Adolescent Research Review
https://doi.org/10.1007/s40894-019-00130-0

SYSTEMATIC REVIEW

# Peer Influence and Adolescent Substance Use: A Systematic Review of Dynamic Social Network Research

**Angela K. Henneberger**[1] · **Dawnsha R. Mushonga**[2] · **Alison M. Preston**[1]

Received: 29 August 2019 / Accepted: 16 December 2019


**Abstract**
Peer influence is one of the most proximal risk factors for adolescent substance use, and decades of theoretical and empirical research point to the importance of disentangling two interrelated processes that often co-occur: (1) peer selection is the process whereby adolescents choose to interact with one another; and (2) peer socialization is the process whereby individual behavior is shaped over time. Recent advancements in social network analyses, including the application of stochastic actor based models to developmental studies, have helped to disentangle the contributions of peer selection and socialization to adolescent substance use. The current study is the first systematic review of this literature, aiming to identify the extent to which adolescent substance use is associated with peer selection and socialization and highlighting patterns in study design across studies. Forty studies that met inclusion criteria were identified and systematically coded for study design characteristics (e.g., number of time points; number of covariates) and significant peer selection and socialization effects by substance use outcome. This review found support for peer selection effects on adolescent alcohol and tobacco use. Additionally, most studies reported peer socialization effects for adolescent alcohol use. However, relatively few studies reported socialization effects for tobacco use. Few studies reported on the peer effects associated with adolescent drug use. Variations in study design, including variations in the bounds of the network and in the covariates included in modeling, helped to identify areas for future research. Future research that helps to further clarify the roles of specific peer selection and socialization mechanisms will help with the development and refinement of prevention and intervention programs focused on reducing adolescent substance use.

**Keywords** Peer influence · Peer selection · Peer socialization · Social network analysis · Substance use · Adolescence

## Introduction

Peer influence is one of the most proximal risk factors for adolescent substance use, and the link between peers' use and adolescent alcohol, tobacco, and other drug use is well-documented (Hawkins et al. 1992). Network theory (Friedkin 1998) and social network analysis (Wasserman and Faust 1994) are increasingly being applied to understand substance use in adolescence. Decades of theoretical and empirical research (see Brechwald and Prinstein 2011) on peer influence point to the importance of disentangling two interrelated processes that often co-occur: (1) peer selection is the process whereby adolescents choose to interact with one another (Lazarsfeld and Merton 1954); and (2) peer socialization is the process whereby individual behavior is shaped over time (Friedkin 1998). Relatively recent advancements in social network methods, including advancement and application of stochastic actor based models (Steglich et al. 2010) to developmental science, have enabled researchers to more accurately statistically disentangle these co-occurring processes (see Veenstra et al. 2013). The goal of the current study is to systematically review the extent to which the emerging body of empirical research applying stochastic actor based models supports the association between peer selection and socialization and adolescent substance use. Additionally, this review aims to identify patterns in study

✉ Angela K. Henneberger
ahenneberger@ssw.umaryland.edu

Dawnsha R. Mushonga
dmushonga@ubalt.edu

[1] University of Maryland School of Social Work, 525 W. Redwood St., Baltimore, MD 21201, USA

[2] School of Health and Human Services, University of Baltimore, 10 W. Preston Street, Baltimore, MD 21201, USA

Published online: 02 January 2020

design characteristics to provide insights for future research applying stochastic actor based models to improve the understanding of peer processes and adolescent substance use.

## The Landscape of Adolescent Substance Use

The landscape of adolescent substance use has rapidly changed in the United States over the past two decades. Tobacco use, in particular, is changing forms, with adolescents reporting using vaporizers (such as e-cigarettes) to inhale nicotine at alarming rates (Meich et al. 2019), increasing as much as ninefold for high school students between 2011 and 2014 (Arrazola et al. 2015; CDC 2015). Aside from experimentation, one of the most commonly reported reasons for e-cigarette use among adolescents was to have a good time with friends (Patrick et al. 2016). Additionally, marijuana is becoming legal for medicinal and recreational use in many states, which may have implications for adolescent substance use (Hopfer 2014). For example, legalization may lead to an increase in adolescent marijuana use due to ease of access, lower levels of social stigma, and possible declines in price (Hopfer 2014). Additionally, legalization may lead to increased access to alternative forms of marijuana, including edibles and vaporized marijuana, which may have higher potencies than traditional marijuana in smoked form (Hopfer 2014). Indeed, the rates of using vaporized marijuana increased among adolescents in 2018 (Meich et al. 2019). An additional changing landscape over the past two decades is the rise in the opioid epidemic in the United States. Analyses from the National Survey on Drug Use and Health indicated that nonmedical use of prescription opioids is rising for adolescents ages 12–17 (Sung et al. 2005). The highest risk subgroups of adolescents included females, blacks, lower SES adolescents, and adolescents with friends who use illicit drugs (Sung et al. 2005), the latter highlighting the importance of research examining the peer processes associated with drug use in adolescence. However, the most recent statistics indicated that rates of illicit drug use by adolescents held steady in 2018 (Meich et al. 2019).

## Peer Mechanisms Associated with Substance Use in Adolescence

Network theory highlights the importance of peer influence as a process that impacts human behavior (Friedkin 1998; Moody et al. 2010), and peer influence becomes particularly relevant during adolescence (Gardner and Steinberg 2005). Peer influence occurs as a result of two interrelated and co-occurring processes, which are often reciprocal in nature: peer selection and peer socialization. Peer selection and socialization are inherently intertwined because the direction of peer socialization depends on the which friends adolescents select (Osgood et al. 2013). For example, selecting friends with high levels of substance use would lead to opportunities for peer socialization toward substance use.

Two complementary theoretical models help to explain the occurrence of peer selection and socialization. First, social learning theory suggests that adolescent behavior is shaped by the behavior of peers through modeling and social reinforcement, especially when the social reinforcement is from a desired peer group (Bandura 1977). From this theoretical perspective, adolescents select which peers and behaviors are desired, model the behaviors of those peers, and subsequently, socialization occurs through reinforcement (e.g., deviancy training; Dishion et al. 1996). For example, adolescents who observe that high status peers drink alcohol will model drinking behaviors to receive reinforcement, and subsequently drinking behavior will become more likely over time. Second, identity-based theories suggest that adolescents may conform to social norms of desired peer groups in order to improve one's sense of self or identity (Festinger 1954). From this theoretical perspective, adolescents select peers based on social group norms and the peer group may be socialized toward conformity over time. For example, adolescents may align themselves with peers who use substances because the adolescent believes that substance use is the norm and behavior may be shifted toward substance use within this social setting. Understanding the underlying mechanisms associated with adolescents' susceptibility to peer influence is germane to preventing adolescent substance use and promoting healthy youth development.

The traditional approach to examining the effect of peer influence on adolescent substance use is to use regression analyses with longitudinal data. In this approach, an adolescent typically self-reports on his/her own substance use and the substance use of his/her friends. Friends' substance use is then used to predict change in individual substance use over time. The resulting estimate is interpreted as the estimate of peer influence. Findings from studies using the traditional approach indicate that peers' substance use is related to an increase in adolescents' substance use over time (Dishion and Loeber 1985; Fergusson et al. 2002; Simons-Morton and Farhat 2010; Wang et al. 2009). Research using the traditional approach is limited because it is unable to disentangle co-occuring selection and socialization processes. Here, the concern is that adolescents select friends based on levels of substance use, which confounds the estimate of the effect of peer socialization on substance use.

## Social Network Analysis as a Method to Disentangle Peer Selection and Socialization Effects

Social network analysis (Wasserman and Faust 1994) is used to examine the interrelations between a set of actors (e.g., peers; friends) and any information known about those

actors (e.g., behaviors; attitudes). Social network analyses differ from the traditional regression-based approach described above because individuals in the social network report on their own friendships and on their own behavior over time. That is, the researcher collects data on the interrelations between the group of individuals in the network and on the behaviors of the individuals in the network. Applications in developmental science typically provide data for interconnected youth in classrooms, schools, or neighborhoods. A nomination procedure is used where students are asked to name peers within the classroom, school, or neighborhood to form a relational tie. For example, a tie between individual *i* and *j* can be represented $i \rightarrow j$, whereby individual *i* selected individual *j* in the relationship. In some applications, an unlimited nomination procedure is used, whereby individuals can make as many nominations as they wish. In other applications, a limited nomination procedure is used, whereby individuals can make a limited number of nominations set by the researcher. A major advantage of social network analysis is that it can be used to disentangle co-occurring processes to provide unique estimates of peer selection and socialization on behavioral outcomes.

Dynamic social network analyses, in particular, can simultaneously model the co-occurring change in peer networks and behavior over time. Stochastic actor based modeling is a simulation-based approach that leverages dynamic social network analyses to simultaneously model peer selection and socialization effects, after controlling for naturally ocurring network and behavioral tendencies (Snijders et al. 2010; Snijders 2011; Steglich et al. 2006, 2010; Veenstra and Steglich 2012). Relational ties between individuals drive the simulation process. For example, when individual *i* selects individual *j* ($i \rightarrow j$), it is presumed that individual *j* is in a position of influence over individual *i*. Peer selection is estimated by modeling change in relationships over time. For example, at time 1, individual *i* may not be tied to individual *j*, who has high levels of alcohol use. If individual *i* then adds a tie to *j* between times 1 and 2, a tendency toward selection based on alcohol use is indicated (see Fig. 1a). Peer socialization is estimated by modeling change in behavior over time. For example, at time 1, individual *i* is tied to individual *j*, who has high levels of alcohol use. If individual *i* changes his behavior towards that of *j* between times 1 and 2, a tendency toward socialization based on alcohol use is indicated (see Fig. 1b).

Stochastic actor based models have a number of unique advantages. First, selection and socialization are modeled simultaneously, so hypotheses and conclusions about one process can be made while controlling for the other. This is an advantage over the traditional method of studying peer influence, where peer selection and socialization are confounded in regression estimates. Second, multiple selection and socialization parameters can be tested simultaneously to

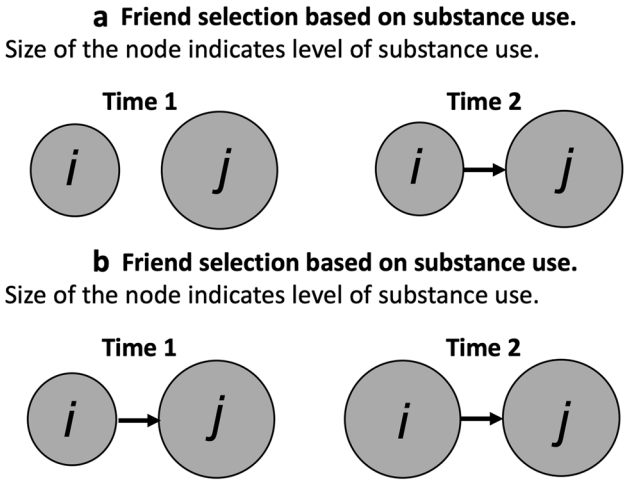


**Fig. 1** **a**, **b** Friend selection based on substance use. Size of the node indicates level of substance use

test competing hypotheses about how selection and socialization operate within the network. For example, it is possible to test theories about whether adolescents select friends who have higher levels of substance use or whether adolescents select friends based on similar levels of alcohol use. Third, stochastic actor based models provide the ability to control for a number of known network and behavioral tendencies to statistically improve the estimates of peer selection and socialization. For example, known tendencies in social networks include the tendency toward reciprocity (i.e., individuals tend to befriend peers who have already selected them as a friend) and transitivity (i.e., individuals tend to befriend friends of friends). Natural changes in behavior also exist, such as the natural tendency for substance use to increase, on average, throughout adolescense. Structural, network, and behavioral tendencies are included by adding parameters to the model, which helps to more accurately estimate the peer selection and socialization parameters.

Stochastic actor based models also make a number of modeling assumptions (see Snijders et al. 2010 for a summary) that are important to consider when reviewing empirical studies. Study design decisions made early in the research process when the researcher is considering sample selection or data collection may impact the results in light of the assumptions of the statistical modeling approach. First, the stochastic actor based model assumes an underlying continuous time paramenter. Although social networks and behavior are collected at discrete points in the time, the model creates micro-steps between observed time points to operationalize continuous time. As such, one important consideration when implementing stochastic actor based modeling is the number of time points and the time between time points of data collection. Second, the change process is assumed to be driven by a Markov process (Katz and Proctor

1959), whereby at any point in time, the current state of the network determines further evolution probabalistically, with no additional effects of network states at prior times. Third, the model assumes purposeful actors, whereby individuals in the network control their outgoing friendship ties. Fourth, at any given micro-step, only one probabilistically selected individual is able to change only one outgoing friendship. Finally, the model requires an ordinal outcome because behavior changes in a stepwise manner in the simulation process. As such, it is important to consider the scaling of the outcome variable to ensure that differences between levels of the ordinal categories are distanced such that change can be detected.

### Research Applying Stochastic Actor Based Modeling to Adolescent Substance Use

Relatively recent advancements in social network analysis, including advancements in stochastic actor based models, have led to a proliferation of applications in developmental science. Emerging empirical research applying stochastic actor based modeling points to the unique contribution of peer selection and socialization to substance use outcomes during adolescence. However, findings are mixed, indicating the need to synthesize the current emerging body of evidence to better understand what is currently known and how future research can help to further clarify the peer processes associated with adolescent substance use. Some studies report significant peer selection effects for adolescent alcohol (Light et al. 2013; Mundt et al. 2012; Osgood et al. 2013) and tobacco (Mathys et al. 2013; Mercken et al. 2009) use, whereas other studies report no significant selection effects for alcohol (Mathys et al. 2013) and tobacco (Huang et al. 2014a, b; Huisman 2014) use. Similarly, results are mixed for peer socialization, with some studies reporting significant socialization effects on adolescent alcohol (Kiuru et al. 2010; Osgood et al. 2013) and tobacco (Haas and Schaefer 2014; Ragan 2016; Steglich et al. 2012) use, and others reporting no significant socialization effects (Huang et al. 2014a, b; Mathys et al. 2013). In comparison to the number of studies examining alcohol and tobacco use, relatively few studies have used stochastic actor based models to examine adolescent drug use and much of the current evidence base for drug use comes from the National Longitudinal Study of Adolescent Health (Add Health; Bearman et al. 1997). Some studies reported a link between peer selection and socialization and marijuana use (Schaefer 2018), whereas some studies report nonsignificant effects (Mathys et al. 2013).

An additional distinct advantage of studies applying stochastic actor based modeling is the ability to differentiate between several mechanisms of peer selection and socialization. For example, adolescents may select friends with similar levels of substance use to themselves, a well-known tendency for behavioral outcomes, including substance use (i.e., homophily; Brechwald and Prinstein 2011). Here, peer influence would come from adolescents whose substance use correlated positively with one's own, which would result in greater uniformity in substance use, but would not necessarily raise the overall rate of substance use during adolescence (Osgood et al. 2013). Second, adolescents may generally select friends with higher levels of substance use. This process would be consistent with substance use serving as a gateway for membership in a desired peer group, and is consistent with prior research indicating an association between adolescent popularity and alcohol (Mayeux et al. 2008) and tobacco (Alexander et al. 2001; Valente et al. 2005) use. Here, peer influence would result in diffusing substance use across adolescents, which would raise the overall rate of substance use during adolescence (Osgood et al. 2013).

## Current Study

The landscape of adolescent substance use is rapidly changing, and concurrently, statistical methods to disentangle peer processes are being advanced and applied to developmental studies on adolescent substance use. Theoretical and empirical research highlight the unique importance of peer selection and socialization in the development of adolescent substance use. A proliferation of recent empirical research studies apply stochastic actor based models to help disentangle the peer selection and socialization processes to examine the unique contributions of each to the development of substance use in adolescence. Yet, to date, there have been no known systematic reviews of this expanding body of research. The goal of this systmatic review is to examine the extent to which empirical research applying stochastic actor based models supports the association between peer selection and socialization and adolescent substance use. Additionally, this review aims to identify patterns in study design characteristics to provide insights for future research applying stochastic actor based models to improve the understanding of peer processes and adolescent substance use.

## Methods

Eligible studies were identified by conducting an in-depth literature search on electronic databases including PsycINFO, ERIC, Academic Search Complete, SocINDEX, Scopus, PubMed, PsycARTICLES, JSTOR, Psychology and Behavioral Sciences Collection, and Google Scholar. The literature search used variations of the following search terms to identify relevant publications: "peer selection", "adolescents", "social network analysis", "substance use" or "drinking" or "smoking", "stochastic actor based modeling", and

"simulation investigation for empirical network analysis". In addition, the Siena webpage and bibliographies of relevant studies were reviewed to supplement the electronic search. No restrictions were placed on the date of publication for studies. To be included in the current study, studies had to meet the following inclusion criteria: (1) the study focused on adolescents; (2) the study focused on substance use outcomes (alcohol, tobacco, or other drugs, including marijuana); (3) the study applied stochastic actor based modeling to longitudinal social network data (i.e., the study reported on at least two waves of social network and behavioral data); and (4) the study was published in a peer-reviewed journal.

The database searches returned 594 studies based upon the entered search terms. Review of the bibliographies of those studies returned an additional 114 studies, yielding a total of 708 studies for review. The second author and a graduate research assistant independently screened the identified studies and excluded 633 studies for not meeting inclusion criteria or for being duplicates (i.e., the exact same study was returned multiple times in the search engine). The remaining 75 articles were reviewed in-depth, which resulted in 33 additional articles being excluded by reviewers, primarily for not applying stochastic actor based modeling. Two additional articles were excluded because they were simulation studies that focused on varying intervention parameters. When discrepancies arose between reviewers, the first author reviewed the publication to determine eligibility. A total of 40 studies met the full inclusion criteria for the current study.

Each of the 40 studies that met inclusion criteria was reviewed in-depth by at least two members of the research team. Table 1 provides the first author, year of publication, sample characteristics, and peer selection and socialization results for the 40 studies included in this review. A coding instrument was created by the authors using the most recent version of the RSiena manual (Ripley et al. 2019). Data were entered into a Microsoft Excel table that included the study design characteristics, the structural controls, covariates, and the effects from each study.

### Study Design Characteristics

First, the number of time points for data collection were coded on a continuous scale ranging from 2 to 9, and the time between time points was coded in months. Second, the data collection network type—classroom, grade, school, or community—was coded as a 0 or 1 for the absence or presence of each. Third, whether friendship nominations were collected using a limited (the researcher determines the number of friends a participant is able to nominate) or unlimited (the participant can nominate as many friends as s/he would like) collection procedure was coded. Fourth, the application of stochastic actor based models requires an ordinal outcome variable, and the number of ordinal categories utilized to model behavioral outcomes was recorded. Fifth, the types of structural network effects (e.g., outdegree, reciprocity, transitivity) that were used as controls and the covariates (e.g., gender, race/ethnicity, class/grade ego/alter or similarity) used as controls in the social network models were coded. The codes for structural network effects and structural network covariates were not mutually exclusive. Descriptive analyses were used to determine the proportion of studies that included each study design characteristic.

### Selection and Socialization Parameters and Effects

The most recent version of the RSiena manual (Ripley et al. 2019) was used to identify parameters typically associated with peer selection and socialization. Peer selection is typically measured by 3 network parameters: (1) *ego* effect, which measures the effect of the variable on the tendency to make a friendship nomination; (2) *alter* effect, which measures the effect of the variable on the tendency to receive a friendship nomination; and (3) *similarity* effect, which measures whether friendships were more likely among individuals who were similar on the variable. Peer socialization is respresented in the stochastic actor based model in various ways. The *average similarity* effect measures the tendency of individuals to be similar to other individuals on the variable of interest in such a way that the total influence is the same regardless of the number of individuals to which the focal individual is directly connected. The *total similarity* effect measures the tendency of individuals to be similar to other individuals in the network on the variable of interest in such a way that the total influence of the other individuals is proportional to the number of individuals. The *average alter* effect measures the tendency that individuals whose nominated peers have a higher average value on the variable of interest, also themselves tend to have higher values on the variable of interest. The presence/absence of each selection and socialization parameter and the presence/absence of a significant effect for each parameter were coded for each study. Descriptive statistics were used to determine the proportion of studies reporting a significant effect for each selection and socialization parameter for each substance use outcome examined.

## Results

### Descriptive Statistics

Ninety-five percent of the studies using stochastic actor based models to examine adolescent substance use were published since 2010 (see Table 2). Sixty-five percent were published between 2010 and 2014 and 30% were published

**Table 1** Summary of studies, sample characteristics, and peer effects for studies applying stochastic actor based modeling to examine adolescent substance use

| Author (year) | Sample characteristics* | Peer effects | | | | | |
|---|---|---|---|---|---|---|---|
| | | Alcohol use | | Tobacco use | | Other drug use | |
| | | Sel | Soc | Sel | Soc | Sel | Soc |
| Burk et al. (2012) | N = 950; age 10–16; 53% male; USA | ++ | ++ | | | | |
| DeLay et al. (2013) | N = 1419; age 16.36 (1.49); 49% male; 27% of fathers and 19% of mothers high white-collar occupations, 36% fathers and 17% mothers in blue-collar occupations; FinEdu study; Finland | | | ++ | NS | | |
| Giletta et al. (2012) | N = 704; age = 15.53 (1.01); 53% male; 35% of parents had less than high school degree, 14% of parents had postgraduate degree; Italy | ++ | ++ | | | | |
| Huang et al. (2014a, b) | N = 1419; 10th grade; 51% female; 66% Hispanic; Social Network Study; Southern California | ++ | NS | NS | NS | | |
| Huisman (2014) | N = 875; age = 13–14; 51.4% female, Holland | | | NS | NS | | |
| Huisman and Bruggeman (2012) | N = 961; age = 13.5 (.60); four urban and one rural school; Holland | | | ++ | ++ | | |
| Kiuru et al. (2010) | N = 1419; age = 16.4 (1.49); 49% male; FinEdu; Finland | ++ | ++ | ++ | NS | | |
| Knecht et al. (2011) | N = 3041; age = 12.1 (.49); 49% female; 120 classrooms in 14 schools; Holland | ++ | ++ | | | | |
| Light et al. (2013) | N = 6609; age = 12.5 (1.07); 50% female, 49% male, 1% did not report a gender; 12 schools; 40% non-White; School Social Environments study; USA | ++ | | | | | |
| Mathys et al. (2013) | N = 450; age = 15.5; 53% female; 66% White, 15% African American, 15% Hispanic American; mid-sized Northeastern city, USA | NS | NS | ++ | NS | NS | NS |
| Mercken et al. (2009) | N = 7704; age = 12–13; 47-64% female; 17 Danish schools (N = 843), 11 Finnish schools (N = 1326), 9 Dutch schools (N = 2524), 8 Portuguese schools (N = 1590), 4 UK schools (N = 792), and 21 Spanish schools (N = 629) | | | ++ | ++ | | |
| Mercken et al. (2010a) | N = 1326; age = 13.4; 47% female; 11 schools; ESFA study; Finland | | | ++ | ++ | | |
| Mercken et al. (2010b) | N = 1163; age = 13.6; 52% male; 9 schools; ESFA study; Finland | | | ++ | ++ | | |
| Mercken et al. (2012a) | N = 1204; age = 13.6; 48.4% female; 10 schools; ESFA study; Finland | | | ++ | ++ | | |
| Mercken et al. (2012b) | N = 1716; age = 12.2 (.38); 51.5% male; 11 schools; ESFA study; Britain | ++ | ++ | | | | |
| Mercken et al. (2013) | N = 254; age = 15.2; 75.6% female; 48% natives, 52% second-generation immigrants; ASSIST study; Belgium | | | ++ | | | |
| Osgood et al. (2013) | N = 13,214; age = 11.5; 49% male; predominantly White (non-White varied 4–39%); at least 15% FARMs eligible; PROSPER study, Iowa and Pennsylvania | ++ | ++ | | | | |
| Osgood et al. (2015) | N > 13,000; 6th grade; 49% male; 26 rural and semi-rural school districts; PROSPER study; Iowa and Pennsylvania | ++ | ++ | ++ | ++ | | |
| Pearson et al. (2006) | N = 160; age = 13; Teenage Friends and Lifestyle Study; Scotland | ++ | ++ | ++ | NS | NS | ++ |
| Rabaglietti et al. (2012) | N = 457; age = 16.1; 57% female; 6% unemployment rate for families in sample, 9% of sample's parents were divorced, 3% lived in single-parent households, 37% of parents completed primary school, 39% completed high school, 10% had some vocational specialization, 14% completed college | ++ | ++ | | | | |
| Ragan et al. (2013) | N > 12,000; 6th–9th grade; 49% male; 61–96% White, at least 15% eligible for free or reduced-cost lunches; 27 non-metropolitan communities; PROSPER study, USA | ++ | ++ | | | | |
| Ragan (2014) | N > 11,000; 6th–9th grade; 49% male; 61–96% White, at least 15% eligible for free or reduced-cost lunches; 27 non-metropolitan communities; PROSPER study, USA | ++ | ++ | | | | |
| Ragan (2016) | N > 9000; 6th–9th grade; 49% male; predominantly White, substantial portion low-income; 27 school districts in rural and semi-rural Iowa and Pennsylvania; PROSPER study | | | ++ | ++ | | |

**Table 1** (continued)

| Author (year) | Sample characteristics* | Peer effects | | | | | |
|---|---|---|---|---|---|---|---|
| | | Alcohol use | | Tobacco use | | Other drug use | |
| | | Sel | Soc | Sel | Soc | Sel | Soc |
| Steglich et al. (2012) | N = 629; age = 12.5–12.7; 46–56% female; 3 schools from ASSIST study; School A-small semi-urban school in England with 6% of students receiving free school meals, School B—large urban school in England with 23.9% receiving free school meals, School C—large semi-urban school in Wales with 8.3% receiving free school meals | | | ++ | ++ | | |
| Van Ryzin et al. (2016) | N = 1289; age = 12.1; 53.2% female; 8 middle schools; 77.4% European American; Pacific Northwest | ++ | | ++ | | | |
| Add health studies | | | | | | | |
| Cheadle et al. (2015) | N = 2296; 7th–12th grade; 49% female<br>Jefferson High School—1531 students; large, racially heterogeneous high school (6% White, 23% Black, 39% Hispanic, and 32% Asian)<br>Sunshine High School—765 students; middle-sized, predominantly White high school (7% non-white) | ++ | ++ | | | | |
| de la Haye (2013) | N = 1612; 7th–12th grade; 51.3% male<br>School 1—1193 students; age = 16.34 (0.85); Ethnically heterogeneous in a major metropolitan area (39.7% Hispanic, 23.1% non-Hispanic White, 24.7% non-Hispanic Black, 33% Asian, and 1.3% Other)<br>School 2—419 students; age = 16.47 (0.84); Predominantly white in a mid-sized town (1% Hispanic, 98.8% non-Hispanic White, and 1.4% Asian) | | | | | ++ | NS |
| de la Haye (2015) | N = 1612; 7th–12th grade; 51.3% male<br>School 1—1193 students; age = 16.34 (0.85); Ethnically heterogeneous in a major metropolitan area (39.7% Hispanic, 23.1% non-Hispanic White, 24.7% non-Hispanic Black, 33% Asian, and 1.3% Other)<br>School 2—419 students; age = 16.47 (0.84); Predominantly white in a mid-sized town (1% Hispanic, 98.8% non-Hispanic White, and 1.4% Asian) | | | | | ++ | ++ |
| Haas and Schaefer (2014) | N = 2430; 7th–12th grade<br>Jefferson High School—757 students; age = 15.73 (1.2); 51% male; 92% White, 4% Black, 3% Hispanic, 1% Asian, and 1% Other; located in mid-sized town in Midwest<br>Sunshine High School—1673 students, age = 16.09 (1.04); 52% male; 5% White, 22% Black, 40% Hispanic, 32% Asian, and 1% Other; located in a suburban community in the West | | | ++ | ++ | | |
| Lakon et al. (2015a) | N = 3154; 9–12th grade; one rural Midwestern school, one suburban Western school; 40% non-White<br>School 1—2178 students<br>School 2—976 students | | | ++ | ++ | | |
| Lakon et al. (2015b) | N = 2260; 9th–12th grade<br>Sample 1—12 small high schools, 1284 students; 50.93% female; parent education: 6.46% less than high school, 39.3% high school, 31.7% some college or trade school, and 22.6% college graduate; Sample 2—"Jefferson", 976 students, 48.46% female; rural, predominantly White; parent education: 5.2% less than high school, 38.3% high school, 36.5% some college or trade school, and 20% college graduate | | | ++ | ++ | | |
| Long et al. (2017) | N = 1796; 9th–11th grade<br>School A—640 students; age = 16.5 (.97); 53.6% male; Midwestern public school; 98.8% White, less than 1% Black; Parental Education: 8.4% less than high school, 35.9% high school, 30.6% some college, and 14.2% college graduate; School B—1156 students; age = 16.4 (.83); 51.4% male; Western public high school; 23.4% White, 25.2% Black, 3.8% American Indian, 32.4% Asian/Pacific Islander, 22.7% Other; Parental Education: 22.6% less than high school, 15.4% high school, 21.8% some college, 14.3% college graduate | ++ | ++ | | | | |
| Mundt et al. (2012) | N = 2563; 7th–11th grade; age = 15.8 (1.3); 50.8% male; 60.9% Non-Hispanic White, 16.4% African American, 1.6% Native American, 18% White Hispanic, and 3.4% Asian | ++ | NS | | | | |

**Table 1** (continued)

| Author (year) | Sample characteristics* | Peer effects | | | | | |
|---|---|---|---|---|---|---|---|
| | | Alcohol use | | Tobacco use | | Other drug use | |
| | | Sel | Soc | Sel | Soc | Sel | Soc |
| Schaefer (2018) | N = 1373; 497 from Jefferson and 876 from Sunshine; age = 15.6 (.88); 48.87% female; 36.56% White; 13.69% Black; 25.49% Hispanic; 18.79% Asian; 5.39% Other | ++ | NS | ++ | NS | ++ | ++ |
| Schaefer et al. (2013) | N = 509; age = 15.4; 97% White | | | ++ | ++ | | |
| Schaefer et al. (2012) | N = 509; age = 15.4; 97% White; 46.60% female | | | ++ | ++ | | |
| Tucker et al. (2014) | N = 1612; 10th–11th grade<br>School 1—1193 students; age = 16.34 (.85); 51.3% male; 39.7% Hispanic, 23.1% White, 24.7% Black, 33% Asian, and 1.3% Other; Parent education: 24.6% less than high school, 20.2% high school, 29.3% some college or trade school, 19.2% college graduate<br>School 2—419 students; age = 16.47 (0.84); 56.8% male; 1% Hispanic, 98.8% White, and 1.4% Asian; Parent education: 3.9% less than high school, 32.5% high school, 34.8% some college or trade school, 28.9% college graduate | | | | | ++ | NS |
| Wang et al. (2015) | N = 2260; 7th–12th grade; 12 small schools—1284 students; 50.93% female; parent education: 6.7% less than high school, 38.9% high school, 30.8% some college or trade school, and 23.6% college graduate; Jefferson—976 students; 48.46% female; parent education: 5% less than high school, 38.2% high school, 37.1% some college or trade school, and 19.7% college graduate | ++ | ++ | | | | |
| Wang et al. (2016) | N = 2260; 7th–12th grade; 12 small schools—1284 students; 50.93% female; parent education: 6.7% less than high school, 38.9% high school, 30.8% some college or trade school, and 23.6% college graduate; Jefferson—976 students; 48.46% female; parent education: 5% less than high school, 38.2% high school, 37.1% some college or trade school, and 19.7% college graduate | ++ | ++ | ++ | ++ | | |
| Wang et al. (2017) | N = 3154; 7th–12th grade; Sunshine—2178 students; Jefferson—976 students | ++ | ++ | | | | |

*Sel* selection, *Soc* socialization, *NS* not significant,++ significant effect reported

Blanks indicate that the effect was not studied

*Age reported as mean years (SD) where applicable

between 2015 and 2018. Fifty percent of studies used data collected prior to the year 2000. Sixty-five percent of studies used an American sample and 35% of studies used an European sample. Fifty-three percent of studies examined alcohol use, 58% examined tobacco use, and 15% examined drug use.

Sixty-one percent of studies used data from one of three sources. First, 38% of studies used data from the National Longitudinal Study of Adolescent Health (Add Health; Bearman et al. 1997), which included social network data collected from two schools. The characteristics of the two schools differ, with one school having a large, ethnically diverse heterogeneous student body located in a major metropolitan area, and the other having a small predominantly white student body located in a mid-sized town. Studies used data from Wave I (1995) and Wave II (1996), with grade-level cohorts in grade 10/11 at Wave I and grade 11/12 at Wave II. Students were able to nominate five best male and five best female friends enrolled in their school. Second, 13% of studies used data from the PROSPER study (Spoth et al. 2007), which was a prevention trial in 28 small public school districts in Iowa and Pennsylvania. Participants were predominantly white and data for social network studies come from the fall of 2002 and 2003 sixth grade cohorts, with data collection time points in the Spring of sixth through ninth grades. Students in each community attended a single high school in ninth grade, but many communities had multiple schools in earlier grades. Students were able to nominate up to two best friends and five additional close friends in their same grade and school. Third, 10% of studies used data from the European Smoking Prevention Framework Approach (De Vries et al. 2003), which was an intervention trial with social network data coming from 11 Finnish schools, located in Helsinki. The 11 schools were control group schools in the intervention study. Data were collected from 7th grade students in 1998, and follow-up

**Table 2** Descriptive statistics for studies examining adolescent substance use using stochastic actor based modeling

| Study characteristic | *N* (%) |
|---|---|
| Year published | |
| 2015–2018 | 12 (30) |
| 2010–2014 | 26 (65) |
| < 2010 | 2 (5) |
| Year of first data collection | |
| 1994–2000 | 20 (50) |
| 2001–2010 | 9 (22) |
| > 2010 | 0 (0) |
| N/A | 11 (28) |
| Continent of origin | |
| American | 26 (65) |
| European | 15 (35) |
| Substance use outcome[a] | |
| Alcohol | 21 (53) |
| Tobacco | 23 (58) |
| Drugs | 6 (15) |
| Data source | |
| Add health | 15 (38) |
| PROSPER | 5 (13) |
| European smoking prevention framework approach | 4 (10) |
| Other | 16 (40) |

A total of 40 studies were included in this review. Other data source includes primary data collection

[a]$n = 7$ studies examined more than one substance use outcome. N/A was used when not enough information was provided to code the study characteristic

occurred 12, 24, and 30 months later. Students were able to nominate 5 friends inside and outside of their school. Forty percent of studies used data from another source, including primary data collection and other longitudinal data sets. Due to the large percentage of studies using the Add Health data, Add Health studies were analyzed and reported separately from all other studies throughout the rest of this review.

## Study Design Characteristics

Table 3 presents the results of the study design characteristics. The studies included in this review utilized a range of study designs. The Add Health studies used an average of 2.4 time points for data collection, with a range of 2–3, whereas the studies using other samples used an average of 3.4 time points with a range of 2–8. The average time in months between time points for Add Health studies was 10.47, with a range of 6–12 months, and the average time between time points for samples using other samples was 12.39 months, with a range of 6–30 months. All of the Add Health studies used a school-level friendship network, whereas most of the studies using other samples used a grade network (72%). Most of the studies included in this review (100% of Add Health studies and 84% of all other studies) used a limited nomination procedure to collect social network nominations. Most studies (60% of Add Health studies and 68% of studies using all other samples) included 5–6 ordinal outcome variable categories.

All studies included in this review included a structural network effect for outdegree (outdegree or outdegree-density), reciprocity, and transitivity. The most common transitivity structural effect included was transitive triplets, followed by 3-cycles and transitivity. Additionally, most studies included a gender network covariate. Race/ethnicity was included as a network covariate to a lesser extent. All Add Health studies included a class/grade/age network covariate, whereas only about a third of studies using all other samples included class/grade/age covariates. The studies using the European Smoking Prevention Framework Approach sample included school achievement network covariates. Sixty-seven percent of Add Health studies included parent education as a network covariate, and some of the Add Health studies included parental support and monitoring as network covariates.

## Selection and Socialization Parameters and Significant Effects

As Table 4 indicates, there is largely support for peer selection effects on adolescent alcohol and tobacco use. Ninety-two percent of Add Health studies and 93% of studies using all other samples reported significant selection effects for alcohol use. One hundred percent of Add Health studies and 88% of studies using all other samples reported significant selection effects for tobacco use. Findings were mixed for adolescent drug use, with 100% of Add Health studies reporting significant selection effects for drug use and 0% of studies using all other samples reporting significant selection effects for drug use. Support for peer selection largely came from significant alter and similarity effects. Ego effects were rarely significant.

Support for peer socialization effects on adolescent substance use was mixed. Seventy-five percent of Add Health studies and 85% of studies using all other samples reported significant socialization effects for alcohol use. Ninety percent of Add Health studies and 57% of studies using all other samples reported significant socialization effects for tobacco use. Sixty-seven percent of Add Health studies and 50% of studies using all other samples reported significant socialization effects for other drug use. Average alter was the most commonly examined peer socialization effect.

**Table 3** Study design characteristics for studies examining adolescent substance use using stochastic actor based modeling

| Study design characteristic | Add health ($N=15$)<br>*M (SD); R* | All other samples ($N=25$)<br>*M (SD); R* |
|---|---|---|
| Number of time points | 2.40 (.51); 2–3 | 3.40 (1.50); 2–8 |
| Time between time points (months) | 10.47 (2.54); 6–12 | 12.39 (7.37); 6–30 |
| | N (%) | N (%) |
| Network type | | |
| Classroom | 0 (0) | 1 (4) |
| Grade | 0 (0) | 18 (72) |
| School | 15 (100) | 6 (24) |
| Community | 0 (0) | 0 (0) |
| Nomination procedure | | |
| Limited | 15 (100) | 21 (84) |
| Unlimited | 0 (0) | 4 (16) |
| Number of ordinal categories[a] (outcome) | | |
| 2 | 1 (7) | 1 (4) |
| 3 | 2 (13) | 5 (20) |
| 4 | 2 (13) | 1 (4) |
| 5–6 | 9 (60) | 17 (68) |
| 7+ | 1 (7) | 1 (4) |
| Structural network effects | | |
| Outdegree | 9 (60) | 12 (48) |
| Outdegree-density | 6 (40) | 13 (52) |
| Reciprocity | 15 (100) | 25 (100) |
| Transitivity | 3 (20) | 12 (48) |
| Transitive triplets | 15 (100) | 14 (56) |
| 3-cycles | 12 (80) | 13 (52) |
| Structural network covariates | | |
| Gender ego/alter | 9 (60) | 18 (72) |
| Race/ethnicity ego/alter | 3 (20) | 9 (36) |
| Class/grade/age ego/alter | 9 (60) | 7 (28) |
| Gender similarity | 13 (87) | 23 (88) |
| Race/ethnicity similarity | 9 (60) | 13 (52) |
| Class/grade/age similarity | 15 (100) | 9 (36) |

$N=3$ studies used different numbers of ordinal categories for multiple outcomes examined. The largest number of ordinal categories was coded for this table

## Discussion

Peer influence processes play an important role in the development of substance use in adolescence, and the link between peers' substance use and adolescent substance use is well-established in the empirical literature (Hawkins et al. 1992). A long line of empirical research applies a regression-based approach where adolescents' self-report of friends' substance use is used to predict change in individual substance use over time, and a positive link between friends' use and adolescent use is well-documented (Dishion and Loeber 1985; Fergusson et al. 2002; Simons-Morton and Farhat 2010; Wang et al. 2009). Recent advancements in social network analyses, including advancements in and applications of stochastic actor based models, have expanded researcher's ability to disentangle two co-occurring, and often reciprocal, effects of peer influence: peer selection and socialization (Snijders et al. 2010; Snijders 2011; Steglich et al. 2006, 2010; Veenstra and Steglich 2012). The current review reported that 95% of the studies applying stochastic actor based models to examine adolescent substance use were published within the last decade, which highlighted the proliferation of recent empirical research in this area. The current review found evidence for both peer selection and socialization, with most significant effects deriving from similarity and alter parameters. The reported evidence for peer socialization of tobacco use was not as consistent as the reported evidence for peer socialization of alcohol use. Few

**Table 4** Selection and socialization parameters examined and proportion significant in adolescent substance use studies using stochastic actor based modeling

| Parameter | Add health ($N=15$) | | | | | | All other samples ($N=25$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alcohol ($N=12$) | | Tobacco ($N=10$) | | Drugs ($N=7$) | | Alcohol ($N=15$) | | Tobacco ($N=16$) | | Drugs ($N=2$) | |
| | Total | Sig | Total | Sig | Total | Sig | Total | Sig | Total | Sig | Total | Sig |
| | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) |
| Selection (any) | 12 (100) | 11 (92) | 10 (100) | 10 (100) | 7 (100) | 7 (100) | 15 (100) | 14 (93) | 16 (100) | 14 (88) | 2 (100) | 0 (0) |
| Alter | 12 (100) | 10 (83) | 10 (100) | 6 (60) | 7 (100) | 5 (71) | 15 (100) | 8 (53) | 16 (100) | 7 (44) | 2 (100) | 0 (0) |
| Ego | 12 (100) | 3 (25) | 10 (100) | 1 (10) | 7 (100) | 2 (29) | 14 (93) | 5 (36) | 15 (94) | 4 (27) | 2 (100) | 0 (0) |
| Similarity | 12 (100) | 10 (83) | 10 (100) | 10 (100) | 7 (100) | 7 (100) | 15 (100) | 14 (93) | 16 (100) | 13 (81) | 2 (100) | 0 (0) |
| Socialization (any) | 12 (100) | 9 (75) | 10 (100) | 9 (90) | 7 (100) | 3 (43) | 13 (87) | 11 (85) | 14 (88) | 8 (57) | 2 (100) | 1 (50) |
| Average similarity | 1 (8) | 0 (0) | 5 (50) | 4 (80) | 1 (14) | 1 (100) | 2 (15) | 2 (100) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Total similarity | 2 (17) | 1 (50) | 1 (10) | 1 (100) | 0 (0) | 0 (0) | 3 (23) | 3 (100) | 2 (14) | 1 (50) | 0 (0) | 0 (0) |
| Average alter | 9 (75) | 8 (89) | 4 (40) | 4 (100) | 4 (57) | 2 (50) | 8 (62) | 6 (75) | 12 (86) | 7 (58) | 2 (100) | 1 (50) |

Total indicates the total number of studies examining the parameter. Percent of the total was calculated as the percent of studies that examined the parameter divided by the number of studies that examined that outcome. When models were run separately for two unique samples from Add Health, they are reported as separate studies for this table

Significant indicates the total number of studies that found a significant effect for the parameter. Percent significant was calculated by dividing the total number of studies that found a significant effect for the parameter by the total number of studies that examined the parameter

*Sig* significant

studies applied stochastic actor based modeling to examine adolescent drug use, and the majority of studies that did used the Add Health sample. The results indicated variation in study design characteristics, including important variations in the bounds of networks and in the network and behavioral covariates used in modeling. In the following section, initial insights into the associations between peer selection and socialization and adolescent substance use are highlighted and discussed. Next, the reported variations in study designs are discussed within the context of directions for future research on adolescent substance use. Finally, the strengths and limitations of this review and the included studies are evaluated and implications for adolescent development and prevention and intervention are provided.

## Support for Peer Selection and Socialization Effects on Adolescent Substance Use

Consistent with network theory (Friedkin 1998), the current review of empirical research applying stochastic actor based modeling found support for both peer selection and socialization. Reviewing the research applying stochastic actor based modeling provided the distinct ability to separately examine the contributions of the dynamic and co-occurring peer selection and socialization processes, which are confounded when using the traditional regression-based approach for studying peer influence on substance use. An additional benefit of stochastic actor based models is the ability to test distinct hypotheses about the mechanisms of peer selection and socialization effects.

Significant peer selection effects were found for most studies examining peer selection. The most commonly significant selection effects were found for alter (i.e., adolescents who use substances were more likely to be added or retained as friends) and similarity (i.e., friendships were more likely among adolescents who were similar on levels of substance use). The preference for friends who have high levels of substance use is consistent with identity theories (Festinger 1954), and aligning oneself with substance using peers may be seen as a gateway toward membership in a desired peer group. This finding is consistent with prior research linking adolescent popularity to alcohol (Mayeux et al. 2008) and tobacco use (Alexander et al. 2001; Valente et al. 2005). Overall, this pattern of peer selection in the network may lead to diffusing substance use among adolescents, with additional adolescents initiating substance using behavior (Osgood et al. 2013). The preference for friends who have similar levels of substance use is also consistent with identity theories. Aligning oneself with similar individuals may help to increase patterns of conformity to group norms and may lower cognitive dissonance that would arise when associating with individuals who are dissimilar to one's self (e.g., Festinger 1954). Overall, this pattern of peer selection in the network may lead to more clustered groupings of substance use within the network, but would not lead to overall increases in the number of adolescents engaging in substance use behaviors (Osgood et al. 2013). Further evaluating and differentiating the roles of these two important peer selection mechanisms will help to improve the understanding of peer selection as a process that sets the

stage for the type of peer influence that might occur in the network.

Significant peer socialization effects were found fairly consistently for studies examining adolescent alcohol use, but somewhat less consistently for studies examining adolescent tobacco use. Only 57% of studies reporting on a sample other than Add Health found significant socialization effects for adolescent tobacco use. The most commonly significant socialization effects were found for average alter (i.e., adolescents tended to change their alcohol use toward the level of alcohol use of their nominated friends) and average similarity (i.e., adolescents tended to change their alcohol use toward the mean of their friends' alcohol use). The reported peer socialization effects for alcohol use are consistent with social learning theory (Bandura 1977), whereby adolescent behavior is shaped by the behavior of peers through modeling and social reinforcement, especially when the social reinforcement is from a desired peer group. Additionally, the significant peer socialization effects for adolescent alcohol use are consistent with the well-documented evidence for deviancy training (Dishion et al. 1996). The mixed results for socialization effects on adolescent tobacco use are somewhat inconsistent with network theory (Friedkin 1998). However, the findings may be due to the unique nature of smoking behavior. For example, the socialization processes associated with alcohol and tobacco may vary due to the differing acceptability of use. Although some studies have linked popularity with adolescent tobacco use (Alexander et al. 2001; Valente et al. 2005), others have linked tobacco use with marginalization from traditional peer groups (Christakis and Fowler 2008; La Greca et al. 2001). Some adolescents may have less favorable views of tobacco use due to social stigma and segregation, which comes in the form of designated smoking areas, which are typically isolated from nonsmokers. Additionally, smoking may be more initially addictive than alcohol, making smoking continuation more likely, regardless of social influence processes.

Few studies reported on adolescent drug use, which is particularly relevant and timely given its changing landscape over the past few decades. Marijuana is becoming legal in many states (Hopfer 2014) and nonmedical use of prescription opioids has risen over the past two decades (Sung et al. 2005). Theory and empirical studies applying the traditional regression-based approach to examine peer influence as a risk factor for drug use highlight the importance of peers' contributions (e.g., Bauman and Ennett 1994). Yet, the changing landscape of adolescent drug use makes research applying social network analyses particularly difficult for several reasons. First, access to samples of adolescents who engage in drug use may be more difficult to obtain, when compared to access to adolescents who use alcohol and tobacco. The specific population of adolescents using other drugs, including marijuana and opioids, may be particularly hard to initially engage and subsequently keep engaged in research studies. Second, in comparison to rates of alcohol and tobacco use, use of other drugs, such as opioids, is relatively rare (Meich et al. 2019). As such, sample sizes would need to be large to be able to detect significant peer selection and socialization processes. Social network studies are expensive in terms of time and money, and many studies reviewed in the current review were embedded within larger developmental or intervention studies. The cost associated with implementing a social network study with large enough sample sizes to detect significant effects for drugs such as opioids is likely to be high. Finally, the illegal nature and social stigma surrounding use of some drugs may reduce the likelihood of accurate reporting on use, which may bias social network studies and further complicate the understanding of the contributions of peer processes to adolescent drug use.

## Variability in Study Design Characteristics

Study design characteristics varied across studies, which helps to underscore a number of areas for future research to help advance the understanding of adolescent substance use. First, most studies used a limited nomination procedure with networks bounded at the grade or school levels. The benefit of this approach is that data collection and entry are easier and the stochastic actor based models can run more efficiently, with less computing power necessary to estimate effects. However, it is well-documented that the risky behavior of older peer groups, including older siblings, predicts adolescent risk-taking, including substance use (e.g., D'Amico and Fromme 1997). This linkage may be captured in studies that used school-level networks, but would not be captured in studies using grade- or classroom-level networks. The bounding of networks at the grade or school levels may also lead to peer effects being driven by geographic location and school size. For example, in small rural schools with limited peer ties, the effects of peers may be different than in larger urban schools with more diverse opportunities for peer interaction. Similarly, schools that follow neighborhood boundaries and schools that are non-geographically based may differ in the role of peers on substance use because access to friends outside of school may differ. Peers in the neighborhood may be particularly important for the development of risk-taking behaviors like substance use (Brooks-Gunn et al. 1997), and neighborhood peer networks may not fully be captured in school networks that are non-geographically based. Future research on the effects of cross-grade, cross-school, and cross-community peer networks on substance use will help to further clarify the effects of peers across developmental ages and contexts.

Second, the network covariates included in studies varied widely. Most studies included a network covariate for

gender, but additional covariates varied across studies, and often included race/ethnicity and classroom/grade/age. Additionally, studies using the European Smoking Prevention Framework sample typically included academic achievment as a covariate, and studies using Add Health data sometimes included parenting variables, such as parental monitoring, as covariates. A limitation of stochastic actor based models is that, like traditional regression based approaches, unmeasured confounders may be codetermining the probabilities for network selection and behavioral socialization (Steglich et al. 2010). For example, there may be an unobserved individual characteristic (e.g., academic achievement) that guides ties in the network (i.e., individuals select peers based on levels of academic achievement). If substance use levels change dependent on academic achievement levels, peer selection and socialization effects on academic achievement may spuriously be attributed to substance use levels. An experimental design is the only way to fully limit the effects of unmeasured confounders. However, the inclusion of additional covariates known to be associated with peer relationships and substance use may help to more accurately estimate the effects of peer selection and socialization on substance use outcomes. Several groups of covariates are important to consider. Demographic characteristics, such as gender and race/ethnicity, parenting characteristics, such as parental monitoring and family cohesion, academic characteristics, such as academic achievement, and co-occurring behavioral characteristics, such as aggressive and delinquent behavior, have traditionally been linked with susceptibility to peer influence (Brechwald and Prinstein 2011) and with the development of substance use in adolescence (Hawkins et al. 1992). The addition of covariates is important to consider in future research to further narrow the understanding of the distinct relation between peer processes and adolescent substance use. Doing so will help to ensure that findings should indeed be attributed to the influence of peers on substance use and not to a co-occuring process, characteristic, or behavior.

## Strengths and Limitations

Peer influence is a dynamic and complex process, whereby selection and socialization processes contribute to substance use outcomes. This review summarized the emerging research on peer selection and socialization processes for three common substance use outcomes—alcohol, tobacco, and other drug use. Reviewing the emerging literature applying stochastic actor based models helped to distinguish between estimates of peer selection and socialization, and highlighted specific mechanisms of peer selection and socialization that are supported by empirical research. Additionally, this review examined study design characteristics for emerging applications of stochastic actor based models, which highlighted a number of areas for future research to advance the understanding of adolescent substance use, including a focus on the effects of cross-grade, cross-school, and cross-community peer networks and expanding the covariates used in models to strengthen the confidence in estimates of peer selection and socialization effects.

This study should be interpreted within the context of the following limitations. First, despite the unique advantages that stochastic actor based models have for estimating selection and socialization, one limitation is that effect sizes are not able to be calculated based on the results of stochastic actor based models, so no information is provided on the magnitude of effects, limiting the ability to compare the magnitude of the effects of peer selection and socialization parameters. Instead, this study reports evidence in terms of the overall percentage of studies reporting a significant effect. It is possible that some studies report significant effects that are not practically meaningful, and it is also possible that some nonsignificant effects are due to limited statistical precision and power. Second, most of the studies included in this review used data from one of three studies: Add Health, PROSPER, or the European Smoking Prevention Framework Approach. Data were from American and European samples, and samples were predominantly White. Prior research indicates cross-cultural variation in peer processes and developmental outcomes (e.g., Chen et al. 2006; Choukas-Bradley et al. 2015), and future research using using more diverse samples of adolescents is critical for furthering the understanding of peer processes related to adolescent substance use. Third, most of the studies included in this review used data collected prior to 2010, with 50% of studies reporting on data collected prior to 2000, which is important to highlight given the rapidly changing landscape of adolescent substance use over the past two decades (Hopfer 2014; Sung et al. 2005). An additional consideration related to the timing of data collection is the increase in social media connectivity, which has transformed peer interactions to redefine network boundaries and influence. There is growing evidence that social media connectivity and online social networks contribute to levels of adolescent substance use (e.g., Huang et al. 2014a, b). Yet, almost all of the studies examined in this review collected data prior to the increase in social media connectivity in the daily experience of adolescent lives, and as such, it is important for future research to consider selection and socialization effects on adolescent substance use without assuming physical proximity in a classroom, school, or community network. Finally, this review summarized research on adolescent substance use, without considering co-occurring behavioral outcomes, such as delinquent and aggressive behaviors (e.g., Loeber et al. 1998). A more complete understanding of the contribution of peer processes to adolescent substance use could be gained from simultaneously examining substance

use within the context of co-occurring behaviors (see Sijtsema and Lindenberg (2018) for a review of the literature applying stochastic actor based modeling to adolescent antisocial behavior).

### Implications for Adolescent Development and Prevention of Substance Use

Separately estimating the effects of peer selection and socialization has distinct advantages for furthering the understanding of adolescent substance use, with specific implications for the development of prevention and intervention programs. This review highlighted the importance of peer selection for contributing to the development of adolescent alcohol and tobacco use. While it is well-recognized that network theoretical concepts, including a focus on peer influence, have traditionally been incorporated into the development of adolescent prevention programming (see Gest et al. 2011), a recent review of empirically validated universal school-based prevention programs targeting substance use in middle school indicated that programs focused more heavily on peer socialization when compared to peer selection (Henneberger et al. 2019). Peer selection is particularly important because it sets the stage for the direction of socialization that may occur. The current review highlights the potential opportunity for uniquely targeting peer selection to prevent substance use in adolescence. For example, interventions that aim to prevent selecting peers who smoke or aim to reduce the likelihood that alcohol and smoking are seen as "cool" would be consistent with the selection findings highlighted in this review. The evidence for peer socialization effects on adolescent alcohol use is well-aligned with the traditional social influence prevention approach that aims to reduce negative peer pressures. However, the inconsistency in findings related to the socialization of tobacco use suggests that traditional social influence approaches may not be particularly relevant for smoking behaviors. Additional research on selection and socialization for newer forms of tobacco, including e-cigarettes would help to further clarify the roles of peer processes in substance use. The most recent statistics indicate that vaping may be diverting some adolescents away from cigarettes, but may simultaneously be introducing an additional population of adolescents to new forms of nicotine (Meich et al. 2019).

## Conclusion

A substantial body of research points to the critical importance of peer influence for the development of adolescent problem behaviors, including substance use. However, recent methodological advancements in social network analysis have improved researchers' ability to differentiate between two co-occurring peer influence processes: peer selection, the process whereby adolescents choose friends, and peer socialization, the process whereby behavior is shaped over time. The current study systematically reviewed the research applying stochastic actor based models to examine the peer selection and socialization processes associated with the development of substance use in adolescence. A recent proliferation of empirical research in this area was highlighted, with 95% of the studies included in this review published within the last decade. The results of most of the studies found support for peer selection effects on adolescent alcohol and tobacco use. Most studies reported peer socialization effects for adolescent alcohol use, but relatively few studies reported socialization for tobacco use. Few studies reported on the peer effects associated with adolescent drug use. Variations in study design, including variations in the bounds of the network and in the covariates included in modeling, helped to identify areas for future research. Directions for future research include focusing on cross-school, cross-community, and even Internet peer networks with diverse samples of adolescents, improving selection and socialization estimates by adding covariates to improve the accuracy of estimating relations, and measuring the effects of peer processes on newer forms of substance use, including e-cigarettes and edible marijuana. Doing so will help to further clarify the roles of specific peer selection and socialization mechanisms to help inform the development and refinement of prevention and intervention programs focused on reducing adolescent substance use.

**Acknowledgements** Work on this review was supported by a Competitive Innovative Research award from the University of Maryland School of Social Work to Angela Henneberger. The authors would like to thank reviewers for comments that helped to clarify our presentation of this review. We also thank Erika Quito for assistance in collecting and coding studies for this review, and we thank Dr. Nancy Deutsch for helpful comments on a previous version of this manuscript.

**Authors' Contributions** AH conceived of the study, participated in its design and coordination, and drafted the manuscript; DM participated in the collection and coding of studies for this review and drafted sections of the manuscript; AP helped to code studies for this review and helped to draft the manuscript. All authors read and approved the final manuscript.

## Compliance with Ethical Standards

**Conflict of interest** The authors report no conflict of interest.

**Ethical Approval** This review was a synthesis of already published quantitative studies. No ethical approval or informed consent were needed.

## References

### *Included in the literature review


Alexander, C., Piazza, M., Mekos, D., & Valente, T. (2001). Peers, schools, and adolescent cigarette smoking. *Journal of Adolescent Health, 29*, 22–30.

Arrazola, R. A., Singh, T., Corey, C. G., Husten, C. G., Neff, L. J., & Apelberg, B. J. (2015). Tobacco use among middle and high school students—United States, 2011–2014. *MMWR, 64*, 381–385.

Bandura, A. (1977). *Social learning theory*. Englewood Cliffs, NJ: Prentice Hall.

Bauman, K. E., & Ennett, S. T. (1994). Peer influence on adolescent drug use. *American Psychologist, 49*(9), 820.

Bearman, P. S., Jones, J., & Udry, J. R. (1997). *The national longitudinal study of adolescent health*. Chapel Hill, NC: Carolina Population Center.

Brechwald, W. A., & Prinstein, M. J. (2011). Beyond homophily: A decade of advances in understanding peer influence processes. *Journal of Research on Adolescence, 21*(1), 166–179.

Brooks-Gunn, J., Duncan, G. J., & Aber, J. L. (1997). *Neighborhood poverty: Context and consequences for children* (Vol. 1). New York: Russell Sage Foundation.

*Burk, W. J., Van der Vorst, H., Kerr, M., & Stattin, H. (2012). Alcohol intoxication frequency and friendship dynamics: Selection and socialization in early, mid- and late adolescent peer networks. *Journal of Studies on Alcohol and Drugs, 73*, 89–98.

Centers for Disease Control and Prevention (CDC). (2015). *Electronic nicotine delivery systems: Key facts*. CDC, Office on Smoking and Health: Atlanta.

*Cheadle, J. E., Walsemann, K. M., & Goosby, B. J. (2015). Teen alcohol use and social networks: The contributions of friend influence and friendship selection. *Journal of Alcoholism and Drug Dependence*. https://doi.org/10.4172/2329-6488.1000224.

Chen, X., French, D. C., & Schneider, B. H. (Eds.). (2006). *Peer relationships in cultural context*. Cambridge: Cambridge University Press.

Choukas-Bradley, S., Giletta, M., Neblett, E. W., & Prinstein, M. J. (2015). Ethnic differences in associations among popularity, likability, and trajectories of adolescents' alcohol use and frequency. *Child Development, 86*(2), 519–535.

Christakis, N. A., & Fowler, J. H. (2008). The collective dynamics of smoking in a large social network. *New England Journal of Medicine, 358*(21), 2249–2258.

D'Amico, E. J., & Fromme, K. (1997). Health risk behaviors of adolescent and young adult siblings. *Health Psychology, 16*(5), 426.

*De La Haye, K., Green, H. D., Jr., Kennedy, D. P., Pollard, M. S., & Tucker, J. S. (2013). Selection and influence mechanisms associated with marijuana initiation and use in adolescent friendship networks. *Journal of Research on Adolescence, 23*(3), 474–486.

*De La Haye, K., Green, H. D., Pollard, M. S., Kennedy, D. P., & Tucker, J. S. (2015). Befriending risky peers: Factors driving adolescents' selection of friends with similar marijuana use. *Journal of Youth and Adolescence, 44*(10), 1914–1928.

*De Vries, H., Mudde, A., Leijs, I., Charlton, A., Vartiainen, E., Buijs, G.,…, & Prins, T. (2003). The European smoking prevention framework approach (EFSA): An example of integral prevention. *Health Education Research, 18*(5), 611–626

DeLay, D., Laursen, B., Kiuru, N., SalmelaAro, K., & Nurmi, J. E. (2013). Selecting and retaining friends on the basis of cigarette smoking similarity. *Journal of Research on Adolescence, 23*(3), 464–473.

Dishion, T. J., & Loeber, R. (1985). Adolescent marijuana and alcohol use: The role of parents and peers revisited. *The American Journal of Drug and Alcohol Abuse, 11*(1–2), 11–25.

Dishion, T. J., Spracklen, K. M., Andrews, D. W., & Patterson, G. R. (1996). Deviancy training in male adolescent friendships. *Behavior Therapy, 27*(3), 373–390.

Fergusson, D. M., Swain-Campbell, N. R., & Horwood, L. J. (2002). Deviant peer affiliations, crime, and substance use: A fixed effects regression analysis. *Journal of Abnormal Child Psychology, 30*(4), 419–430.

Festinger, L. (1954). A theory of social comparison processes. *Human Relations, 7*(2), 117–140.

Friedkin, N. E. (1998). *A structural theory of social influence*. New York: Cambridge University Press.

Gardner, M., & Steinberg, L. (2005). Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: An experimental study. *Developmental Psychology, 41*(4), 625–635.

Gest, S. D., Osgood, D. W., Feinberg, M. E., Bierman, K. L., & Moody, J. (2011). Strengthening prevention program theories and evaluations: Contributions from social network analysis. *Prevention Science, 12*, 349–360. https://doi.org/10.1007/s11121-011-0229-2.

*Giletta, M., Scholte, R. H., Prinstein, M. J., Engels, R. C., Rabaglietti, E., & Burk, W. J. (2012). Friendship context matters: Examining the domain specificity of alcohol and depression socialization among adolescents. *Journal of Abnormal Child Psychology, 40*(7), 1027–1043.

*Haas, S. A., & Schaefer, D. R. (2014). With a little help from my friends? Asymmetrical social influence on adolescent smoking initiation and cessation. *Journal of Health and Social Behavior, 55*(2), 126–143.

Hawkins, J. D., Catalano, R. F., & Miller, J. Y. (1992). Risk and protective factors for alcohol and other drug problems in adolescence and early adulthood: Implications for substance abuse prevention. *Psychological Bulletin, 112*, 64–105.

Henneberger, A. K., Gest, S. D., & Zadzora, K. M. (2019). Preventing adolescent substance use: A content analysis of peer processes targeted within universal school-based programs. *The Journal of Primary Prevention, 40*(2), 213–230.

Hopfer, C. (2014). Implications of marijuana legalization for adolescent substance use. *Substance Abuse, 35*(4), 331–335.

*Huang, G. C., Soto, D., Fujimoto, K., & Valente, T. W. (2014a). The interplay of friendship networks and social networking sites: Longitudinal analysis of selection and influence effects on adolescent smoking and alcohol use. *American Journal of Public Health, 104*(8), e51–e59.

Huang, G. C., Unger, J. B., Soto, D., Fujimoto, K., Pentz, M. A., Jordan-Marsh, M., et al. (2014b). Peer influences: The impact of online and offline friendship networks on adolescent smoking and alcohol use. *Journal of Adolescent Health, 54*(5), 508–514.

*Huisman, C. (2014). Does it matter what friends think, say, or do? The role of friends' smoking attitudes and behavior for Dutch adolescents' smoking behavior. *Substance Use & Misuse, 49*(6), 715–723.

*Huisman, C., & Bruggeman, J. (2012). The social network, socioeconomic background, and school type of adolescent smokers. *International Journal of Behavioral Development, 36*(5), 329–337.

Katz, L., & Proctor, C. H. (1959). The concept of configuration of interpersonal relations in a group as a time-dependent stochastic process. *Psychometrika, 24*(4), 317–327.

*Kiuru, N., Burk, W. J., Laursen, B., Salmela-Aro, K., & Nurmi, J. E. (2010). Pressure to drink but not to smoke: Disentangling selection and socialization in adolescent peer networks and peer groups. *Journal of Adolescence, 33*(6), 801–812.

*Knecht, A. B., Burk, W. J., Weesie, J., & Steglich, C. (2011). Friendship and alcohol use in early adolescence: A multilevel

social network approach. *Journal of Research on Adolescence, 21*(2), 475–487.

La Greca, A. M., Prinstein, M. J., & Fetter, M. D. (2001). Adolescent peer crowd affiliation: Linkages with health-risk behaviors and close friendships. *Journal of pediatric psychology, 26*(3), 131–143.

*Lakon, C. M., Hipp, J. R., Wang, C., Butts, C. T., & Jose, R. (2015a). Simulating dynamic network models and adolescent smoking: The impact of varying peer influence and peer selection. *American Journal of Public Health, 105*(12), 2438–2448.

*Lakon, C. M., Wang, C., Butts, C. T., Jose, R., Timberlake, D. S., & Hipp, J. R. (2015b). A dynamic model of adolescent friendship networks, parental influences, and smoking. *Journal of Youth and Adolescence, 44*(9), 1767–1786.

Lazarsfeld, P. F., & Merton, R. K. (1954). Friendship as social process: A substantive and methodological analysis. In M. Berger & T. Abel (Eds.), *Freedom and control in modern society* (Vol. 2, pp. 18–66). New York, NY: Van Nostrand.

*Light, J. M., Greenan, C. C., Rusby, J. C., Nies, K. M., & Snijders, T. A. (2013). Onset to first alcohol use in early adolescence: A network diffusion model. *Journal of Research on Adolescence, 23*(3), 487–499.

Loeber, R., Farrington, D. P., Stouthamer-Loeber, M., & Van Kammen, W. B. (1998). Multiple risk factors for multiproblem boys: Co-occurrence of delinquency, substance use, attention deficit, conduct problems, physical aggression, covert behavior, depressed mood, and shy/withdrawn behavior. In R. Jessor (Ed.), *New perspectives on adolescent risk behavior* (pp. 90–149). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511571138.005

*Long, E., Barrett, T. S., & Lockhart, G. (2017). Network-behavior dynamics of adolescent friendships, alcohol use, and physical activity. *Health Psychology, 36*(6), 577.

*Mathys, C., Burk, W. J., & Cillessen, A. H. (2013). Popularity as a moderator of peer selection and socialization of adolescent alcohol, marijuana, and tobacco use. *Journal of Research on Adolescence, 23*(3), 513–523.

Mayeux, L., Sandstrom, M. J., & Cillessen, A. H. N. (2008). Is being popular a risky proposition? *Journal of Research on Adolescence, 18*, 49–74.

Meich, R. A., Johnston, L. D., O'Malley, P. M., Bachman, J. G., Schulenberg, J. E., & Patrick, M. E. (2019). *Monitoring the future national survey results on drug use, 975–2018: volume 1, Secondary school students*. Ann Arbor: The University of Michigan.

*Mercken, L., Sleddens, E. F. C., de Vries, H., & Steglich, C. E. G. (2013). Choosing adolescent smokers as friends: The role of parenting and parental smoking. *Journal of Adolescence, 36*(2), 383–392.

*Mercken, L., Snijders, T. A., Steglich, C., & de Vries, H. (2009). Dynamics of adolescent friendship networks and smoking behavior: Social network analyses in six European countries. *Social Science & Medicine, 69*(10), 1506–1514.

*Mercken, L., Snijders, T. A., Steglich, C., Vartiainen, E., & De Vries, H. (2010a). Dynamics of adolescent friendship networks and smoking behavior. *Social Networks, 32*(1), 72–81.

*Mercken, L., Snijders, T. A., Steglich, C., Vartiainen, E., & De Vries, H. (2010b). Smoking based selection and influence in gender segregated friendship networks: A social network analysis of adolescent smoking. *Addiction, 105*(7), 1280–1289.

*Mercken, L., Steglich, C., Knibbe, R., & De Vries, H. (2012a). Dynamics of friendship networks and alcohol use in early and mid-adolescence. *Journal of Studies on Alcohol and Drugs, 73*(1), 99–110.

*Mercken, L., Steglich, C., Sinclair, P., Holliday, J., & Moore, L. (2012b). A longitudinal social network analysis of peer influence, peer selection, and smoking behavior among adolescents in British schools. *Health Psychology, 31*(4), 450.

Moody, J., Feinberg, M. E., Osgood, D. W., & Gest, S. D. (2010). Mining the network: Peers and adolescent health. *Journal of Adolescent Health, 47*(4), 324–326.

*Mundt, M. P., Mercken, L., & Zakletskaia, L. (2012). Peer selection and influence effects on adolescent alcohol use: A stochastic actor-based model. *BMC Pediatrics, 12*(1), 115.

*Osgood, D. W., Feinberg, M. E., & Ragan, D. T. (2015). Social networks and the diffusion of adolescent problem behavior: Reliable estimates of selection and influence from sixth through ninth grades. *Prevention Science, 16*(6), 832–843.

*Osgood, D. W., Ragan, D. T., Wallace, L., Gest, S. D., Feinberg, M. E., & Moody, J. (2013). Peers and the emergence of alcohol use: Influence and selection processes in adolescent friendship networks. *Journal of Research on Adolescence, 23*(3), 500–512.

Patrick, M. E., Miech, R. A., Carlier, C., O'Malley, P. M., Johnston, L. D., & Schulenberg, J. E. (2016). Self-reported reasons for vaping among 8th, 10th, and 12th graders in the US: Nationally-representative results. *Drug and alcohol dependence, 165*, 275–278.

*Pearson, M., Steglich, C., & Snijders, T. (2006). Homophily and assimilation among sport-active adolescence substance users. *Connections, 27*(1), 47–63.

*Rabaglietti, E., Burk, W. J., & Giletta, M. (2012). Regulatory self-efficacy as a moderator of peer socialization relating to Italian adolescents' alcohol intoxication. *Social Development, 21*(3), 522–536.

*Ragan, D. T. (2014). Revisiting "what they think": Adolescent drinking and the importance of peer beliefs. *Criminology, 52*(3), 488–513.

*Ragan, D. T. (2016). Peer beliefs and smoking in adolescence: A longitudinal social network analysis. *The American Journal of Drug and Alcohol Abuse, 42*(2), 222–230.

*Ragan, D. T., Osgood, D. W., & Feinberg, M. E. (2013). Friends as a bridge to parental influence: Implications for adolescent alcohol use. *Social forces, 92*(3), 1061–1085.

Ripley, R. M., Snijders, T. A. B., Boda, Z., Voros, A., & Preciado, P. (2019). *Manual for RSIENA*. Oxford: University of Oxford, Department of Statistics, Nuffield College.

*Schaefer, D. R. (2018). A network analysis of factors leading adolescents to befriend substance-using peers. *Journal of Quantitative Criminology, 34*(1), 275–312.

*Schaefer, D. R., Adams, J., & Haas, S. A. (2013). Social networks and smoking: Exploring the effects of peer influence and smoker popularity through simulations. *Health Education & Behavior, 40*(1_suppl), 24S–32S.

*Schaefer, D. R., Haas, S. A., & Bishop, N. J. (2012). A dynamic model of US adolescents' smoking and friendship networks. *American Journal of Public Health, 102*(6), e12–e18.

Sijtsema, J. J., & Lindenberg, S. M. (2018). Peer influence in the development of adolescent antisocial behavior: Advances from dynamic social network studies. *Developmental Review, 50*, 140–154. https://doi.org/10.1016/j.dr.2018.08.002.

Simons-Morton, B. G., & Farhat, T. (2010). Recent findings on peer group influences on adolescent smoking. *The Journal of Primary Prevention, 31*(4), 191–208.

Snijders, T. A. (2011). Statistical models for social networks. *Annual Review of Sociology, 37*, 131–153.

Snijders, T. A. B., van de Bunt, G. G., & Steglich, C. E. G. (2010). Introduction to stochastic actor-based models for network dynamics. *Social Networks, 32*, 44–60. https://doi.org/10.1016/j.socnet.2009.02.004.

Spoth, R., Redmond, C., Shin, C., Greenberg, M., Clair, S., & Feinberg, M. (2007). Substance-use outcomes at 18 months past baseline: The PROSPER community–university partnership trial. *American Journal of Preventive Medicine, 32*(5), 395–402.

*Steglich, C., Sinclair, P., Holliday, J., & Moore, L. (2012). Actor-based analysis of peer influence in A Stop Smoking in Schools Trial (ASSIST). *Social Networks, 34*(3), 359–369.

Steglich, C., Snijders, T. A., & Pearson, M. (2010). Dynamic networks and behavior: Separating selection from influence. *Sociological Methodology, 40*(1), 329–393. https://doi.org/10.1111/j.1467-9531.2010.01225.x.

Steglich, C., Snijders, T. A., & West, P. (2006). Applying SIENA: An illustrative analysis of the coevolution of adolescents' friendship networks, taste in music, and alcohol consumption. *Methodology: European Journal of Research Methods for the Behavioral and Social Sciences, 2*(1), 48.

Sung, H. E., Richter, L., Vaughan, R., Johnson, P. B., & Thom, B. (2005). Nonmedical use of prescription opioids among teenagers in the United States: Trends and correlates. *Journal of Adolescent Health, 37*(1), 44–51.

*Tucker, J. S., De La Haye, K., Kennedy, D. P., Green, H. D., & Pollard, M. S. (2014). Peer influence on marijuana use in different types of friendships. *Journal of Adolescent Health, 54*(1), 67–73.

Valente, T. W., Unger, J. B., & Johnson, C. A. (2005). Do popular students smoke? The association between popularity and smoking among middle school students. *Journal of Adolescent Health, 37*, 323–329.

*Van Ryzin, M. J., DeLay, D., & Dishion, T. J. (2016). Being well-liked predicts increased use of alcohol but not tobacco in early adolescence. *Addictive Behaviors, 53*, 168–174.

Veenstra, R., Dijkstra, J. K., Steglich, C., & Van Zalk, M. H. (2013). Network–behavior dynamics. *Journal of Research on Adolescence, 23*(3), 399–412.

Veenstra, R., & Steglich, C. (2012). Actor-based model for network and behavior dynamics. In B. Laursen, T. Little, & N. A. Card (Eds.), *Handbook of developmental research methods* (pp. 598–618). New York: Guilford Press.

*Wang, C., Hipp, J. R., Butts, C. T., Jose, R., & Lakon, C. M. (2015). Alcohol use among adolescent youth: The role of friendship networks and family factors in multiple school studies. *PLoS ONE, 10*(3), e0119965.

*Wang, C., Hipp, J. R., Butts, C. T., Jose, R., & Lakon, C. M. (2016). Coevolution of adolescent friendship networks and smoking and drinking behaviors with consideration of parental influence. *Psychology of Addictive Behaviors, 30*(3), 312.

*Wang, C., Hipp, J. R., Butts, C. T., Jose, R., & Lakon, C. M. (2017). Peer influence, peer selection and adolescent alcohol use: A simulation study using a dynamic network model of friendship ties and alcohol use. *Prevention Science, 18*(4), 382–393.

Wang, J., Simons-Morton, B. G., Farhat, T., & Luk, J. W. (2009). Socio-demographic variability in adolescent substance use: Mediation by parents and peers. *Prevention Science, 10*(4), 387–396.

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications* (Vol. 8). Cambridge: Cambridge University Press.