Peer social network processes and adolescent health behaviors: a systematic review

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Title: Peer social network processes and adolescent health behaviors: a systematic review

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Abstract

Research has highlighted the importance of peers for determining health behaviors in adolescents, yet these behaviors have typically been investigated in isolation. We need to understand common network processes operating across health behaviors collectively, in order to discern how social network processes impact health behaviors. Thus, this systematic review of studies investigated adolescent peer social networks and health behaviors. A search of six databases (CINAHL, Education Resources Information Centre, Embase, International Bibliography of the Social Sciences, Medline and PsycINFO) identified 55 eligible studies. The mean age of the participants was 15.1 years (range 13 - 18; 51.1% female). Study samples ranged from 143 to 20,745 participants. Studies investigated drinking (31%), smoking (22%), both drinking and smoking (13%) substance use (18%), physical activity (9%) and diet or weight management (7%). Study design was largely longitudinal (n=41, 73%) and cross-sectional (n=14, 25%). All studies were set in school and all but one study focused on school-based friendship networks. The Newcastle-Ottawa scale was used to assess risk of bias: studies were assessed as good (51%), fair (16%) or poor (33%). The synthesis of results revolved around two network behavior patterns: 1) health behavior similarity within a social network, driven by homophilic social selection and/or social influence, and 2) popularity: health behavior engagement in relation to changes in social status; or network popularity predicting health behaviors. Adolescents in denser networks had statistically significant lower levels of harmful behavior (n=2/2, 100%). Findings suggest that social network processes are important factors in adolescent health behaviors.

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1. Introduction

Adoption and engagement in health behaviors is seldom an individual decision, as individuals are influenced by the people with whom they spend time (i.e. the social networks within which they are embedded, with ties connecting them to other individuals through social relationships, facilitating diffusion of behavior and information[1]). As an adolescent matures, peers (individuals who are at a similar life stage[2]) become increasingly important in determining behavior, particularly given the increase in the amount of extra-curricular time spent socializing[3] coupled with increasing independence from family[4]. Additionally, adolescents become increasingly motivated to fit into social group identities and to adopt the normative behaviors of their peers[5].

Previous systematic reviews found significant relationships between health behaviors of adolescents and their peers[6–12]. Peers and friendship groups played an important role in shaping adolescent physical activity (PA) behavior (n=7 studies, aged 6-18 years)[7]. A further review concluded friends' PA behavior had significant influence on adolescents' PA behavior, and adolescents' PA behaviors were associated with friends' PA behaviors, alongside encouragement, support and engagement with friends in PA (significant positive results in n=40/81 studies, aged <19 years)[8]. Similarly, a third review concluded that friends' PA behavior had a significant influence on individuals' PA behavior and peer networks exerted greater influence on boys' PA behavior than girls' PA behavior (n=13 studies, aged 6-18 years)[9]. Furthermore, Fletcher et al found significant similarities between school friends' eating behaviors and bodyweight (n=10 studies, aged 11-18 years) though definitive conclusions regarding network processes could not be ascertained due to inconsistencies between study findings[6]. Zhang et al found similar evidence (n=7/8 studies focused on adolescents' friendship networks) and concluded that friends were similar in weight status and related behaviors, and that friendship networks and weight outcomes or behaviors were interdependent[10]. This review also provided evidence for specific network effects. For example, friends' body mass index (BMI) predicted changes in adolescent's BMI and selection effects contributed to similarities in weight[10]. A review on smoking behavior demonstrated the importance of network structure[11]. In particular, adolescents who were identified as 'isolates' (i.e. individuals with no friends) were more likely to smoke compared to others in the network (n=10 studies)[11]. Furthermore, adolescents who affiliated with

alcohol drinking peers had a significantly higher risk of individual alcohol use (n=22 studies)[12].

Previous systematic reviews identified *homophilic social selection* (i.e. selection of friends on the basis of similarities in behavior, attitudes or demographic characteristics[13–15]) and *social influence* (i.e. influence from peers to change behavior due to spending time together, shared activities, peer norms and modelling of habits[16]) as network processes that are common across health behaviours. Alongside these, there is a need to synthesize the importance of *popularity* (i.e. receiving a high number of friendship nominations[17,18]) across health behaviours. There is mixed evidence regarding the relationship between popularity and health behaviors, particularly for smoking. For example, a study found popular adolescents (aged 11-12 years) were more likely to engage in smoking behavior compared to their less popular peers[18]. In contrast, other research suggests that smoking may be associated with social isolation or having fewer friends (aged 11-19 years)[19], and popular individuals generally may be more influential than their less popular peers[20]. Thus, there is a need to investigate the role of popularity across a range of health behaviors and improve understanding about the implications of social status in relation to determining health behavior choices, which has implications for broader network diffusion. For example, the 'majority illusion paradox' suggests that popular nodes have greater influence and power to skew the observations of others within the network[21].

The network processes identified above may be synthesized as two network-behavior patterns (which provide understanding about individuals' behavior within a social network) and four underlying mechanisms. Firstly, the pattern of health behavior similarity among socially connected youth (network autocorrelation) may be driven by (a) similarity/homophily-based social selection and/or (b) social influence. Secondly, associations between health behaviors and network popularity may be driven by (a) tendencies to select network partners who exhibit a given health behavior (i.e. engagement in the given behavior leads to changes in popularity), and/or (b) network popularity predicting behavior change (i.e. popular youth are more likely to adopt or avoid a behavior).

Whilst the impact of peer networks upon individual health behaviors has been widely researched, this research has focused on only single behaviors[6–11]. Health behaviors tend to cluster together[22,23], yet we lack a clear understanding about how network processes influence

these behaviors collectively[24]. Gateway theories suggest engagement in one form of health-harming behavior leads to opportunities for engagement in other risky behaviors[25]. Furthermore, Jessor's 'problem behavior theory'[26] suggests that early adolescent engagement in 'problem behaviors' is an attempt to "demonstrate maturity, independence and repudiating conventionality"[23]. In particular, previous evidence supports clustering of health-harming smoking and drinking behaviors[27]. Research indicates clustering occurs at both ends of the spectrum; individuals may engage in no health harming behaviors (or health-enhancing behaviors), or a high level of health-harming behaviors[22] (or health-enhancing behaviors).

Given the complex relationships between individual health behaviors[28] better understanding about social network processes and how they relate to health behaviors may be useful to inform design and implementation of future health behavior change interventions with adolescents. Social networks may facilitate or impede health behavior change through a number of mechanisms[24] (i.e. through modelling peer behavior[29], or establishment of peer social norms[30]). Understanding the social environments that an intervention is delivered in can allow for tailoring, thereby potentially increasing the effectiveness[24]. Social networks do not act in isolation and impact behavior across multiple levels of the social environment within a complex system of influences[31]. Berkman's conceptual model provides understanding about how social networks are conditioned by social-structural conditions, and provide opportunities for behavioral mechanisms to impact health through a series of pathways[32].

The role of social network processes on adolescent health behaviors requires further exploration in order to advance our understanding about how social network processes operate. Previous reviews focused on dyadic level approaches, involving, for example, the incorporation of peers as 'buddies', with the aim of encouraging intervention adoption[33]. Clearly, there is a recognized need now for a review that focuses on studies of social network processes that move beyond the dyad-level[6,10]. The explicit use of social network data to map the structure of social connections among groups of people and distinguish social network processes from general peer support and social support has been studied previously[34,35] typically focusing on individuals' perceptions about social phenomena (i.e. social norms)[36–38] or on dyads[39]. The nature and extent to which the myriad of social network processes impact on various health behaviors during adolescence remains unknown. The present study addressed this gap by conducting a systematic review of studies that investigated the

association between peer network processes and health behaviors in adolescents (aged 13-18 years), particularly in relation to the extent to which specific network processes were observed across common adolescent health behaviors.

2. Methods

The PRISMA guideline for systematic reviews was followed[40].

2.1 Systematic search

Searches were conducted for studies published up to October 2018 on CINAHL, Education Resources Information Centre (ERIC), Embase, International Bibliography of the Social Sciences (IBSS), Medline and PsycINFO. Keywords relating to social networks, health behaviors and adolescence were searched (see Appendix A).

2.2 Eligibility criteria

Studies were selected based on the pre-defined eligibility criteria outlined in Table 1.

2.3 Study selection

After removing duplicates, titles and abstracts were screened in accordance with the eligibility criteria. The relevant full texts were screened by two independent researchers (SM, RH) and discrepancies resolved by face-to-face discussion. Reference lists of included studies were hand-searched for additional eligible articles.

2.4 Data extraction

Data were extracted from included studies using a pre-defined form by one researcher (SM) and independently cross-checked by two other members of the research team (PB, AC). Extracted data included study details; social network and health behavior measures; analysis method and results.

2.5 Risk of bias and study quality

The Newcastle-Ottawa Scale (NOS) for cross-sectional studies was used to assess the risk of bias[41]. Although included studies varied in their study design, many studies used a cross-sectional measure of the network or measured the health behavior at only one time-point.

Therefore, to allow for consistent assessment of bias across the range of studies, the NOS for cross-sectional studies was used. The studies were assessed for risk of bias by two independent researchers (SM, RH) and discrepancies dealt with through face-to-face discussions. We converted the risk of bias categories to study quality categories defined by the Agency for Health Research and Quality (AHRQ) (good, fair and poor quality) as reported in previous literature[42]. Findings from the risk of bias and study quality assessment did not determine the inclusivity of studies.

2.6 Evidence synthesis

The results from eligible studies are presented as two network-behavior patterns (i.e. clusters of behavior within a social network) with underlying mechanisms: (1) health behavior similarity which could be driven by (a) homophilic social selection; and/or (b) social influence; and (2) the association between popularity and health behaviors, which could be driven by (a) engagement in behavior(s) leading to changes in adolescent's social status and (b) network popularity predicting health behavior(s). An additional category was included for 'other' processes. These processes were presented in relation to each health behavior. A qualitative narrative synthesis was conducted. The methodological heterogeneity of the studies precluded conducting a meta-analysis.

3. Results

A total of 8,779 articles were identified from the search; 225 articles were identified for full text screening, and 46 articles included. Nine articles were identified from manual searching of reference lists, resulting in a total of 55 included studies. Figure 1 provides details of the process.

3.1 Study characteristics

Characteristics from each study are summarized in results Tables 2-7. Studies investigated alcohol drinking (n=17, 31%), cigarette smoking (n=12, 22%), both drinking and smoking combined (n=7, 13%), substance use (n=10, 18%), PA (n=5, 9%) and dietary/weight-related behaviors (n=4, 7%). The mean age of the participants was 15.1 years (range 13 – 18) and 51.1% were female. Study populations ranged from 143 to 20,745 participants. The majority (n=40, 73%) of the studies were based in The United States of America (USA), of which 70% (n= 28/40) were from the National Longitudinal Study of Adolescent to Adult Health

(Add Health) study, a longitudinal, nationally representative sample of adolescents in grades 7-12 during the 1994-5 school year, which followed adolescents into adulthood and collected data on a range of social, economic, environmental, behavioral and biological data[43]. The remaining studies were set in the United Kingdom (UK) (n=2, 4%), Australia (n=4, 7%), Europe (n=6, 11%), Canada (n=1, 2%) and Asia (n=2, 4%).

All studies used name generation techniques to collect social network data[44] (Appendix B, Tables B1-6). With the exception of one study[45], the studies measured and focused on friendship networks. Additional network measures included peer-perceived and relational aggression networks[45]; romantic dyad networks[46,47]; peer leader networks[48]; 'group project' networks[48] and best friend dyads[39,49,50]. Three studies also measured popularity[45,51,52]. Further detail regarding the social network questions, alongside demographic characteristics and study design can be found in Appendix B, Tables B1-6.

The following section is presented as an overview of the findings for health behavior similarity among socially connected youth (and associated mechanisms) and popularity and health behaviors (and associated mechanisms). Further detailed study findings are provided in Appendix C.

3.2 Health behavior similarity among socially connected youth

3.2.1 Homophilic social selection

Nine studies investigated homophilic social selection but not social influence[47,52–59]. One study controlled for social influence effects[56]. The health behaviors investigated were alcohol drinking (n=3)[52–54]; cigarette smoking (n=2)[55,56]; both drinking and smoking (n=1)[47]; PA (n=2)[57,58] and dietary-related behaviors (n=1)[59] (Table 2). Five studies were cross-sectional[52,55,57–59] and four were longitudinal[47,53,54,56]. Four studies were rated 'good quality'[53–55,59]; two 'fair quality'[52,57] and three 'poor quality'[47,56,58]. Overall, homophilic social selection was significantly and positively associated with health behavior(s) in 8/9 studies[47,52,53,55–59].

3.2.2 Social influence

Fifteen studies investigated the association between social influence, but not homophilic social selection, and health behaviors[39,48,49,60–71]. Studies which reported only findings for the association of peer influence either did not report selection[39,48,49,62–64,67–69,71] or controlled for selection, but did not explicitly report findings on the association between social selection and health behavior[60,61,65,66,70]. The health behaviors investigated were alcohol drinking (n=5)[49,66–69]; cigarette smoking (n=2)[65,70]; both drinking and smoking (n=4)[60–62,71]; substance use (n=2)[48,63]; PA (n=1)[39] and dietary-related behaviors (n=1)[64] (Table 3). Five studies were cross-sectional[39,49,60,69,71] and 10 were longitudinal[48,61–68,70]. Ten studies were rated 'good quality'[48,60,64–71]; two were rated 'fair quality'[49,63] and three 'poor quality' [39,61,62]. Overall, social influence was significantly associated with health behavior(s) in 14/15 studies[39,48,49,60–63,65–71].

3.2.3 Homophilic social selection and social influence

Twenty-two longitudinal studies investigated both homophilic selection of friends on the basis of similarity in health behavior(s) and social influence leading adolescents to change their behaviors to become more similar to their friends' behaviors[46,50,51,72–90]. The health behaviors investigated were alcohol drinking (n=5)[46,80,84–86]; cigarette smoking (n=7)[79,81,82,87–90]; both drinking and smoking (n=2)[72,73]; substance use (n=4)[51,74–76]; PA (n=2)[77,78] and dietary/weight-related behaviors (n=2)[50,83] (Table 4). These included nine 'good quality'[46,50,73,76,77,80,84,88,89], three 'fair quality'[51,78,81] and nine 'poor quality'[72,74,75,79,82,85–87,90] studies. The majority of studies acknowledged the presence of both homophilic social selection and social influence processes, but did not disentangle the relative contribution of either process[46,50,83,85,87,88,90,72–76,79,81,82]. Seven studies used Stochastic Actor Oriented Models (SAOM) to attempt to disentangle the social processes[51,77,78,80,84,86,89]. Overall, significant associations were found for only homophilic social selection in one study investigating alcohol behavior[84] and for only social influence in one study investigating low-nutrient-energy-dense (LNED) foods[50]. Both homophilic social selection and social influence were associated with health behavior(s) in 20 studies[46,51,80–83,85–90,72–79].

3.3 Popularity and health behaviors

3.3.1 Popularity: engagement in health behavior(s) leading to changes in social status

Thirteen studies investigated the association between popularity driven by engagement in behaviors, which resulted in a change in adolescents' popularity levels[50,54,91–93,57,66,70,73,77,79,85,90]. The health behaviors investigated were alcohol drinking (n=6)[54,66,85,91–93]; cigarette smoking (n=3)[70,79,90]; both drinking and smoking (n=1)[73]; PA (n=2)[57,77] and dietary-related behaviors (n=1)[50] (Table 5). Three studies were cross-sectional[57,91,92] and ten studies were longitudinal[50,54,66,70,73,77,79,85,90,93]. Seven studies were rated 'good quality'[50,54,66,70,73,77,91], three 'fair quality'[57,92,93] and three 'poor quality'[79,85,90]. Overall, 11/13 studies found positive and significant associations between popularity and engagement in health behaviour(s)[50,57,93,66,70,73,77,79,90–92].

3.3.2 Popularity: network popularity predicting health behavior(s)

Fifteen studies associated network popularity with predicting health behavior(s)[45,51,52,55,56,63,67,68,76,81,84,94–97]. The health behaviors investigated were alcohol drinking (n=5)[45,52,67,68,84]; cigarette smoking (n=4)[55,56,81,94] and substance use (n=6)[51,63,76,95–97] (Table 6). Four studies were cross-sectional[52,55,95,96] and 11 studies were longitudinal[45,51,56,63,67,68,76,81,84,94,96,97]. Seven studies were rated 'good quality'[55,67,68,76,84,94,95], three 'fair quality'[51,63,81] and five 'poor quality'[45,52,56,96,97]. Overall, 13/15 studies found positive and significant associations for network popularity predicting health behavior(s)[45,51,52,55,56,67,68,81,84,94–97].

3.4 Other

Studies which investigated the association between 'other' social network processes and health behaviors included two 'good quality' longitudinal studies which measured network density[67,98] (Table 7). One study using the Add Health data found adolescents in denser networks had lower levels of alcohol use[67] and another American study found adolescents in denser networks had lower odds of smoking and marijuana use[98]. This study also found isolates were more likely to be smokers compared to group members[98].

3.5 Risk of bias and study quality

Table 8 reports the risk of bias and study quality. The included studies averaged six stars out of 10 (range 2-8). Risk of bias was assessed on three main categories; selection,

comparability and outcome. The adapted NOS used, with the sub-heading breakdown can be found in Appendix D. The heterogeneity of the statistical analysis methods used across the studies (i.e. exponential random graph modelling (ERGM), SAOM, regression models) made it difficult to assess the comparability, therefore no studies were excluded on the basis of their risk of bias, and bias was not considered when extracting data from studies and collating the evidence. The risk of bias categories were converted to study quality (good, fair and poor quality) as reported in previous literature[42]. Twenty-eight studies were 'good', nine were 'fair' and 18 were 'poor' quality. The findings highlighted a substantial proportion of poor quality evidence, particularly within the areas of smoking, substance use and PA.

4. Discussion

The results from this systematic review highlight a body of evidence supporting the importance of peer networks on adolescent health behaviors through social processes. There is limited evidence (due to a lack of studies) to support the presence of other network processes, with network density identified as important in two studies. Furthermore, the mixed study quality indicates the heterogeneity of the research methods utilized within the studies and calls for consistent methodology for conducting and reporting of social network analysis studies.

4.1 Health behavior similarity among socially connected youth

This review provides support for homophilic social selection and social influence as important social processes associated with health behaviors, however the results highlighted mixed study quality. Generally, the studies investigated school-based friendship networks and indicated that adolescents selected friends who had similar health behaviors to themselves. Selection of friends on the basis of similar health behaviors can protect individuals from developing unhealthy behaviors (i.e. for adolescents who abstain from health-harming behaviors or engage in health-enhancing behaviors, selection of friends who exhibit similar behaviors may lead to reinforcements of such healthy habits.) In contrast, selection of friends on the basis of similar health-harming behaviors may be detrimental, given greater exposure to the behavior[29]. Findings from a previous systematic review determined that adolescents who have friends who exhibit 'risky' behaviors are at increased risk of engaging in the behavior[99]. Results indicated that adolescents were influenced by their peers to change their health behavior or to become more similar to their friends' behavior. Research has shown that

adolescents desire to conform to social norms, and fit in with their peers to reduce social ostracism[100] and as a result, they are susceptible to peers' behavioral choices[48]. This is supportive of previous research which found that influence, whether positive or negative, was associated with friends' behaviors[29]. Furthermore, this review highlighted that influence may be present across all types of peer relationship ties (i.e. friends or romantic partners). However, due to lack of research outside of (mainly school-based) friendship networks, it is not possible to assess the extent to which different types of relationship ties have different influential power.

4.2 Network popularity

Popularity was identified as an important process in adolescent health behavior. The association between popularity and health behaviors could be driven by increases in social status as a result of (dis)engaging in the behavior(s), or changes in the behavior as a result of social status. The results indicated that popularity was associated with increasing health behavior levels, particularly health-harming behaviors. The findings also suggested that more popular adolescents might do more PA[57,77]. Further research is required to determine causality, as it is not possible to determine if being popular increased health behavior engagement or if engaging in the behaviors increased popularity. There was some indication that drinking only increased popularity levels when it was below a certain level (i.e. the class average[91]), suggesting that adolescents may engage in some health-harming behaviors to raise their social profile. However, a lack of evidence in this area warrants further research.

4.3 Other social network processes

This review identified a lack of research outside of the commonly investigated network processes of homophilic social selection, social influence and popularity. Whilst the evidence base was limited, findings from two studies indicated a positive association between individuals in denser networks and lower levels of harmful health behaviors. Previous research has indicated density, and other social network factors, may be an important moderator of diffusion using opinion leaders in social network interventions[24]. Furthermore, there is indication that network properties (i.e. density, reciprocity) may provide opportunities for behavioral mechanisms that impact health through different pathways (i.e. social engagement may impact alcohol drinking through health behavioral pathways)[101]. Whilst this suggests social network factors may have important implications for adolescent health

behaviors, there is a need for further research to investigate how these social network factors may best be utilized within intervention design.

4.4 Implications for health behavior change interventions

Social network interventions have been identified as effective in health behavior change[24,102]. However, evidence has shown network components are generally underutilized within health behavior interventions[103,104]. Many social network interventions within health behavior research have focused on individual approaches[105,106] (i.e. identifying individuals based on a network property to promote positive behavior change)[107]. For example, ASSIST (A Stop Smoking In Schools Trial), is based on the diffusion of innovations theory which utilizes influential pupils to cascade anti-smoking information and has been shown to cost-effectively lead to a reduction in adolescent smoking prevalence[108,109]. The ASSIST framework has also been adopted in other areas of adolescent health behaviour research, including PA[110], healthy eating for obesity prevention[111], drug use prevention[112] and sexual health[113]. This review has highlighted incorporation of social network processes within behavior change interventions may increase the effectiveness of such efforts. Furthermore, integration of these processes within intervention design may allow for other social network intervention approaches, such as segmentation, induction or alteration approaches[107] to be utilized more effectively within intervention design.

4.5 Directions for future research

Previous research has identified clustering of health risk factors across multiple age groups[22], including healthy behaviors[114], and risk behaviors[114–116]. There is therefore an opportunity to investigate common network processes and clusters of behavior, given that this review has identified the presence of shared network processes at work across different health behaviors. A previous review investigating clustering of obesogenic behaviors in youth found cluster patterns were complex, and health-enhancing and health-harming behaviors can co-occur[117]. Research has also shown that clustering is affected by multiple sociodemographic factors including socioeconomic status, parental education, gender and age[117,118]. There is a need to tailor interventions to specific populations, taking into account sociodemographic and socioeconomic differences[118]. Further research is required to investigate mechanisms of social networks impacting on health behavior clustering. In particular, this review highlighted a lack of evidence surrounding health-enhancing behaviors (i.e. PA and dietary behaviors).

Investigation of association between social networks and these behaviors collectively may be useful for encouraging positive healthy behaviors in adolescents. Furthermore, there is a need to investigate distribution of health behaviors across social networks. This may have important implications for intervention design, as it would allow for tailoring of the social network intervention, by providing rationale for specific network strategies to encourage health-enhancing behavior change.

Furthermore, research is required outside of friendship networks, to identify other influencing factors, which may contribute to some individuals being more influenced by certain types of relationship ties. Social networks have been described as dynamic[119] indicating that network ties are not static and network processes will not operate at a fixed rate. To the best of our knowledge, there is a relative lack of recent longitudinal studies spanning across multiple years. This review has identified studies which used longitudinal modelling (i.e. SAOM) were of higher quality and were able to identify dual processes such as both homophilic selection and influence processes impacting on health behaviors. There is a need for further longitudinal investigation of social network processes outside of the commonly investigated processes identified within this review, with clustering of health behaviors.

Study design by which dynamic social networks can be captured may benefit through the use of ecological momentary assessment (EMA), by which handheld devices (i.e. smartphone technology) capture real-time experiences within natural settings[120]. Such methods have been highlighted for the ability to capture change in behavior, such as PA[121] and have been deemed successful in previous research[122].

Some studies using data from Add Health showed inconsistent findings[53,54,91]. For example, two 'good quality' studies which investigated homophilic social selection found inconsistent findings for alcohol drinking. Positive and significant associations were found for homophily-based selection effects in one study[53] but not a second study[54]. Whilst both studies used the same dataset, they differed in analytical sample size (7,768[53] compared to 3,561[54] participants) and analytical methodology (regression models[53] compared to SAOM[54]). These findings highlight the need for a reporting framework in social networks research to better compare studies that use similar research methods. This framework would allow for consistent conducting and reporting of social network analyses, by detailing the specific social network measure, network boundary, analytical technique and other important

methodological aspects which may contribute to heterogeneity of findings. Furthermore, it would be beneficial for researchers to document their power analysis (where possible) so that it is clear to the reader if the study is powered (or not) to detect expected effect sizes. There have since been advances in power analyses for social network models in recent years that researchers can now utilize which would enhance statistical reporting of studies[123].

4.6 Strengths and limitations

To our knowledge, our review is the first to investigate the association between adolescent social networks and important health behaviors collectively, without focusing on a particular health behavior.

A limitation of the evidence base is that it is heavily influenced by one study, Add Health[43]. Forty of the included studies (73%) were set in the USA, of which 70% (n= 28/40) were from Add Health. Although Add Health was a representative sample of adolescents in USA, studies in this review used data collected from 1994–2002. Therefore, it is possible that rates of health behaviors may be different when compared to adolescents today. Furthermore, significant advances in digital social media have solidified social media platforms in everyday life[124] and much adolescent peer to peer interaction is communicated via these methods[125]. The way behaviors interact may be different today in the social media age. In particular, concerning evidence has indicated that peer influence effects for risk behaviors (i.e. smoking) may be more easily transmitted via online networks[15]. Whilst representative at the time, Add Health did not incorporate such social network measures.

Due to the heterogeneity of the research methods of the included studies, it was not possible to conduct a meta-analysis. Therefore, a limitation of this review is that we are unable to formally assess publication bias, with, for example an analysis of funnel plots or other methods. However, it highlights an inherent problem for assembling evidence from transdisciplinary research spanning both social network and traditional health research methods. For example, there are few studies of 'other' social network processes and health behaviors, however it is possible that they have been investigated in some earlier models but have been dropped from the final model in favor of parsimony. This highlights the challenges of combining transdisciplinary methods and calls for a consistent method of measuring social

networks and investigating social network processes with regard to health behaviors. This might also facilitate more formal assessments of publication bias in future research.

It is important to consider that only one study was set in a low-income country[68], therefore the findings may be generalizable only to adolescents in high-income countries, and there is a need for health behavior and social network studies to be conducted in low-middle income countries. The studies included in the review included a combination of longitudinal and cross-sectional studies, however many used a cross-sectional measure of the network or of the health behavior. The NOS adapted for cross-sectional studies[41] was therefore applicable for a consistent measure of risk of bias across the studies. However, it should be acknowledged that a limitation of this review is that the risk of bias tool was not adapted for different study design. Furthermore, the included studies were limited to English language only. It is important to consider context when interpreting the findings of this review. Whilst we have highlighted the importance of social network processes and their association with health behaviors in adolescents, it should be acknowledged that these processes do not operate in isolation, but are acting within a broader range of socio-environmental influences[31]. Previous research has shown that social networks have an important role within the broader social environment context[32]. However, there is a need to consider other mechanisms by which social networks interact within the social environment to impact health behaviors.

5. Conclusion

This systematic review has identified two network-behavior patterns and four main underlying mechanisms as important network processes contributing to all included health behaviors. Health behavior similarity could be driven by (a) homophilic social selection; and/or (b) social influence. Associations between network popularity and health behaviors could be driven by (a) increases in social status as a result of (dis)engaging in the behavior(s), or (b) changes in the behavior as a result of social status. A substantial body of evidence investigating smoking, drinking and substance use behaviors was identified, with limited evidence to support PA, dietary or weight-management related behaviors. Overall, the review supports evidence for homophilic social selection, individuals selected friends on the basis of similar health behaviors; social influence, individuals were influenced by their friends to adopt or adapt a behavior; and associations between network popularity and health behaviors.

This review also identified a lack of research surrounding 'other' social network processes, however there was some indication that density potentially played an important role. It also identified the focus on school-based friendship networks, with a lack of research about other types of relationships. This systematic review highlights the importance of peer social networks for establishing and determining an array of individual health behavior choices, and further longitudinal research into these processes is required to better understand how these processes operate over time and across collective behaviors, with the potential to be incorporated within health behavior change interventions.

Word count: 4,893

Table 1: Eligibility criteria

1.	The study investigated the association between peer social networks and health behavior(s) in adolescents. Peer social networks were defined as relationships (i.e. friendships, acquaintances, classmates, romantic partners) between adolescents. Social networks that included familial or parental relationships were outside the scope of this study and studies which only included these or primarily focused on networks other than peer networks were excluded. Studies were included if the social network data was collected using specific network questions in questionnaires or surveys, through the use of name or position generators (i.e. name up to five of your best male and best female friends in your class)[43].
2.	The primary population were adolescents (mean age within 13-18 years old).
3.	The study targeted specific health behavior(s) including alcohol, smoking, substance use, PA and weight-related behaviors (including diet). Adolescence is a critical life-phase for physical and cognitive development, and establishing lifelong habits[126–128]. The World Health Organization (WHO) identified smoking, drinking and substance abuse amongst major risks and solutions in the prevention of adult health problems[129]. Furthermore, from global PA trends it is estimated that less than 20% of 13-15 year olds are meeting the daily guidelines of 60 minutes of moderate to vigorous PA (MVPA)[130]. Similarly concerning trends suggest an increase in global consumption of energy dense foods which contribute to increased risk of obesity[131]. Adolescence is a crucial time to address obesity, as research has shown obesity in adolescence tracks in to adulthood[132] which contribute to a range of social, health and economic issues[133]. Adolescence is an important time to intervene to prevent the development of health-harming behaviors and encourage healthy habits in an effort to reduce the risk of chronic disease later in life[134]. Other health behaviors were beyond the scope of this systematic review.
4.	The study measured homophilic social selection, social influence, popularity or a network structural parameter (i.e. density; a measure of how connected individuals in the network are to each other[135]). Homophilic social selection in the peer network context was defined as the tendency for adolescents to purposefully select friends on the basis of similarities in socio-demographic factors, health behaviors or interests[13–15]. 'The process of social influence in the peer network context was defined as one or more person(s) or friend(s) in the network influencing another[13] and resulting in

	peers becoming more similar over time in terms of their health behavior due to spending time together, shared activities, peer norms and modelling of habits[16]. Network popularity was defined as the presence of a high in-degree within a friendship network, measured by receiving a high number of friendship nominations[17,18].
5.	The study statistically tested the association(s) between the specified heath behavior and social network parameter(s)/process(es). The statistical methods employed by the studies were not restricted, due to the heterogeneity of the studies' analysis techniques (including standard statistical techniques for independent data such as regression, or analytical techniques accounting for the dependent relational nature of the data, such as ERGM and SAOM).
6.	The full text was available in English.
7.	There was no restriction on the year of publication.
8.	Study design included longitudinal, cross-sectional, observational and interventional peer-reviewed publications.

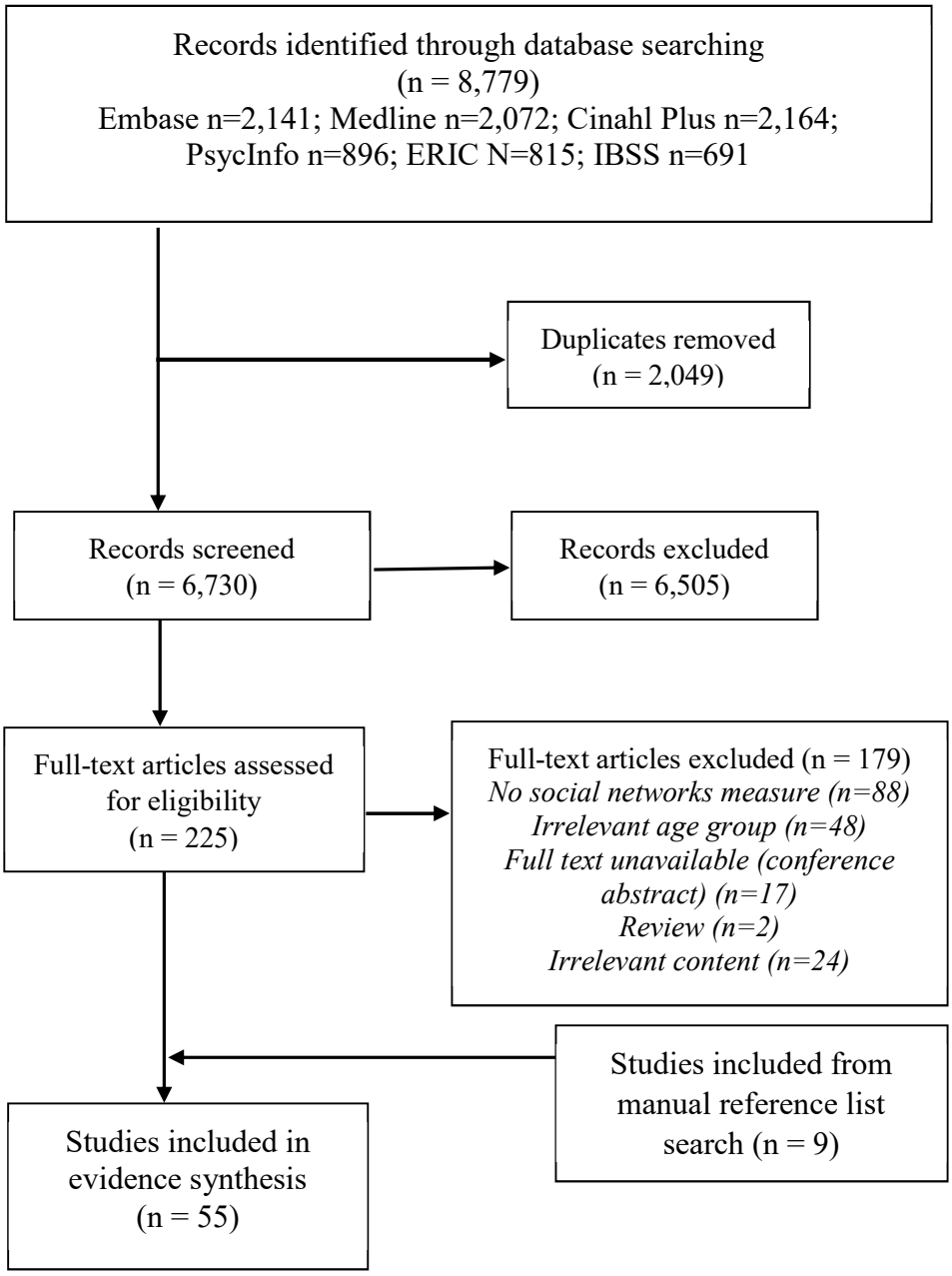

Figure 1: Study Flow Diagram

Table 2: Studies investigating homophilic social selection (but not social influence)

Reference	Study details	Outcome	Study quality
Alcohol drinking			
Crosnoe, Muller and Frank, 2004[53] Setting: Home and school Longitudinal	N = 7,758; 53% female; mean age 15.72 years *(SD not reported^)* Country: USA (using Add Health data)	+ve: Non-drinkers had friends who drank the least: mean 0.80, SD 1.00; frequent drinkers(1) had friends who drank the most: mean 1.81, SD 1.26	Good
Cheadle et al., 2013[54] Setting: Home and school Longitudinal	N = 3,561; 49% female; mean grade 10.27 *(age not specified)* Country: USA (using Add Health data)	*Small, positive but NS association for selection friends with similar drinking habits*	Good
Fujimoto and Valente, 2015[52] Setting: School Cross-sectional	N = 1,707; 52% female; mean age 15.07 years (SD 0.43) Country: USA	+ve: Friends' drinking was significantly associated with individual's drinking: AOR 1.88**, SE 0.36	Fair
Cigarette smoking			
Alexander et al., 2001[55] Setting: Home and school Cross-sectional	N = 2525, 50% female; mean age 15.5 years (SD 1.50) Country: USA (using Add Health data)	+ve: Adolescents were more than twice as likely to smoke: OR 1.91***, SE 0.11 if they had smoking friends, compared to adolescents who had no smoking friends +ve: Adolescents were twice as likely to smoke if their best friend smoked: OR 2.00***, SE 0.36	Good
Schaefer, Adams and Haas, 2013[56] Setting: Home and school Longitudinal	N = 509; 46.6% female; *mean age not reported* Country: USA (using Add Health data)	+ve: Adolescents with similar levels of smoking were more likely to be friends: coef 0.68***, SE 0.12	Poor
Drinking and smoking combined			
Kreager, Haynie and Hopfer, 2013[47]	N = 1,488, 50% female; mean age 13-15 *(SD not reported)*	+ve: Romantic partner's behavior was associated with individual smoking: coef 0.77**. Individual	Poor

Setting: School Longitudinal	Country: USA (using Add Health data)	smoking was associated with having smoking friends: coef 1.19* +ve: Individual drinking was associated with having drinking friends: coef 0.64** - 1.34** *NS association between individual and partner's drinking*	
Physical Activity			
De la Haye et al., 2010[57] Setting: School Cross-sectional	N = 385; 64% female; mean age 13-14 years *(SD not reported)* Country: Australia	+ve: Positive and significant effects(2) of engaging in similar amounts of organized PA was found for both male and female friends in 2 out of 3 networks in the final model: male PE -0.10 - -0.08; SE 0.03 - 0.03(1); female PE -0.06 - 0.07; SE 0.03 - 0.04	Fair
Schofield et al., 2007[58] Setting: School Cross-sectional (Four-day observational study)	N = 318; 100% female; mean age 16 years (SD 0.80) Country: Australia	+ve: Correlation between individual and friend (1st – 3rd nominated friends) was stronger for reciprocated friends: coef 0.45 - 0.16 than non-reciprocated friends: coef -0.06 - 0.16 +ve: Individual PA was associated with PA of 1st nominated friend only: coef 0.41**** *(2nd and 3rd NS)*	Poor
Dietary-related behaviors			
Bruening et al., 2012[59] Setting: School Cross-sectional	N = 2,043; female 46.2%; mean age 14.2 years (SD 1.9) Country: USA	+ve: Individual breakfast intake was associated with friend group: coef 0.26***, 95% CI 0.14 - 0.38 and best friends' intake: coef 0.19*, 95% CI 0.06 - 0.32 *NS association for friend group/best friends and individual fruit intake or friend group and vegetable intake* +ve: Vegetable intake was associated with the best friends' intake: coef 0.09*, 95% CI 0.01 - 0.18	Good

		+ve: Individual wholegrain intake was associated with the intake of the friend group: coef 0.14***, 95% CI 0.06 - 0.23 and best friends' intake: coef 0.13*, 95% CI 0.04 - 0.21 +ve: Individual dairy intake was associated with the intake of the friend group: coef 0.08*, 95% CI 0.02 - 0.15 and best friends' intake: coef 0.09*, 95% CI 0.03 - 0.14	

**p<0.05, **p<0.01, ***p<0.001*

^Italic script indicates missing information or non-significant findings

+ve: Study showed positive and statistically significant association

AOR: Adjusted Odds Ratio; CI: Confidence Intervals; coef: coefficient; NS: Non-Significant at 5% significance level; OR: Odds Ratio; PA: Physical Activity; PE: Parameter Estimate; SD: Standard Deviation; SE: Standard Error

(1) Frequent drinkers drank alcohol more than once a month [53]

(2) ERGM practice assumes significance if the PE is more than twice it's SE [57]

Table 3: Studies investigating social influence (but not homophilic social selection)

Reference	Study details	Outcome	Study quality
Alcohol drinking			
Ali and Dwyer, 2010[69] Setting: Home and school Cross-sectional	N= 20,097, 51% female; mean age 15 years *(SD not reported^)* Country: USA (using Add Health data)	+ve: Only same-grade peers' drinking was significantly associated with increased individual drinking: coef 0.41*, SE 0.15 (10% increase in classmates' drinking resulted in an increase in individual's drinking and frequency of alcohol consumption by approximately 4%) *NS association between friend and individual drinking*	Good
Giletta et al., 2012[66] Setting: School Longitudinal	N = 704; 47% female; mean age 15.53 years *(SD not reported)* Country: Italy	+ve: Individual alcohol use became more similar to their peers' use over time: PE 0.48, SE 0.15*** +ve: Same sex dyadic friendships became more similar over time in their alcohol misuse for both male and female same-sex dyads but not for mixed sex dyads: coef 0.22*** – 0.47*	Good
Gallupe and Bouchard, 2015[67] Setting: Home and school Longitudinal	N = 13,351; 50% female; mean age 14.75 years (SE 0.01) Country: USA (using Add Health data)	+ve: Associating with alcohol using friends at TP 1 predicted individual alcohol use at TP 2: coef 0.35**, SE 0.01	Good
Lee et al., 2015[68] Setting: School Longitudinal	N = 1,808; 53% female, *(age not reported)* Country: Northern Taiwan	+ve: Adolescents who had drinking peers tended to drink more often during the past year: aPRR 3.02, 95% CI 1.92 - 4.75***, whereas those who had peers against drinking tended to drink less: aPRR 0.21, 95% CI 0.16 - 0.27***	Good
Gaughan, 2006[49] Setting: Home and school Cross-sectional	N = 2,902; 52% female; mean age 16.55 years (SD 1.46) Country: USA (using Add Health data)	+ve: Same-sex dyadic friendships mutually influence each others' drinking: coef 0.41*** - 0.77***, SE 0.01 - 0.17; however males in a mixed sex friendship influence their female friends to drink: coef 0.35* - 0.38**, SE 0.12 - 0.16, but are not influenced by them	Fair

Cigarette smoking			
Ali and Dwyer, 2009[65] Setting: Home and school Longitudinal	N = 20,745, 51% female; mean age 15.2 years (SD 1.74) Country: USA (using Add Health data)	+ve: School grade-level peer smoking influenced adolescent smoking to a greater extent: OLS 0.40** - 0.15**, SE 0.03 - 0.02, compared to influence from nominated peers: OLS 0.21** - 0.15**, SE 0.01 - 0.02, at all 3 waves	Good
Lakon, Hipp and Timberlake, 2010[70] Setting: Home and school Longitudinal	N = 6,504; 38.2% female; mean age 14.87 years (SD 1.73) Country: USA (using Add Health data)	+ve: Friends' smoking behavior was associated with increasing individual smoking at both TPs: coef 0.77**, SE 0.05 and coef 0.32**, SE 0.05	Good
Drinking and smoking combined			
Fujimoto and Valente, 2012b[60] Setting: Home and school Cross-sectional	N = 13,187; 52% female; mean age 15.04 years (SD 1.70) Country: USA (using Add Health data)	+ve: Adolescents were most influenced to drink by direct friends: OR 1.57*** over indirect(3) friends (2-4 distances out): OR 1.44*** - 1.16** Adolescents were most influenced to smoke by their direct friends: OR 2.36***, over indirect(3) friends at distance 2: OR 2.30***. *NS influence effect from friends at distances 3-4*	Good
Fujimoto and Valente, 2012a[71] Setting: Home and school Cross-sectional	N = 2,533; 50% female; mean age 15.49 years (SD 1.49) Country: USA (using Add Health data)	+ve: Adolescents were influenced more by their friend group than their best friends for drinking: AOR 2.62*** v 1.55***, and smoking: AOR 3.32*** v 2.39***	Good
Urberg, Degirmencioglu and Pilgrim, 1997[61] Setting: School Longitudinal	N = 1,028; 50.6% female; *mean age not reported* (6th -10th grade) Country: USA	+ve: Initiation of individual smoking was predicted by close friend smoking: coef 0.73*** and drinking coef 0.37** +ve: Friend group predicted current smoking: coef 2.20*** and close friend predicted current drinking: coef 0.32*	Poor

French, Purwono and Rodkin, 2014[62] Setting: School Longitudinal	N = 992, 52.8% female; mean age 8th grade 13.37 (SD 0.45); 10th grade 15.36 (SD 0.52) Country: Bandung, West Java	+ve: Controlling for use at TP 1, friends' and classmates alcohol use predicted boys' alcohol use at TP 2: (no label) 1.01* and 3.26*** respectively *(NS effect for girls)* Friends' and classmates' smoking predicted use for both boys: 1.45** and 1.49**; and girls:1.52*** and 2.43***	Poor
Substance use			
Valente et al., 2007[48] Setting: School Longitudinal (intervention)	N = 541; 38% female; mean age 16.3 years (SD 1.36) Country: USA	+ve: Relative to control, TND intervention(4) was not associated with changes in substance use, but receiving TND-network intervention was associated with decreased marijuana use: coef -0.64, 95% CI -1.09 - -0.19* and cocaine use: coef -0.37, 95% CI -0.63 - -0.10* -ve: The interaction of peer use and TND-network was associated with increases in substance use: coef 0.17**, 95% CI 0.08 - 0.26 (it could accelerate negative peer influence)	Good
Coronges, Stacy and Valente, 2011[63] Setting: School Longitudinal	N = 567, 43% female; *age not reported* Country: USA	+ve: Friends' drug use increased individual use for marijuana: OR 1.95, SE 0.73* *NS effect for friends' drug use increasing individual use for alcohol*	Fair
Physical Activity			
Lopes, Gabbard and Rodrigues, 2013[39] Setting: School Cross-sectional	N = 268; 47.8% female, aged between 13-18 years *(SD not reported)* Country: Portugal	+ve: Best friend dyads show a moderate and significant degree of association with VPA, MPA and sitting time behavior: VPA coef 0.32***; MPA coef 0.31***and sitting coef 0.21* *NS effect for walking*	Poor
Dietary-related behaviors			
Ali et al., 2012[64]	N = 20,745; 50% female; mean age 15.18 years (SD 1.16)		Good

Setting: Home and school Longitudinal	Country: USA (using Add Health data)	*NS effects for close friends' BMI or same-school peers' BMI on adolescents' BMI*	

**p<0.05, **p<0.01, ***p<0.001*

^Italic script indicates missing information or non-significant findings

+ve: Study showed positive and statistically significant association; -ve: study showed negative and statistically significant association

aPRR: adjusted prevalence rate ratio; BMI: Body Mass Index; CI: Confidence Interval; coef: coefficient; MPA: Moderate Physical Activity; NS: Non-Significant at 5% significance level; OLS: Odd Least Squares; OR: Odds Ratio; PA: Physical Activity; PE: Parameter Estimate; SD: Standard Deviation; SE: Standard Error; TP: Time-point

(3) Indirect friends are friends of a friend; or friends of a friend of a friend; i.e. indirectly tied to the adolescent through another tie[60]

(4) Post intervention results of receiving the TND (Towards No Drug abuse) intervention, or TND-network (nominated peer leaders delivered discussions and teams identified through group project nominations)[48]

Table 4: Studies investigating both homophilic social selection and social influence

Reference	Study details	Selection	Influence	Study quality
Alcohol drinking				
Mundt, Mercken and Zakletskaia, 2012[84] Setting: Home and school Longitudinal	N = 2,563; 49% female; mean age 15.80 years (SD 1.3) Country: USA (using Add Health data)	+ve: Friend selection was associated with similar alcohol use: coef 1.28, SE 0.21***	*NS influence effect based on alcohol consumption. NS association for more frequent drinking by immediate friends leading to increased frequency of individual alcohol consumption*	Good
Mercken et al., 2012[80] Setting: School Longitudinal	N = 1,204; 48.8% female, mean age at baseline 13.60 years (SD not reported) Country: Finland	*NS association for alcohol consumption-based selection effects in period 1 (TP 1 – TP 2)* Adolescents who had high alcohol consumption tended to select friends who likewise had high alcohol consumption at periods 2 (TP 2 – TP 3): x^2 40.07* and 3 (TP 3 – TP 4): x^2 34.29*	+ve: During TP 1 – TP 2, adolescents alcohol consumption was influenced by their friends' alcohol consumption: x^2 38.25* *NS effect from TP 2 – TP3, and TP 3 – TP 4*	Good
Kreager and Haynie, 2011[46] Setting: Home and school Longitudinal	N = 14,738, 50% female; mean age 14.18 years (females, SD 1.51); 14.78 years (male, SD 1.65) Country: USA (using Add Health data)	+ve: 1 SD increase in (a) partner's prior drinking increases respondents' odds of binge drinking by 32%, (b) friends' prior drinking increases the odds of binge drinking by 30%, and (c) friends-of-partner prior drinking increases the odds of binge drinking by 81%	+ve: After controlling for prior individual drinking, 1 SD increase in romantic partner's prior drinking increased individual's odds of binge drinking by 43% (OR 1.43**) *Friends' prior drinking was no longer associated with increased individual drinking after controlling for own prior drinking*	Good

Long, Barrett and Lockhart, 2017[85] Setting: Home and School Longitudinal	N = 1,796; 47.8% female; mean age 16.40 years *(SD not reported)* Country: USA (using Add Health data)	+ve: Friend selection was associated with similar alcohol use in both schools: coef 0.93-1.46, SE 0.23 - 0.34***	+ve: Adolescents changed their alcohol use behavior to become more similar to their friends in one of two schools: coef 0.62, SE 0.30*	Poor
Wang et al., 2017[86] Setting: Home and School Longitudinal	N = 3,154; *(% female not reported);* 7th - 12th grades Country: USA (using Add Health data)	+ve: Friend selection was associated with similar alcohol use (in one of two schools): coef 0.18, SE 0.03*	+ve: Adolescents were influenced to drink by their friends (in both schools): coef 0.38 - 0.48*, SE 0.07 - 0.16	Poor
Cigarette smoking				
Mercken et al., 2010[89] Setting: School Longitudinal	N = 1,326; 47% female; mean age 13.4 years *(SD not reported)* Country: Finland	+ve: Adolescents who were smokers, selected smoking friends: coef 0.09***, SE 0.02 *(significant only for a) unilateral(5) friendships – the interaction decreased for reciprocated friends)* Network autocorrelation attributed to smoking-based selection was higher than the proportion allocated to influence for all 3 waves (31 - 46% v 15 - 22%)	+ve: Adolescents adjusted their smoking status to become more similar to their friends' smoking status: coef 0.21**, SE 0.07	Good
Go et al., 2012[88] Setting: Home and School Longitudinal	N = 2,065; 50.5% female; *mean age not reported* (11% 7th grade, 11.3% 8th, 10.9% 9th, 31.5% 10th, 28.7% 11th, 6.6% 12th) Country: USA (using Add Health data)	+ve: Smoking initiation was associated with selecting a new smoking friend: OR 2.18***, 95% CI 1.27 - 3.76	+ve: Each consistent smoking friend (1 degree away) increases the likelihood of an adolescent initiating smoking by 80% (OR 1.79***, 95% CI 1.38 - 2.34)	Good

Valente, Fujimoto, Soto et al., 2013[81] Setting: School Longitudinal	N = 1,950; 58.6% female; mean age 14 years *(SD not reported)* Country: USA	+ve: Respondents who changed smoking status and made new friends with others of the same smoking status were more likely to become a smoker at TP 2: AOR 1.32 (p= 0.05)	+ve: Friend's smoking (at baseline) was associated with initiation of individual smoking at TP 2: AOR 1.72*, SE 0.43 (sociocentric measure) Increase in perceived friends' smoking was associated with becoming a smoker AOR: 1.84***, SE 0.12, CI 1.61 – 2.09 (egocentric measure)	Fair
Go et al., 2010[87] Setting: Home and School Longitudinal	N = 1,223; 52% female; mean age 15.5 years (SD not stated) Country: USA (using Add Health data)	+ve: Initial smokers and non-smokers were more likely to join a smoking friendship group and non-smoking friendship group over time, respectively: OR 1.95***, 95% CI 1.35 - 2.83	+ve: Initial non-smokers in a smoking friendship group were about 1.5 times more likely (than those in a non-smoking group) to start smoking by TP 2: OR 1.48, 95% CI 1.03 - 2.15 +ve: Initial smokers in a non-smoking group were twice as likely to be non-smokers by TP 2 compared to initial smokers in a smoking group at TP 1: OR 2.13, 95% CI 1.1 - 4.06	Poor
Huisman and Bruggeman, 2012[79] Setting: School Longitudinal	N = 961; 51.4% female; mean age 13.47 years (SD 0.6) Country: The Netherlands	+ve: Adolescents selected friends with similar smoking status: coef 0.07***	+ve; Adolescents are influenced by friends to adopt their smoking behavior: coef 0.21*	Poor
Aloise-Young, Graham and Hansen, 1994[82] Setting: School	N = 1,145; 59% female (part 1); 55% (part 2); *(mean age not reported (7th grade))* Country: USA	+ve: Smoking similarity increased the chances of a unilateral(5) friend becoming a reciprocal friend by 15.2%. Although reciprocal friends	+ve: In comparison with a friendship group outsider with a non-smoking best friend, a group outsider whose best friend smokes is twice as likely	Poor

Longitudinal		started out more similar in their smoking behavior: r 0.23**, than unilateral friends: r 0.09*, the new reciprocal friends were as similar: r 0.47** as the continuing reciprocal friends: r 0.37** at TP 2	to begin smoking during the next year (probability 22.7 v 11.2) (OR 2.38*)	
Schaefer, Haas and Bishop, 2012[90] Setting: Home and School Longitudinal	N = 509; 46.6% female; mean age 15.39 years *(SD not reported)* Country: USA (using Add Health data)	+ve: Adolescents selected friends with similar smoking behavior: coef 0.68***, SE 0.13	+ve: Adolescents adopted their friends' smoking behavior over time: coef 2.88***, SE 0.86	Poor
Drinking and smoking combined				
Wang et al., 2016[73] Setting: Home and School Longitudinal	N = 2,260; 49.9% female; *mean age not reported* (7^{th}-12^{th} grades) Country: USA (using Add Health data)	+ve: Adolescents selected friends with similar smoking: coef 0.20* - 0.24*, SE 0.03 - 0.06 and drinking: coef 0.13* - 0.14*, SE 0.04 - 0.07 behaviors	+ve: Adolescents changed their smoking: coef 0.48* - 0.77*, SE 0.12 - 0.14, and drinking: coef 0.32* - 0.45*, SE 0.12 - 0.15 behavior to become more similar to their friends over time	Good
Kiuru et al., 2010[72] Setting: School Longitudinal	N = 1,419; 48.6% female; mean age 16.36 years (SD 1.49) Country: Finland	+ve: Adolescents selected friends with similar levels of smoking: PE 0.53***, SE 0.12 and drinking: PE 0.90**, SE 0.37	+ve: Individual alcohol use changed to become more similar to friends' alcohol use: PE 0.78**, SE 0.28 *NS association for adolescents adopting similar smoking behavior to their friends*	Poor
Substance use				
Wang et al., 2018[76] Setting: Home and School	N = 3,128 *(% female and age not reported)*	+ve: Smoking similarity between peers was significant for smoking in one of two schools: coef 0.24*, SE 0.10;	+ve: Individuals in both schools were influenced by their friends to smoke: coef 0.54*** - 0.77***, SE 0.13 - 0.15; drink:	Good

Longitudinal	Country: USA (using Add Health data)	drinking similarity was significant in both: coef 0.12*-0.13**, SE 0.05; marijuana similarity was significant in both: coef 0.27*** - 0.22*, SE 0.07 - 0.09	coef 0.28** - 0.38*, SE 0.12 - 0.16 and use marijuana: coef 1.43** - 1.32***, SE 0.38 - 0.49	
Mathys, Burk and Cillessen, 2013[51] Setting: School Longitudinal	N = 450; 53% female; mean age 15.5 years *(SD not reported)* Country: USA	+ve: Adolescents selected friends with similar smoking: PE 0.53, SE 0.26* *NS effects for friend selection based on similar alcohol or marijuana*	+ve: Adolescent alcohol behaviors was significantly predicted by friends alcohol behavior: PE 0.62, SE 0.26* *NS effects for influence based on smoking or marijuana*	Fair
Pearson, Steglich and Snijders, 2006[74] Setting: School Longitudinal	N = 160, *% female not reported,* aged between 13-15 years *(SD not reported)* Country: Scotland	+ve: Alcohol drinkers selected friends with similar drinking habits: PE 0.96, SE 0.38* *NS effects for smoking and marijuana.*	+ve: Adolescents adapted their marijuana and alcohol use behavior to become more similar to their friends': PE 3.54, SE 1.43* and PE 1.63, SE 0.43*** respectively *NS effect for smoking*	Poor
Poulin et al., 2011[75] Setting: School Longitudinal	N = 143; 60% female; mean age 14.55 years *(SD not reported)* Country: Canada (French Canada)	Adolescents who used substances were more likely to select friends who likewise used substances: smoking PE 0.50*** - 0.33**; alcohol PE 0.19* - 0.37**; marijuana PE 0.33** - 0.49**	+ve: Number of new substance using friends predicted individual use over time: smoking PE 0.18*; alcohol PE 0.26**; marijuana PE 0.11* - 0.17**	Poor
Physical Activity				
Simpkins et al., 2013[77] Setting: Home and school Longitudinal	N = 1,896; 46.6% female (school A), 48.1% female (school B), mean age 15.97 years *(SD not reported)*	+ve: Individuals selected friends on the basis of similar PA levels: coef. 1.38 – 2.94; SE 0.67* - 1.28*	+ve: Adolescents adopted similar PA levels to their friends over time: coef 0.45; SE 0.16*** - 0.23*	Good

	Country: USA			
De la Haye et al., 2011[78] Setting: School Longitudinal	N = 378; 46% female; mean age 13.6 years (SD 0.4) in group 1; 13.7 years (SD 0.04) years in group 2 Country: Australia	+ve: Friendship selection (best friend) significantly predicted by similarities in PA: PE 0.62, SE 0.25*	+ve: Adolescents' PA behavior changed over time so it became or remained similar to that of their best friend's: PE 2.67, SE 0.89** Network autocorrelation models showed stronger effects for influence (29 - 47%) than selection (11 - 23%)	Fair
Dietary/weight-related behaviors				
De la Haye et al., 2013[50] Setting: School Longitudinal	N = 378; 46.3% female; mean age 13.6 years (13.6 years (SD 0.4) in school 1 and 13.7 years (SD 0.4) in school 2) Country: Australia	*NS effect in either school that adolescents selected friends whose intake of LNED foods was similar to themselves*	+ve: Over time, adolescents' intake of LNED foods became more similar to their friends' intake of LNED foods (school 1: PE 0.88; SE 0.41*; school 2: PE 1.07; SE 0.46*)	Good
Shoham et al., 2012[83] Setting: School Longitudinal	N = 1,775; 49% female; mean age 16.1 (SD 1.1) in school 1, and 16.5 (0.9) in school 2 Country: USA (using Add Health data)	In both schools, adolescents chose friends with similar BMI (school 1: PE 0.54, CI 0.14 - 0.95; school 2: PE 1.30, CI 0.68 - 1.91) In school 1, homophilic social selection was found for active sports, adolescents chose friends who played similar sports: PE 0.59, CI 0.21 - 0.96. This finding was not significant in either school when all forms of PA were included	BMI average similarity score in school 1: PE 14.10, CI 7.76 - 20.44. Adolescents are more likely to try to match the average BMI of their friends. Adolescents were likely to be influenced by extremes of peer behavior, to change their screen time behavior and playing active sport behavior to match their friends (can increase or decrease the behavior dependent on friends' behavior)	Good

**p<0.05, **p<0.01, ***p<0.001*

^Italic script indicates missing information or non-significant findings

+ve: Study showed positive and statistically significant association
AOR: Adjusted Odds Ratio; BMI; Body Mass Index; CI: Confidence Interval; coef: coefficient; LNED: low-nutrient energy-dense; NS: Non-Significant at 5% significance level; OR: Odds Ratio; PE: Parameter Estimate; r: correlation between predicted and observed values of y in a regression analyses; SD: Standard Deviation; SE: Standard Error; TP: Time-Point, x^2: Fishers combination test
(5) Unilateral friend indicates the friendship is non-reciprocated (it is a one-sided friendship). A reciprocated friendship indicates both members of the friendship tie nominate each other [8982]

Table 2: Popularity: engagement in health behavior(s) leading to changes in social status

Reference	Study details	Outcome	Study quality
Alcohol drinking			
Cheadle et al., 2013[54] Setting: Home and school Longitudinal	N = 3,561; 49% female; mean grade 10.27 *(age not specified)* Country: USA (using Add Health data)	*NS association for alcohol use and popularity*	Good
Giletta et al., 2012[66] Setting: School Longitudinal	N = 704; 47% female; mean age 15.53 years *(SD not reported)* Country: Italy	+ve: Adolescents who drank more alcohol were more popular (received more friendship nominations: PE 0.11, SE .02***)	Good
Balsa et al., 2011[91] Setting: Home and school Cross-sectional	N = 12,547; 52% female; mean age 15.7 years *(SD not reported^)* Country: USA (using Add Health data)	+ve: If boys' drinking frequency was below classmates' ave., any alcohol consumption increased popularity: coef 3.35**, SE 1.05. *NS for girls.* 'Getting drunk' increased boys' popularity further (if the frequency of getting drunk was below classmates' ave.) coef 4.24**, SE 1.41. *NS for girls.* *NS association with popularity if drinking frequency or getting drunk are above peer average levels. NS association in girls.*	Good
Ali, Amialchuk and Nikaj, 2014[92] Setting: Home and school Cross-sectional	N = 19,871; 50.5% female; mean age 15.17 years *(SD not reported)* Country: USA (using Add Health data)	+ve: Any past year individual alcohol consumption increased popularity (in-degree): PE 0.47**, SD 0.15. Greater increase in popularity by being drunk over just any alcohol consumption: (in-degree) PE 1.00**, SD 0.29	Fair
Gallupe, 2014[93] Setting: Home and school Longitudinal	N = 13,539; 51% female; mean age 15.82 years (SD 1.57) Country: USA (using Add Health data)	+ve: Alcohol use was associated with increased popularity (in-degree) in the low-alcohol group(6) coef 0.08**, SE 0.02 but *NS association in the high alcohol group(6) and popularity*	Fair

Long, Barrett and Lockhart, 2017[85] Setting: Home and School Longitudinal	N = 1,796; 47.8% female; mean age 16.4 years *(SD not reported)* Country: USA (using Add Health data)	*NS association between popularity and alcohol use*	Poor
Cigarette smoking			
Lakon, Hipp and Timberlake, 2010[70] Setting: Home and School Longitudinal	N = 6,504; 38.2% female; mean age 14.87 years (SD 1.73) Country: USA (using Add Health data)	+ve: Smoking was associated with increased popularity - in-degree centrality increased by 2.3%: coef 0.02**, SE 0.01	Good
Huisman and Bruggeman, 2012[79] Setting: School Longitudinal	N = 961; 51.4% female; mean age 13.47 years (SD 0.6) Country: The Netherlands	+ve: Smoking was associated with increased popularity – smokers were more likely to receive friendship nominations: coef 0.42***	Poor
Schaefer, Haas and Bishop, 2012[90] Setting: Home and School Longitudinal	N = 509; 46.6% female; mean age 15.39 years *(SD not reported)* Country: USA (using Add Health data)	+ve: Smokers were more popular – study showed a positive effect for nominating students with higher levels of smoking as a friend: coef 0.13*, SE 0.06	Poor
Drinking and smoking combined			
Wang et al., 2016[73] Setting: Home and School Longitudinal	N = 2,260; 49.9% female; *mean age not reported* (7^{th} - 12^{th} grades) Country: USA (using Add Health data)	+ve: In the one large school, increased smoking was associated with being more popular: coef 0.06*, SE 0.03 *(NS in small schools)* +ve: Drinkers were more popular in the small schools (coef 0.14*, SE 0.06) compared to larger school (coef 0.40*, SE 0.02)	Good
Physical Activity			
Simpkins et al., 2013[77] Setting: Home and school Longitudinal	N = 1,896; 46.6% female (school A), 48.1% female (school B), mean age 15.97 years *(SD not reported)*	+ve: More active adolescents were more popular: coef -0.02 - -0.09; SE 0.01* - 0.02*** and selected more friends: coef 0.06, SE 0.02***	Good

	Country: USA (using Add Health data)		
De la Haye et al., 2010[57] Setting: School Cross-sectional	N = 385; 64% female; mean age 13 - 14 years *(SD not reported)* Country: Australia	Mixed findings: Participation in organized PA was positively associated with being more popular in 2 of 3 male networks PE 0.17 - 0.15, SE 0.06 - 0.08 (2) *NS in female networks*	Fair
Dietary-related behaviors			
(De la Haye et al., 2013)[50] Setting: School Longitudinal	N = 378; 46.3% female; mean age 13.6 years (13.6 years (SD 0.4) in school 1 and 13.7 years (SD 0.4) in school 2) Country: Australia	+ve: LNED intake was associated with increasing popularity in one school, adolescents tended to befriend friends who had LNED values slightly above the mean (school 2: PE -0.19, SE 0.08*) more than peers with low or very high values	Good

**p<0.05, **p<0.01, ***p<0.001*

^Italic script indicates missing information or non-significant findings
+ve: Study showed positive and statistically significant association
ave: average; coef.: coefficient; LNED: low-nutrient energy-dense; NS: Non-Significant at 5% significance level; SD: Standard Deviation; SE: Standard Error; PA: Physical Activity; PE: Parameter Estimate
(2) ERGM practice assumes significance if the PE is more than twice it's SE [57]
(6) The low-alcohol group had a mean level of alcohol use of 0.68; high alcohol group had a mean level of alcohol use of 4.42; ranging from 0_never to 6_every day/almost every day [93]

Table 3: Popularity: Network popularity predicting health behavior(s)

Reference	Study details	Outcome	Study quality
Alcohol drinking			
Gallupe and Bouchard, 2015[67] Setting: Home and school Longitudinal	N = 13,351; 50% female; mean age 14.75 years (SE 0.01) Country: USA (using Add Health data)	+ve: More popular adolescents were likely to drink more alcohol coef 0.07**, SE 0.01	Good
Lee et al., 2015[68] Setting: School Longitudinal	N = 1,808; 53% female, *(age not reported)* Country: Northern Taiwan	+ve: Receiving one more peer nomination (in-degree) was associated with increased occasions of drinking by 6%: aIRR 1.06, 95% CI 1.01 – 1.10*	Good
Mundt, Mercken and Zakletskaia, 2012[84] Setting: Home and school Longitudinal	N = 2,563; 49% female; mean age 15.8 years (SD 1.3) Country: USA (using Add Health data)	+ve: Increase in popularity was associated with increased alcohol use: coef 0.08, SE 0.02*	Good
Choukas-Bradley et al., 2015[45] Setting: School Longitudinal	N = 364; 53.6% female; mean 15.08 years (SD 0.55) Country: USA	+ve: Higher levels of popularity were associated with a higher probability of alcohol use in males *(NS in females)*	Poor
Fujimoto and Valente, 2015[52] Setting: School Cross-sectional	N = 1,707; 52% female; mean age 15.07 years (SD 0.43) Country: USA	+ve: Only in-degree based on perceived popularity was significantly associated with drinking (AOR 1.35***, SE 0.11), *NS association for drinking and in-degree based on friend nominations*	Poor
Cigarette smoking			
Alexander et al., 2001[55] Setting: Home and School	N = 2525, 50% female; mean age 15.5 years (SD 1.5)	+ve: Adolescents who had higher levels of popularity and whose schools had higher smoking	Good

Cross-sectional	Country: USA (using Add Health data)	prevalence had a small but increased risk of smoking (OR 1.08***, 95% CI 1.01 – 1.15, SE 0.04)	
Robalino and Macy, 2018[94] Setting: Home and School Longitudinal	N = 7,500; *(% female & age not reported – used data from Add Health study[43]);* 7th-12th grades Country: USA (using Add Health data)	+ve: Probability of individual smoking increases with increasing popularity of peer smokers from 1996 – 2009: mean 0.05*** - 0.03***, SE 0.01 - 0.01. The mean popularity of non-smokers decreases the effect -0.06***, SE 0.02	Good
Valente, Fujimoto, Soto et al., 2013[81] Setting: School Longitudinal	N = 1,950; 58.6% female; mean age 14 years *(SD not reported)* Country: USA	+ve: Increased popularity was associated with becoming a smoker AOR 1.56***, SE 0.25	Fair
Schaefer, Adams and Haas, 2013[56] Setting: Home and School Longitudinal	N = 509; 46.6% female; *mean age not reported* Country: USA (using Add Health data)	+ve: When smokers were popular, increases in peer influence increased smoking prevalence, but when they were unpopular, stronger peer influence decreased smoking prevalence	Poor
Substance use			
Kramer and Vaquera, 2011[95] Setting: Home and school Cross-sectional	N = 15,353, 51.6% female; aged 12-18 years *(SD not reported)* Country: USA (using Add Health data)	+ve: Compared to socially isolated(7) peers, individuals who received more friendship nominations were more likely to drink: OR 1.66***, SE 0.14 (compared to socially isolated: 0.67***, SE 0.07) and binge drink: OR 1.61***, SE 0.19 (compared to socially isolated: 0.73**, SE 0.09) *NS effects for popularity and smoking or marijuana use*	Good
Wang et al., 2018[76] Setting: Home and School	N = 3,128 *(% female and age not reported)*	*NS evidence for all 3 substances that more popular adolescents were more likely to increase use over time*	Good

Longitudinal	Country: USA (using Add Health data)		
Coronges, Stacy and Valente, 2011[63] Setting: School Longitudinal	N = 567, 43% female; *mean age not reported* Country: USA	*NS effect for individual centrality (popularity) and alcohol or marijuana use*	Fair
Mathys, Burk and Cillessen, 2013[51] Setting: School Longitudinal	N = 450; 53% female; mean age 15.5 years *(SD not reported)* Country: USA	+ve: Popularity moderated friendship selection based on alcohol use: PE 0.12, SE 0.04** – popular adolescents were more likely to select friends with high drinking levels *NS effects for popularity moderating marijuana use or tobacco use*	Fair
Pearson et al., 2006[96] Setting: School Cross-sectional	N = 3,146; 50.3% female; aged 13-15 years *(SD not reported)* Country: Scotland	+ve: Drug and alcohol use were more likely in popular compared to unpopular adolescents (very popular v unpopular drug use: OR 1.61* v 0.56***; very popular v unpopular alcohol use: OR 1.76*** v 0.63***) *NS effects for smoking*	Poor
Moody et al., 2011[97] Setting: School Longitudinal	N = 12,245; *% female not stated; mean age not reported* (6th & 9th grade) Country: USA	+ve: A 10% increase in average popularity increases substance use (smoking, alcohol, marijuana) by 0.02 The predicted trajectory slope shows substance use increases for those adolescents who are at either end of the popularity scale (strongly increasing or decreasing popularity levels)	Poor

**p<0.05, **p<0.01, ***p<0.001*

^Italic script indicates missing information or non-significant findings
+ve: Study showed positive and statistically significant association

aIRR: Adjusted Incidence Rate Ratio; AOR: Adjusted Odds Ratio; CI: Confidence Interval; coef: coefficient; NS: Non-Significant at 5% significance level; PE: parameter estimate; SD: Standard Deviation; SE: Standard Error; OR: Odds Ratio
(7) Kramer and Vaquera (2011) define socially isolated students as receiving no friendship nominations by their class peers, marginally social adolescents as receiving one friendship nomination, and socially saturated adolescents as receiving more than one standard deviation above the mean number of friendship nominations in the class (adolescents who received 9 or more nominations)[95]

Table 7: 'Other' network processes and health behaviors

Reference	Study details	Outcome	Study quality
Alcohol drinking			
Gallupe and Bouchard, 2015[67] Setting: Home and school Longitudinal	N = 13,351; 50% female; mean age 14.75 years (SE 0.01) Country: USA (using Add Health data)	+ve: Adolescents in denser networks had lower levels of alcohol use: coef 0.10**, SE 0.01	Good
Substance use			
Ennett et al., 2006[98] Setting: School Longitudinal	N = 5,104; 50.5% female; *mean age not reported*^ (equally divided among 6th, 7th and 8th graders) Country: USA	+ve: Adolescents with higher density networks had lower odds of recent smoking at age 15: OR 0.92*** and marijuana use: OR 0.93* +ve: Social position: isolates were significantly more likely to report recent smoking than group members, however growth in alcohol use was less for isolates than for group members	Good

**p<0.05, **p<0.01, ***p<0.001*

^Italic script indicates missing information
+ve: Study showed positive and statistically significant association
Coef: coefficient; SE: Standard Error; OR: Odds Ratio

Table 8: Risk of bias and study quality

Health behavior	Newcastle-Ottawa Scale Risk of Bias				Study quality
	Selection	**Comparability**	**Outcome / exposure**	**Total**	
Alcohol drinking					
[69]	***	**	**	7	Good
[92]	**	**	**	6	Fair
[91]	***	**	**	7	Good
[54]	***	**	**	7	Good
[45]	***		**	5	Poor
[53]	***	**	**	7	Good
[52]	**	**	**	6	Fair
[67]	***	**	**	7	Good
[93]	**	**	**	6	Fair
[49]	**	**	**	6	Fair
[66]	****	**	**	8	Good
[46]	***	**	**	7	Good
[68]	***	**	**	7	Good
[85]	***		**	5	Poor
[84]	***	**	**	7	Good
[86]	*	**	**	5	Poor
[80]	****	**	**	8	Good
Cigarette smoking					
[55]	***	**	**	7	Good
[65]	***	**	**	7	Good
[82]	***		**	5	Poor
[87]	***		**	5	Poor
[88]	***	**	**	7	Good
[79]	*	**	**	5	Poor
[70]	***	*	**	6	Good
[89]	***	**	**	7	Good
[94]	***	**	**	7	Good
[90]	*	**	**	5	Poor
[56]			**	2	Poor
[81]	**	**	**	6	Fair
Drinking and smoking combined					
[62]	***		**	5	Poor
[60]	***	**	**	7	Good
[71]	***	**	**	7	Good

72	***		**	5	Poor
47	**		**	4	Poor
61	*	**		3	Poor
73	***	*	**	6	Good
Substance use					
63	**	*	**	5	Fair
98	***	**	**	7	Good
95	***	**	**	7	Good
51	**	**	**	6	Fair
97	***		**	5	Poor
74	**		**	4	Poor
96	***			3	Poor
75	*		**	3	Poor
48	***	**	**	7	Good
76	****	**	**	8	Good
Physical Activity					
78	**	**	**	6	Fair
57	**	**	**	6	Fair
39	***		**	5	Poor
58	***		**	5	Poor
77	***	**	**	7	Good
Diet/weight-related behaviors					
64	***	**	**	7	Good
59	****	**	**	8	Good
50	****	**	**	8	Good
83	****	**	**	7	Good

6. References

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