of the bond as well as the stability of both over time.

Although we found modest effects for our neighborhood component, two findings of note were the curvilinear relationship between neighborhood economic resources and the density of personal networks and friends' smoking behavior. Adolescents living in middle-income neighborhoods have networks with the highest density, suggesting a relative cohesion among their personal ties. At the same time, adolescents in middle-income neighborhoods have the fewest smokers in their networks, suggesting a relatively low effect from influence of friends' smoking behavior. It is notable that adolescents in both low and high-income neighborhoods have networks with more smokers.

While friends' smoking behavior was not affected by any of the network characteristics under study, it increased past month smoking at the first time point. The lack of any effects of network characteristics on friends' smoking behavior suggests that while these characteristics may be important for promoting smoking behavior among youth [12] [11], they are not important for the smoking behavior of youths' friends. This finding runs counter to the many studies indicating homogeneity in the smoking status of friends. The findings that friends' smoking behavior reduced both in-degree centrality and best male friend reciprocation suggest that having friends who smoke actually decreases popularity and the reciprocation of friendship ties. Overall, such findings suggest that having friends who smoke is not well received among the greater social milieu of youth in our study.

Our findings may suggest some evidence for a partial feedback loop: personal network characteristics increase the emotional support received by adolescents, which then appears to lead to more smoking at both waves. In addition, we see that adolescent smoking at time one flows back in the other direction through the system by bringing about more friends who smoke (through a selection effect) and then leading to greater in-degree centrality. This greater in-degree centrality and greater distance to reachable people then leads to more emotional support, and thus the loop begins again. While we do not have evidence for a full loop, our findings are nearly indicative of one that encompasses the amplifying effects of personal network characteristics on emotional support, the reinforcing effect of emotional support on smoking at time one, and then smoking at time one on popularity and distance to reachable others. Such a "reinforcing" loop might suggest that smoking brings social gains in the way of emotional support and popularity in the social system under study.

Our findings also have implications for extant and future studies which have employed the general strategy of examining relationships between network characteristics and smoking among youth. We highlight that whereas prior research has found a positive association between the popularity of students (as measured by in-degree) and adolescent smoking and assumed conceptually that the direction flows from popularity to smoking [12], we specified a system that allowed this directionality to flow in either direction. As a consequence, we were able to detect more evidence that smoking behavior and peers who smoke affect one's popularity, rather than the reverse. This finding has potential to inform future models investigating the relationship between in-degree centrality and smoking among youth. More broadly, this finding suggests that a social behavior, cigarette smoking, could alter an important positional attribute of a social network. It is notable that it is individuals who show a relatively high degree of autonomy—in that they smoke but do not hang out with fellow smokers—who are the most popular based on in-degree. Alternatively,,smokers who affiliate with friends who smoke are generally no more popular than average adolescents.

Other implications of our findings include examining how the pathways represented in the systems model under study differ across gender and racial/ethnic groups given the possible group differences. Secondly, future studies warrant examination of how other types of social support, such as confidant support, might function in lieu of emotional support in our study model. Confidant support has been associated with positive health outcomes [50, 51]and is relevant given the notable effects of reciprocated ties and emotional support, both likely characteristics of a confidant relationship, on adolescent smoking in this study.

Limitations

The present study has some limitations. First, the network elicitation items were limited in the number of friendship nominations. Capping friendship nominations is a common strategy, though it is a potential drawback among studies utilizing network generator items. It remains unclear how social position and network structure would differ if the number of nominations were not capped at this level. Secondly, network data were not collected for the full national sample at wave two, therefore we could not account for network variables at time two in our models. It is unclear how the inclusion of these variables might have changed our results. Future studies should include network variables at multiple time points to observe the evolution of the system. Third, because we conducted a secondary analysis, we were restricted in the types of network variables, social processes, and outcomes available for study. Nevertheless, we investigated theoretically informed pathways comprising a larger system of adolescent smoking. Lastly, what constitutes a friendship tie is also of note, as it is unclear whether there was uniformity in the strength, duration, and frequency of contact in friendship ties.

Implications for Prevention

In spite of these limitations, our findings provide insight into the importance of the strength of reciprocated friendships and the emotional support they can transact to help adolescents support each other in remaining non-smokers or in quitting smoking. These friendship pairs could be targeted for a school based intervention, to help both adolescents in a pair remain non-smokers or help one another stop smoking. This could be done by educating youth in these pairs on how to use emotional support as reinforcement for helping one another remain a non-smoker (among non-smoking pairs) and for considering quitting (among smoking pairs). Secondly, adolescents could learn self-regulatory techniques (e.g., journaling) to help one another identify cues in the social environment that either trigger interest in smoking or trigger

smoking behavior. All participating adolescent pairs could form task forces in schools and lead smoking awareness campaigns. Reciprocated relationship pairs would become a channel through which anti-smoking messages permeate personal and school networks.

Findings suggest targeting adolescents who smoke, have non-smoking friends, and who are not yet popular. Research suggests that popular youth can set norms in a school context [12]. A corollary is that if popular youth smoke, others will emulate them. Building on past research[12] suggesting that popular youth will need to adopt anti-smoking norms in order for effective programs, we suggest that interventions should target youth who smoke *before* they become popular. Perhaps these youth are not yet frequent smokers, given that they affiliate with non-smoking friends, and thus may be tolerant of anti-smoking norms. Such adolescents could be educated on the risks of smoking with the hope that they would adopt anti smoking norms, which their non smoking friends might reinforce. This intervention would disseminate through adolescents' personal networks and solidify anti-smoking norms over time as these messages spread from personal to school networks.

Conclusion

The present study suggests the merit of utilizing a systems science approach to conceptualizing complexity in the social context of adolescent smoking. We find evidence of direct pathways and feedback processes. Emotional support was a pathway linking personal network characteristics and past month smoking, while the peer influence process of friends' smoking behavior was not. We found some evidence of a feedback process as past month smoking had a direct effect on the popularity of students (in-degree centrality). Overall, findings

suggest complexity in the social context of adolescent smoking and a need for theory to account for it.

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Table 1. Descriptions and summary statistics of study variables. N = 6,504 adolescents

Variable name	How measured	Range of values	Mean	SD
Smoking and support (individual level)				
Past month smoking (days, logged), wave 1	number of days the respondent smoked cigarettes during the previous month (log transformed)	0 = no days to 30= 30 days	4.921	10.082
Past month smoking (days, logged), wave 2	number of days the respondent smoked cigarettes during the previous month (log transformed)	0 = no days to 30= 30 days	5.182	10.299
Emotional support (proportion)	proportion of friends in the respondent's personal network with whom they have discussed a problem in the last seven days	0 to 1	0.347	0.327
Friends' smoking behavior	respondents' perception of how many of their three best friends smokes	0 = no friends to 3 = three friends	0.817	1.066
Personal network measures (individual level)				
In-degree centrality	the number of persons in the network who nominated the respondent as a friend	1 to 31 people	5.551	3.692
Personal network density	the number of existing ties in a respondent's network divided by the total possible number of ties	Theoretically from 0 to 1, actually from 0.09 to 1	0.412	0.203
Mean distance to reachable people	This is computed by 1) determining all the people the respondent could reach in the network either directly or indirectly, 2) computing the minimum number of path lengths to reach each person, and 3) computing the mean of those distances	1 to 21.39	5.284	1.620
Ties outside the school	Number of friendship nominations made to non-school members	0 to 10	1.406	2.144
			Percentage	
Best male friend reciprocates	whether or not the respondent's best male friend reciprocated their tie choice	0 = did not reciprocate, 1= reciprocate	54.4%	
Best female friend reciprocates	whether or not the respondent's best female friend reciprocated their tie choice	0 = did not reciprocate, 1= reciprocate	62.7%	
School network measures (school level)				
			Mean	**SD**
School network density	the proportion of existing ties to the number of possible ties in a school	Theoretically from 0 to 1, actually from nearly 0 to .35	0.017	0.037
Size of school network	number of persons in the school network	30 to 2559 students	671.5	488.5
Mutuality index	the tendency for ties to be reciprocated relative to expections based on chance. Higher values indicate more mutuality	Theoretical range from 0 and 1. Actual range from .23 to .53	0.377	0.052

Neighborhood measures (block group level)

Median home value	Median value of homes in block group, 1990	$15,000 to $300,000	95,407	62,950
Racial/ethnic heterogeneity	based on a dispersion formula (see text for equation)	0 to 1	0.340	0.294
Residential stability	the proportion of residents who moved into their unit between 1985 and 1990, categorized into three groups with one standard deviation above and below the mean as the cutoffs	Low, medium, high	1.996	0.562

Demographic characteristics and smoking risk variables (individual level)

Age	age of the respondent at the time of the survey	10 to 19 years of age	14.871	1.729
Mother's education	Highest level of mother's educational achievement	1=eighth grade or less, 2=9th to 12th grade, 3=high school graduate or GED, 4= vocational school, 5=some college, 6=graduated from college, 7= professional or graduate training	5.275	2.344
Parent smoking	Number of parents who smoke	0=none, 1=one parent smokes, 2=both parents smoke	1.050	0.781
Wear seatbelts	frequency *wearing seatbelts* when riding in a car	0=never, 1=rarely, 2=sometimes, 3=most of the time, 4=always	3.071	1.190
Motorcycle riding	frequency rode *a motorcycle* in the last 12 months	0=never, 1=once or twice, 2=about once a month, 3=about once a week,	0.363	0.863
			Percentage	
Cigarettes in home	Are cigarettes easily available in the home	0=no, 1= yes	30.5%	
African American	Self-reported race/ethnicity	1=African American, 0=not	24.6%	
Asian	Self-reported race/ethnicity	1=Asian, 0=not	4.4%	
Latino	Self-reported race/ethnicity	1=Latino, 0=not	13.5%	
Other race	Self-reported race/ethnicity	1=Other race, 0=not	3.3%	
White (reference category)	Self-reported race/ethnicity	1=White, 0=not	54.2%	
Female	Gender	1=Female, 0=male	38.2%	

Table 2. Full simultaneous equations model, fixing selection effect of friends smoking to same size as influence effect on individual smoking. N = 6,504 adolescents

	(1) Personal network density	(2) Best female friend reciprocates	(3) Best male friend reciprocates	(4) Reachable alters distance	(5) Ties outside the school	(6) In-degree centrality	(7) Friends' smoking behavior	(8) Emotional support (proportion)	(9) Past month smoking, time 1	(10) Past month smoking, time 2
Past month smoking	0.005	0.002	0.007	0.034	0.009	0.023 **	0.085			0.553 **
	(0.005)	(0.007)	(0.008)	(0.021)	(0.021)	(0.007)	---			(0.018)
Emotional support (proportion)									0.381 *	0.660 **
									(0.155)	(0.169)
Friends' smoking behavior	-0.047	0.012	-0.106 *	-0.169	0.139	-0.153 **			0.765 **	0.323 **
	(0.039)	(0.052)	(0.054)	(0.158)	(0.171)	(0.057)			(0.050)	(0.045)
Personal network measures										
In-degree centrality							0.233 *	0.087 **		
							(0.118)	(0.010)		
Ties outside the school							-0.019	0.032 **		
							(0.035)	(0.003)		
Mean distance to reachable people							0.046	0.001		
							(0.066)	(0.004)		
Best male friend reciprocates							0.188	0.022		
							(0.225)	(0.015)		
Best female friend reciprocates							-0.324	0.050 **		
							(0.232)	(0.018)		
Personal network density							0.083	-0.052 **		
							(0.199)	(0.015)		
School network measures										
School network density	0.117 **	0.058 **	0.051 *	-0.899 **	0.019	0.289 **	-0.137 †	-0.009		
	(0.025)	(0.022)	(0.023)	(0.153)	(0.161)	(0.064)	(0.080)	(0.015)		
Size of school network	0.024	0.040	0.035	0.138	0.096	0.766 **	-0.251 **	0.019		
	(0.036)	(0.038)	(0.038)	(0.184)	(0.247)	(0.208)	(0.071)	(0.018)		
Size of school network squared						-0.243 **				
						(0.063)				
Mutuality index	0.467 †	0.582 *	0.947 **	0.365	1.542	0.714 *	0.164	0.229 †		
	(0.244)	(0.238)	(0.232)	(1.682)	(1.437)	(0.354)	(0.511)	(0.123)		

Neighborhood (block group) measures										
Median home value	0.106 **	0.029	0.015	0.399 **	0.217 *	-0.005	-0.125 *	-0.010	-0.002	-0.009
	(0.031)	(0.026)	(0.025)	(0.132)	(0.102)	(0.036)	(0.055)	(0.011)	(0.125)	(0.096)
Median home value squared	-0.035 †						0.080 **			
	(0.019)						(0.028)			
Racial/ethnic heterogeneity	0.063 *	0.077 *	-0.035	0.138	-0.098	-0.008	0.014	0.040 *	0.099	-0.208
	(0.031)	(0.036)	(0.051)	(0.137)	(0.207)	(0.057)	(0.060)	(0.020)	(0.126)	(0.165)
Residential stability	0.001	-0.032 †	-0.002	-0.069	0.016	-0.080 **	0.019	-0.008	0.120 *	-0.111 †
	(0.016)	(0.018)	(0.021)	(0.060)	(0.067)	(0.023)	(0.025)	(0.011)	(0.055)	(0.061)
Demographic characteristics										
African American	-0.060 *	-0.115 **	-0.091 *	0.023	0.489 **	-0.110 **	-0.218 **	-0.062 **	-0.967 **	-0.790 **
	(0.024)	(0.034)	(0.036)	(0.108)	(0.153)	(0.038)	(0.056)	(0.013)	(0.115)	(0.119)
Asian	0.000	0.028	-0.004	0.327 †	-0.132	-0.094	-0.044	-0.036	-0.438 *	-0.184
	(0.033)	(0.049)	(0.054)	(0.174)	(0.226)	(0.064)	(0.067)	(0.026)	(0.198)	(0.242)
Latino	0.031	-0.074 *	-0.075 †	0.088	-0.026	-0.104 *	-0.036	-0.052 **	-0.460 *	-0.305
	(0.032)	(0.036)	(0.044)	(0.082)	(0.126)	(0.042)	(0.058)	(0.013)	(0.190)	(0.203)
Other race	-0.035	-0.070 †	-0.063	0.039	0.188	-0.101 **	0.031	0.008	0.072	-0.362 **
	(0.030)	(0.038)	(0.040)	(0.063)	(0.123)	(0.036)	(0.053)	(0.013)	(0.134)	(0.138)
Age	0.026 **	0.025 **	0.029 **	0.056 **	0.098 **	0.001	0.087 **	0.023 **	0.213 **	0.019
	(0.006)	(0.007)	(0.008)	(0.021)	(0.032)	(0.010)	(0.013)	(0.003)	(0.029)	(0.029)
Female	0.048 **	0.315 **	-0.156 **	-0.013	0.495 **	0.111 **	0.068	0.164 **	-0.131	-0.058
	(0.015)	(0.020)	(0.021)	(0.078)	(0.068)	(0.025)	(0.082)	(0.011)	(0.090)	(0.076)
Mother's education							-0.028 **		-0.027	-0.029
							(0.007)		(0.019)	(0.021)
Parent smoking							0.101 **		0.270 **	0.209 **
							(0.015)		(0.041)	(0.043)
Wear seatbelts							-0.092 **		-0.259 **	-0.091 *
							(0.013)		(0.037)	(0.037)
Motorcycle riding							0.094 **		0.323 **	0.062
							(0.012)		(0.050)	(0.041)
Cigarettes in home							0.207 **		0.729 **	-0.032
							(0.037)		(0.096)	(0.101)
R-squared	0.050	0.134	0.033	0.324	0.035	0.048	0.254	0.338	0.437	0.313

*** p < .01(two-tail test), * p < .05 (two-tail test), † p < .05 (one-tail test). Standard errors in parentheses. Models estimated using maximum likelihood estimator, with standard errors corrected for clustering within schools. Chi square = 79.6, df = 58, p = .03*

Figure 1. A Systems Model of Contextual Structures and Flows of Social Processes Influencing Adolescent Smoking