The Role of Friends in Adolescent Overweight and Weight-Related Behaviors:

A social network perspective

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Appendix A: Paper 3 Reprint
This thesis examined processes that may be driving the clustering and proposed “spread” of obesity amongst adolescent friends and within their wider friendship networks (Fowler & Christakis, 2008; Halliday & Kwak, 2009). Specifically, the aims were to determine 1) if similarities in weight status amongst friends were explained, at least to some extent, by their body mass indexes (BMIs) assimilating over time, and 2) whether this was underpinned by friends’ influence on obesity-related behaviors. Findings from two cross-sectional studies and one longitudinal study are presented in four papers, of which one has been published and the remaining three submitted for publication.

Paper 1 examined associations between adolescents’ BMI and their school-based friendships longitudinally \((N = 156)\), using stochastic actor-oriented models (SAOM) for social networks (Snijders, Steglich, & Schweinberger, 2007). Weight status was found to play a significant role in adolescents’ friendship choices, with overweight youth often marginalized by, and segregated from, their nonoverweight peers. Although there was a trend for friends’ BMIs to assimilate over the 16-month study, this effect was not statistically significant. Similarities in BMI amongst friends were therefore explained by friendship choices rather than “contagion” effects.

The conditions under which overweight youth are marginalized by their peers were further explored in Paper 2. This study looked at the role of school classroom norms favoring healthiness, and specifically the norms endorsed by high-status students, in weight-related marginalization amongst pre-adolescents. In this cross-sectional study \((N = 503)\), exponential random graph models (ERGM) (Robins, Pattison, Kalish, & Lusher, 2007) were used to test for associations between weight status and friendships in school classes with
weak versus strong health norms. Overweight students, and particularly overweight girls, were found to be marginalized by their peers in classes with strong health norms; however overweight youth were well integrated in classrooms lacking clear norms on healthiness. The results suggest that local norms may impact the relevance of attributes like weight status to adolescent friendships and thus the prevalence of weight-based stigma in peer groups, providing some useful insights for future interventions.

Whether weight-related health behaviors clustered and spread amongst adolescent friends was investigated in the final two papers. The first, cross-sectional, study (Paper 3) looked at several obesity-related behaviors within three adolescent friendship networks ($N=385$) and tested for similarities amongst friends using ERGMs. The strongest evidence of behavioral similarity was found for organized physical activity (PA); therefore the final paper (Paper 4) longitudinally examined the social processes driving this association using SAOMs ($N=378$). Similarities in PA amongst friends over their first year of high school were found to be explained by friendship selection and influence: adolescents were likely to befriend peers whose attitudes towards PA, and engagement in PA, were similar to their own; and adolescents subsequently emulated their friends’ behaviors so that friends’ participation in PA became increasingly alike. Friends’ influence on PA was not found to be mediated via adolescents’ beliefs about PA, including their perceptions of peer norms, suggesting that this influence process was less internalized than some health behavior theories would suggest (e.g., Ajzen, 1991).

As a whole, the studies presented in this thesis suggest that the clustering of overweight in adolescent friendship networks is initially driven by processes of weight-based friendship selection and the marginalization of overweight adolescents by their peers. Excess weight was not found to be contagious in the short term, and longer studies applying
similar methods are needed. Nonetheless, some obesity-related behaviors were found to cluster in friendship networks, and for PA this was partially explained by adolescents adopting their friends’ behaviors. Friends’ influence on adolescent PA, and potentially other obesity-related behaviors, is a plausible mechanism that could result in the contagion of obesity in the longer-term. Intervening in, and potentially harnessing these social processes, provides a means to foster peer contexts that encourage healthy behaviors and help to reduce young people’s obesity risk in future.
THESIS DECLARATION

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____________________________________________________________

Kayla de la Haye

Signed: __________________________  Date: ____________________
Each and every person in my support network, thank you.

I would also like to gratefully acknowledge the financial support I received from the CSIRO Preventative Health Flagship and the University of Adelaide.
CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time
-T. S. Eliot

Prelude

This thesis examined processes potentially underpinning the reported clustering and “spread” of obesity in social networks (Fowler & Christakis, 2008; Renna, Grafova, & Thakur, 2008; Trogdon, Nonnemaker, & Pais, 2008). The focus was on adolescents, an important age group to target in obesity prevention, and the role of their friends in influencing changes to their weight. A social network perspective was adopted, and new statistical models for networks were applied to determine the extent that overweight clustered amongst adolescent friends in an Australian sample, and whether or not this resulted from friends’ influence on adolescent weight. Secondly, whether obesity-related behaviors also clustered and were transmitted amongst adolescent friends was examined, to determine if this is a potential mechanism driving the contagion of excess weight. It is hoped that these findings can inform future obesity prevention efforts in adolescents, and can contribute to a growing ecological and dynamic system perspective in public health that sees health outcomes as collective and connected phenomena.

This first chapter provides a broad overview of the thesis, and reviews previous findings and theory that established the basis for this research. Recent figures on the state of the “obesity epidemic” are summarized, followed by growing evidence that the social environment plays an important role in the complex system of factors that have caused, and continue to maintain, high rates of obesity in adults and children. This literature provides
evidence that interpersonal influence and larger social systems govern health behaviors and outcomes, such as obesity. The recent application of social network analysis to the study of social influences on obesity and other public health issues is summarized, at which point a general overview of social network analysis theory and methods is given. The study of adolescent obesity through a social network framework has provided many interesting insights into broad social processes that might impact overweight in young people, and it has also stimulated many new questions. The processes by which obesity might spread through a social network are particularly unclear, and addressing this is the key aim of this thesis. This introductory chapter concludes by specifying the main research questions that are addressed in each of the manuscripts that make up the body of this work.

Chapter 2 outlines a number of methodological considerations relevant to testing the research questions, and discusses some of the strengths and limitations of past research methods. The statistical models for social networks applied in this thesis, including the exponential random graph model (ERGM) and stochastic actor-oriented model (SAOM) for longitudinal networks and behavior, are introduced and described. An exegesis follows this in Chapter 3, and includes a broad overview of the main research agenda, and then a brief summary of the aims, methods, and findings from each paper, and the conceptual links between them. This third chapter concludes by bringing together the key findings from each paper, and a brief discussion of some overall conclusions.

Chapter 4 through Chapter 7 comprise of four manuscripts, one that has been published, and three that have been submitted for publication and are currently under review. Each manuscript is preceded by a statement from all authors detailing their contribution to the preparation of the manuscript. Also, as a note to the reader of this thesis, all tables and figures have numbered consecutively within each chapter and
manuscript. The eighth and final chapter provides an overall summary of results from each of the studies, and a discussion of the broad thesis conclusions. The limitations of the project are addressed in this final chapter, as are the practical and theoretical implications of the conclusions, and suggestions for future research. References for all chapters are provided at the end of this thesis and a copy of the published manuscript (Paper 3) is included in the appendix.

The Obesity Epidemic: Prevalence, Consequences, and Causes

Much of the world’s population lives in communities where overweight, a state in which one has excess body fat, is the norm rather than the exception. This phenomenon is commonly referred to as the “obesity epidemic”. In Australia, 68% of males and 55% of females are overweight or obese (Australian Bureau of Statistics, 2009), while in the United States the proportions are slightly higher: 72% of males and 64% of females (Flegal, Carroll, Ogden, & Curtin, 2010). The prevalence of overweight amongst children and adolescents is also concerning; the most recent Australian estimates suggest this figure is between 20% and 25% (Commonwealth Scientific Industrial Research Organisation & University of South Australia, 2008; Olds et al., 2004) while it is upwards of 60% in the U.S. (Ogden, Carroll, Curtin, Lamb, & Flegal, 2010). High rates of overweight and obesity are a relatively recent trend, having increased substantially over the past two to three decades (Popkin, Conde, Hou, & Monteiro, 2006). Although the latest reports suggest that obesity rates in adults and children have plateaued (Flegal, et al., 2010; Olds, Tomkinson, Ferrar, & Maher, 2009), there is yet no evidence of a decline. Thus, suggestions that the “obesity epidemic” is passé appear to be misinformed.

1 In the Australian data, overweight and obesity were defined using internationally validated age and gender specific BMI cut-offs (Cole, Bellizzi, Flegal, & Dietz, 2000), while they were defined in the American data using the 2000 CDC BMI-for-age growth charts (Ogden et al., 2002).
Overweight and obesity are categories that describe varying degrees of excess body fat and can be assessed using a number of anthropometric measures. In population studies they are commonly classified using a measure of body mass index (BMI), a ratio of weight (kg) over height (m²), where excess weight (in relation to height) serves as an indicator of excess fat mass. For adults, overweight is defined as having a BMI of 25.0 to 29.9 and obese as having a BMI of 30.0 or greater, while the classification of overweight and obesity amongst children and adolescents varies with age and gender (Cole, et al., 2000; Ogden, et al., 2002). Although more precise measures of body composition and fat mass are available, BMI is both a useful and practical tool for categorizing adiposity in large samples: it is derived from relatively unobtrusive measures, and is highly correlated with proportion of body fat (Freedman & Sherry, 2009) as well as long-term mortality and secondary complications of obesity (Wyatt, Winters, & Dubbert, 2006).

Excess fat mass is known to have a negative impact on a range of health outcomes, and the ramifications of a high prevalence of overweight and obesity in the population are profound. Obesity is associated with numerous physical ailments, including increased risk for type 2 diabetes, cardiovascular disease, and some cancers (Cameron et al., 2003). Overweight and obesity, particularly early in life, are also associated with long-term psychosocial consequences: lower educational achievement, lower family income, and lower marriage rates (Zametkin, Zoon, Klein, & Munson, 2004). As a result, countries with a high prevalence of obesity incur substantial economic and societal costs; in Australia this was estimated to be 8.3 billion dollars in 2008 alone (Access Economics, 2008). A number of initiatives have sought to address the obesity epidemic via health promotion and education, as well as policy change. Children and adolescents, as well as adults who are overweight or at-risk for overweight, have been the primary targets of these initiatives, with the aim of
reversing current trends and diminishing obesity rates in the future. To ensure that these programs and strategies are effective, they need to be informed by a comprehensive research base which has identified the key factors that contribute to overweight and obesity in the population.

The importance of targeting obesity amongst a younger cohort is made clear in a recent review of the literature by Zametkin et al. (2004), which reports that obese children and adolescents are at increased risk of a number of medical conditions including cardiovascular disease, pulmonary and endocrine problems (associated with the onset of type 2 diabetes mellitus), as well as orthopedic, gastroenterological, and neurological difficulties. More immediate issues threatening the psychological wellbeing of obese children and adolescents include lower self-esteem, higher prevalence of negative body images, and social discrimination, with obese children often rated as the least desirable playmates by school peers. And not only are there a number of adverse physical and mental health issues associated with childhood obesity, being obese or overweight—particularly in adolescence—greatly increases one’s odds of being overweight in early adulthood (Crossman, Anne Sullivan, & Benin, 2006). Because adolescence is a particularly critical time in the formation of lifelong habits when behaviors are still somewhat malleable, understanding the important factors shaping obesity-related behaviors amongst this age cohort provides a mechanism for halting and potentially reversing the trend of rapidly growing waistlines (Jeffery et al., 2000).

*Explanations for the Increasing Prevalence of Obesity*

At the individual level, obesity is influenced by genetic, metabolic, behavioral, and environmental factors (Egger & Swinburn, 1997). Although, in clinical samples of children and adolescents who are overweight or obese, medical conditions (hormonal or genetic)
have been found to account for only 10% of cases (Zametkin, et al., 2004). The rapid increase in the prevalence of this condition at a population level seems to coincide primarily with behavioral and environmental changes that have increased the expression of genetic risk (Wardle, Carnell, Haworth, & Plomin, 2008), and led to increased energy intake and diminished overall energy output in the wider population (Banwell, Hinde, Dixon, & Sibthorpe, 2005).

Young people’s intake of additional energy in recent decades has been attributed to the persistent over-consumption of energy-dense food and drink (Jahns, Siega-Riz, & Popkin, 2001). Dietary patterns characterized as being energy-dense, high-fat, and low-fiber have also been found to predict increased body fat in children (Johnson, Mander, Jones, Emmett, & Jebb, 2008). Greater consumption of particular types of foods seem to account for these dietary shifts, including snack foods (Jahns, et al., 2001), fast food (Bowman, Gortmaker, Ebbeling, Pereira, & Ludwig, 2004), and sweetened drinks (Han, Lawlor, & Kimm, 2010). Despite increased caloric intake, the poor nutrient profile of these energy-dense eating patterns has also led to reduced diet quality (Jahns, et al., 2001).

Compounding this energy imbalance is a reduction in energy output, attributed to declining levels of physical activity and the adoption of more sedentary lifestyles. Physical activity measures show a negative association with obesity, with low levels of physical activity both contributing to, and resulting from excess weight (Cameron, et al., 2003). Although this relationship is circular, physical inactivity independently predicts child obesity risk (Han, et al., 2010) as well as obesity later in life (Pietiläinen et al., 2008). Olds et al. (2004), in a report on activity patterns amongst Australian children and adolescents, found that over the past two decades there has been an overall decline in physical activity resulting in a decrease in aerobic fitness. This was largely caused by a decline in active play and
locomotion: namely physical activities other than organized sport, which comprises a key part of children’s overall energy expenditure, particularly for girls.

As children’s participation in physical activities declined, their leisure time has been increasingly replaced by sedentary activities, contributing to a reduction in daily energy expenditure. In Australian children and adolescents, screen time, which includes time spent watching television and cinema, computing, playing video games, and texting, has been found to be a strong competitor for leisure time (Olds, et al., 2004). This trend is also evident in the U.S. where the average child watches three to five hours of television daily, with 67% of children watching at least two hours a day (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; Zametkin, et al., 2004). Research also suggests that there is a strong relationship between screen time, physical activity, and propensity for obesity: children who watch more television are less likely to do vigorous physical activity and are likely to have higher BMIs (Andersen, et al., 1998). In an experimental study, reducing screen time resulted in a significant decrease in BMI compared to a control group of children (Zametkin, et al., 2004).

Based on findings such as these, many health promotion initiatives have sought to change behavioral patterns in the population, especially amongst children, by encouraging healthy dietary change and/or increased physical activity. There has been a strong focus on changing individual behavior through public health messages and education, although there is growing recognition that the obesogenic environments in which individuals are situated also need to be addressed. Food consumption and physical activity and inactivity, like many health behaviors, are influenced by individual drivers such as attitudes and beliefs as well as a range of external factors present in the vast range of settings in which these behaviors occur. Egger and Swinburn’s ecological model of obesity (1997) proposes that both physical
and socio-cultural environments can be obesogenic, or obesity promoting, and influential on individual behaviors. Researchers have identified many aspects of the physical environment that encourage sedentary behavior and over-consumption of energy-dense foods, and there is growing recognition that the norms, values, and assumptions entrenched in one’s social environment, at both a macro level (e.g., culture and communities) as well as a more micro level (e.g., family and peers), can also be obesogenic (Banwell, et al., 2005).

**Obesity in a Social Context: Social Influence on Weight and Weight-Related Behaviors**

Given the social nature of both physical activity and food consumption, the mounting evidence that socio-cultural factors influence obesity-related behaviors is not unexpected (Banwell et al., 2005). From a social-psychological perspective, health behaviors are seen to be established and maintained in the context of the social environment and social norms: they “are not necessarily deep-rooted personality traits but rather reflect the social milieu in which one interacts” (Boardman, Saint Onge, Rogers, & Denney, 2005, p. 238). Numerous theories put forth to explain the mechanisms through which social factors influence individual behavior propose that both direct processes (e.g., imitation) and more indirect processes (e.g., internalization of group norms and attitudes) can be influential. For example, social learning theory (Bandura, 1977) emphasizes how behaviors are modeled and reinforced by significant others. The theory of planned behavior (Ajzen, 1991), commonly employed to predict health behaviors, focuses on perceptions of behavioral norms as a pathway through which others influence our intentions and subsequent behavior. And social identity theory has emphasized how group membership, and motivations to establish in-group similarities and out-group differences, can drive behavior (Tajfel, 1982). Although the proposed mechanisms may differ, theories of social influence universally recognize
interpersonal interactions as a key conduit through which the social environment shapes behavior.

Evidence of group-level differences in the prevalence of obesity, including ethnic, socio-economic, and neighborhood effects, highlights the potential importance of social factors and social influence on weight-related health behaviors. Some research suggests that behaviors are influenced indirectly, via perceptions of weight norms (Hammond, In press). For example, Boardman and colleagues (2005) found moderate neighborhood-level effects whereby individuals living in neighborhoods with high levels of obesity were significantly more likely to become obese. They suggest that the experience of living in communities where obesity is the norm could “minimize the social costs associated with being obese” (p. 238). In the United States, there is also evidence that weight norms, measured as “desired weight”, have increased as the population has gained weight (Burke & Heiland, 2007). A social environment characterized by a greater proportion of overweight friends, family, and co-workers, could shift individuals’ perceptions of weight norms, impacting their future weight management and regulation of behaviors such as eating and exercise.

Interesting findings have also emerged from research into the direct impact of the social environment on specific obesity-related behaviors. A review of the literature on food consumption clearly indicates that social influence on individual eating behavior is pervasive and complex (Feunekes, de Graaf, Meyboom, & van Staveren, 1998; Hammond, In press; Herman & Polivy, 2005). An individual’s food consumption significantly increases when in the presence of others (de Castro, 1990), however the nature of the relationship with those present also has an effect on this influence (de Castro, 1994; Feunekes, et al., 1998).
Research also suggests that social groups influence our attitudes towards and beliefs about eating (Balaam & Haslam, 1998).

A review of the physical activity literature, by McNeill, Kreuter, and Subramanian (2006), indicates that several dimensions of the social environment, including social networks, social cohesion, and neighborhood effects, play an important role in energy expending behavior. They highlight evidence that social support interventions, such as “buddy systems” and group-based activities, increase the time and frequency of physical activity. The authors also report that increased social contact and support from family positively impacts individual physical activity levels.

Social Influence on Adolescent Health Behaviors

Young people’s health behaviors are likely to be influenced by a range of family, peer, and community contexts (Williams, Holmbeck, & Greenley, 2002), however as adolescents spend increasing time with friends and place greater value on these relationships (Peterson, 1989), the potential for peer influence on the development of beliefs and behaviors is heightened. The Sullivan-Piaget thesis was one of the first formal theories recognizing the importance of peer relations, and particularly relationships with same-age friends, as a major force driving children’s social development and learning (Youniss, 1980). That adolescent behavior is to some extent determined by the norms and behaviors of their peers is now assumed in many development and learning theories, including social learning theory, primary socialization theory, and social identity theory (Kobus, 2003). Peers are seen to provide adolescents with behavioral models and norms, access to information and opportunities, as well as feedback on their actions. Particularly in the early stages of adolescence, behaviors are often motivated by a desire to conform to perceived peer expectations (Berndt, 1979). There is strong evidence that peers have an impact on the
development and maintenance of adolescent health behaviors, however studies have largely focused on risky behaviors such as smoking, alcohol, and drug use (Duan, Chou, Andreeva, & Pentz, 2009; Hoffman, Sussman, Unger, & Valente, 2006; Korhonen et al., 2008). Research exploring the importance of peers on behaviors related to overweight and obesity is lacking, although findings from the few studies broaching this issue suggest that it is a topic worthy of further research.

Although adolescents’ diets are strongly governed by their family food environment, about half of their consumption of low-nutrient, energy-dense foods occurs out of home (Briefel, Wilson, & Gleason, 2009). Adolescent reports confirm that lunches and snacks are often eaten with friends, and that friends discuss food somewhat regularly (Feunekes, et al., 1998). Consumption of snack foods and alcohol, as well as overall energy intake, have been found to correlate with the intake of an adolescents’ best friends (Feunekes, et al., 1998). Lab-based studies have also indicated that young people match the food intake of friends more so than unfamiliar peers (Salvy, Howard, Read, & Mele, 2009). Furthermore, in studies of disordered eating adolescent friends have been found to share similar dieting practices, extreme weight loss behaviors, and binge eating behaviors (Hutchinson & Rapee, 2007). Researchers have proposed that similarities in eating practices amongst friends result from peer influence (Monge-Rojas, Nunez, Garita, & Chen-Mok, 2002), and are also motivated by goals for peer approval (Unger et al., 2004). For example, seeking peer acceptance has been put forward as an explanation for the association between acculturation to American norms with higher frequency of fast-food consumption and lower levels of physical activity amongst Hispanic and Asian-American youth (Unger, et al., 2004).

Research suggests that peers also influence young people’s physical and leisure activities. In a study from the Australian Sports Commission (Olds, et al., 2004), cluster
analysis identified distinct activity patterns amongst groups of children, including “techno active” (high screen time) and “female socializers”, although no relational data were available to explore friendships within these groups. In this same study, children most commonly reported in interviews that their involvement in sporting activities would be facilitated by the ability to play with friends, with girls indicating that socializing was their main motivation for participation in sports. Social support has also been found to be positively related to physical activity, with support from friends (as compared to parents or siblings) being the strongest predictor of higher levels of physical activity (Duncan, Duncan, & Strycker, 2005). Although male adolescents are more likely to report having physically active friends (Leatherdale & Wong, 2008), girls’ participation in physical activities has been found to be predicted by having close friends who are active (Voorhees et al., 2005). When considering a range of individual and contextual factors, Voorhees and colleagues found that the main predictor of girls’ activity levels was the perceived frequency of physical activity of their three closest friends. As causality is inconclusive, because highly active girls may be selecting friends who are also highly active, further study is warranted.

Evidence of peer influence on sedentary leisure activities is sparse, with studies having predominantly focused on Internet use. The prevalence of Internet usage amongst children and adolescents has increased immensely over the past decade, not only for information seeking but increasingly for online socialization and communication, typically with peers (Eastin, 2005). It is therefore not surprising that adolescents’ perceptions of their peers’ Internet use has been found to predict self-efficacy and usage (Eastin, 2005). Overall screen time, including TV watching, Internet use, and video gaming has also been found to be lower amongst adolescents who report that their close friends are physically active (Leatherdale & Wong, 2008). Because young people’s screen-use, physical activity, and
dietary practices are correlated (Gorely, Marshall, & Biddle, 2004), peer influence on one activity may have consequences for other behaviors. It will therefore be important to simultaneously consider peer effects on a range of obesity-related behaviors in future research.

Overall these findings indicate that there is an important relationship between adolescents’ friendships and their engagement in obesity-related behaviors. However, drawing firm conclusions about the processes driving these effects is limited by a number of factors, especially the prominence of cross-sectional study designs. Additionally, only a small number of papers have looked explicitly at the influence of friends’ behaviors on adolescent behavior, with many of these having relied on participant reports of their friends’ activities rather than self-report. Studies of peer influence on smoking have found adolescents’ estimates of their friends’ smoking behavior to be biased, resulting in peer similarities to be overestimated (Kobus, 2003). The interpretation of causal mechanisms has also been hindered by limitations of the methods used to study interpersonal influence. This issue will be discussed in greater detail in subsequent sections of the literature review and in the following methods chapter (Chapter 2). These critiques have prompted calls to refine peer influence research, and have encouraged researchers to adopt novel and more sophisticated methods. The growing use of social network analysis for this purpose, and advantages of this approach, will be the topic of the subsequent section.

**Social Influence via Interpersonal Relations and the Study of Social Networks**

The body of research summarized above highlights the important role of the social environment, be that family, peers, or larger social and cultural groups, in promoting or inhibiting obesity and related health behaviors. It is also evident that social influence occurs to a large extent in the context of interpersonal relations. The adoption of a social network
framework—a set of theories and tools to study relational phenomena—has therefore been a natural progression for researchers in this field. Social network methods provide tools for the analysis of social relations, and most importantly how patterns of relationships among social entities (e.g., individuals) within a defined social system impact individual and more global outcomes (Hanneman & Riddle, 1995; Wasserman & Faust, 1994). Although the origins of social network analysis date back several decades, its application to the study of health is relatively new, and its application to the study of obesity has only begun. Before discussing the findings of this recent research by Christakis, Fowler, and others, who have examined obesity in the context of large social networks, additional background on the theory, methods, and applications of social network analysis will be outlined.

*The Social Network Paradigm: Background, Theory and Methods*

The origins of the social network perspective are multi-disciplinary, having been driven by concepts within social psychology, sociology, anthropology, physics, and mathematics, particularly graph theory, statistical and probability theory, and algebraic models (Wasserman & Faust, 1994). The study of social networks seeks to gain an understanding of the social system as a whole through the coalitions and relations amongst its components. These relationships (referred to as ties) between social entities (such as individuals or organizations) can represent any affiliation of interest: close friendship, acquaintance, marriage, group co-membership, monetary transactions, communication, etc. How these ties emerge and evolve into larger networks, and the social processes shaping and being shaped by these complex social structures, is often the focus of empirical research.

It is useful to contrast how social network theory and methods differ from other research approaches. Firstly, individuals (commonly referred to as actors), being located
within a social network, are understood to be *interdependent* rather than independent and autonomous. The focus is therefore not on the individual as the unit of analysis but rather on “an entity consisting of a collection of individuals and the linkages among them” (Wasserman & Faust, 1994, p. 5). This perspective is also based upon assumptions that individuals within networks interact with each other, and that these interactions are significant to those involved. Social scientists have long believed that social networks influence both individuals and groups (Borgatti, Mehra, Brass, & Labianca, 2009; Watts, 2004), with ties conceptualized as potential avenues through which information, ideas, or resources can flow, providing opportunities for, or constraints against, individual actions. Social network theorists also emphasize the importance of actors’ positions in the global network; individuals’ attitudes, perceptions, and behaviors are influenced not only by their immediate connections, but also based on where they are situated in the larger social system (Friedkin, 1998).

Empirical analysis of social networks involves measurement of both actors and their ties within the network of interest. This means that participants not only report on their own attributes, but also on their relationships with others. Sociometric measures are typically used to quantify relationships, whereby participants identify who they share a relationship with by naming them or identifying them on a roster. The quality or strength of a relationship might also be assessed using rating scales. Researchers must determine which actors as well as which ties to sample, with differing strategies resulting in different aspects of social networks being revealed. *Complete* network designs ideally require that information is collected about each actor’s ties with all other actors in the network, thereby taking a *census* of the network of interest and giving a complete picture of relations in the defined population. The resulting network data is typically represented as an adjacency
matrix (also referred to as a sociomatrix) or as a network graph (Figure 1). This complete network approach allows for powerful descriptions of social structures and analyses of network hypotheses.

Figure 1. An adjacency matrix and the corresponding non-directed network graph. In the matrix, ties between actors are coded as 1, and in the graph, nodes represent actors and lines represent a tie between two nodes (i.e., the presence of a relationship).

The analysis of network data can be descriptive or inferential. There are a number of techniques to measure and describe specific network structures (i.e., particular patterns or configuration of ties), enabling a more formal understanding of the key features of our social environments (Carrington, Scott, & Wasserman, 2006). Network structures can be described at a global or local level, with reference to the network as a whole or location of actors within it (Wasserman & Faust, 1994). Some of the descriptive measures that are often of theoretical interest are summarized in Table 1.

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2 As a note to the reader, all figures, tables, and footnotes are numbered consecutively within each chapter of this thesis.

3 Matrices and graphs can represent directed or non-directed relationships. A directed network graph uses arrow heads to indicate the direction of the relationship between two nodes (e.g., if i nominates j as a friend, the arrow points from i to j). A non-directed graph does not specify relationship direction.
Table 1. Summary of Descriptive Network Measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-degree</td>
<td>The sum of directed ties that are received by an actor.</td>
</tr>
<tr>
<td>Out-degree</td>
<td>The sum of directed ties that an actor sends to other nodes.</td>
</tr>
<tr>
<td>Geodesic</td>
<td>The shortest path (sequence of ties) that connects two actors.</td>
</tr>
<tr>
<td>Centrality</td>
<td>The extent to which an actor is central in the network, based on their direct and indirect ties. This is often evaluated based on an actor’s in-degree, and the extent to which they are connected to other high-degree nodes.</td>
</tr>
<tr>
<td>Size</td>
<td>The number of actors in a network.</td>
</tr>
<tr>
<td>Density</td>
<td>A measure of the actual number of ties as a proportion of total possible ties in the network.</td>
</tr>
<tr>
<td>Reciprocity</td>
<td>The proportion of directed ties in the network that are reciprocated.</td>
</tr>
<tr>
<td>Degree distribution</td>
<td>The distribution of in-degrees or out-degrees across all actors in the network.</td>
</tr>
<tr>
<td>Clustering</td>
<td>Measures of local closeness, called clustering coefficients, based on the densities of actors’ local neighborhoods.</td>
</tr>
<tr>
<td>Transitivity</td>
<td>The proportion of 2-path relations (where ties exist between i and j, and j and k) that form triads (where ties exist between i and j, j and k, and i and k).</td>
</tr>
<tr>
<td>Cliques</td>
<td>Subgroups of densely connected nodes, identified based on degree (i.e., high density) or based on reachability (i.e., short path lengths).</td>
</tr>
</tbody>
</table>

Moreover, social network analysis goes beyond the description of network structures, and provides statistical methods to test network theories. These probabilistic network models enable the researcher to estimate parameters that represent particular patterns or configurations of ties that might be observed in the graph, and that reflect various social processes. Because this modeling approach assumes that the formation of ties is not only shaped by actors, but also by structural processes, model parameters can be specified for structural and actor-level effects. Structural effects reflect the self-organizing nature of social networks, whereby the likelihood of a relationship between two actors is dependent on the relationships that surround them (Robins & Pattison, 2005). For example, actors are often more likely to have a social connection, such as friendship, if they share a
common friend (a process referred to as transitivity) (e.g., Burk, Steglich, & Snijders, 2007). Relationships between pairs of individuals are therefore not assumed to be independent of one another; rather the complex dependencies between dyads can be explicitly modeled.

The structure of social networks is also assumed to be impacted by the attributes of the actors. Individuals may seek relational partners with particular characteristics, so that ties are more likely to form between certain dyads and actors’ characteristics, to some extent, may determine their social status and position in the network. Moreover, actors’ attributes could be influenced by their relationships or by their position in the network. The tie configurations that arise from these types of interactions between actor-level variables and relational structures are specified as actor-attribute effects in the models. Statistical inferences regarding which structural and actor-attribute effects were most likely to have generated the observed network can therefore be made (Robins, Pattison, Kalish, & Lusher, 2007). For cross-sectional data, where there is a single observation of the network, the exponential random graph model (ERGM) can be applied. For longitudinal data, where multiple observations of the network are made, stochastic actor-oriented models (SAOMs) for social networks are appropriate. Both models will be described in greater detail in the following chapter (Chapter 2).

Overall, these social network models and broader theoretical framework are well suited to test hypotheses about the relationships between social ties and individual-level attributes such as health outcomes or behaviors. In particular, this approach allows us to explore the impact of inter-personal processes, such as social influence, in broader social structures. Because the network perspective assumes that relationships, or ties in a network, are interdependent, traditional statistical models that assume data are independent are not appropriate. Therefore, statistical models for social networks that
account for complex dependencies have been developed, and allow researchers to test hypotheses about social and structural processes shaping the networks they observe. As summarized by Wasserman and Faust (1994), the social network paradigm “provides a precise way to define important social concepts, a theoretical alternative to the assumption of independent social actors, and a framework for testing theories about structured social relationships” (p. 17).

Social Network Analysis: Applications in Public Health

Social network analysis has been increasingly applied in the field of public health and health psychology to understand how relational factors impact health outcomes and behavior, over and above individual-level effects. This has been spurred by critiques that models of health behavior and behavior change underestimate the importance of inter-individual factors (e.g., Bond, Valente, & Kendall, 1999), and an awareness that studying one aspect of the social environment, such as relationships between independent pairs of individuals, does not capture processes occurring at a macro level (Smith & Christakis, 2008). As emphasized by Gestalt theory, there are emergent properties at the level of the network, with the whole being greater than the sum of its parts.

The adoption of a social network perspective in this field has resulted in a growing literature outlining how relationships, and the properties of these relational structures, are associated with health outcomes (Smith & Christakis, 2008). A common phenomenon observed in empirical social networks is assortativity, or network autocorrelation, where individuals who are connected (i.e., share a relationship) tend to be more alike on an attribute than individuals who are not directly connected. For example, adolescent friends have been found to be similar on a number of health risk behaviors, including smoking (Mercken, Snijders, Steglich, Vartiainen, & de Vries, 2010) and drug use (Bauman & Ennett,
Health outcomes have also been associated with local and global features of network structure, including the density or sparseness of social ties, and the extent to which relationships cluster into tight-knit social groups. In sexual contact networks, the extent that relationships cluster and form “hubs” has been found to impact the rate of disease transmission (Smith & Christakis, 2008). Individuals’ location in their social network has also been associated with their health. Social isolation has been found to be a key factor predicting mortality risk (Holt-Lunstad, Smith, & Layton, 2010), and social positions that are central versus peripheral in the network are associated with both health risks and health benefits (Valente, 2010).

Public health researchers are especially interested in the processes underpinning associations between network structures and health, and in particular how health-related behaviors, information, and phenomena spread through social ties. Much of the early work in this area utilized diffusion of information and social contagion models to determine how behaviors are adopted or changed via network influence, as well as how this process of behavior change can be influenced or accelerated to improve public health. These models are premised on the notion that individual decision making is influenced by the behavior and opinions of others, and that “the aggregation of individual to collective decision making can be understood in terms of social contagion, where decisions are ‘transmitted’ from one individual to another in a manner reminiscent of disease” (Watts, 2004, p. 260). One of the first studies applying this theory to health phenomena was by Coleman and colleagues (Coleman, Katz, & Menzel, 1957), who examined communication networks amongst physicians. The authors found that discussions amongst colleagues impacted their adoption of a new drug, facilitating the diffusion of this practice through these informal networks. Subsequent studies have also explored social contagion under a number of different
structural conditions, and the effect of these on the speed and efficacy of information or behavior transmission (Watts, 2004).

In a recent review of the literature, Smith and Christakis (2008) emphasized that social connections influence our health through a number of mechanisms, not only via the transmission of health-related resources and information. Social networks are also sources of perceived and actual social support, and are contexts for social influence on health behaviors via shared norms, behavior modeling, and social control. However, despite evidence that social network characteristics are relevant to a number of health outcomes and health behaviors, there continues to be a limited understanding of the biological and psychological pathways underpinning these effects. What is clear is that these social influence processes are likely to be complex, dynamic, and responsive to local contextual and environmental factors. A research agenda seeking to build a more rigorous knowledge base of how these specific mechanisms and processes impact different aspects of health will have important theoretical and practical implications.

Although social factors are known to influence obesity rates as well as related health behaviors, it is only in the past few years that social network methods have been applied to study inter-personal effects on obesity risk. Researchers have begun by establishing associations between obesity and the structure of relationships in social networks; however the processes underpinning these associations again remain under-researched. The subsequent section outlines findings from these studies, the conclusions that have been drawn, and the questions that arise for future investigations.

The Application of Social Network Analysis to the Study of Obesity

One of the first papers to investigate obesity longitudinally in the context of a large social network (Christakis & Fowler, 2007) was published in the New England Journal of
Medicine, garnering a great deal of media attention (e.g., Kolata, 2007). Using individual and relational data collected from over 12,000 adult participants in the Framingham Heart Study, the authors found that obesity tended to cluster in this large social network as a result of a “person-to-person spread of obesity”. Over the 30 years of the study, an individual’s chances of becoming obese increased if they were socially connected to someone who was obese. The authors argued that this effect was strongest amongst friends, where an individual’s chances of becoming obese increased by 57% if they had a friend who was obese, compared to siblings and spouses (40% and 37% increased risk respectively), although the confidence intervals for these effects did overlap. The risk of becoming obese was also stronger when the obese friend or sibling was the same gender as the individual. Having controlled for initial similarities using a time-lagged measure of obesity, the authors claimed that these findings were evidence that excess weight in close social ties, particularly friends, could cause individuals to gain excess weight.

In the same paper, Christakis and Fowler (2007) also reported that the contagion of obesity spread beyond dyadic ties: an individual’s risk of becoming obese was not only influenced by the weight status of their friend (one degree of separation), but also by the weight status of their friend’s friend (two degrees of separation), and their friend’s friend’s friend (three degrees of separation). However, there are some methodological limitations to consider when interpreting these “hyper-dyadic” contagion effects. First, because a census approach was not used to collect the relational data (only one or two friendship ties were recorded for each actor, as opposed to a census of all ties), it is plausible that the extent of clustering and transitivity within this network was underestimated. As illustrated in Table 2, what appears to be a “hyper-dyadic” contagion effect, where an individual is more likely to
become obese when their friend’s friend is obese, may actually be a consequence of missing information of a friendship between the individual, and the friend of their friend.

Table 2. Interpretation of Dyadic and Hyper-dyadic Contagion Effects with Missing versus Complete Relational Data

<table>
<thead>
<tr>
<th>Contagion effect</th>
<th>Time 1</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missing relational data:</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Contagion of obesity from a friend’s friend (two-degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete relational data:</td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Contagion of obesity from a direct friend (one-degree)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* White nodes represent non-obese individuals, and black nodes represent obese individuals. Ties between nodes represent friendship nominations.

A further methodological issue related to network structures beyond the level of a dyad, is the application of logistic regression models to make statistical inferences about network effects. As outlined earlier in the introduction to social network theory and methods, there are complex structural dependencies inherent in social networks (Robins, Pattison, et al., 2007): a relationship between two individuals, such as friendship, is likely to be dependent on the presence (or absence) of friendship ties between other actors in the network. In particular, transitivity—where actors become friends because they share a common friend—is a process driven by the network structure that explains the formation of friendship triads. The use of statistical models that assume dyadic independence is clearly not appropriate when dyads embedded in a network are likely to be highly dependent. Not accounting for these structural processes in the initial formation of friendship ties and thus structuring of the overall network, means that the processes causing similarities and
clustering of obesity amongst friends, including contagion effects, are not well specified in
the model. The implications of not explicitly modeling structural processes, and the
potential of statistical models for social networks to overcome these issues, will be discussed
in greater detail in the subsequent methods chapter (Chapter 2).

Obesity in Adolescent Social Networks

Despite the limitations of the Christakis and Fowler study, there are a number of
intriguing effects that warrant further investigation. At the very least, their findings suggest
that obesity clusters amongst socially connected adults, possibly as a result of a social
contagion process. Whether obesity clusters and spreads in the social networks of young
people, who are a primary target for obesity-prevention initiatives, has been the focus of
subsequent research. Most of these studies have sought to determine if adolescents’
weight status is influenced by the weight status of their friends, using data from the
National Longitudinal Adolescent Health Survey (Add Health) (Cohen-Cole & Fletcher, 2008b;
Fowler & Christakis, 2008; Halliday & Kwak, 2009; Renna, et al., 2008; Trogdon, et al., 2008).
In a large subsample of the Add Health cohort, self-reported information on school-based
friendships, height, and weight were collected over two waves (12 to 16 months apart) from
participants in grades 7 through 12. Importantly, the sociometric measures were more
complete than those used in the Framingham Heart Study: adolescents could name up to 5
male and 5 female friends as opposed to the one or two friendships recorded in the
Framingham data. As a result, the Add Health data are likely to provide a more realistic
representation of triads and clustering in the friendship network.

Overall, these studies found that adolescents’ BMIs were similar to the BMIs of their
nominated friends (Halliday & Kwak, 2009; Trogdon, et al., 2008) and that adolescents with
obese friends were more likely to be obese (Fowler & Christakis, 2008). However, authors
have used different analytical methods and assumptions and so have come to differing conclusions regarding the processes underpinning these effects. Some analyses pointed to evidence of obesity contagion, where having a friend with excess weight was found to result in weight gain in the adolescent (Fowler & Christakis, 2008; Renna, et al., 2008; Trogdon, et al., 2008). Females and adolescents with higher BMIs were found to be the most susceptible to this contagion effect (Renna, et al., 2008; Trogdon, et al., 2008), as were same-sex friends (Renna, et al., 2008). Moreover, the effect was directional so that adolescents’ BMIs were only influenced by the friends that they had nominated, not by peers who had nominated them as a friend (Fowler & Christakis, 2008). However, other authors have found that the observed similarities in BMI amongst friends were better explained by adolescents forming friendships with peers whose weight was similar to their own (referred to as selection effects), and because of shared contexts that resulted in parallel weight gain amongst friends within a school (referred to as confounding effects) (Cohen-Cole & Fletcher, 2008b; Halliday & Kwak, 2009). Unfortunately, the statistical methods employed in these studies also assumed dyadic independence; therefore the potential confounding influence of structural effects was not accounted for in the models.

An additional study by Valente and colleagues (Valente, Fujimoto, Chou, & Spruijt-Metz, 2009) used social network methods to look at associations between weight status and friendships in another sample of American adolescents. The results confirmed that overweight adolescents tended to have overweight friends, and logistic regression models showed that friends’ average BMI was positively associated with an increased risk of overweight in adolescents. Importantly, the authors also tested friend similarities in weight status using ERGMs: statistical models for social networks that account for structural effects.
The ERGM results supported the initial findings that adolescent friends were significantly alike in weight status.

What is evident from this series of studies is that obesity is not randomly distributed in the population but tends to cluster in friendship networks of adolescents and adults: findings that provide an impactful and novel perspective on inter-individual factors associated with overweight. Although this suggests that friends may influence adolescents’ weight, the processes that lead to this clustering are unclear. Friendship selection, social influence, and other confounding effects (including structural effects) have been put forward as plausible explanations, and further research is needed to assess the extent to which each of these processes explains the observed associations. Additionally, if similarities in weight status amongst adolescent friends are explained by social contagion, exactly what is being transmitted through these social ties remains unexplained. These questions are the primary focus of this thesis.

Potential Mechanisms Underpinning the Clustering of Obesity

The peer environment is clearly an important context to address in strategies seeking to reduce and prevent adolescent obesity. Adolescent friends are alike in the extent to which they have excess body fat, resulting in the clustering of obesity in larger social networks. There are several competing explanations for these observed similarities in weight that are supported by substantial empirical research and that need to be accounted for in future studies.

Social contagion and social influence. Similarities in weight status and BMI amongst adolescent friends could result from contagion effects, where having a friend who is overweight causes an individual to gain weight. Evidence of a contagion effect implies that there is something being transmitted via these friendships, such as information, social
support, or social norms. Christakis and Fowler (2007) argued that it was shared weight norms that were being transmitted within adult friendship networks rather than shared behaviors, because friends’ geographic distance had no impact on the reported effect. Adults who had an obese friend were at a 57% increased risk of becoming obese, however an obese friend living thousands of miles away impacted someone’s risk of becoming obese as much as a friend living next door. If the transmission of similar behaviors was driving the effect, one would expect that geographic proximity might facilitate this influence process.

Amongst adolescents, friends may also be important referents for weight norms, however the literature reviewed earlier provides strong evidence that friends directly influence many health behaviors, including those associated with energy intake and expenditure. The transmission of similar obesity-related behaviors between adolescent friends as a result of social influence is a plausible mechanism that could cause obesity to spread in wider friendship networks.

**Friendship selection.** Social scientists have long noted that social groups, especially young people’s peer groups, are fairly homogenous because individuals tend to have friends with similar attributes to themselves: a phenomenon labeled “homophily” (Cohen, 1977; Kandel, 1978). Studies have found adolescent peers to be homophilic on a number of attributes, including demographics, behavior, values, attitudes and beliefs (McPherson, Smith-Lovin, & Cook, 2001). In the past, researchers frequently assumed that peer similarity was a result of social influence, however homophily has often been found to be a product of a complex interaction of friendship selection and dissolution, and processes of socialization. In a review of this literature, Ryan (2001) suggested that the “sharing of certain characteristics contributes to friendship formation, and this similarity is strengthened further by continued association” (p. 1137).
The role of obesity in the formation of young people’s friendships has been well established. Weight-based stigma, defined as negative attitudes and beliefs about people with excess weight, is prominent amongst children and adolescents (Latner & Stunkard, 2003). This stigma manifests in numerous ways, but has an especially strong impact on the friendships of overweight youth. Studies measuring friendship nominations in groups of adolescents have found that overweight youth are less likely to be named as a friend compared to their nonoverweight peers (Crosnoe, Frank, & Muener, 2008; Valente, et al., 2009). Overweight youth also tend to befriend each other, perhaps because initiating friendships with nonoverweight peers has been unsuccessful (Crosnoe, et al., 2008; Valente, et al., 2009). As a result of these dyadic processes, overweight children tend to be marginalized in their peer groups, and occupy peripheral positions in larger friendship networks (Strauss & Pollack, 2003). Weight-based friendship selection therefore impacts the overall structure of larger friendship networks, and the distribution of obesity within. Studies seeking to explain the clustering of obesity amongst adolescent friends need to adequately account for these processes.

Confounding influences. Similarities in weight status amongst friends could also be explained by shared demographic, social, and environmental factors. For example, the health behaviors of students in the same school may be similarly affected by policies and resources, impacting students’ likelihood of gaining excess weight. Because friendships in large populations of adolescents tend to cluster within schools, these shared contexts may explain similarities in BMI amongst friends (Cohen-Cole & Fletcher, 2008b). Not only can confounding influences explain friends’ parallel weight changes, they might also explain initial friendship choices. Adolescent friendships are more likely to be established between peers who share similar attributes such as gender, ethnicity, and socio-economic status.
Because these individual-level variables have also been associated with obesity risk (Ogden, et al., 2010), homophilic friendship selection could also contribute to parallel changes in weight amongst friends. For example, if male adolescents are more likely to befriend each other and males have a greater risk of gaining excess weight, these selection processes could contribute to friend similarities in BMI. Thus, to adequately assess causal mechanisms for the clustering of obesity in social networks, future studies need to control for confounding influences on weight status and friendship choices, in addition to testing weight-related friendship selection and contagion.

**Aims of the Thesis**

The research summarized in this chapter emphasizes the need for interventions that encourage young people to be physically active and reduce their consumption of energy-dense foods, so that they develop and maintain healthy habits that will reduce their risk of obesity now and in future. The peer context is clearly relevant to this objective. Adolescents’ friends appear to be an important source of influence on behaviors associated with obesity (e.g., Duncan, et al., 2005; Leatherdale & Wong, 2008; Salvy, et al., 2009; Unger, et al., 2004), and may also be important referents for weight norms (Burke & Heiland, 2007). Additionally, friends tend to be alike in the extent that they have excess weight (Valente, et al., 2009), although the processes causing this similarity are not clear.

The application of social network methods to the study of obesity has provided some insight into how these interpersonal processes play out in larger social structures. Similarities in BMI and weight status amongst adolescent friends result in the clustering of obesity in large friendship networks. Researchers have proposed that this clustering is driven by a contagion effect (Fowler & Christakis, 2008; Renna, et al., 2008; Trogdon, et al., 2008), where obesity spreads from one friend to another, implying that the diffusion of
obesity through social ties has facilitated the rapid increase of obesity rates in the population. However, there are other competing processes that could lead to weight-related similarities amongst friends, including friendship selection based on weight status, and confounding influences on friendships and BMI. To determine if obesity diffuses through adolescent friendship networks, longitudinal research that measures change in friendships and weight is needed to assess the relative contribution of each of these processes to the clustering of obesity. Therefore, the first aim of this thesis is to determine if similarities in weight status and BMI amongst adolescent friends, in the context of evolving friendship networks, are explained by weight-based friendship selection, or the contagion of excess weight, or both.

The second focus of this thesis is to examine the processes that could be underpinning a person-to-person spread of obesity. There is a strong literature base indicating that behaviors associated with obesity are likely to be directly influenced by social ties, and that peers may be particularly influential in adolescent health behaviors. Friends may share similar eating patterns, exercise behaviors, and sedentary leisure activities and influence changes to these behaviors in each other over time. The diffusion of these behaviors amongst friends is a plausible mechanism that could be driving the spread of obesity in adolescent peer networks. This thesis will seek to determine if adolescent friends are similar on a range of obesity-related behaviors, and whether behavioral similarities amongst friends, in the context of friendship networks, are explained by processes of social influence.
CHAPTER 2. METHODOLOGICAL CONSIDERATIONS AND STATISTICAL MODELS

The primary aim of this thesis is to investigate the social processes underpinning the clustering of obesity in adolescent friendship networks, to determine if obesity “spreads” amongst adolescent friends. The second aim is to examine obesity-related behaviors in adolescent friendship networks to see if friends share similar behaviors, and if peer influence on these behaviors is a process that could be underpinning the reported contagion of obesity.

A social network framework will be applied to test these research questions so that these interpersonal processes can be examined in the context of larger social systems. Social network analysis and newly developed statistical models for social networks are well suited to this aim because they allow us to test network hypotheses using models that account for complex dependencies amongst social ties. Associations between network structures and individual attributes, such as weight status, can be tested using exponential random graph models (ERGM) (Robins, Pattison, Kalish, & Lusher, 2007). Teasing out the causal process that underpin these associations, including processes of selection and influence, can be achieved with stochastic actor-oriented models (SAOM) for longitudinal network data (Snijders, Steglich, & Schweinberger., 2007). A description of these models and how they will be applied to examine the research questions will be outlined in this chapter.

Although there are a handful of studies that have looked at obesity in social networks, and in particular the friendship networks of adolescents, limitations in their design and analytic approach have restricted the conclusions that can be drawn. These methodological considerations will be discussed in more detail throughout this chapter, and will inform the design of the studies in this thesis. Social network theory and analysis has
also been successfully applied in studies of peer influence on risk behaviors in adolescents, particularly smoking and substance use, and this literature provides many useful methodological insights. In particular, strategies for measuring complete friendship networks of young people have been well-developed by these researchers.

Overall, this chapter will summarize some of the key methodological considerations relevant to the research aims of this thesis, including study design, methods of data collection, and analytic approaches. The chapter will conclude by describing the statistical network models that will be used to test the thesis hypotheses, including their assumptions and limitations, as well as their advantages over traditional statistical frameworks.

**Methodological Considerations for the Study of Adolescent Friendship Networks**

*The Sampling and Measurement of Adolescent Attributes and Friendships*

Investigating social contagion effects on individual outcomes such as obesity and health behaviors requires information on the attributes of participants (called *egos*), and information on the attributes of their social partners (called *alters*). Researchers have gone about this in two ways: by having study participants report on their own characteristics and on the characteristics of their alters (who are not study participants), and secondly by recruiting individuals and their alters into the study and having them each report on their own characteristics. There are a number of issues to consider with regards to these sampling and data measurement approaches when studying friendships amongst young people and their role in contagion.

*Perceived versus actual reports.* As highlighted in Chapter 1, many peer influence studies have been based on *perceived reports* in which adolescents describe the characteristics or behaviors of their friends (e.g., how frequently their friends do physical
activity. These perceived reports have been used to assess whether friends share similar behaviors or attributes or to determine if friends’ attributes predict changes to participant outcomes (i.e., contagion processes). Although this method facilitates data collection, particularly for large groups of peers, several authors have questioned the validity of this practice (Bauman & Ennett, 1996; Ryan, 2001). Studies have found that adolescents perceive their friends to be more similar to them than they actually are (Ryan, 2001), and that adolescents project their own behavior onto their peers (Bauman & Ennett, 1996). Therefore, perceived reports are more appropriately applied in studies testing the impact of descriptive norms (i.e., perceptions of other’s attributes or behaviors) on adolescent outcomes (e.g., Rice, Donohew, & Clayton, 2003), whereas peer similarity and contagion is better assessed using actual reports, where egos and alters report on their own attributes. Notably, adolescents’ perceptions of their peers’ substance use has been found to be equally, if not more influential on their own use, than peers’ actual behavior (Rice, et al., 2003; Urberg, Shiang-Jeou, & Liang, 1990). As suggested by the theory of planned behavior (Ajzen, 1991), perceived norms may be a psychological pathway through which the social environment influences behavioral intentions, and thus a mechanism through which behaviors diffuse through social connections.

A further disadvantage of measuring peer attributes via perceived reports is that it oversimplifies the study of social processes to self and other (where the other can be an individual or more generalized social group). This dyadic perspective does not capture complex social processes associated with patterns or characteristics of broader social structures (which will be described more fully throughout this chapter) that could potentially facilitate or constrain health behaviors, or have implications for outcomes such as obesity (Smith & Christakis, 2008). Analysis of network data, where egos and alters are recruited into
the study, each reporting on their own attributes and relationships, provides a richer account of relationship structures, and allows us to test how these impact individual outcomes and inter-personal processes.

**Partial versus complete network designs.** There are a number of sampling methods for collecting network data that capture different components of relational structures at local and global levels (see Figure 1) (Morris, 2004):

- **local or egocentric network** designs gather data from a sample of focal participants (egos) from a population of interest, and have them report on their alters;
- **partial network** designs sample focal participants (egos) and use snowball sampling to recruit their alters into the study, and possibly their alters’ alters, etc.;
- **complete network** (or whole-network) designs define the boundary of a social group of interest (e.g., students at a school, or employees in an organization) and recruit all individuals from that group into the study.

![Figure 1](image)

*Figure 1. Local and global aspects of network structures captured by different sampling designs.*

As highlighted by the figure above, egocentric and partial network designs neglect a great deal of the global network characteristics, and are also limited by their use of perceived reports. Moreover, the information that is missing is not at random so that there
is also the potential for biased statistical inference. Complete network designs capture relational and individual-level information from all actors in a defined population, and so are ideal for investigating homophily and contagion in the context of larger social systems. In complete networks with \( n \) actors, there are \( n \times (n-1) \) possible directed ties (actors cannot have a tie to themselves), and because each actor reports on their ties to others we can map the presence and absence of ties between all actor pairs. Knowing which actors do not share a relationship can be particularly useful when assessing selection effects based on actor- attributes: we can determine how characteristics (e.g., being obese) are associated with receiving, and not receiving, friendship nominations. Therefore, at the cost of having to recruit an entire population of interest, rather than just a sample, we gain a wealth of information on the local and global patterns of ties within the social group, and dependencies between network structures and actor-level variables.

Studies of complete social networks must also define the boundaries of the social group. This is a theoretical and practical issue: researchers need to identify a population connected via the relationship(s) of interest, and also need to limit the boundaries of this group to individuals who can be recruited into the study. Researchers looking at adolescent friendship networks often define their population of interest as peers in a classroom, grade-level, or school, who are all invited to take part in the study. Adolescent friendships are primarily school-based (Urberg, Değirmencioğlu, Tolson, & Halliday-Scher, 1995), which lends some validity to imposing boundaries on school-based friendship networks, however friendships with peers outside of school may also be relevant to health outcomes and behaviors (Dolcini, Harper, Watson, Catania, & Ellen, 2005). Although this dominant focus on school-based friendships has been a major critique of peer influence studies, recruiting
Peers and friends: Definition and measurement. A further methodological issue to consider is the definition and measurement of social relationships of interest. Peer influence studies have defined peers as best friends, groups of close friends, large stereotyped crowds, and even all students at a school. These constructs reflect a wide range of social relationships, from close friendships to acquaintances and loose affiliations, with varying degrees of intimacy. Theory should inform which relationships are sampled, based on which social partners are likely to be an important source of influence for the particular behavior or outcome in question. As summarized in Chapter 1, adolescents’ close friends appear to play an important role in behaviors such as the consumption of snack foods and participation in sports, and social network studies suggest that friends are also alike in weight status. Fortunately, there is a strong consensus on how friendships are defined: for children and adolescents they are typically conceptualized as a close, reciprocal relationship between a dyad, characterized by mutual positive affect and regular interaction (Erdley, Nangle, & Gold, 1998).

Although adolescent friendships are well defined, the operationalization of this construct has been varied. Sociometric measures of friendships often include one or both of the following: 1) friendship or liking nominations, where participants list (or identify from a roster) their friends, or peers that they “like the most”, and 2) peer ratings, where participants rate others in terms of positive evaluations (e.g., how much they like this person), or frequency of interaction. Based on these various measures, friends have been defined as dyads who share unilateral or mutual friend nominations, who mutually elicit strong positive evaluations on rating scales, or some combination of these two (Erdley, et al.,
However, who to count as friends remains an issue of debate. For example, there is some evidence that limiting friendships to mutually nominated dyads may be overly restrictive, particularly when the number of possible friend nominations is constrained (Erdley, et al., 1998).

Complete network studies of large peer groups typically rely on free-recall friendship nomination measures, rather than having participants rate each member of the population, primarily for reasons of practicality and to avoid respondent fatigue. To ensure that respondents only list their close friends, many of these studies specified a limit on the number of nominations; often between 3 and 10 friends (e.g., Berndt, 1995; Halliday & Kwak, 2009). There is evidence to suggest that adolescent peer groups have an average of 5 or 6 members, however the number of members can range from 2 to 12 (Ryan, 2001). Individual differences in the number of outgoing ties (called out-degrees) may be lost by specifying a set or limited number of nominations: participants with few friends may list names to simply meet the criterion (Ryan, 2001), and those with many friends may be limited in their nominations, with variability at both ends of the out-degree distribution being lost. Providing approximately 10 spaces for friend nominations, without specifying a set number of friends, is likely to allow for diversity in out-degrees and capture valid and reliable friendship data, and is an approach now commonly applied in the literature (e.g., Gest, Davidson, Rulison, Moody, & Welsh, 2007; Urberg, et al., 1995).

To summarize, in studies of complete social networks, determining which relationships or “tie variables” to sample, and the operationalization of these relational constructs, are crucial components of the study design. As outlined above, the development of valid and reliable measures of adolescent friendships is ongoing, and decisions regarding sampling and measurement should be informed by the research question at hand.
The Analysis of Complete Adolescent Friendship Networks

Various analytic strategies have been applied to study social contagion and social influence amongst adolescent friends, and some of the limitations of these approaches were alluded to in Chapter 1. Before providing an overview of the statistical models developed to look at social processes in complete social networks, a more comprehensive summary of these limitations will be presented in an effort to justify the use of more complex, and computationally intensive, models.

From friendship dyads and groups, to friendship networks. Although methods for describing social networks have been available for several decades (Wasserman & Faust, 1994), statistical models for network data have only been recently developed. The challenge has therefore been to test relational or network hypotheses using traditional statistical models. To do this, researchers have collapsed, aggregated, or manipulated network data so that it conforms to the requirements of available statistical tests. In the peer influence literature, a great deal of research has investigated processes at the level of friendship dyads. However, as highlighted in Chapter 1, friendships are imbedded in larger social structures, and the characteristics of these structures are likely to be important to the influence and contagion processes of interest.

Researchers have also focused on influence within peer groups, and in the area of adolescent smoking and drug use have used social network techniques to identify these groupings (e.g., Ennett & Bauman, 1993). Criteria based on specific configurations of friendship ties were used to identify individuals as a member of a “clique” or “dyad”, or as a “social isolate”. The network was then partitioned into discrete peer groups, or cliques,

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1 “Cliques” were defined as groups of friends with three or more members. “Dyads” were pairs of individuals whose only reciprocated friendship tie was each other, and “social isolates” individuals with no reciprocated friendship ties in the network.
consisting of three or more members, and inferential statistics were employed to assess group homophily or test if group membership could predict smoking behavior. Although this approach has been useful, there are a number of shortcomings to consider. First, individuals who could not be categorized into a clique, such as isolates, dyads, or liaisons (members of more than one clique), were often excluded from analysis (e.g., Abel, Plumridge, & Graham, 2002; Ennett & Bauman, 1993). Additionally, within peer friendship networks it is not uncommon for individuals to have ties to numerous peer clusters, and drawing boundaries around discrete cliques, or cohesive areas within the network, is often problematic. Numerous criteria are available for defining cliques within networks, and although regularly employed in many peer relations studies, remain subjective and somewhat arbitrary. Partitioning individuals into distinct clusters also loses much of the complexity captured by the network approach.

New statistical models for complete social networks are able to take into account the complex patterns of relationships amongst all members of that network, and assess how these various patterns or configurations of ties are associated with individual attributes such as weight status or health behaviors. These models, which will be described in greater detail in subsequent paragraphs, enable the researcher to look at emerging structures and patterns of friendship ties, rather than imposing pre-defined constructs.

*The violation of independence assumptions.* Many of the traditional statistical approaches employed to study similarities or influence in friendship dyads or peer groups assume that these social entities are independent of one another. However, in reality, friendship dyads may be connected to many other friendship pairs, and peer group members often share ties with other groups. Social network theorists emphasize that that relationships between dyads are not independent of each other (i.e., dyadic independence),
but that there are complex dependencies between these tie variables (Robins, Pattison, et al., 2007). The presence of a friendship between two individuals is therefore not only determined by their own preferences and attributes, but also social processes based on the configurations of other friendship ties around them. The tendency for transitivity, where friends of friends are more likely to be friends, is a classic example of this. The implications are that these relational dependencies explain the presence of friendship ties, and thus the overall structure of the network, and statistical models with appropriate assumptions are required. Moreover, we are often interested in explicitly modeling dependencies amongst social units and how it relates to our hypotheses, rather than ignoring it or treating it as error (Robins & Pattison, 2005). The very nature of the network perspective implies dependence amongst all individuals and relationships within the network, and as a result these data do not meet the underlying assumptions of many statistical approaches.

The use of traditional inferential statistics for analyzing network data must also be questioned as data are not collected by probability methods: complete network samples are not randomly selected, but rather are a census of a population or network of interest. Moreover, when assessing similarities between connected individuals in these types of complete network studies, there will be repeated occurrences of the same measure: individual attributes occur in the data not only as actor’s own characteristic, but also again as a “friend characteristic” for other actors. Complete network data are clearly not independent.

Although the specific implications of using models that make these independence assumptions are unclear, it is possible that clustering and similarity effects are overestimated if structural processes, and their role in friendship selection, are not accounted for in network data. Figure 2 illustrates how we may draw differing conclusions
about the extent to which friends are similar in weight status, and the causes underpinning this, based on different dependence assumptions.

\[ \text{Dyadic Independence} \quad \text{Complex Dependence} \]

\[ \bullet = \text{overweight actor}; \quad \rightarrow = \text{friend nomination} \]

*Figure 2. Similarity and contagion when assuming dyadic independence versus dyadic dependence.*

In the dyadic independence model, we observe three friendship dyads and all actors are overweight. We conclude that friendships are more probable between individuals who are similar in weight than between actors who are dissimilar, and having controlled for initial friend similarities, that this is a result of contagion. However in a model that that accounts for relational dependence within triads (transitivity), we observed a friendship triad where all actors are overweight. We conclude that friendships are more probable between individuals who are similar in weight, but that the observed similarities result from two processes (having controlled for initial weight similarities): 1) contagion effects (to a lesser extent), and 2) transitivity, because friendship dyads tend to cluster together into a triad when they share a common friend. Statistical models for social networks explicitly specify parameters for structural effects such as transitivity, and account for this potentially confounding effect on friendship choices and the overall network structure.
Modeling continuous change in longitudinal studies. A final limitation of previous approaches to modeling contagion and social influence in social networks is the inability to simultaneously account for changes to friendships and actor-level variables. Previous studies have almost solely focused on how friendship predicts changes to actors’ behavior or attributes, despite evidence that adolescent friendships change a great deal (Degirmencioglu, Urberg, Tolson, & Richard, 1998). Considering how friendships change, in relation to the individual outcomes of interest, is necessary to adequately model processes of social selection, and as highlighted in the previous section, selection effects (including structural processes) need to be accounted for to realistically assess social contagion.

Moreover, in traditional statistical methods, change between observation moments (i.e., panels of data) are not allowed, with the state of the network at Time 1 assumed to predict the outcomes at Time 2. Newly developed SAOMs for longitudinal network analysis allow us to simulate unobserved changes to both friendships and actor-attributes that occur between observed panels of data. This allows researchers to infer the most likely trajectories, and social processes, governing observed changes to networks and behaviors, and Figure 3 highlights why this might be important.
Observed changes between observations

<table>
<thead>
<tr>
<th>Time 1</th>
<th>Friends’ weight status differs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 2</td>
<td>Contagion of overweight</td>
</tr>
</tbody>
</table>

Possible unobserved changes between observations

<table>
<thead>
<tr>
<th>Time 1</th>
<th>Friends’ weight status differs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friendship dissolves</td>
</tr>
<tr>
<td></td>
<td>Actor 2 becomes overweight</td>
</tr>
<tr>
<td>Time 2</td>
<td>Friendship re-established based on similar weight</td>
</tr>
</tbody>
</table>

= overweight actor;  = nonoverweight actor;  = friend nomination

Figure 3. Observed changes, and possible unobserved changes, to weight status and friendship ties (adapted from Mercken, Snijders, Steglich, & de Vries, 2009).

Without modeling continuous changes to weight status and friendships between the two time points, we might conclude that friends are similar at Time 2 because of contagion. When unobserved changes to friendships and weight status are modeled, and various competing social processes are considered, we might conclude that friends are similar at Time 2 because of homophilic friendship selection. As outlined in Chapter 1, various processes are likely to result in friendships being associated with adolescents’ weight status, and therefore the clustering of excess weight amongst friends. Longitudinal models for networks and behavior—SAOMs—are able to simulate the most probable trajectories of unobserved changes to friendships and weight status or related behaviors, and allow the researcher infer whether processes of friendship selection, peer influence, or confounding influences, were likely to have governed the observed changes.
The Application of New Statistical Models for Social Networks

Although there is evidence that obesity clusters in adolescent friendship networks, and that friends share similar weight-related behaviors, the mechanisms underpinning these associations are unclear. Future research needs to consider a range of possible causal mechanisms more explicitly, including selection, influence, and confounding effects. A number of methodological considerations relevant to this aim have been outlined in this chapter, and it is clear that standard statistical models are not appropriate for the research questions at hand. Statistical models for complete network data are required.

Over the past decade, and particularly in the past few years, the field of social network analysis has experienced major theoretical developments, coinciding with rapid advances in computing power. The development of statistical models, and particularly exponential random graph models (Robins, Pattison, et al., 2007; Robins, Snijders, Wang, Handcock, & Pattison, 2007) and stochastic actor-oriented models (Snijders, et al., 2007) has been a major area of advance. Although the overall approach and relevance of these models for testing network effects has been alluded to throughout this review, the following paragraphs will provide a more detailed introduction to each model, their assumptions, and how they can be applied to test the research questions central to this thesis.

Exponential Random Graph Models for Single Network Observations

Exponential random graph models (ERGMs) allow researchers to quantitatively model observed networks (the networks produced from cross-sectional data collection), in order to propose and examine hypotheses regarding the possible local processes that generated the overall structure of the graph. As described by Wasserman and Robins (2005, p. 5), ERGM analyses enable “an effective and informed move from local, micro phenomena to overall, macro phenomena.” The network observed at a particular point in time
represents just one pattern of relationships amongst actors, from vast number of possible patterns (Robins, Pattison, et al., 2007). For example, in a group of 50 students there would be close to 2,500 possible ties (i.e., relationships), and as researchers we observe a particular version of a myriad of possible tie patterns. ERGMs allow us to estimate parameters that are likely to explain this particular pattern of network ties, with the overall aim of specifying a model which produces a distribution of graphs similar to the one we have observed.

A key assumption of these models is that networks are self-organizing: “relational ties come into being in ways that may be shaped by the presence or absence of other ties (and possibly node-level attributes)” (Robins, Pattison, et al., 2007). Therefore, local social processes result in particular tie configurations, which are the “building blocks” that give rise to the observed global pattern of relationships. These local tie configurations reflect structural processes, such as reciprocity and transitivity, as well as social processes associated with the attributes of individuals (Robins, Snijders, et al., 2007; Snijders, Pattison, Robins, & Handcock, 2006). Individual attributes are thought to shape local network structures via processes of social influence and social selection: actors are influenced by other actors, particularly close associates or partners, whereby their attributes (e.g., norms, attitudes, behavior, health,) change as a result of social influence; and actors tend to select network partners who have particular (often similar) attributes. As a result, social networks are often characterized by autocorrelation, where connected actors share similar individual characteristics, as well as associations between individual attributes and social status.

Table 1 below summarizes a range of structural and individual-level parameters, and their corresponding tie configurations, that are commonly included in models of adolescent friendship networks (e.g., Espelage, Green, & Wasserman, 2007).
Table 1. *Parameters Commonly Included in ERGMs for Directed Friendship Networks*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tie configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocity</td>
<td>[Diagram]</td>
<td>Models the tendency for ties to be reciprocated.</td>
</tr>
<tr>
<td>Popularity</td>
<td>[Diagram]</td>
<td>Models the in-degree distribution and tendency for popularity.</td>
</tr>
<tr>
<td>Expansiveness</td>
<td>[Diagram]</td>
<td>Models the out-degree distribution and reflects social activity or expansiveness.</td>
</tr>
<tr>
<td>Transitivity</td>
<td>[Diagram]</td>
<td>Models the tendency for 2-paths to close, meaning for ‘a friend of a friend to become a friend’ (i.e., shared friendship).</td>
</tr>
<tr>
<td>Sender</td>
<td>[Diagram]</td>
<td>Models the tendency for ties to be sent from nodes with a particular attribute (black node) to any node (white node).</td>
</tr>
<tr>
<td>Receiver</td>
<td>[Diagram]</td>
<td>Models the tendency for ties to be sent from any node (white node) to nodes with a particular attribute (black node).</td>
</tr>
<tr>
<td>Homophily</td>
<td>[Diagram]</td>
<td>Models the tendency for ties to be sent to nodes with similar or different scores on a continuous attribute.</td>
</tr>
</tbody>
</table>

This modeling approach has developed from earlier $p_1$ (dyadic independence) and $p_2$ (dyadic independence, accounting for actor-attribute dependencies) modeling traditions.

ERGMs, also known as $p^*$ models, now enable the researcher to make complex dependence assumptions relating to the presence of network ties, and therefore specify a range of sophisticated model parameters which have been found to adequately represent many real-life social networks (Robins & Morris, 2007; Robins, Snijders, et al., 2007). Structural and individual-level effects are estimated simultaneously to determine which of these processes best explain the network structure. Whether a configuration is more or less prevalent in the observed network than expected by chance is reflected by a positive or negative parameter estimate. A number of computing packages, such as PNet and statnet, are available for ERG

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2 A formal description of the model and dependence assumptions can be found in Robins, Pattison et al. (2007) and Snijders et al. (2006).
modeling. PNet (Wang, Robins, & Pattison, 2006) uses Monte Carlo Markov Chain (MCMC) maximum likelihood estimation, which refines the parameter values by comparing the observed graph to the distribution of random graphs. Effects are tested using a $t$-ratio, and are deemed significant when the parameter estimate is two times greater than its standard error (Snijders, et al., 2006). Models are considered a “good fit” when they produce a distribution of graphs that are similar to the observed network on a number of graph characteristics, including but not limited to those characteristics that were explicitly modeled.

ERGMs are appropriate for testing hypotheses about how network ties and individual attributes are associated in single observations of adolescent friendship networks. Parameters can be specified to test whether friends tend to be alike in weight status or behaviors, and whether these attributes are associated with social status. Importantly, these models allow us to account for complex structural dependencies in the network, and improve upon previous analytic methods which assumed independence between dyads or friendship cliques. This approach to network modeling can build on our understanding of how of individual characteristics, inter-individual processes, and global network structure are interrelated, and how these relationships impact obesity within an adolescent population.

**Stochastic Actor-Oriented Models for Longitudinal Network Data**

ERGMs allow us to look at obesity and health behaviors in the context of complete social networks, and test for associations between friendships and health outcomes at a particular point in time. However, some of the key questions arising from the literature on obesity in friendship networks are regarding causality, and require a longitudinal analytic approach. The literature suggests that similarities in weight amongst friends could result
from friendship choices, or contagion, or both. The processes underpinning associations between friendships and obesity-related behaviors are also likely to be complex. To draw conclusions about the causal mechanisms underpinning these associations, statistical models that consider changes to friendships and health attributes are required.

**Description of the model.** The stochastic actor-oriented model (SAOM) has been developed specifically for longitudinal data, and the co-evolution of networks and actor-level variables (Snijders, et al., 2007; Snijders, van de Bunt, & Steglich, 2010). It is a dynamic perspective of the social environment that considers how changes to actors’ relationships are related to changes in their behaviors or attributes (Burk, Steglich, & Snijders, 2007). Therefore the model enables us to test hypotheses about the mechanisms driving changes to the network, such as selection and structural effects, while simultaneously testing factors that predict changes to actor attributes, such as peer influence or other confounding effects.

This modeling approach requires a minimum of two observations (or panels) of complete network data, including relational and individual measures, with each panel representing a snapshot of the network at a different point in time. Dependent variables are the network and the actor-attribute of interest. For ties that are treated as a binary variable, the network can be represented as directed adjacency matrix where cells are coded 1 for the presence of a tie, or 0 for the absence of a tie. The dependent actor-attribute typically referred to as the dependent behavior, can be any dichotomous or discrete ordinal variable hypothesized to be influence by the network (e.g., weight status or obesity-related behaviors).

SAOMs are “actor decision models” in that changes to friendships and behavior are seen to be driven by individuals (Light & Dishion, 2007). The overall approach of the algorithm is to randomly select an actor in the network and determine the probabilities
associated with that actor making particular changes to a relationship or their behavior. To do this, unobserved changes in friendships and individual attributes are modeled using continuous-time Markov chains, by simulating the most likely series of changes, or micro-steps, that resulted in the observed changes in the network or behavior. At each micro-step, actors can create or dissolve a network tie, or choose to make no change; or they can change their behavior by one unit, or decide to makes no change. Changes are modeled conditioned upon the state of the network at time 1 (which is not explicitly modeled), and actors’ decisions at each micro-step are assumed to be based on the current state of the network, not on past states. Actors are therefore reacting to tie or behavior changes made by other actors, resulting in a mutual dependence between network and behavior changes (Snijders, et al., 2010).

These unobserved changes that actors make to their ties and behavior are described by two components of the model. The rate function captures the frequency of micro-steps between observation moments, and the objective function captures the probabilities associated with making particular types of changes. The objective function is a linear combination of effects, or “social rules”, that are hypothesized to govern these changes. To examine both selection and influence processes, two interdependent models for network changes and behavior changes are estimated simultaneously, each with rate and objective functions. The network dynamics submodel includes effects predicting changes to actors’ relationships, such as structural processes (e.g., reciprocity and transitivity), behavior-based selection, or covariate-based selection. The behavior dynamics submodel includes effects predicting changes to the dependent behavior variable, including network effects (e.g., contagion), effects of individual covariates, and parameters to model the overall distribution of the behavior. Some common parameters included in models of adolescent friendship
networks and behavior are summarized in Table 2. To test for selection and influence processes that could result in friend similarities, effects of homophilic friendship selection (same/similar attribute effect) and behavioral contagion (behavior similarity effect) are included.

Table 2. Common SAOM Parameters for Network and Behavior Dynamics in Adolescent Friendship Networks

<table>
<thead>
<tr>
<th>Network dynamics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural effects</strong></td>
<td></td>
</tr>
<tr>
<td>Outdegree</td>
<td>Overall tendency to form friendship ties</td>
</tr>
<tr>
<td>Reciprocity</td>
<td>Preference to reciprocate an existing friendship nomination</td>
</tr>
<tr>
<td>Transitivity</td>
<td>Preference to nominate a friend who is a friend of a current friend</td>
</tr>
<tr>
<td><strong>Actor attribute effects</strong></td>
<td></td>
</tr>
<tr>
<td>Ego attribute</td>
<td>Main effect of actor attribute on outgoing friendship nominations</td>
</tr>
<tr>
<td>Alter attribute</td>
<td>Main effect of alters’ attribute on receiving friendship nominations</td>
</tr>
<tr>
<td>Same attribute</td>
<td>Preference to nominate a friend with the same binary/categorical attribute</td>
</tr>
<tr>
<td>Similar attribute</td>
<td>Preference to nominate a friend who is similar on a continuous attribute</td>
</tr>
<tr>
<td><strong>Dyadic attribute effects</strong></td>
<td></td>
</tr>
<tr>
<td>Same dyadic covariate</td>
<td>Effect of a dyadic attribute (characteristic of a pair of actors) on friendship nominations</td>
</tr>
<tr>
<td><strong>Behavior dynamics</strong></td>
<td></td>
</tr>
<tr>
<td>Linear shape</td>
<td>Overall tendency towards high values on the behavioral variable</td>
</tr>
<tr>
<td>Quadratic shape</td>
<td>Overall tendency towards a unimodal distribution on the behavioral variable</td>
</tr>
<tr>
<td>Covariate effects</td>
<td>Effect of a covariate on actor behavior</td>
</tr>
<tr>
<td>Behavior similarity</td>
<td>Tendency to adopt the behaviors of alters (i.e., contagion)</td>
</tr>
</tbody>
</table>

Model specification and estimation. These models are implemented in the SIENA (Simulation Investigation for Empirical Network Analysis) 4.0 software (Ripley & Snijders, 2010). Parameter estimates are obtained using MCMC procedures, whereby each estimation of the model takes parameter values from the previous run, and updates these until any further changes are not found to improve the fit, using a method of moments fit criteria. The estimated parameters indicate which unobserved trajectories, and underlying
social processes, are the most probable given the observed state of the network at each time point (Burk, et al., 2007). Models should be specified using a forward selection process to avoid issues of collinearity amongst effects, and to establish evidence of network dependence (evidenced by significant structural effects) and evidence that network and behavior dynamics are interdependent (evidenced by significant selection and/or influence effects) (Burk, et al., 2007; Snijders, et al., 2010).

Advantages of SAOMs over standard statistical models. There are a number of important advantages of SAOMs that overcome limitations of standard statistical models for longitudinal network data. The first is the ability to model complex dependence assumptions, and to determine whether relational structures beyond the level of dyads and groups impact individual outcomes. The second is the potential to model unobserved changes to the network and behavior in order to assess more accurately the mechanisms underpinning observed changes in the data. A third advantage is the ability to specify a range of effects predicting changes to both friendships and behaviors, allowing us to control for competing mechanisms that might explain associations between the dependent behavior variable and network structure. In particular, the potential to model alternate friendship selection mechanisms, including structural and covariate effects, is an issue previously unaddressed in standard statistical approaches. For example, using structural equation models to test for obesity contagion amongst friends, we could control for initial similarities in weight amongst friends, as well as confounding influences on changes to weight status, but could not control for confounding influences on friendship selection. However, SAOMs are able to account for the role of excess weight, covariates, and structural effects on friendship choices, and controlling for this, the extent to which weight status similarities result from contagion processes.
The application of SAOMs in the study of adolescent risk behaviors. SAOMs are particularly suited to questions of network autocorrelation, and underlying processes of selection and influence: i.e., why are connected individuals more similar than individuals who are not socially connected? In the area of adolescent smoking, SAOMs have been successfully applied to this issue. Adolescent peer groups tend to be strongly polarized by smoking behavior: smokers tend to be in peer groups with other smokers, and vice versa (Abel, et al., 2002; Pearson & Michell, 2000). Longitudinal studies using this modeling approach have found that that similarity in smoking amongst friends was more strongly explained by peer selection than peer influence (Merken, et al., 2009).

The application of SAOMs to the current thesis. The questions posed in the current thesis can be effectively addressed using this modeling approach. The clustering of obesity amongst adolescent friends is potentially driven by a number of social processes outlined in the literature, including:

- contagion: adolescents become overweight because they have overweight friends (e.g., Fowler & Christakis, 2008)
- weight-based friendship selection: overweight youth are marginalized by their peers, and befriend other overweight youth (e.g., Strauss & Pollack, 2003)
- confounding influences on weight status: friends share similar environments or attributes that lead to parallel changes in weight (e.g., Cohen-Cole & Fletcher, 2008b)
- confounding influences on friendships: homophilic friendship selection based on covariates associated with overweight (e.g., gender), and structural effects such as transitivity that lead to shared friendships amongst similar dyads.

SAOMs provide a framework to test whether these competing processes explain friend similarities in weight status. Following from that, we can also apply this framework to test
how these same processes explain associations in weight-related behaviors amongst adolescent friends, to determine if peer influence on health behaviors is a mechanism that might underpin the spread of obesity.
Preamble

The origins of this thesis began in 2006, and were driven by the growing focus on obesogenic environments as causal factors of the obesity epidemic, rather than the more traditional perspective of obesity as a personal disorder in which adopting healthy behaviors is a matter of personal choice (Caballero, 2007; Egger & Swinburn, 1997). This ecological approach “regards obesity as a normal response to an abnormal environment, rather than vice versa” (Egger & Swinburn, 1997, p. 477). Indeed, it is remarkable that there are segments of the population who are not overweight given the pervasive availability of energy-dense foods and the minimal need to expend energy in daily activities.

Obesity prevention strategies have increasingly sought to understand and alter aspects of the environment that are obesity-promoting, with a strong focus on changing physical features such as outdoor recreation spaces, food availability, and active-transportation options (Caballero, 2007). The potential for social environments to be obesogenic has also been acknowledged: contexts from the micro (e.g., family) to the macro (e.g., cultural group) level can engender values, norms, and practices that encourage excessive energy intake or sedentary lifestyles (Egger & Swinburn, 1997). As outlined in Chapter 1, these social and cultural environments arise through, and are negotiated via, interpersonal interactions. An understanding of the social processes that shape health behaviors in these contexts could help to inform the design of ecologically-orientated interventions.

Additionally, the prevention of overweight in children is a crucial strategy for reducing population obesity rates in future because there is the opportunity to intervene before lifestyle habits are firmly established, and because achieving and maintaining weight
loss after individuals have become overweight is rarely successful (Jeffery, et al., 2000).

Although family and various other socio-cultural environments are likely to shape young people’s health behaviors, this thesis focused on the peer context in adolescents because of the limited research on this topic, and because, as summarized in Chapter 1, friends may play a particularly important role their participation in physical activities and in their consumption of energy-dense foods. Through reviewing the literature on peer influence, it also became apparent that there were a number of methodological issues limiting the conclusions that could be drawn from past research and these were outlined in Chapter 2. Approaching this research with a social network perspective could overcome many of these limitations, and provided a means to broaden our understanding of the wider social processes shaping obesity-related health behaviors in peer contexts.

The research agenda for this thesis was to investigate obesity and related health behaviors in adolescents’ friendship networks, and to examine how peers shaped these health behaviors and outcomes longitudinally. The research processes unfolded in several stages. The first examined cross-sectional data from an Australian study of middle adolescents, which had been collected six months prior to the commencement of this thesis. The data, which had not been previously analyzed or published, included measures of school-based friendships and several obesity-related behaviors, and was the basis for Paper 3. At the same time, a longitudinal study was planned and implemented at two high schools in Australia, to measure changes in friendships, obesity-related behaviors, and body mass index (BMI) in two grade 8 cohorts. This age group was targeted because grade 8 is the first year of high school for most Australian students and thus a transition period in which friendships and peer groups are being formed. Originally, the aim had been to follow students over a full school year, but due to delays with the schools and in gaining parental
consent, the three waves of data were collected over six months. Although this was an acceptable time frame to measure behavioral change, it was not ideal for assessing changes in BMI and so an extension to the project was sought for a further year. Only one of the two participating schools consented to take part in this fourth and final wave of the study, and as a result the analysis of BMI data was limited to one school (Paper 1), whereas the behavioral data from both schools was analyzed in Paper 4.

While these studies were underway, a series of papers were published showing that obesity clustered in the social networks of both adults and adolescents (e.g., Christakis & Fowler, 2007; Fowler & Christakis, 2008). Additionally, the results suggested that socially connected individuals were alike in weight status due to an “interpersonal contagion” of obesity (Fowler & Christakis, 2008). These findings certainly influenced the agenda of this thesis, and also further emphasized that our understanding of the mechanisms that might be underpinning these effects was limited. Moreover, the methodological limitations of these published studies called into question the validity of the purported contagion effect, especially amongst adolescent friends (as argued in Chapter 2), and highlighted the need for more sophisticated statistical models to test network effects.

Finally, some preliminary analyses of the BMI data from the main longitudinal study suggested that selection effects, and the marginalization of overweight students by their peers, were playing an important role in participants’ friendship choices and thus the structure of these friendship networks. This prompted further investigation into the processes driving weight-based stigma, and a reading of the peer relations and bullying literature that has advanced some sophisticated hypotheses and theories about peer rejection. This research suggests that children who deviate from local norms are likely to be rejected by their peers (Wright, Giammarino, & Parad, 1986), and that high-status youth play
an especially important role in establishing which behaviors and attributes are perceived to be valued and salient in peer settings (Dijkstra, Lindenberg, & Veenstra, 2008). Whether local norms impact the relevance of excess weight in the peer context, and the rejection of overweight youth by their peers, was an interesting question. The opportunity to address this arose through access to the TRacking Adolescents’ Individual Lives Survey (TRAILS), a large cohort study of adolescents from the Netherlands. Data from a “peer nomination” subsample collected in the second wave of the study (2003 - 2004) were obtained, that included measures of participants’ classroom-based friendships, BMI, popularity, and overall healthiness. How differences in classroom health norms moderated the rejection of overweight youth by their peers was subsequently tested.

Because the various components of this project have been written up as stand-alone manuscripts, at different stages of the research process, and for journals with differing scopes and writing styles, the following four chapters do not flow as they would in a traditional dissertation. Thus, to aid the reader of this thesis in following the progression of the research program and overall argument, this chapter will briefly outline and explain each of the papers in an effort to tie them together, prior to their reading.

**Paper Summaries**

**Paper 1. Weight Similarities Amongst Adolescent Friends: Homophily or Contagion?**

This first paper longitudinally investigated adolescents’ BMIs in one school-based friendship network, with the aim of assessing the social processes causing friends to be alike in weight status, and the subsequent clustering of obesity in their social networks. The sample consisted of a nearly complete cohort of Australian grade 8 students ($N = 156$) who participated in four waves of data collection over 16 months. At each wave, participants...
reported on their friendships to grademates, and had their height and weight measured by researchers to calculate their BMI. To overcome many of the methodological issues raised in Chapter 2, stochastic actor-oriented models (SAOMs) were used to simultaneously test for effects of BMI on friendship selection, and the influence of friends’ BMIs on adolescent BMI, while also controlling for confounding influences on both processes.

The result showed that excess weight was an important factor in students’ friendship choices, but that there was no evidence of “obesity contagion”. Specifically, participants preferred to initiate friendships with peers of the same weight status (overweight/nonoverweight), and overweight students tended to be marginalized by their peers. Interestingly, similarities in weight status were not found to predict the reciprocation of friendship ties, indicating that the transition from a unilateral to mutual friendship was not driven by these same weight preferences. Over and above these selection effects, there was a trend for adolescents’ BMIs to become increasingly similar to the BMIs of their nominated friends; however this contagion effect was not statistically significant. This suggests that studies of longer duration, which employ a similar methodological approach, are needed to draw conclusions about whether excess weight in adolescents is predicted by having overweight friends. The results also emphasized the need to adequately model friendship selection effects in future studies of obesity in adolescent social networks, and highlighted the potential of SAOMs to address these types of research questions. Moreover, the findings supported previous research showing that weight-based stigma has important implications for the friendship relations of overweight youth, and thus the overall structuring of adolescents’ peer environments.
Overweight youth who experience weight-based stigma are known to be at increased risk of loneliness, depression, low-self-esteem, and reduced quality of life (Gray, Kahhan, & Janicke, 2009). Because weight-based friendship selection was a prominent effect in Paper 1, this second study further examined the processes that lead to overweight youth being marginalized by their peers by testing how contextual factors moderate this process.

As outlined in Chapter 1, children who deviate from local norms, especially norms endorsed by high status youth, are likely to experience rejection from their peers. Therefore this second study tested whether school classroom norms around healthiness affected weight-related marginalization. Data were derived from a subsample of TRAILS participants ($N = 503$), and exponential random graph models (ERGMs) were used to test whether weight status was associated with friendships in 28 school classes with weak versus strong health norms. The results indicated that overweight youth, and particularly overweight girls, were only marginalized in classes with strong health norms—where status was associated with healthiness—as they received fewer friendship nominations and tended to befriend other overweight peers. However in classes that lacked clear norms on healthiness—where high status students were not characterized as being healthy—overweight students were well integrated in their peer group.

These findings suggest that strategies seeking to reduce weight-based stigma may benefit from targeting the norms endorsed by high status youth. More broadly, the results imply that contextual factors such as local norms are likely to play an important role in moderating social processes like friendship selection, and possibly social influence, within adolescent social networks.
Paper 3. Obesity-Related Behaviors in Adolescent Friendship Networks

Although there was little evidence from Paper 1, or in the literature more broadly, to support the hypothesis that obesity spreads amongst adolescent friends, it is possible that this process plays out over a longer time frame (Christakis & Fowler, 2007). The literature outlined in Chapter 1 suggested that friends influence behaviors associated with obesity in adolescents, and this was put forward as a potential mechanism that could underpin the contagion of excess weight. As a preliminary investigation of this hypothesis, this third paper examined a range of obesity-related behaviors in the context of three adolescent friendship networks ($N = 385$). ERGMs for single network observations were applied to determine if friends were alike on these various behaviors. The strongest evidence of behavioral similarities amongst friends was for organized physical activity, such as supervised sports and training. Female friends were also found to engage in similar screen-based activities including Internet use and video gaming, while there was some evidence that male friends consumed similar amounts of energy-dense foods. Moreover, because similar friends tended to cluster into close-knit, reciprocated, friendship groups, these behaviors—and thus obesity risk—also clustered in the larger network. Whether or not friends were alike in these behaviors because of social influence, or because they formed friendships with peers who already engaged in similar activities, needed to be pursued in further longitudinal research.

Paper 4. How Physical Activity Shapes, and is Shaped By, Adolescent Friendships

Because the strongest evidence for shared obesity-related behaviors amongst friends was found for physical activity (PA) in Paper 3, the final longitudinal study focused solely on this behavior. The aim was to determine the extent to which friendship selection, and friend influence, explained behavioral similarities amongst friends, and to examine the social-
psychological mechanisms underpinning these processes. In two Australian grade 8 cohorts (\( N = 378 \)), self-reported participation in PA, cognitions about PA, and friendship ties to grademates were measured three times over one school year. SAOMs were again applied to test for interdependencies between the friendship networks and behavior, and to assess whether these processes were mediated via adolescents’ cognitions.

The results indicated that selection and influence processes contributed to friend similarities: friendships were more likely to form between peers with similar PA behaviors, and participants also emulated their friends’ behaviors over time. The results also suggested that this latter peer influence process was driven by behavioral imitation rather than mediated via internal beliefs such as perceived peer norms, which has both theoretical and practical implications. Moreover, adolescents’ adoption of their friends’ behaviors is a process through which obesity risk, and potentially obesity, could spread through these social ties.

**Final Comments on the Collection of Papers**

Overall, this series of papers provides a number of insights into the social processes that give rise to associations between adolescent friendships and excess weight, and how these peer contexts might shape adolescents’ health behaviors and obesity risk. In particular, the findings highlight that the relationship between young people’s friendship networks, and their health outcomes and behaviors, is dynamic and interdependent. Adolescents shaped their peer environment based on attributes such as weight status and physical activity participation, and their health behaviors (i.e., physical activity) were also influenced by the behaviors of their friends. Although there was no significant effect of obesity contagion in Paper 1, the results from Paper 3 and Paper 4 did indicate that
behaviors associated with obesity clustered and spread amongst friends, a potential mechanism for the clustering and spread of obesity in future.

For each of these papers, the conclusion and implications are discussed in each of the manuscripts. The final chapter of this thesis (Chapter 8) reframes these conclusions in the scope of the broader thesis aims, and provides an in-depth discussion of the overall conclusions, implications, and directions for future research.
Weight Similarities Amongst Adolescent Friends: Homophily or Contagion?

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Journal of Adolescent Health, 2010; Submitted paper

Statement of Contributions

Kayla de la Haye (Candidate)

I was responsible for the design and implementation of the research project, including the collection of all data. I performed all statistical analyses, interpreted the results, and wrote the manuscript, with input from all co-authors. I have acted as corresponding author since the manuscript’s submission. I certify that the statement of contribution is accurate.

Signed:                     Date:  07/10/10
Garry Robins (External supervisor)

I contributed to the conceptual design of the study and in particular provided guidance on the measurement of network data, strategies for data analysis, and interpretation of the statistical models. I have also commented on drafts of the manuscript. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed:  Date:  11/10/10

Philip Mohr (Co-supervisor)

I contributed to the planning of this project, and have given advice on the study’s implementation. In my role as co-supervisor, I have provided input into the interpretation of the results and revisions to the manuscript. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed:  Date:  06/10/10

Carlene Wilson (Primary supervisor)

As primary supervisor, I oversaw the development of this work, and contributed to the planning of the project, interpretation of the results, and in framing the research arguments. I have also provided comments on drafts of this manuscript. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed:  Date:  11/10/10
Abstract

Purpose: To determine if weight-based similarities amongst adolescent friends result from social influence processes, controlling for the role of weight on friendship selection and other confounding influences.

Methods: Four waves of data were collected from a grade 8 cohort of adolescents ($N = 156, M_{age} = 13.6$) over their first two years of high school. At each wave, participants reported on their friendship relations to grademates, and had their height and weight measured by researchers to calculate their body mass index (BMI). Newly developed stochastic actor-oriented models for social networks were used to simultaneously assess the role of weight on adolescents’ friendship choices, and the impact of friends’ BMI on changes to adolescent BMI.

Results: Although there was a trend for adolescents’ BMIs to become increasingly similar to the BMI of their friends over this 16-month study, this effect was not statistically significant ($p = .23$). Similarities in friends’ weight were found to be driven predominantly by friendship selection, whereby adolescents, particularly those who were not overweight, preferred to initiate friendships with peers whose weight status (overweight/nonoverweight) was the same as their own.

Conclusions: Weight-based similarities amongst friends were largely explained by the marginalization of overweight adolescents by their peers, rather than the “contagion” of overweight amongst friends. These findings highlight the importance of adequately modeling friendship selection processes when estimating network effects on overweight.
Weight Similarities Amongst Adolescent Friends: Homophily or Contagion?

The current high rates of childhood obesity have been attributed to a complex system of individual, social, and environmental factors. The role of social networks in the propagation of obesity has been emphasized in a recent series of studies, which suggest that excess weight spreads as a result of interpersonal “contagion”. In adults, an individual’s likelihood of becoming obese was found to increase if they shared a social connection, and particularly a friendship, with someone who was obese (Christakis & Fowler, 2007). Similar findings amongst adolescent friends have also been reported (Cohen-Cole & Fletcher, 2008b; Fowler & Christakis, 2008; Halliday & Kwak, 2009; Renna, Grafova, & Thakur, 2008; Trogdon, Nonnemaker, & Pais, 2008).

These longitudinal studies looking at obesity in adolescents’ friendship networks have been based on data from the National Longitudinal Adolescent Health Survey (Add Health). Information on friendship ties to schoolmates was collected in a subsample of this population over two waves (12 to 20 months apart, when participants were in grades 7 through 12), as was self-reported height and weight. Adolescents’ body mass index (BMI), a ratio of weight (kg) to height (m²), was found to be similar to the BMI of their nominated friends, and these similarities increased over time. Several authors have argued that these findings are evidence of network effects, whereby friends’ BMIs directly influenced adolescents’ BMIs (Fowler & Christakis, 2008; Renna, et al., 2008; Trogdon, et al., 2008). These network effects were directional, as adolescents were “influenced” by friends that they nominated but were not influenced by peers who nominated them as a friend (Fowler & Christakis, 2008), and were strongest for girls and adolescents with higher BMIs (Trogdon, et al., 2008), and amongst same-gender friends (Renna, et al., 2008). However, Cohen-Cole and Fletcher (2008b) argued that friends’ assimilation in BMI was not explained by network
effects, but rather by adolescents forming friendships with peers who were similar in weight (called *homophily* or *selection effects*) as well as friends’ shared school contexts (*confounding influences*). In the most recent re-analysis of these data (Halliday & Kwak, 2009), the authors concluded that they could not differentiate whether weight-based similarities amongst friends were attributed to homophily or influence processes. Within the limitations of the data and analytic methods used, it has not been possible to consider the dynamic changes across time to both friendships and weight, or to adequately account for relevant confounding influences. The wider research community has subsequently cautioned against the interpretation of these results as “contagion” (Couzin, 2009; Ellen, 2009).

Concern that these studies do not adequately account for the role of weight in friendship formation is well founded. Overweight youth, and particularly overweight girls, are stigmatized and marginalized by their peers, impacting their opportunity to form friendships (Tang-Péronard & Heitmann, 2008). Overweight youth are less likely to be nominated as friends by their peers (Crosnoe, Frank, & Muener, 2008; Strauss & Pollack, 2003; Valente, Fujimoto, Chou, & Spruijt-Metz., 2009), although not because they are socially withdrawn, as they tend to nominate as many, if not more friends, than their non-overweight counterparts (Crosnoe, et al., 2008; Strauss & Pollack, 2003; Valente, et al., 2009). Overweight adolescents also tend to be peripheral, rather than central, in their social networks because they have fewer friends and because the friends they do have tend to be of lower social status (Strauss & Pollack, 2003). These studies have also found adolescent friends to be similar in weight (Crosnoe, et al., 2008; Valente, et al., 2009), although whether this is explained by marginalized overweight youth becoming friends with one another, or because friends influence each other’s weight, remains unclear. Based on the literature
outlined above, it seems plausible that both selection effects and network effects are contributing to this outcome. Additionally, peer victimization and the experience of low social status have been found to predict changes in BMI (Adams & Bukowski, 2008; Lemeshow et al., 2008). The shared experience of marginalization by overweight youth who befriend each other may be a further confounding influence.

What is now required is an analytic strategy that models friendship selection and network influence simultaneously, and that controls for confounding influences to both processes. Stochastic actor-oriented models (SAOMs) have been developed explicitly for this purpose; they model the interdependencies between changes to social networks and the attributes of the individuals within them (Snijders, Steglich, & Schweinberger, 2007). Additionally, they improve on previous methods because they account for dependencies inherent in relational data (Snijders, Pattison, Robins, & Handcock, 2006), and for unobserved changes to both social ties and individual attributes that occur between measurement moments. At a basic level, these models use continuous time Markov chains to simulate the most probable changes, or micro-steps, that actors make to their attributes and friendship ties. A range of parameters can be specified to determine which social processes (captured as effects) govern these changes. SAOMs therefore allow us to assess the impact of weight on friendship formation, and controlling for this, the impact of friends’ weight on changes to adolescent weight. Moreover, we can control for confounding influences likely to predict changes to friendships and BMI, which may also explain associations in weight amongst friends.

The current study looks at changes to an adolescent school-based friendship network, and to students’ BMIs, over their first two years of high school. Based on four panels of data, including objective anthropometric measures, SAOMs were applied to test
for weight-related selection and influence effects. We anticipate that BMI, and particularly BMIs defined as overweight, will impact the formation of friendships amongst peers. Controlling for this will enable us to test for evidence of network effects, evidenced by friends’ BMIs becoming increasingly similar over time.

**Method**

*Sample and Procedure*

Participants were recruited from a grade 8 cohort at a metropolitan school in Australia, where students were in their first year of high school. Information letters were mailed to students’ homes inviting them to participate in the study and providing them and their parents/guardians with the opportunity to opt-out. The letter also stated that participants would be entered into a draw for one of several $20 gift vouchers.

Data was collected four times over 16 months: three waves during students’ grade 8 year, and a fourth wave when they were finishing grade 9. A total of 156 students (55.1% males) participated in the study, representing 91.8% of all students enrolled in year 8 at any point over the first year of the study. New students who joined the school in year 9 were not invited to participate. Participants ranged in age from 12.3 to 15.6 years (*M* age 13.6, *SD* = 0.4) at the first wave of data collection, and approximately one third (29.5%) identified as having an ethnicity other than Anglo-Australian.

*Measures*

At each wave, participants had their height and weight measured by researchers, and completed a questionnaire supervised by teachers in class. The 25-minute questionnaire, which was part of a larger study, captured information on respondents’ friendship ties and demographics.
Friendships. Participants listed the names of their close friends, defined as “friends you hang around with the most” who were in their grade at school. Friends could be of either gender and there was no limit on the number of nominations, although 10 spaces were provided. Participants were then instructed to circle their best friends from amongst the names they had listed, and these best friend nominations were used to represent friendships in all subsequent analyses. The friendship network was represented as a directed adjacency matrix, where cells coded as 1 denoted a unilateral friendship between participant $i$ and $j$, and 0 the absence of friendship.

Anthropometric measures. Participants’ weight and height were measured by researchers using a Soehnle electronic scale and a portable stadiometer, to calculate their BMI ($\text{kg/m}^2$). BMIs were recoded as a 16 point scale for the SAOMs, where each unit was equivalent to a 1-unit change in BMI, but with outliers ($n = 2$) recoded. Internationally validated age and gender specific BMI cut-offs (Cole, Bellizzi, Flegal, & Dietz, 2000) were used to classify respondents as overweight or obese.

Control attributes. Attributes known to be associated with BMI and the formation of adolescent friendships were also controlled. Participants recorded their gender (1 = male, 2 = female) and whether or not they identified with an ethnicity other than Anglo-Australian (1 = other ethnicity). They also indicated the typical amount of pocket money (i.e., allowance) they had available to them each week on a 4-point scale (1 = less than $10, 2 = $10 to $20, 3 = $20 to $30, 4 = more than $30). Class lists were obtained to create a dyadic covariate where pairs of students who shared a home group class were coded as 1.
Analytic Strategy

Interdependencies between changes to friendship ties and BMI were tested using SAOMs, which are implemented in the SIENA (Simulation Investigation for Empirical Network Analysis) 4.0 software (Ripley & Snijders, 2010) and described in a number of recent publications (Snijders, et al., 2007; Snijders, van de Bunt, & Steglich, 2010; Steglich, Snijders, & Pearson, In press). The models assume that actors make choices about changing their friendship ties or BMI given the current state of the network. A rate function estimates the number of micro-steps, or opportunities for change, that occur between observed measurement moments, while the probabilities of actors making particular choices are dependent on an objective function. Rules that govern changes to friendships and BMI are therefore captured in the objective function, which is a linear combination of specified effects, as in generalized linear models. There are two components to the model, each with rate and objective functions: a friendship dynamics submodel that predicts changes to friendship ties, and a BMI dynamics submodel that predicts changes to BMI. These submodels are estimated simultaneously, each controlling for effects in the other.

Our model was specified using a forward selection process (Snijders, et al., 2010), and only covariates with significant effects were retained in the final model to avoid issues of collinearity. Descriptions of parameters included in the final model are listed in Table 1. Four effects tested whether changes to friendship ties were governed by BMI. The first tested the impact of actors’ BMI on their propensity to nominate a new friend (adolescent BMI), and the second tested the impact of peers’ BMI on the propensity for them to receive an actor’s friendship nomination (potential friend BMI). Two additional effects assessed whether BMI similarity between actors and potential friends impacted the likelihood of actors establishing a new unilateral friendship (similar BMI friend), and the likelihood of
actors reciprocating an existing unilateral friendship (similar BMI reciprocated friend).

Effects of covariates on friendship formation, including gender, ethnicity, and pocket money were also controlled. Additionally, a wealth of examples in the social networks literature show that friendship choices are not only influenced by the attributes of the individuals, but also by the structure of the friendship network (e.g., Mercken, Snijders, Steglich, & de Vries, 2009). In a group of adolescents, peers who have nominated an adolescent as a friend are often more likely than others to receive a friendship nomination (reciprocating ties), as are friends of friends (transitivity). Adolescents also have a “cognitive limit” for friendships, and tend to have a relatively small number of potential social ties (outgoing friendship ties). These structural effects on friendship choices were also controlled.

In the BMI dynamics submodel, the hypothesized network effect was tested by the effect of friend BMI on changes to adolescent BMI. A positive estimate would indicate that adolescents’ BMIs change so that they become more similar to the sum of their friends BMIs.¹ Effects of covariates on changes to BMI were also controlled, as were linear and quadratic shape effects to model the overall distribution of BMI over time.

Effects are tested based on t-ratios of the estimate divided by the standard error. Estimates can also be interpreted as odds ratios (ORs), and reflect the likelihood of an actor who is making a change to their friendships or BMI, choosing between two possible outcomes. These ORs are conditional in that they assume other aspects of the actor’s local network are held constant.

¹ The effect of friends’ average BMI, and the sum of friends’ BMIs, on adolescent BMI were both tested, with the latter found to be the best fit. This suggests that the total number of friends with higher (or lower) BMIs may be more influential than friends’ average amount of excess weight.
Table 1. *Description of the SAOM Effects for Testing Selection and Influence Processes*

<table>
<thead>
<tr>
<th>Effects on friendship dynamics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMI effects</strong></td>
<td></td>
</tr>
<tr>
<td>Adolescent BMI</td>
<td>Effect of BMI on outgoing friendship nominations</td>
</tr>
<tr>
<td>Potential friend BMI</td>
<td>Effect of BMI on receiving friendship nominations</td>
</tr>
<tr>
<td>Similar BMI friend</td>
<td>Preference to nominate friends based on similar BMI</td>
</tr>
<tr>
<td>Similar BMI reciprocated friend</td>
<td>Preference to reciprocate friendship nominations based on similar BMI</td>
</tr>
<tr>
<td><strong>Covariate effects</strong></td>
<td></td>
</tr>
<tr>
<td>Adolescent covariate</td>
<td>Effect of the attribute on outgoing friendship nominations</td>
</tr>
<tr>
<td>Potential friend covariate</td>
<td>Effect the attribute on receiving friendship nominations</td>
</tr>
<tr>
<td>Same covariate friend</td>
<td>Preference to nominate friends who share the same binary attribute</td>
</tr>
<tr>
<td>Similar covariate friend</td>
<td>Preference to nominate friends who are similar on a continuous attribute</td>
</tr>
<tr>
<td>Same dyadic covariate</td>
<td>Effect of a dyadic attribute (characteristic of a pair of actors) on friendship nominations</td>
</tr>
<tr>
<td><strong>Structural effects</strong></td>
<td></td>
</tr>
<tr>
<td>Outgoing friendship ties</td>
<td>Tendency to form friendship ties, relative to the number of potential friends</td>
</tr>
<tr>
<td>Reciprocating ties</td>
<td>Preference to reciprocate an existing friendship nomination</td>
</tr>
<tr>
<td>Transitivity</td>
<td>Preference to nominate a friend who is a friend of a current friend</td>
</tr>
<tr>
<td><strong>Effects on BMI dynamics</strong></td>
<td></td>
</tr>
<tr>
<td>BMI friend</td>
<td>Effect of friends’ BMIs (summed) on adolescent BMI</td>
</tr>
<tr>
<td>Covariate</td>
<td>Effect of a covariate on adolescents’ own BMI</td>
</tr>
</tbody>
</table>

*Note. Because associations in BMI amongst friends may be impacted by the strength of the relationship (Fowler & Christakis, 2008), we specified weight-related selection and influence effects for mutual (reciprocated) friends and for non-mutual friendships. In the model selection process, the effect of reciprocated friends on BMI dynamics was found to be nonsignificant and so was omitted from the final model.*
Results

Descriptive Results

Table 2 summarizes changes to participants’ BMI and friendship ties. Average BMIs were in a healthy range and the proportions of overweight and obese students were comparable to current national figures (Commonwealth Scientific and Industrial Research Organisation & University of South Australia, 2008). Participants consistently nominated an average of 3 to 4 best friends, and about one third of these friendships were reciprocated. Although participants’ average number of friends remained relatively stable, who they were friends with varied: despite maintaining close to two stable friends between waves, they dissolved and established a similar number of friendships. Change in the composition of the network at each wave due to students joining or leaving the school (described in Table 2) was also accounted for in the models (Huisman & Snijders, 2003).

The extent to which friends’ BMIs were alike at each wave, known as network autocorrelation, is also summarized in Table 2. Coefficients for Moran’s I and Geary’s c are measures of spatial correlation applied here to assess if connected individuals in a matrix (i.e., pairs of actors that share a unilateral or mutual friendship) are similar on BMI, in comparison to what would be expected if individuals were randomly paired. The coefficients indicate that friends’ BMI were somewhat alike over the first two waves of the study but there is less evidence of similarity in the third wave, and no evidence that friends were similar by the fourth wave.
Table 2. Descriptive Statistics for Weight Status and Friendship Relations

<table>
<thead>
<tr>
<th></th>
<th>Wave 1</th>
<th>Wave 2</th>
<th>Wave 3</th>
<th>Wave 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$ (SD) pocket money$^a$</td>
<td>2.0 (0.9)</td>
<td>2.0 (1.0)</td>
<td>2.0 (0.9)</td>
<td>2.1 (1.1)</td>
</tr>
<tr>
<td>$M$ (SD) BMI</td>
<td>20.1 (3.4)</td>
<td>20.6 (3.9)</td>
<td>20.5 (3.9)</td>
<td>21.1 (3.2)</td>
</tr>
<tr>
<td>% Overweight</td>
<td>12.3</td>
<td>18.0</td>
<td>16.5</td>
<td>15.7</td>
</tr>
<tr>
<td>% Obese</td>
<td>4.9</td>
<td>4.7</td>
<td>4.5</td>
<td>2.9</td>
</tr>
<tr>
<td>% missing BMI data</td>
<td>21.2</td>
<td>17.9</td>
<td>14.7</td>
<td>35.3</td>
</tr>
<tr>
<td><strong>Network characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$ (SD) friends nominated</td>
<td>3.4 (2.5)</td>
<td>3.6 (2.3)</td>
<td>3.5 (2.4)</td>
<td>3.5 (2.5)</td>
</tr>
<tr>
<td>Reciprocity index</td>
<td>.33</td>
<td>.33</td>
<td>.37</td>
<td>.26</td>
</tr>
<tr>
<td>% missing friendship data</td>
<td>13.5</td>
<td>12.8</td>
<td>10.3</td>
<td>32.7</td>
</tr>
<tr>
<td>Network autocorrelation for BMI$^b$</td>
<td>.19 (.73)</td>
<td>.15 (.72)</td>
<td>.06 (.74)</td>
<td>-.10 (1.03)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$ new friendship ties</td>
<td>1.6</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>$M$ stable friendship ties</td>
<td>1.9</td>
<td>2.1</td>
<td>1.5</td>
</tr>
<tr>
<td>$M$ friendship ties dissolved</td>
<td>1.5</td>
<td>1.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Composition change (joined, left)</td>
<td>6, 1</td>
<td>5, 0</td>
<td>0, 24</td>
</tr>
</tbody>
</table>

Note. The reciprocity index is the proportion of friendship nominations that were reciprocated.

$^a$1 = less than $10, 2 = $10 to $20, 3 = $20 to $30, 4 = more than $30.

$^b$Network autocorrelation coefficients: Moran’s $I$ (Geary’s $c$ in parentheses). Moran’s $I$ ranges from -1 to 1, with values greater than 0 indicating positive autocorrelation (meaning that friends are very similar on BMI), and values less than 0 indicating negative autocorrelation. Geary’s $c$ ranges between 0 and 2 with a value less than 1 indicating positive autocorrelation.

Modeling the Evolution of the Friendship Network and BMI

To determine if adolescents’ friendships and BMI were interdependent and if this resulted from selection or influence processes, a SAOM was estimated for the evolution of the friendship network and BMI (Table 3).
Table 3. *SAOM Estimates for Friendship Network and BMI Dynamics*

<table>
<thead>
<tr>
<th>Friendship dynamics</th>
<th>PE</th>
<th>(SE)</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate period 1</td>
<td>8.379</td>
<td>(0.790)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate period 2</td>
<td>6.535</td>
<td>(0.508)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate period 3</td>
<td>18.464</td>
<td>(2.252)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**BMI effects**

<table>
<thead>
<tr>
<th></th>
<th>PE</th>
<th>(SE)</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescent BMI</td>
<td>0.011</td>
<td>(0.011)</td>
<td>1.01</td>
<td>0.99 - 1.03</td>
</tr>
<tr>
<td>Potential friend BMI</td>
<td>-0.014</td>
<td>(0.011)</td>
<td>0.99</td>
<td>0.96 - 1.01</td>
</tr>
<tr>
<td>Similar BMI friend</td>
<td>0.853</td>
<td>(0.369)*</td>
<td>1.06</td>
<td>1.01 - 1.11</td>
</tr>
<tr>
<td>Similar BMI reciprocated friend</td>
<td>-2.395</td>
<td>(0.901)**</td>
<td>0.85</td>
<td>0.76 - 0.96</td>
</tr>
</tbody>
</table>

**Covariate effects**

<table>
<thead>
<tr>
<th></th>
<th>PE</th>
<th>(SE)</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescent gender</td>
<td>-0.182</td>
<td>(0.076)*</td>
<td>0.83</td>
<td>0.72 - 0.97</td>
</tr>
<tr>
<td>Potential friend gender</td>
<td>0.343</td>
<td>(0.072)**</td>
<td>1.41</td>
<td>1.22 - 1.62</td>
</tr>
<tr>
<td>Same gender friend</td>
<td>0.601</td>
<td>(0.064)**</td>
<td>1.82</td>
<td>1.61 - 2.07</td>
</tr>
<tr>
<td>Adolescent ethnicity</td>
<td>-0.072</td>
<td>(0.072)</td>
<td>0.93</td>
<td>0.81 - 1.07</td>
</tr>
<tr>
<td>Potential friend ethnicity</td>
<td>0.011</td>
<td>(0.065)</td>
<td>1.01</td>
<td>0.89 - 1.15</td>
</tr>
<tr>
<td>Same ethnicity friend</td>
<td>0.143</td>
<td>(0.064)*</td>
<td>1.15</td>
<td>1.02 - 1.31</td>
</tr>
<tr>
<td>Adolescent money</td>
<td>-0.116</td>
<td>(0.031)**</td>
<td>0.89</td>
<td>0.84 - 0.95</td>
</tr>
<tr>
<td>Potential friend money</td>
<td>0.003</td>
<td>(0.031)</td>
<td>1.00</td>
<td>0.94 - 1.07</td>
</tr>
<tr>
<td>Similar money friend</td>
<td>0.166</td>
<td>(0.100)</td>
<td>1.06</td>
<td>0.99 - 1.13</td>
</tr>
<tr>
<td>Same class friend</td>
<td>0.377</td>
<td>(0.072)**</td>
<td>1.46</td>
<td>1.27 - 1.68</td>
</tr>
</tbody>
</table>

**Structural effects**

<table>
<thead>
<tr>
<th></th>
<th>PE</th>
<th>(SE)</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outgoing friendship ties</td>
<td>-3.180</td>
<td>(0.084)**</td>
<td>0.04</td>
<td>0.04 - 0.05</td>
</tr>
<tr>
<td>Reciprocating ties</td>
<td>1.957</td>
<td>(0.136)**</td>
<td>7.08</td>
<td>5.42 – 9.24</td>
</tr>
<tr>
<td>Transitivity</td>
<td>0.416</td>
<td>(0.024)**</td>
<td>1.52</td>
<td>1.45 - 1.59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>PE</th>
<th>(SE)</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate period 1</td>
<td>1.332</td>
<td>(0.211)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate period 2</td>
<td>0.985</td>
<td>(0.146)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate period 3</td>
<td>3.451</td>
<td>(0.493)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shape</td>
<td>0.477</td>
<td>(0.076)**</td>
<td>1.61</td>
<td>1.39 - 1.87</td>
</tr>
<tr>
<td>Quadratic shape</td>
<td>-0.026</td>
<td>(0.013)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friend BMI</td>
<td>1.210</td>
<td>(1.015)</td>
<td>1.08</td>
<td>0.95 - 1.24</td>
</tr>
</tbody>
</table>

*Note. PE = parameter estimate. Rate parameters represent the estimated number of opportunities each actor has to change their friendship ties or one unit of BMI, and are assumed to differ from zero. An odds ratio is not reported for the Quadratic shape effect as this effect is not linear.*

* p < .05, two-tailed. ** p < .01, two-tailed.
Friendship dynamics. The effect of BMI on friendship choices was tested in the friendship dynamics submodel. Participants showed a preference to form friendships with peers whose BMI was similar to their own, compared to peers who were dissimilar, indicated by the significant positive effect of “similar BMI friend” (OR = 1.06, 95% CI 1.01-1.11). However, the interaction of this effect with mutual friendships was significant and negative, indicating that similarities in BMI were not a driver for reciprocating friendship ties, and in fact similarities seemed to discourage mutual friendships (similar BMI reciprocated friend OR = 0.85, 95% CI 0.76 – 0.96). There were no significant effects of BMI on the number of friends nominated (adolescent BMI) or on the number of friendship nominations received (potential friend BMI).

The formation of friendships amongst grademates was also predicted by covariates and structural effects. Participants were more likely to nominate friends who were of the same gender (OR = 1.82, 95% CI = 1.61 - 2.07), the same ethnic background (OR = 1.15, 95% CI = 1.02 - 1.31), and who were in their home group class (OR = 1.46, 95% CI = 1.27 - 1.68). There were also main effects of gender and pocket money on friendship nominations. Compared to males, female students nominated fewer friends (OR = 0.83, 95% CI = 0.72 - 0.97) but received more friendship nominations (OR = 1.41, 95% CI = 1.22 - 1.62). Students with more pocket money also nominated fewer friends (adolescent money OR = 0.89, CI = 0.84 - 0.95). The structure of the friendship network also predicted the formation of friendship ties. Participants preferred to maintain a relatively low number of potential friends, as indicated by the negative outgoing friendship ties effect. They were also more likely to befriend a grademate who had nominated them as a friend (positive reciprocating ties effect) and who was a friend of a friend (positive transitivity effect).
BMI dynamics. Controlling for factors impacting the formation of friendships, and in particular the tendency for unilateral friendships to form amongst peers with similar BMIs, the BMI dynamics submodel tested effects predicting changes to participants’ BMI (Table 3). The effect of friend BMI on adolescent BMI was positive but not statistically significant ($p = .23$), indicating that although there was a trend for a network effect, it did not significantly explain BMI similarities amongst friends. The significant positive linear shape effect indicates that overall, participants’ BMI’s tended to move towards higher BMI values, and the negative quadratic shape signifies a push towards a unimodal distribution of BMI. Changes to BMI were not found to be explained by any of the covariates considered in this study (including gender and ethnicity), assessed during the forward model selection process.

*Modeling the Evolution of the Friendship Network and Overweight*

Because weight-related similarity amongst friends was found to be explained by the selection of friends with similar BMIs, we tested whether this preference held across the BMI spectrum, or if it was driven by the marginalization of overweight adolescents in particular. This model included four effects for overweight (where 1 = overweight or obese) on 1) the number of friends nominated (adolescent overweight), 2) the number of friendship ties received (potential friend overweight), 3) the selection of friends with the same weight category (same overweight friend), and 4) the reciprocation of friendship ties based on the same weight category (same overweight reciprocated friend). Effects of BMI on friendship dynamics were score tested against this model (Schweinberger, 2010) to see if they predicted friendship nominations over and above effects of overweight.

The results show that weight category significantly predicted friendship choices, controlling for the same structural and covariate effects as the previous model (Table 4). Compared to their nonoverweight peers, overweight participants nominated more friends
(OR = 1.39, 95% CI = 1.02 – 1.90), and were marginally less likely to receive friendship nominations (OR = 0.77, 95% CI 0.59 – 1.00). Adolescents also showed a preference for unilateral friends of the same weight category (OR = 1.65, 95% CI = 1.03 – 2.63), meaning that participants were 65% more likely to initiate a friendship with a peer of the same weight category. However, sharing the same weight category mitigated against reciprocating friendships (OR = 0.34, 95% CI = 0.14 – 0.81). The score tests for BMI-related effects on friendship dynamics were not significant (Table 4) indicating that BMI did not account for any additional effect on friendship choices over and above the effects of weight category.
**Table 4. SAOM Estimates for the Effects of Overweight on Friendship Dynamics**

<table>
<thead>
<tr>
<th>Friendship dynamics</th>
<th>PE</th>
<th>(SE)</th>
<th>OR</th>
<th>OR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate period 1</td>
<td>8.269</td>
<td>(0.713)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate period 2</td>
<td>6.508</td>
<td>(0.555)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate period 3</td>
<td>18.432</td>
<td>(3.138)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight category effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adolescent overweight</td>
<td>0.329</td>
<td>(0.159)</td>
<td>1.39</td>
<td>1.02 – 1.90</td>
</tr>
<tr>
<td>Potential friend overweight</td>
<td>-0.267</td>
<td>(0.137)</td>
<td>0.77</td>
<td>0.59 – 1.00</td>
</tr>
<tr>
<td>Same overweight friend</td>
<td>0.501</td>
<td>(0.239)</td>
<td>1.65</td>
<td>1.03 – 2.63</td>
</tr>
<tr>
<td>Same o/weight reciprocated friend</td>
<td>-1.077</td>
<td>(0.445)</td>
<td>0.34</td>
<td>0.14 – 0.81</td>
</tr>
<tr>
<td>Covariate effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adolescent gender</td>
<td>-0.169</td>
<td>(0.074)</td>
<td>0.84</td>
<td>0.73 – 0.98</td>
</tr>
<tr>
<td>Potential friend gender</td>
<td>0.326</td>
<td>(0.069)</td>
<td>1.38</td>
<td>1.21 – 1.59</td>
</tr>
<tr>
<td>Same gender friend</td>
<td>0.581</td>
<td>(0.061)</td>
<td>1.79</td>
<td>1.58 – 2.01</td>
</tr>
<tr>
<td>Adolescent ethnicity</td>
<td>-0.066</td>
<td>(0.074)</td>
<td>0.94</td>
<td>0.81 – 1.08</td>
</tr>
<tr>
<td>Potential friend ethnicity</td>
<td>0.014</td>
<td>(0.069)</td>
<td>1.01</td>
<td>0.89 – 1.16</td>
</tr>
<tr>
<td>Same ethnicity friend</td>
<td>0.128</td>
<td>(0.063)</td>
<td>1.14</td>
<td>1.00 – 1.29</td>
</tr>
<tr>
<td>Adolescent money</td>
<td>-0.110</td>
<td>(0.033)</td>
<td>0.90</td>
<td>0.84 – 0.95</td>
</tr>
<tr>
<td>Potential friend money</td>
<td>0.001</td>
<td>(0.030)</td>
<td>1.00</td>
<td>0.94 – 1.06</td>
</tr>
<tr>
<td>Similar money friend</td>
<td>0.165</td>
<td>(0.096)</td>
<td>1.06</td>
<td>0.99 – 1.13</td>
</tr>
<tr>
<td>Same class friend</td>
<td>0.377</td>
<td>(0.072)</td>
<td>1.46</td>
<td>1.27 – 1.68</td>
</tr>
<tr>
<td>Structural effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outgoing friendship ties</td>
<td>-3.465</td>
<td>(0.198)</td>
<td>0.03</td>
<td>0.02 – 0.05</td>
</tr>
<tr>
<td>Reciprocating friend ties</td>
<td>2.575</td>
<td>(0.025)</td>
<td>13.13</td>
<td>6.19 – 27.82</td>
</tr>
<tr>
<td>Transitivity</td>
<td>0.417</td>
<td>(0.198)</td>
<td>1.52</td>
<td>1.44 – 1.60</td>
</tr>
<tr>
<td>Score tests for BMI effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adolescent BMI</td>
<td>-0.013</td>
<td>0.26</td>
<td>1</td>
<td>.607</td>
</tr>
<tr>
<td>Potential friend BMI</td>
<td>0.022</td>
<td>1.51</td>
<td>1</td>
<td>.219</td>
</tr>
<tr>
<td>Similar BMI</td>
<td>-0.435</td>
<td>0.98</td>
<td>1</td>
<td>.322</td>
</tr>
<tr>
<td>Similar BMI reciprocated friend</td>
<td>-0.116</td>
<td>0.44</td>
<td>1</td>
<td>.506</td>
</tr>
</tbody>
</table>

**Note.** PE = parameter estimate. Rate parameters represent the estimated number of opportunities each actor has to change their friendship ties, and are assumed to differ from zero. The relatively large SE for the reciprocity effect is a result of this parameter being strongly correlated with the Same overweight reciprocated friend effect. The convergence diagnostics for this model were good nonetheless.

+ $p < .10$, two-tailed. * $p < .05$, two-tailed. ** $p < .01$, two-tailed.
To summarize, weight-based similarities amongst friends were found to be driven by adolescents’ preference to form new friendships with grademates whose weight category was the same as their own. To clarify whether this was the case for both nonoverweight and overweight students, parameter estimates were interpreted in terms of the “attractiveness” of particular tie changes. This can be thought of as the contribution of a single tie to the objective function of the SAOM, similar to log-odds in that a positive value indicates a preference to form ties (see Snijders, et al., 2010). As illustrated in Table 5, nonoverweight adolescents showed a preference to befriend nonoverweight peers (0.19), but a strong aversion to overweight peers (-0.77). Overweight students were not opposed to forming friendships with nonoverweight peers (-0.06), but were nonetheless more likely to nominate friends who were also overweight (0.33). Therefore when making changes to friendship ties, participants preferred to befriend peers whose weight category was the same as their own, but this partiality was most pronounced in nonoverweight adolescents.

<table>
<thead>
<tr>
<th>Adolescent weight category</th>
<th>Potential friend weight category</th>
<th>Potential friend weight category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonoverweight</td>
<td>Overweight</td>
</tr>
<tr>
<td>Nonoverweight</td>
<td>0.19</td>
<td>-0.77</td>
</tr>
<tr>
<td>Overweight</td>
<td>-0.06</td>
<td>0.33</td>
</tr>
</tbody>
</table>

**Additional Analyses**

Because the network autocorrelation coefficients for BMI declined substantially in Wave 4 (Table 2), we also explored interactions between weight-related selection effects and time. This was assessed by creating a dummy for each of the three time periods, and testing interactions between each time dummy and each weight-related effect on friendship dynamics. Although none of these interactions were found to be statistically significant, the
preference to befriend peers with similar BMIs was somewhat weaker in Period 3, indicated by a trend for a negative interaction between Period 3 dummy and “similar BMI friend” (PE = -0.605, SE = 0.409, p = .138).

Whether gender impacted weight-based friendship selection was also explored by including parameters for interactions between adolescent gender and weight-based selection effects. These effects were not statistically significant.

Discussion

This study examined processes underpinning weight similarities amongst adolescent friends by using innovative network models that simultaneously test for mechanisms of friendship selection and influence. In this cohort of adolescents, excess body weight was found to be an important factor in the friendship choices of students over their first two years of high school. There was a trend for overweight students to receive fewer friendship nominations than their nonoverweight peers, despite nominating a greater number of friends. Participants were also found to initiate, or desire friends, whose weight status was the same as their own, with nonoverweight students showing a particularly strong aversion to befriendning overweight peers. Interestingly, similarities in weight were not a driver for desired friendships to be reciprocated, and in fact friendships between peers whose weight status differed were more likely to endure. It may not be surprising that stronger, reciprocated friendships were based on attributes other than weight, although why this might result in mutual friends differing in weight status needs to be explored in future research. One possible explanation is that overweight adolescents feel safe aspiring to friendships with other overweight peers, but should they receive friendship offers (unilateral nominations) from nonoverweight peers, may prefer to reciprocate friendships with students who differ on a status-related characteristic such as weight, in an attempt to
advance their own social standing (Dijkstra, Cillessen, Lindenberg, & Veenstra, In press). This process could explain the decrease in network autocorrelation found for BMI amongst friends (both mutual and unilateral) over time, along with the trend that preferences to initiate friendships based on similar weight status declined by Wave 4.

Controlling for the role of weight in the structuring of adolescents’ friendship ties, as well as other potentially confounding covariates such as gender and ethnicity, there was a trend for friends’ BMIs to become increasingly alike. Although this was suggestive of a network effect, whereby adolescents’ weight was influenced by their friends’ weight, it did not significantly predict changes to adolescent BMI over the 16 months of the study. Thus, weight-based similarities amongst friends were primarily explained by overweight students befriending one another because they were marginalized by their nonoverweight peers, rather than the “contagion” of overweight between friends.

Although these findings support previous research showing the impact of weight-based stigma on the friendship relations of overweight youth, they suggest that the interpretation of network effects in the Add Health studies should be revisited. In this sample of early adolescents, similarities in weight amongst friends who shared the same school context were largely explained by friendship choices when selection and influence processes were modeled simultaneously. Although the total duration of this study was comparable to those based on Add Health, ours was strengthened by the collection of more frequent panels of data, enabling a more accurate estimation of processes underpinning changes to friendship ties and BMI. Additionally, we controlled for structural dependencies contributing to the formation and clustering of friendship ties. The current findings were also based on objective anthropometric measures, whereas Add Health captured self-reported height and weight. Increasing similarities in self-reported BMI in the Add Health
data could, to some extent, be explained by friends’ perceptions of their weight becoming increasingly alike. The generalizability of the current study was limited by the small sample size and narrow age range, and because friendships outside of the grade cohort were not considered. Replicating this research with a large representative sample over a longer timeframe would therefore be fruitful.

Despite no evidence for a network effect in this study, it seems plausible that this may emerge over a longer period of time. In a peer context where excess weight is salient to the formation of relationships, it is likely that these same friends act as important social referents for norms around weight, potentially impacting future weight management (Burke & Heiland, 2007). Moreover, friends may also influence weight-related health behaviors in adolescents, a further mechanism by which their BMIs could assimilate (de la Haye, Robins, Mohr, & Wilson, 2010). The “spread” of overweight could also be explained by confounding influences. The negative impact of weight-based stigma on adolescents’ social, emotional, and physical wellbeing is substantial (Puhl & Latner, 2007), and this shared experience of marginalization amongst overweight friends could result in parallel changes in BMI (Adams & Bukowski, 2008; Lemeshow, et al., 2008). Should additional research provide stronger evidence that friends influence each other’s weight, understanding the mechanisms through which this occurs will be crucial to addressing social network effects on obesity through health policy and interventions. Moreover, aiming to reduce weight-based stigma amongst young people, and its impact on the structure of their friendship networks, will likely be a key step in addressing or harnessing network “contagion”.
CHAPTER 5. PAPER 2

Integration or Marginalization. The Importance of Class Norms in Friendship Relations of Overweight Children. The TRAILS Study

Kayla de la Haye, University of Adelaide and CSIRO Preventative Health Flagship
Jan Kornelis Dijkstra, University of Groningen
Ronald Stolk, University Medical Centre Groningen

Child Development, 2010; Submitted paper

Statement of Contributions

Kayla de la Haye (Candidate)

I was responsible for primary authorship of this paper, and collaborated with co-authors on its conceptualization and design. I conducted the statistical analyses, with input from Dr. Dijkstra, and took the lead role in interpreting the results and writing and revising the manuscript, again with input and advice from co-authors. I have served as corresponding author, and primarily responsible for responses to reviewers and revisions to the paper. I certify that the statement of contribution is accurate.

Signed:     Date:   07/10/10
Jan Kornelis Dijkstra (Co-author)

I served as second author of this paper, and contributed to the conceptualization and preparation of the manuscript. I facilitated access to the data, and collaborated with Ms. de la Haye on strategies for data analysis and interpretation of the results. I have also commented on drafts and provided input on revisions to the manuscript. I give my permission for this paper to be incorporated in Ms. de la Haye’s submission for the degree of PhD at the University of Adelaide.

Signed:         Date:   02/09/10

Ronald Stolk (Co-author)

I served as a co-author of this paper and am a Primary Investigator on the TRAILS study. I facilitated access to the data, provided input into the interpretation of the results, and gave advice on drafts of the manuscript and responses to reviewers’ comments. I give my permission for this paper to be incorporated in Ms. de la Haye’s submission for the degree of PhD at the University of Adelaide.

Signed:       Date:   07/09/10
Abstract

Overweight children are often marginalized by their peers, with adverse consequences for their psychosocial development. This study examined the way in which school classroom norms favoring healthiness affect weight-related marginalization. Cross-sectional social network modeling was used to examine friendship relations in classes with a weak versus a strong health norm, using data from a sub-sample of TRAILS (N = 503, M age 11.4). Only in classes with a strong health norm were overweight children, and particularly overweight girls, less likely to receive friendship nominations and more likely to befriend each other. The integration of overweight children in the peer group seems to be facilitated in classrooms lacking clear norms on healthiness, while overweight children are more likely to be marginalized in classes with strong health norms.
Integration or Marginalization. The Importance of Class Norms in Friendship Relations of Overweight Children. The TRAILS study

An important challenge for children is being embedded in peer groups through the development of friendship relations (Corsaro & Eder, 1990; Giordano, 2003). Failing to gain a sense of belonging in the peer group has been associated with poor psychosocial outcomes (Gifford-Smith & Brownell, 2003). Body weight is one aesthetic feature shown to be relevant to the establishment of friendship relations because children often hold negative attitudes and beliefs towards peers who are overweight (Gray, Kahan, & Janicke, 2009). This weight-based stigma manifests in numerous ways, including the bias, rejection, and victimization of overweight youth (Puhl & Latner, 2007). Children who experience weight-based stigma have been found to be at an increased risk of social isolation, loneliness, depression, low self-esteem, and reduced quality of life in (Gray, et al., 2009). Moreover, despite high rates of childhood obesity (Ogden, Carroll, & Flegal, 2008) potentially normalizing excess body weight, obese children seem to be stigmatized even more so than when rates were relatively low (Latner & Stunkard, 2003).

The impact of weight-based stigma on young people’s friendships has been well documented. Overweight children are less attractive as friends, as they tend to receive fewer friendship nominations than their non-overweight peers (Crosnoe, Frank, & Muener, 2008; Valente, Fujimoto, Chou, & Spruijt-Metz, 2009). As a result of this social exclusion they tend to be found at the periphery of their peer networks (Strauss & Pollack, 2003), despite nominating as many, or more, friends than their non-overweight peers (Crosnoe, et al., 2008; Strauss & Pollack, 2003; Valente, et al., 2009). Moreover, overweight children are likely to select each other as friends (Crosnoe, et al., 2008; Valente, et al., 2009), and these weight-based similarities between children and their close social ties have been found to
strengthen over time (Christakis & Fowler, 2007; Fowler & Christakis, 2008; Halliday & Kwak, 2009). Together, these findings highlight the importance of excess body weight as a social marker for the establishment of friendships, and how weight-based stigma is manifest through the marginalization of overweight youth by their peers (Crosnoe, et al., 2008).

Yet, children’s peer relations are formed in specific contexts, most prominently school classrooms. Classroom contexts have been found to differ in the extent to which behaviors and characteristics are seen as attractive, and, consequently, affect friendship formation (Wright, Giammarino, & Parad, 1986). In the realm of bullying and aggression, it has been shown that as behaviors are more positively evaluated, the more they are adopted and seen as normative in the peer group (Chang, 2004; DeRosier, Cillessen, Coie, & Dodge, 1994; Jackson, Barth, Powell, & Lochman, 2006; Sentse, Scholte, Salmivalli, & Voeten, 2007; Stormshak, Bierman, Bruschi, Dodge, & Coie, 1999). According to this social misfit model, deviation from the norm enhances risk of rejection and marginalization by peers (Wright, et al., 1986). Extending this, Dijkstra, Lindenberg, and Veenstra (2008) have argued that it is the characteristics of high-status, popular children that are important in establishing social norms. Thus, behaviors and characteristics are seen in a more positive light when associated with status (Dijkstra, et al., 2008; Dijkstra, Lindenberg, Verhulst, Ormel, & Veenstra, 2009). In line with this, they showed that bullying was more positively evaluated when popular adolescents were involved as opposed to the overall class (Dijkstra, et al., 2008).

This leads to two implications for understanding the role of overweight in children’s friendships. First, class norms regarding excess body weight may impact the establishment of friendship relations with overweight children, and second, norms associated with status are likely to be powerful in affecting the evaluation of weight-based characteristics. Because obesity is strongly related to perceptions of unhealthiness in the wider public (Evans,
Finkelstein, Kamerow, & Renaud, 2005), we consider status-related class norms by evaluating the association of popularity with healthiness.

It is hypothesized that overweight children are more likely to be marginalized in classes where high-status students endorse “healthy norms” (i.e., classes with a strong association between popularity and healthiness), compared to classes where high-status is not as strongly linked with health (i.e., classes with a weak association between popularity and healthiness). This will be evidenced by overweight children receiving fewer friendship nominations than their non-overweight peers, and by a tendency for overweight children to select each other as friends. Because there is evidence that marginalization is experienced to a greater extent by girls than boys (Tang-Péronard & Heitmann, 2008), the hypothesized effects are expected to be stronger for girls.

As gender and social economic status are important determinants steering friendship preferences (Kupersmidt, DeRosier, & Patterson, 1995), both attributes are controlled for. Statistical models for social networks, so called exponential random graph models or ERGMs, were used to account for the complex structure of friendship networks and inherent dependencies within them (Robins, Pattison, Kalish, & Lusher, 2007; Robins, Pattison, & Wang, 2009).

Method

Sample

A “peer nomination” subsample was used from the first assessment wave of a larger cohort study TRacking Adolescents’ Individual Lives Survey (TRAILS) (de Winter et al., 2005; Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004; Veenstra et al., 2005). The TRAILS target sample consisted of preadolescents living in five municipalities in the north of
the Netherlands, including both urban and rural areas. Friendship relations were only assessed in classes with at least ten TRAILS respondents. Classes with participation rates under 60% were excluded from this study to ensure reliable estimates of friendship patterns. This yielded a target sample of 28 school classes with information on friendship nominations received of 713 children, containing both TRAILS participants (N = 503) and their classmates (N = 210). Only the TRAILS respondents participated in the friend nominations, and similarly, information on all other variables was only available for respondents, resulting in a target sample of 503 children (M age: 11.38, SD = 0.48, range 10.3 to 12.9; sex: 54.1% girls). Information on friendship nominations received by non-respondents was retained in subsequent analyses to gain a more complete representation of the structural characteristics of the friendship networks.

Measures

**Friendship relations.** Friendships were assessed by asking participants to nominate an unlimited number of their best friends in the class (of any gender), including classmates not participating in TRAILS.

**Anthropometry.** Participants’ height (SECA 208, Seca, Hamburg, Germany) and weight (SECA 761, Seca) were measured individually by trained research assistants. To identify students who were overweight, body mass index (BMI) was calculated by dividing weight (kg) by height (m) squared. Internationally validated age and gender specific BMI cut-off points (Cole, Bellizzi, Flegal, & Dietz, 2000) were used to classify participants as non-overweight or overweight (the latter including overweight and obese classifications).

**SES.** Social Economic Status was measured through household income, and education and occupation levels of both parents, based on parent reports (Ganzeboom &
Treiman, 1996). These variables were standardized and combined into one scale (internal consistency = .84), which captured 61.2% of the variance in the five items. For our analyses, SES was categorized into three categories; low (25%), middle (50%), and high (25%).

**Class norm on health.** The class norm on health was based on the class correlation between teacher ratings of students’ popularity and physical health. Because children have the same teacher throughout the entire school year in the Dutch primary school system, information from teachers was considered valid and reliable. Popularity was based on teacher ratings from the Revised Class Play (Luthar & McMahon, 1996; Masten, Morison, & Pellegrini, 1985). Teachers rated each pupil on a five point scale, from completely agree to totally disagree, on six aspects of popularity, such as “I consider this pupil as someone who is a good leader” and “I consider this pupil as someone everyone listens to”. The internal consistency of the scale was α = .91. Physical health was based on teacher ratings for the question “What do you think about the physical health of this student”. Answer categories ranged from bad to excellent on a five point scale. This measure was found to be significantly correlated with a range of teacher-rated health outcomes including diet, exercise, BMI, and sleep (results not presented here).

Correlations between popularity and healthiness were calculated for each class separately, reflecting the extent to which health is positively evaluated in classes as shown by its association with status. School classes were then split into two groups: classes with a “weak health norm” whose correlations fell below the mean r value (N = 14, mean r = .27, range -.13 to .41), and classes with a “strong health norm” whose correlations fell above the mean (N = 14, mean r = .62, range .50 to .90).
Statistical Analyses

Friendship nominations within each classroom were represented as an adjacency matrix, and to increase the power for the model estimation these were combined into two large matrices, one for each health norm-based group. Because friendship ties between classes were not possible, “structural zeros” were defined for cells in the matrix between classes, which are recognized by the social network software as being an impossible tie.

Exponential random graph models were fit for both groups using PNet (Wang, Robins, & Pattison, 2006), a program which uses a Markov Chain Monte Carlo approach to estimate model parameters and standard errors. Effects for structural dependencies (such as reciprocity and transitivity), control-attribute effects, and effects testing associations between weight status and friendship ties, were estimated simultaneously to identify those most likely to explain the structure of the observed networks (Robins, et al., 2009; Snijders, Pattison, Robins, & Handcock, 2006). Effects are deemed significant when the ratio of the parameter estimate to the standard error exceeds 2 (Snijders, et al., 2006). Significant positive parameter estimates indicate the effect is more prevalent than would be expected by chance, given other effects in the model, and the reverse is true for negative estimates.

To assess relationships between children’s attributes and their friendship ties, four types of effects were included in the models. A “sender effect” represents the association between an attribute and the number of friendship nomination given, and a “receiver effect” represents the association between an attribute and the number of friendship nominations received. To determine if friends were alike on an attribute, “similarity effects” were included for binary variables (representing the tendency for friends to have the same score), and “difference effects” were included for continuous attributes (representing the absolute difference in scores between friends).
Differences in significant effects between the “strong norm” and “weak norm” groups were compared qualitatively: because each effect is conditional upon the other effects in the model, parameter estimates from different ERGMs cannot be quantitatively compared.

**Results**

**Descriptives and Correlations**

Descriptive statistics for both groups of classes are presented in Table 1. The mean number of friendship nominations given and received was significantly higher in classes with a strong health norm ($t (501) = 2.03, p = .043$, and $t (708) = 4.20, p < .001$, respectively). Students in classes with a strong health norm also scored significantly higher on measures of popularity ($t (496) = 2.28, p = .023$) and physical health ($t (492) = 3.20, p = .001$). Although the two groups did not differ on BMI, the proportion of children classified as overweight was significantly greater in classes with a weak health norm (19.3%) than in classes with a strong norm (12.8%, $\chi^2 (1) = 4.03, p = .045$).
Table 1. Descriptive Statistics for Both Categories of Classes

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Weak Health Norm</th>
<th>Strong Health Norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>N total</td>
<td>342</td>
<td>371</td>
</tr>
<tr>
<td>N non-respondents</td>
<td>107</td>
<td>103</td>
</tr>
<tr>
<td>N classes</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>% male</td>
<td>50.6</td>
<td>47.4</td>
</tr>
<tr>
<td>M (SD) Number of overweight children per class</td>
<td>3.4 (2.0)</td>
<td>2.4 (1.1)</td>
</tr>
<tr>
<td>M (SD) Nominations given</td>
<td>6.4 (3.9)</td>
<td>7.1 (4.3)</td>
</tr>
<tr>
<td>M (SD) Nominations received</td>
<td>4.4 (2.3)</td>
<td>5.2 (2.6)</td>
</tr>
<tr>
<td>M (SD) SES</td>
<td>2.1 (0.7)</td>
<td>2.1 (0.7)</td>
</tr>
<tr>
<td>M (SD) BMI</td>
<td>18.2 (3.2)</td>
<td>17.7 (2.7)</td>
</tr>
<tr>
<td>% overweight</td>
<td>19.3</td>
<td>12.8</td>
</tr>
<tr>
<td>M (SD) popularity</td>
<td>3.2 (0.8)</td>
<td>3.3 (0.9)</td>
</tr>
<tr>
<td>M (SD) physical health</td>
<td>3.8 (0.6)</td>
<td>4.0 (0.7)</td>
</tr>
</tbody>
</table>

Note. Data for Nominations received were available for both TRAILS respondents and non-respondents. For all other characteristics data were only available for TRAILS respondents.

Correlations are presented in Table 2. In classes with a weak health norm, there was a significant negative association between SES and overweight, which was not found in classes with a strong health norm. Moreover, there was a greater positive association between popularity and SES, and popularity and physical health, in classes with a strong health norm. Importantly, although classes were split based on the class-correlations between popularity and healthiness, the correlation coefficients between popularity and overweight did not differ significantly between the two groups. This confirms that the class norms being assessed are based around a broader construct of healthiness, rather than simply reflecting an association between weight status and popularity. Further supporting this argument are the weak to moderate negative correlations between overweight and physical health, which do not significantly differ between groups.
Table 2. Correlations for Both Categories of Classes

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gender</td>
<td>.11</td>
<td>-.09</td>
<td>-.02</td>
<td>-.09</td>
<td></td>
</tr>
<tr>
<td>2. SES*</td>
<td>-.02</td>
<td>-.43*</td>
<td>.19*</td>
<td>.26*</td>
<td></td>
</tr>
<tr>
<td>3. Overweight</td>
<td>-.16</td>
<td>-.08</td>
<td>-.25*</td>
<td>-.31*</td>
<td></td>
</tr>
<tr>
<td>4. Popularity</td>
<td>-.05</td>
<td>.33*</td>
<td>-.16*</td>
<td>.27*</td>
<td></td>
</tr>
<tr>
<td>5. Physical health</td>
<td>.05</td>
<td>.30*</td>
<td>-.29*</td>
<td>.55*</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Correlations above the diagonal are for classes with a weak norm (n = 235); below the diagonal for classes with a strong norm (n = 268). Italics indicate significant differences between correlations.

* Polyserial correlations were used to assess relationships between SES, and popularity and physical health, and polychoric correlations were used to assess relationships between SES, and gender and overweight.

* *p < .05.

Structural Network Effects

All structural network effects were significant and similar across both groups of classes (Table 3). The positive reciprocity effects evidence a tendency for friendship ties to be reciprocated. The negative alternating-in-star and positive 2-in-star parameters indicate that students who received a low number of friendship nominations were most common, and that only a few students received many nominations, whereas the negative alternating-out-star and positive 2-out-star effects show a tendency for most students to nominate a small number of friends. Additionally, students who received many friendship nominations tended to nominate relatively few friends, indicated by the negative 2 path parameter. The positive transitive closure and negative multiple connectivity effects showed that “friends of friends” tended to be friends, particularly when there were multiple shared friendships.

Control Attribute Effects

Gender and socio-economic status (SES) played an important role in the structuring of the friendship networks for both groups. Participants in both groups were more likely to nominate same-gender peers as friends. Friendship ties were more likely when differences
in SES decreased, particularly in classes with strong health norms, indicated by the negative
SES difference parameter. To control for differences in the structural positioning of
classmates who were non-respondents, compared to TRAILS respondents, we included a
parameter to model their incoming friend nominations. In strong norm classes, there was a
significant effect where non-respondents tended to receive more friendship nominations
than respondents.

Table 3. *Model Parameter Estimates (Standard Errors) for Estimation of Friendship Relations*

<table>
<thead>
<tr>
<th>Effect</th>
<th>Weak Health Norm</th>
<th>Strong Health Norm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reciprocity</td>
<td>1.587 (.150)*</td>
<td>1.521 (.126)*</td>
</tr>
<tr>
<td>2-in-star</td>
<td>.069 (.029)*</td>
<td>.043 (.018)*</td>
</tr>
<tr>
<td>2-out-star</td>
<td>.110 (.009)*</td>
<td>.084 (.005)*</td>
</tr>
<tr>
<td>2 path</td>
<td>-.128 (.016)*</td>
<td>-.117 (.012)*</td>
</tr>
<tr>
<td>Alternating-in-star</td>
<td>-.486 (.185)*</td>
<td>-.579 (.151)*</td>
</tr>
<tr>
<td>Alternating-out-star</td>
<td>-.885 (.195)*</td>
<td>-.737 (.152)*</td>
</tr>
<tr>
<td>Transitive closure</td>
<td>.947 (.063)*</td>
<td>1.146 (.058)*</td>
</tr>
<tr>
<td>Multiple connectivity</td>
<td>-.114 (.027)*</td>
<td>-.121 (.019)*</td>
</tr>
<tr>
<td><strong>Control attribute effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender sender (1 = boys)</td>
<td>-.998 (.107)*</td>
<td>-.620 (.059)*</td>
</tr>
<tr>
<td>Gender receiver</td>
<td>-.814 (.093)*</td>
<td>-.557 (.061)*</td>
</tr>
<tr>
<td>Gender similarity</td>
<td>1.768 (.154)*</td>
<td>1.120 (.092)*</td>
</tr>
<tr>
<td>SES sender</td>
<td>-.133 (.033)*</td>
<td>-.019 (.022)</td>
</tr>
<tr>
<td>SES receiver</td>
<td>.080 (.047)</td>
<td>.127 (.042)*</td>
</tr>
<tr>
<td>SES difference</td>
<td>-.071 (.052)</td>
<td>-.083 (.039)*</td>
</tr>
<tr>
<td>Non-respondent receiver</td>
<td>.206 (.143)</td>
<td>.258 (.116)*</td>
</tr>
<tr>
<td><strong>Weight status effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight sender</td>
<td>.073 (.060)</td>
<td>-.057 (.051)</td>
</tr>
<tr>
<td>Overweight receiver</td>
<td>-.161 (.112)</td>
<td>-.449 (.098)*</td>
</tr>
<tr>
<td>Overweight similarity</td>
<td>-.292 (.275)</td>
<td>.565 (.257)*</td>
</tr>
</tbody>
</table>

* p < .05.
Weight Status Effects

In line with our hypothesis, weight status was only found to be associated with the structure of the friendship network in classes with a strong health norm. In these classes, overweight children were less likely to be nominated as friends than their non-overweight classmates, indicated by the significant negative receiver effect. The non-significant sender effect indicates that weight status was not associated with the number of friendship nominations given. Moreover, in classes with a strong health norm, there was a tendency for friends to be alike in weight status, as shown by the significant positive similarity effect. Conditional odds ratios (not presented here) show that in classes with a strong health norm, friendship ties sent from non-overweight students to overweight students were less likely (OR = 0.64; 95% CI, 0.52 to 0.78) than all other friendship dyad types, including ties sent from overweight students to their non-overweight peers (OR = 0.94; 95% CI, 0.85 to 1.05). In contrast, there was no evidence that weight status was associated with the number of friendship nominations sent or received, or that friends were similar on weight status, in classes with a weak health norm.

To determine if there was stronger evidence of marginalization for overweight girls than overweight boys, additional models were estimated that included gender-specific weight-based network effects. The parameter estimates for these effects are presented in Table 4 (other significant effects being controlled for were similar to those reported in Table 3). The results show that in classes with weak health norms, overweight boys nominated more friends than their peers, whereas overweight girls received less nominations. In classes with a strong health norm, the tendency for overweight students to receive fewer friendship nominations was primarily accounted for by overweight girls, not overweight boys, receiving fewer nominations. Moreover, the effect of similarity on weight status
amongst friends was significant for girls, and marginally significant amongst overweight boys in these classes.

Additional Analyses

Because the prevalence of overweight was lower in classes with strong health norms (12.8%) compared to classes with weak norms (19.3%), we also tested if weight-based marginalization was impacted by class prevalence of overweight. In other words, were overweight students more likely to be marginalized in classrooms with few overweight students, where excess body weight was a more obvious deviation from the majority, as opposed to a deviation from status-based norms? Models were estimated that included weigh-based network effects split by classes with a low versus high prevalence of overweight, based on the median percentage of overweight students per classroom (12.5%). Estimates for these effects are presented in Table 4, again having controlled for the same parameters reported in the previous models. The results show that in classes with weak health norms there was no evidence of overweight students being marginalized, regardless of the classroom prevalence of overweight. In classes with strong health norms, levels of classroom overweight were not found to impact weight-based marginalization: overweight students received fewer friendship nominations in classes with low and higher numbers of overweight students. Although the effect for overweight similarity was no longer statistically significant when split across classes with a low and high prevalence of overweight, the trend for similarity on weight status amongst friends was evident for both types of classes.
Table 4. Model Parameter Estimates (Standard Errors) for Weight Effects Split by Gender and Class Prevalence of Overweight

<table>
<thead>
<tr>
<th>Effect</th>
<th>Weak Health Norm</th>
<th>Strong Health Norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight sender</td>
<td>.250 (.103)*</td>
<td>-.012 (.142)</td>
</tr>
<tr>
<td>Overweight receiver</td>
<td>-.013 (.157)</td>
<td>-.341 (.211)</td>
</tr>
<tr>
<td>Overweight similarity</td>
<td>-.417 (.396)</td>
<td>6.292 (3.362)+</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight sender</td>
<td>-.030 (.079)</td>
<td>-.081 (.061)</td>
</tr>
<tr>
<td>Overweight receiver</td>
<td>-.290 (.146)*</td>
<td>-.516 (.111)*</td>
</tr>
<tr>
<td>Overweight similarity</td>
<td>-.277 (.360)</td>
<td>.677 (.302)*</td>
</tr>
<tr>
<td>Low % overweight a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight sender</td>
<td>.166 (.112)</td>
<td>-.077 (.064)</td>
</tr>
<tr>
<td>Overweight receiver</td>
<td>-.341 (.193)</td>
<td>-.558 (.135)*</td>
</tr>
<tr>
<td>Overweight similarity</td>
<td>-.846 (1.114)</td>
<td>.631 (.445)</td>
</tr>
<tr>
<td>High % overweight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight sender</td>
<td>.042 (.074)</td>
<td>-.016 (.098)</td>
</tr>
<tr>
<td>Overweight receiver</td>
<td>-.081 (.130)</td>
<td>-.312 (.151)*</td>
</tr>
<tr>
<td>Overweight similarity</td>
<td>-.283 (.290)</td>
<td>.402 (.335)</td>
</tr>
</tbody>
</table>

aGroupings are based on the median classroom prevalence of overweight (12.5%).

+ p < .10.  * p < .05.

Discussion

The results of this study demonstrate the importance of the social context in establishing the salience of weight status amongst peers, and its role in the formation of friendships. Overweight children were found to be marginalized by their peers mainly in classes where healthiness was associated with high status. In classes where high status children were not strongly characterized by good health, there was less evidence of weight-based marginalization, with overweight children appearing to be integrated in their peer group.

Using statistical models for social networks (ERGMs) we found that there were a number of social processes likely to explain the structure of the classroom friendship networks. Endogenous network processes, such as establishing relationships with friends of friends, as well as gender and SES attributes, governed the formation of friendships in all
classes. Controlling for these effects, classes differed only in the role that weight status played in the structuring of friendship ties. In classes with strong health norms, overweight children, and particularly overweight girls, tended to receive fewer friendship nominations and befriend other overweight peers. However, overweight children in these classes nominated as many friends as their peers, indicating that marginalization was predominantly driven by exclusion from peers, rather than their own withdrawal.

We proposed that overweight children were marginalized because of classroom norms driven by the health attributes of high-status peers. This interpretation was based on evidence that it is deviation from the characteristics of popular peers, as opposed to characteristics of peers in general, that matters with regards to being liked or disliked by peers (Dijkstra, et al., 2008). However, it also seemed plausible that weight-based marginalization could be driven by the lower proportion of overweight students in classes with strong health norms. Controlling for classroom prevalence of overweight, we found no differences in the extent to which overweight students were marginalized by their peers in classes with strong health norms. Moreover, in classes with weak health norms overweight children were well integrated in the peer group regardless of the prevalence of overweight. These results lend support to the argument proposed by Dijkstra and colleagues (2008) that it is particularly the characteristics endorsed by high-status peers that are deemed socially relevant and valued in the peer group setting. When children deviate from these status-related norms, in this case by being overweight, they are more likely to be actively excluded from the peer group.

This study identifies social contexts in which overweight youth are not stigmatized by their peers, suggesting that the norms of high status children could mitigate whether negative attitudes and beliefs towards overweight youth, or the manifestation of these
beliefs, are sanctioned in the peer setting. These findings warrant further longitudinal research to assess how differing health norms arise in peer groups, and whether contexts where overweight children are well integrated in the peer group are protective of some of the negative psychosocial outcomes associated with childhood obesity. To date, interventions seeking to reduce weight-based stigma by changing young people’s beliefs and attitudes towards obesity have been few, and of limited success (Gray, et al., 2009). Addressing the norms endorsed by high-status children may be useful approach for future interventions.

_Limitations_

The conclusions drawn from this study are limited by the cross-sectional nature of the data. Weight status similarities amongst friends could result from influence processes, whereby body mass assimilates as a result of shared friendship, potentially via similar engagement in obesity-related behaviors (de la Haye, Robins, Mohr, & Wilson, 2010). However, because we find evidence of marginalization only in classes with strong health norms, similarities amongst friends are more likely explained by friendship selection. Given our sample of pre-adolescents, it is also more plausible that selection rather than influence processes explain similarities in weight status amongst friends at this age. Nonetheless, the structuring of friendships around weight status in contexts with strong health norms is likely an important precursor to influence processes. It is plausible that in contexts where health is highly valued, and thus weight status is more salient to the formation of social ties, influence effects over the longer-term will be particularly strong.
Conclusions

Paradoxically, despite strong values placed on appearance and health, and ongoing stigma towards excess weight, obesity rates remain high. What is clear is that stigmatizing and marginalizing overweight children does not serve to discourage overweight, but rather contributes to their increased risk of negative physical and mental health outcomes (Puhl & Latner, 2007). These negative psychological outcomes are not surprising given our findings that overweight children actively seek out friendships, but are marginalized as a result of being excluded by their non-overweight peers. Our study shows that in classrooms characterized by strong norms around healthiness, this weight-based exclusion by peers is particularly pronounced. Consequently, health initiatives that promote healthy behaviors, and in particular their association with social status, may encourage greater marginalization of overweight youth. Addressing weight-based stigma, especially amongst non-overweight children, should therefore be a standard component of obesity prevention efforts, with the aim of improving social integration and overall quality of life of overweight children as well as their physical health. Interventions seeking to change children’s attitudes and beliefs about obesity in order to decrease weight-based bias and stigma should also consider the role of high status peers in establishing health-related norms, and their potential influence in the promotion of more positive attitudes and relational behaviors towards overweight peers.
Obesity-Related Behaviors in Adolescent Friendship Networks

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2010

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Statement of Contributions

Kayla de la Haye (Candidate)

Along with Prof. Wilson, I was responsible for the design and implementation of the research project, including the collection and management of the data. I performed all statistical analyses, interpreted the results, and wrote the manuscript, with input from all co-authors. I served as corresponding author, and took responsibility for responding to reviewers and revisions to the manuscript. I certify that the statement of contribution is accurate.

Signed:      Date:   07/10/10
Garry Robins (External supervisor)

I provided input on the measurement of network data, strategies for data analysis, and interpretation of the results. I have also commented on drafts of the manuscript and provided input on subsequent revisions. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed: Date: 11/10/10

Philip Mohr (Co-supervisor)

I contributed to the interpretation of the results, and provided input on drafts of the manuscript and responses to reviewers’ comments. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed: Date: 06/10/10

Carlene Wilson (Primary supervisor)

I oversaw the planning and implementation of this project, and have provided input into the interpretation of the results, drafts of the manuscript, and in addressing reviewers’ comments. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed: Date: 11/10/10
Abstract

This study examines obesity-related behaviors within adolescent friendship networks, because adolescent peers have been identified as being important determinants of many health behaviors. We applied ERGM selection models for single network observations to determine if close adolescent friends engage in similar behaviors and to explore associations between behavior and popularity. Same-sex friends were found to be similar on measures of organized physical activity in two out of three school-based friendship networks. Female friends were found to engage in similar screen-based behaviors, and male friends tended to be similar in their consumption of high-calorie foods. Popularity (receiving ties) was also associated with some behaviors, although these effects were gender specific and differed across networks.
Obesity-Related Behaviors in Adolescent Friendship Networks

The proportion of children who are overweight or obese is estimated to be between 20% and 25% in Australia (Olds, et al., 2004). The prevalence of childhood obesity in many other affluent countries is equally high and, as in Australia, has risen dramatically over the past couple of decades (WHO, 2003). The economic and societal costs of this “epidemic” are predicted to be immense because obese children have an increased risk for a number of medical conditions as well as negative long-term psychosocial consequences (Zametkin, Zoon, Klein, & Munson, 2004). Overweight adolescents are also at risk of being overweight in early adulthood (Crossman, Sullivan, & Benin, 2006). As their behaviors are more malleable than adults, this age may be an effective time for intervention (Jeffery, et al., 2000), so it is important to understand factors associated with adolescent overweight.

Behaviors associated with rising childhood obesity include food consumption patterns that have increased energy intake, and declining levels of physical activity diminishing overall energy output (Zametkin, et al., 2004). Specifically, fast food has been associated with increased energy and fat intake (French, Story, & Jeffery, 2001), and dietary patterns characterized by over-consumption of energy-dense, low-fiber, and high-fat foods have been associated with increased fatness in children (Johnson, Mander, Jones, Emmett, & Jebb, 2008). Over the past two decades, an overall decline in physical activity amongst children and adolescents has also been reported, which has largely been attributed to decreased active play and locomotion (Olds, et al., 2004). Screen time, which includes time spent watching television, computing, and playing video games, has been found to be a strong competitor for children’s leisure time (Olds, et al., 2004). Research suggests there is a strong relationship between screen time, physical activity, and propensity for obesity; children who watch more television are less likely to do vigorous physical activity and are
more likely to have higher body mass indexes (BMIs) (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998).

Behavioral interventions need to be informed by an understanding of the important factors shaping obesity-related behaviors amongst children and adolescents, and there is a growing body of research highlighting the important role of the social environment. Family, peer, and school environments have been identified as contexts in which adolescents’ health behaviors are established and maintained (Williams, Holmbeck, & Greenley, 2002). As adolescents spend increasing time with friends, the potential for the norms and behaviors of peers to be influential is increased (Peterson, 1989). Peers have been found to influence adolescents’ consumption of snack foods (Feunekes, de Graaf, Meyboom, & van Staveren, 1998) and foods high in saturated fat (Monge-Rojas, Nunez, Garita, & Chen-Mok, 2002). Acculturation to peer norms has also been associated with lower levels of physical activity and higher frequency of fast food consumption amongst Hispanic and Asian-American adolescents (Unger, et al., 2004). Social support from friends has been found to be positively related to physical activity (Duncan, Duncan, & Strycker, 2005), and adolescent girls have been found to be more physically active when they reported that their close friends engaged in high levels of physical activity (Voorhees, et al., 2005). Yet, contrasting results have also been reported: Pearson, Steglich, and Snijders (2006) indicated that adolescents tended to form friendships with school students who differed from them in sporting behaviors. Accordingly, it cannot be taken for granted that adolescent friendships are based around universal behavioral similarity: although similarity on some behaviors (or attributes) may be a central feature of the friendship, dyads may differ on other, less salient, attributes. Adolescent obesity is also a predictor of marginalization and social stigma
amongst peers (Strauss & Pollack, 2003), so that health behaviors associated with overweight may also differ based on social hierarchies or status features of friendships.

In sum, this literature suggests that adolescent friendships are an important social context in which obesity-related behaviors take place. Understanding the role of friendship influences on these behaviors, however, needs to take into account the complex structures of adolescent friendship ties, beyond the simple examination of dyads and the identification of individual membership within small groups. In this article, by using statistical models for networks, we control for basic friendship dependencies at the same time as we examine associations between friendship ties and self-reported behavior. Examination of self-reported behavior, and not perceptions of the behaviors of friends (i.e., perceived reports), is particularly important in adolescent research because this age cohort has been found to project their own behavior onto their peers (Ryan, 2001).\(^1\)

**Social Networks and Health Behaviors**

Measuring the complex patterns of adolescents’ friendship ties can serve to highlight how network structure and behaviors are interdependent. Theories of social influence identify both direct (e.g., imitation) and indirect (e.g., internalization of group norms) mechanisms of interpersonal influence, which arise through social interaction. Social ties can also be influential as conduits of resources, information and social support, and positions or roles within these social-structural contexts can be an additional source of behavioral control (Friedkin, 1998). Social networks have been found to play an important role in adult obesity, with individual weight status strongly influenced by the weight status of close

\(^1\) Although perceived behavior of network partners has been found to be an important source of influence on some health behaviors (Rice, Donohew, & Clayton, 2003; Valente, Watkins, Jato, Van der Straten, & Tsitsol, 1997), this paper is interested in exploring associations between friendship ties and ‘actual’ behavior. Drawing conclusions about the potential social-psychological mechanisms that may underpin associations between friendship ties and obesity-related behaviors is beyond the scope of the current study, but would be a fruitful topic for future research.
friends and other non-biological ties (Christakis & Fowler, 2007). Recent research has also found that adolescents’ weight is associated with their friends’ weight cross-sectionally (Valente, Fujimoto, Chou, & Spruijt-Metz, 2009) and longitudinally: one study has claimed these effects were explained by shared environmental factors (Cohen-Cole & Fletcher, 2008b), while others have reported that network effects on adolescent overweight were indicative of social influence (Fowler & Christakis, 2008; Trogdon, Nonnemaker, & Pais, 2008). Unfortunately, these studies were not able to specify the mechanisms of interpersonal influence on weight status, or whether similarity in weight status was explained by similarity on obesity-related behaviors. As well, only the Valente et al. (2009) study adequately considered the effect of possible shared friendships (i.e., transitivity), a common feature of friendship networks that should be controlled to avoid overestimating network effects.

Associations between network structure and individual attributes, such as health behaviors, can also be driven by processes of social selection. Studies of adolescent smoking have found individuals tend to form friendships with peers who engage in similar smoking behaviors (Kobus, 2003). For single network observations it is not possible to disentangle processes of selection and influence (Steglich, Snijders, & Pearson, In press), but we are able to test for associations between network structure and behavior which, if present, would justify subsequent longitudinal research.

Recent developments in social network analysis, employing Exponential Random Graph (or $p^*$) Models (ERGMs), provide a sophisticated method for modeling the structure of complex social networks (Robins, Pattison, Kalish, & Lusher, 2007). New ERGM specifications allow us to make dependence assumptions about the presence of network ties

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2 Accounting for shared ties amongst “alters” was not possible in the Christakis & Fowler (2007) study given limitations when the data were originally collected.
that go beyond the level of the dyad, to account for formations of larger group structures (Snijders, Pattison, Robins, & Handcock, 2006). These statistical models assume that networks are self-organizing: “relational ties come into being in ways that may be shaped by the presence or absence of other ties (and possibly node-level attributes)” (Robins, Pattison, et al., 2007, p. 177). The formation of ties, and thus the overall network structure, is therefore assumed to be based on structural or “endogenous” processes such as tie reciprocation or transitivity (i.e., shared friendships), as well as “exogenous” processes involving node-level attributes, including social influence and social selection (Robins, Pattison, & Elliott, 2001). In this paper, we apply ERGM selection models for single network observations to understand whether there are associations between node-level attributes and tie-level variables without drawing firm inferences about whether selection or influence (or both) processes are operating.

ERGM parameters represent a range of different tie configurations, each of which relates to specific structural processes or interactions between network ties and individual-level attributes (Robins, Pattison, et al., 2007). These parameters can be estimated simultaneously to determine which effects significantly explain the network structure: i.e., which particular configurations of ties occur more or less than would be expected at chance levels, given the number of nodes and density of the network, and given other effects in the model. This enables us to gain an understanding of the structural building blocks of adolescent friendship networks, and to explore interdependence between individual attributes and friendship ties (such as friend similarity) within these complex social structures.

The present study used ERGMs to investigate associations between adolescents’ friendship networks and obesity-related behaviors. The major aim of the study was to
determine if close adolescent friends are similar on a number of obesity-related behaviors.

Our review of the research literature on obesity suggested that three general areas of behavior might be theoretically and empirically important: high-calorie food consumption (Johnson, et al., 2008), physical activity (Zametkin, et al., 2004), and sedentary screen-based behaviors (Andersen, et al., 1998). The secondary aim was to explore if popularity (receiving friendship ties) was associated with these behaviors, which may serve to highlight additional social processes relevant to the behaviors in question.

**Method**

**Respondents**

Male and female students from two independent middle schools in a major Australian city were invited to take part in the study. Participants from School 1 were in year 8, and predominantly 13 years old (76%). Participants from School 2 were in year 8 (82% were 13 years old) and year 9 (87% were 14 years old). Each school year level was defined as a separate peer network to explore similarities and differences within and across age groups and school contexts. Response rates within each of these three peer networks were excellent, ranging from 81% to 93%. Students and their parents/guardians were informed of the study via an information letter mailed to students’ homes, which included information on the study and provided an opportunity to opt-out of participation. Students were also given the opportunity to opt-out of the study on the day of data collection. To maximize the response rate and obtain optimally complete network data, the information letter also stated that respondents would be entered into a draw for one of two gift vouchers.
Procedure and Materials

Respondents completed a paper-based questionnaire developed for this study in their classroom. The questionnaire assessed self-reported frequency of engaging in an obesity-related behavior; high-calorie food consumption, physical activity, and screen time, “during a normal week of the school year”. The questionnaire also included items measuring students’ age, gender, year level, and friendship ties within the school. Participants’ height and weight were measured in order to calculate BMI, which is included in the subsequent analyses as a control variable.3

High-calorie food consumption. Four items assessed weekly consumption of fast food, savory snack foods, sweet snack foods and high-calorie drinks. To aid understanding and recall, each item provided respondents with examples of these foods. Respondents rated their consumption frequency on a 5-point scale that was slightly modified to suit each food type, where 1 represented the lowest frequency and 5 the highest frequency (e.g., 1 = less than once a week, 5 = three or more times a day). Overall scores for high-calorie food consumption were calculated by taking a mean of the four food items, with Cronbach’s alphas ranging from 0.60 to 0.69 across the three networks.

Physical activity. Four items assessed the weekly quantity and frequency of respondents’ participation in both organized and non-organized physical activities, which were defined as in the Adolescent Physical Activity Recall Questionnaire (Booth, Okely, Chey, & Bauman, 2002). Organized activities were described as “activities played in teams or supervised by coaches, including training and practice”, whereas non-organized activities included “activities that are not supervised by adults and don’t involve training”, with 30

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3 Because weight status has been associated with friendship selection and social marginalization amongst adolescent peers, controlling for BMI allows us to explore associations between friendship ties and obesity-related behaviors independent of these effects.
examples of both activity types provided to aid comprehension and recall. Respondents rated the *frequency* they engaged in both types of activities on a 5-point scale, where 1 = less than once a week and 5 = every day. The weekly *quantity* of activity, measured in number of hours, was also rated on a 5-point scale, where 1 = none and 5 = seven or more hours a week. Overall scores for organized physical activity and non-organized physical activity were calculated by taking a mean of the *frequency* and *quantity* measures for each activity type. Cronbach’s alpha coefficients ranged from 0.87 to 0.93 for organized physical activity, and from 0.77 to 0.79 for non-organized physical activity.

*Screen time.* Six items measured the *number of hours* spent watching TV/movies, playing video/computer games, and using the Internet on “a normal school day”, and on “a normal day of the weekend”. Responses were given on a 5-point scale, where 1 = none and 5 = more than four hours a day. An overall score for TV/movie watching was calculated by taking a mean of the weekday and weekend scores (Cronbach’s alpha coefficients ranged from 0.53 to 0.75). An overall score for “other” screen activities was calculated by taking a mean of the weekday and weekend scores of video/computer gaming and Internet use (Cronbach’s alphas ranged from 0.66 to 0.81).

*Measurement of directed friendship ties.* Respondents listed the first and last names of all of their “close friends” (defined as friends they “hang around with” the most), not including siblings, that attended the same school and were in their year level. Respondents were also provided with a response option indicating that their close friends were not at this school. The number of friends to nominate was not specified, although 15 lines were provided.

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4 Because the “TV/movie watching” summary measure was only based on two items, and the Cronbach’s alpha coefficients for Network 1 and Network 2 were acceptable (both 0.75), the overall score was used despite the low alpha coefficient in Network 3 (0.53).
The three school friendship networks were found to be strongly segregated by gender: the proportion of friendship ties that were inter-gender amongst the two year 8 groups was 18% (School 1) and 17% (School 2), and was 10% amongst the year 9 group. As the social processes underpinning friendship selection, and potentially social influence, likely differ for inter-gender vs. intra-gender friendship ties in early adolescence, we decided to consider only intra-gender friendship ties in this paper and to explore male and female friendship networks separately.\(^5\) The demographic and network characteristics for each of these six friendship networks (three male, three female) are summarized in Table 1, and the descriptive statistics of the behavioral measures are summarized in Table 2.

**Analysis Methods**

Statistical analysis was conducted with PNet (Wang, Robins, & Pattison, 2006), a program for the simulation and estimation of ERGMs. PNet implements Markov Chain Monte Carlo Maximum Likelihood Estimation to estimate model parameters and standard errors, based on a fixed number of nodes. Parameter estimates of zero indicate that the effect being modeled occurs at a rate consistent with chance, whereas a positive parameter suggests the effect is more prevalent and a negative parameter that the effect is less prevalent than chance, given the other effects in the model. Effects are tested using a \(t\)-ratio (the parameter estimate divided by the standard error) and are assessed as significant when the absolute value of this ratio exceeds two (Snijders, et al., 2006).\(^6\) Once convergent estimates were achieved goodness of fit was assessed via simulation of the estimates in PNet.

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\(^5\) Initial analyses of friendship networks that included both males and females found some similar effects to the analyses reported below, but also obscured many effects that were gender based. Accordingly, a separate analysis of male and female friendship networks seems reasonable.

\(^6\) We label an effect as significant following the usual practice in the ERGM literature of a parameter estimate that is more than twice its standard error. Caution needs to be adopted about exact probabilities, however, as underlying distributions are not known.
Each model included parameters for both structural (endogenous) and node-level effects; these parameters and their corresponding graph configurations are outlined in Table 3. Following the suggestion of Snijders et al. (Snijders, et al., 2006), graph density was fixed in most models to facilitate convergence of the estimation algorithm.
Table 1. *Demographic and Network Characteristics of the Adolescent Friendship Networks*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Male friendship networks</th>
<th>Female friendship networks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>N</td>
<td>90</td>
<td>57</td>
</tr>
<tr>
<td>School</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Year level</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Outdegree Mean (SD)</td>
<td>5.2 (3.0)</td>
<td>5.7 (3.2)</td>
</tr>
<tr>
<td>Min, Max</td>
<td>0, 14</td>
<td>0, 15</td>
</tr>
<tr>
<td>Indegree Mean (SD)</td>
<td>5.2 (2.9)</td>
<td>5.7 (3.4)</td>
</tr>
<tr>
<td>Min, Max</td>
<td>0, 11</td>
<td>0, 15</td>
</tr>
<tr>
<td>Behavior</td>
<td>Male friendship networks</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>Fast food&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.9 (0.8)</td>
<td>2.2 (0.9)</td>
</tr>
<tr>
<td>Savory snacks&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.3 (0.9)</td>
<td>2.4 (0.9)</td>
</tr>
<tr>
<td>Sweet snacks&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.4 (0.9)</td>
<td>2.4 (1.0)</td>
</tr>
<tr>
<td>High-calorie drink&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.5 (1.2)</td>
<td>2.8 (1.3)</td>
</tr>
<tr>
<td>Organized PA Frequency&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.2 (1.0)</td>
<td>3.4 (1.0)</td>
</tr>
<tr>
<td>Organized PA Quantity&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.6 (1.1)</td>
<td>3.5 (1.1)</td>
</tr>
<tr>
<td>Non-organized PA Frequency&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.5 (1.1)</td>
<td>3.3 (1.2)</td>
</tr>
<tr>
<td>Non-organized PA Quantity&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.5 (1.1)</td>
<td>3.3 (1.0)</td>
</tr>
<tr>
<td>TV/movies (avg. weekday/end)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3.3 (0.8)</td>
<td>3.5 (0.8)</td>
</tr>
<tr>
<td>Gaming (avg. weekday/end)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.7 (1.0)</td>
<td>2.7 (1.0)</td>
</tr>
<tr>
<td>Internet (avg. weekday/end)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.3 (0.9)</td>
<td>2.6 (1.2)</td>
</tr>
</tbody>
</table>

Note. <sup>a</sup>1 = almost never, 2 = less than once a week, 3 = one to two times a week, 4 = three to six times a week, 5 = every day
<sup>b</sup>1 = less than once a week, 2 = once or twice a week, 3 = three to six times a week, 4 = one to two times a day, 5 = three or more times a day
<sup>c</sup>1 = less than once a week, 2 = once a week, 3 = two to three times a week, 4 = four to six times a week, 5 = every day
<sup>d</sup>1 = none, 2 = one hour or less a week, 3 = two to three hours a week, 4 = four to six hours a week, 5 = seven or more hours a week
<sup>e</sup>1 = none, 2 = less than one hour a day, 3 = one to two hours a day, 4 = three to four hours a day, 5 = more than four hours a day
Table 3. Parameters Included in the ERGMs for the Directed Friendship Networks

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tie configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reciprocity</td>
<td><img src="image1" alt="Tie Configuration" /></td>
<td>Models the tendency for ties to be reciprocated.</td>
</tr>
<tr>
<td>2 Popularity (k-instar)</td>
<td><img src="image2" alt="Tie Configuration" /></td>
<td>Models the in-degree distribution and tendency for popularity.</td>
</tr>
<tr>
<td>3 Expansiveness (k-outstar)</td>
<td><img src="image3" alt="Tie Configuration" /></td>
<td>Models the out-degree distribution and reflects social activity or expansiveness.</td>
</tr>
<tr>
<td>4 Transitive closure (directed k-triangles: AKT-T)</td>
<td><img src="image4" alt="Tie Configuration" /></td>
<td>Models the tendency for 2-paths to close, meaning for 'a friend of a friend to become a friend' (i.e., shared friendship).</td>
</tr>
<tr>
<td>5 Multiple connectivity (directed k-2paths: A2P-T)</td>
<td><img src="image5" alt="Tie Configuration" /></td>
<td>Models nodes that are connected by many 2-paths; a pre-cursor to transitivity.</td>
</tr>
<tr>
<td>6 Sender</td>
<td><img src="image6" alt="Tie Configuration" /></td>
<td>Models the tendency for ties to be sent from nodes with a particular attribute (black node) to any node (white node).</td>
</tr>
<tr>
<td>7 Receiver</td>
<td><img src="image7" alt="Tie Configuration" /></td>
<td>Models the tendency for ties to be sent from any node (white node) to nodes with a particular attribute (black node).</td>
</tr>
<tr>
<td>8 Absolute difference</td>
<td><img src="image8" alt="Tie Configuration" /></td>
<td>Models the tendency for ties to be sent to nodes with similar or different scores on a continuous attribute.</td>
</tr>
</tbody>
</table>

Note. See Snijders et al. (2006) and Robins, Pattison, & Wang (2009) for additional information on model parameters.

To test the hypothesis that friends would be similar on measures of obesity-related behaviors, the models included parameters for an absolute difference effect (parameter 8) for each of the continuous behavioral measures. This effect models the absolute difference of a variable between nodes who share a directed tie: a significant negative parameter estimate indicates a propensity for nodes that are tied to be similar (i.e., have less of a difference than expected by chance) on the attribute in question, given other effects in the model. To explore associations between popularity and individual behavior, parameters for receiver effects (parameter 7) were also included for each continuous behavioral attribute.
Receiver effects model associations between values on an individual variable and in-degree, with positive estimates indicating high values on this attribute are associated with receiving more ties. Sender effects (parameter 6) for each behavioral variable were included as a control and model associations between values on an individual variable and out-degree. All behavioral measures were standardized to normalize data.

Node-level effects for each of the five behavioral measures were first modeled independently. As there were no significant absolute difference effects for TV/movie watching or non-organized physical activity these measures were not included further in the analyses. Final models were developed using a backward selection process whereby node-level effects for all other behaviors were modeled simultaneously to test for competing effects, and non-significant variables removed one step at a time. Parameters for node-level effects associated with BMI (absolute difference, sender, and receiver effects) were also included in the final models, to control for the possibility that associations between friendship ties and behavior may be explained by associations between friendship ties and body mass. In all models, node-level effects were estimated in conjunction with parameters for structural effects (parameters 1 through 5) that were also expected to explain network structure and thus need to be controlled while examining the behavioral effects.

---

7 Models that did not control for BMI-related effects were also run. The significant absolute difference effects did not differ from those reported below suggesting that behavioral similarity amongst friends is not explained by similarity on BMI.
Results

Structural Effects

The final model parameter estimates and standard errors for the structural effects in each of the six friendship networks (three male, three female) are presented in Table 4, with significant parameters denoted by an asterisk (*).

Endogenous effects were found to explain the structure of the observed networks, and thus need to be accounted for when testing the hypotheses. Across all friendship networks, there were significant reciprocity effects, meaning friendship ties tended to be reciprocated between dyads. All six networks also had significant positive transitive closure parameters, coupled with negative multiple connectivity parameters. This combination signifies a tendency for “a friend of a friend to become a friend”, common in adolescent friendship networks (e.g., Espelage, Green, & Wasserman, 2007), and also indicates that the networks were characterized by segmented, clustered friendship groups. Most networks also had significant negative popularity and expansiveness effects, meaning nodes with high in-degrees and out-degrees were not likely, unless they formed as a result of other transitive clique-like structures. This can be interpreted to mean that nodes who are popular or socially expansive are so within the context of cliques or clusters of friends.
Table 4. *Model Parameter Estimates (Standard Errors) for Structural Network Effects*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Male friendship networks</th>
<th>Female friendship networks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>Reciprocity</td>
<td>1.77 (0.21)*</td>
<td>2.05 (0.23)*</td>
</tr>
<tr>
<td>Popularity</td>
<td>-0.76 (0.18)*</td>
<td>-0.06 (0.22)</td>
</tr>
<tr>
<td>Expansiveness</td>
<td>-0.68 (0.18)*</td>
<td>-0.99 (0.29)*</td>
</tr>
<tr>
<td>Transitive closure</td>
<td>1.63 (0.11)*</td>
<td>1.01 (0.10)*</td>
</tr>
<tr>
<td>Multiple connectivity</td>
<td>-0.14 (0.02)*</td>
<td>-0.16 (0.02)*</td>
</tr>
</tbody>
</table>
Difference Effects

The hypothesis that adolescent friends would be similar on obesity-related behaviors was tested by model parameters for absolute difference effects, with significant negative estimates indicating the hypothesis was supported. The parameter estimates and standard errors for the preliminary models (with effects for each behavior modeled independently) and final models are presented in Table 5, with significant parameters denoted by an asterisk (*), and significant or marginally significant effects in bold.

The final models illustrate some clear trends in friend similarity on obesity-related behaviors. In Network 1 and Network 3, both male and female friends were found to engage in similar amounts of organized physical activity, as indicated by the significant negative difference effects in the final models. However in Network 2, there was no evidence that male or female friends were alike on organized physical activity. The final models also suggest there are some important gender differences in tendencies towards behavioral homophily. Female friends in all three networks were found to be alike on “other” screen activities, which include time spent playing video or computer games, and Internet use. There was also a trend (although marginally significant) for male friends in Network 2 to be similar on other screen activities, but this effect was not significant amongst male friends in Network 1 and Network 3. Finally, there was some evidence that male friends were alike in their consumption of high-calorie foods. In the preliminary models there were significant negative difference effects for high-calorie food consumption amongst males in Network 1 and Network 2, however once friend similarity on other behaviors was accounted for in the final models, this effect only remained marginally significant in Network 2. This suggests that although male friendships in these two networks might not have been based on similarity in high-calorie food consumption, as similarity amongst friends seems
better explained by other correlated behaviors, it remains that male friends were nonetheless alike in the amount of high-calorie foods they reported consuming. Finally, across all three networks, there was no evidence that friends (male or female) were similar in the amount of non-organized physical activities they did, or on the amount of TV/movies they watched.

Receiver Effects

Receiver effects modeled associations between individual obesity-related behaviors and popularity (as measured by in-degree). For males, participation in organized physical activity was positively associated with receiving ties in Network 1 (significant estimate of 0.170 ($SE = 0.064$)) and Network 3 (marginally significant estimate of 0.154 ($SE = 0.083$)), indicating that boys who did the most organized physical activity tended to be the most popular. Worth noting is that in these two male friendship networks, both receiver effects and difference effects were significant for organized physical activity. Amongst males in Network 3, there was also a significant positive receiver effect for high-calorie food consumption (parameter estimate = 0.175, $SE = 0.075$), where popular boys also tended to be the highest consumers of unhealthy snack and junk foods.

There were no receiver effects found in the female friendship networks, apart from a marginally significant positive association between in-degree and screen activities in Network 1 (parameter estimate = 0.183, $SE = 0.099$). This can be interpreted as a trend for popular girls to be the highest users of video/computer games and Internet. Again, this receiver effect was paired with a significant difference effect showing a tendency for similarity amongst female friends on screen activities in this network.
Table 5. *Model Parameter Estimates (Standard Errors) for Absolute Difference Effects*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Male friendship networks</th>
<th>Female friendship networks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>Preliminary models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-calorie food</td>
<td>-0.093 (0.040)*</td>
<td>-0.119 (0.045)*</td>
</tr>
<tr>
<td>Organized PA</td>
<td>-0.089 (0.039)*</td>
<td>-0.033 (0.045)</td>
</tr>
<tr>
<td>Non-org. PA</td>
<td>-0.015 (0.035)</td>
<td>-0.030 (0.042)</td>
</tr>
<tr>
<td>TV/movies</td>
<td>0.015 (0.039)</td>
<td>-0.041 (0.045)</td>
</tr>
<tr>
<td>Other screen</td>
<td>-0.007 (0.043)</td>
<td>-0.092 (0.046)*</td>
</tr>
<tr>
<td>Final models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-calorie food</td>
<td>-0.082 (0.044)</td>
<td></td>
</tr>
<tr>
<td>Organized PA</td>
<td>-0.098 (0.032)*</td>
<td>-0.079 (0.037)*</td>
</tr>
<tr>
<td>Other screen</td>
<td>-0.069 (0.035)</td>
<td>-0.099 (0.038)*</td>
</tr>
</tbody>
</table>
Discussion

Adolescent school friends were found to be similar on some obesity-related behaviors, particularly leisure activities. Organized physical activity was an important factor in adolescent friendships in two of the three networks, with male and female friends tending to be alike in the extent that they participated in activities such as sports and training. Female friends in all three networks were found to be similar on sedentary screen-based activities, including video/computer gaming and Internet use. Perhaps surprisingly, male friends in two of the three networks were not alike on screen activities, and whether this reflects differences in the social nature of the screen activities is not known but is an area for future research. With regards to high-calorie food consumption, only male friends in two of the networks were alike in the amount of snack foods and fast food they consumed. However, this tendency for similarity on food consumption seemed to be a consequence of friend similarity on other correlated health behaviors such as physical activity and screen activities.

Although effects of friend similarity on obesity-related behaviors showed some differences across school contexts and age groups, the interpretation of any clear trends driven by these variables was limited by the small number of networks sampled. As contextual factors such as school policies or facilities that impact on food consumption and physical activity are modifiable, it may be important to consider in future how they mediate social influence in a school setting.

Longitudinal research is needed to explore the dynamic processes that underlie behavioral similarity amongst peers. These effects may result from processes of social influence, whereby adolescents adopt behaviors that are similar to those of their friends. It is also likely that adolescents form friendship ties as a result of common extra-curricular
activities, whether they are active or sedentary, that may result in similarity through friendship selection. In any event, our cross-sectional findings point to the potential value of network-based health initiatives that target organized physical activity, screen activities, and high-calorie food consumption at school, because the school-peer environment seems to function to maintain groups of friends whose behaviors are obesity-protecting or obesity-promoting. The clustering of similar friends into small social groups suggests network analysis could be used to design interventions that target particular “unhealthy” friendship groups. Alternatively, interventions harnessing influential peers to promote healthy behaviors and norms have been found to be successful in adolescent school environments (Campbell et al., 2008) and could be trialed to address these particular obesity-related behaviors.

Although our results indicate some behaviors are associated with friendship, it is also of interest to see which behaviors were not the bases of friendship formation in these networks. Adolescent friends were not found to be alike on measures of non-organized physical activity, which includes active play and locomotion, or on time spent watching TV and movies. As friendship selection may be less likely to be based on preferences for active transportation or TV viewing habits than sports or screen activities, there may be little similarity amongst close friends. Additionally, if these activities tend to occur outside of the peer environment, social contexts such as the family may be more influential than peers, and thus a more relevant milieu for interventions. Whether activities engaged in by groups of adolescents can be described as “social” is also matter for debate; some activities may be largely driven by individual or environmental factors.

Previous studies have consistently found friends to be alike on a number of health behaviors, however the results of this study are more varied. Some of these prior results
were based on perceived reports of friends’ behavior, and as noted above, perceived reports in this age group may overestimate behavioral similarity amongst friends (Ryan, 2001). This study has also accounted for transitive closure, whereas previous results based on independent dyadic friendships may be epiphenomenal of the structural dependencies in the network. In fact, “network effects” have been found for health outcomes such as acne and height using regression models commonly employed in peer influence research (Cohen-Cole & Fletcher, 2008a). The authors suggest these implausible network effects are a result of inadequately controlled environmental confounders, however they may also be explained to some extent by failing to control for friendship selection and network structure. Comparisons between results obtained using regression models and ERGMs, when studying longitudinal network effects, is an area that warrants further investigation.8

Additionally, we found evidence that popularity within adolescents’ school friendship networks was associated with some obesity-related behaviors, although these effects were localized within networks suggesting that the underlying social processes may be unique to the local culture developed within each year level cohort. Importantly, the tendency for behaviors to be associated with popularity (receiving ties) occurred only alongside effects for similarity amongst friends on that behavior. For example, amongst male friends in Network 1 and Network 3, there was a tendency for friends to be alike on organized physical activity and for physical activity to be associated with social status, with popular students tending to do the most sport or organized physical activities. This highlights the role popular students may have in making particular health behaviors salient to friendship formation amongst their

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8 Thanks to the suggestions of one reviewer, we also ran dyadic independent network models that did not control for network structure. Although some node-level effects were similar to those reported in this paper, several effects that were significant in the dyadic independent models dropped off in models that included parameters for structural effects. Additionally, a few node-level effects that were not significant in the dyadic independent models became significant once network structure was accounted for. We believe this lends support to claims that controlling for endogenous network processes is important when testing hypotheses of similarity or influence amongst network partners. It is risky to rely on regressions when the data contains the type of independencies implicit in a network representation.
peers, or alternatively may be indicative of social pressures on popular students to adopt behaviors that are socially valued and relevant in their local peer network. These popular students may also be an important source of social influence, particularly within their respective friendship clusters (as indicated by the structural effects showing popularity and expansiveness tended to be localized in smaller friendship groups).

To conclude, research has suggested that weight status in adolescents and adults is influenced by their friendship ties and that over time obesity can spread through social networks (Christakis & Fowler, 2007; Fowler & Christakis, 2008). This paper has applied ERGMs to explore obesity-related behaviors in male and female adolescent friendship networks, and has found that friends are similar on some leisure activities and food consumption behaviors as early as 13 to 14 years of age; a potential mechanism for the social “contagion” of overweight and obesity.
CHAPTER 7. PAPER 4

How Physical Activity Shapes, and is Shaped By, Adolescent Friendships

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Social Science & Medicine, 2010; Submitted paper

Statement of Contributions

Kayla de la Haye (Candidate)

I was responsible for the design and implementation of the research project, including the collection and management of all data. I performed all statistical analyses, interpreted the results, and wrote the manuscript, with input from all co-authors. I have acted as corresponding author since the manuscript's submission. I certify that the statement of contribution is accurate.

Signed:      Date:   07/10/10
Garry Robins (External supervisor)

I contributed to the conceptual design of the study and in particular provided guidance on the measurement of network data, strategies for data analysis, and interpretation of the statistical models. I have also commented on drafts of the manuscript. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed: Date: 11/10/10

Philip Mohr (Co-supervisor)

I contributed to the planning of this project, and have given advice on the study’s implementation. In my role as co-supervisor, I have provided input into the interpretation of the results and revisions to the manuscript. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed: Date: 06/10/10

Carlene Wilson (Primary supervisor)

As primary supervisor, I oversaw the development of this work, and contributed to the planning of the project, interpretation of the results, and in framing the research arguments. I have also provided comments on drafts of this manuscript. I certify that the statement of contribution is accurate and I give permission for the inclusion of the paper in the thesis.

Signed: Date: 11/10/10
Abstract

Objective: Physical activity (PA) participation within adolescent friendship networks was explored longitudinally to determine if friends influenced PA, and if this process was mediated by cognitive mechanisms.

Methods: Self-reported participation in PA, cognitions about PA, and friendship ties to grademates were measured in two cohorts of Australian grade eight students ($N = 378; M$ age = 13.7) three times over one school year. Interdependence between the friendship networks and PA was tested using stochastic actor-oriented models.

Results: Participants tended to befriend peers who did similar amounts of PA, and subsequently emulated their friends’ behaviors. Friends’ influence on PA was not found to be mediated through adolescents’ cognitions towards PA.

Conclusions: The relationship between adolescent friendships and PA is dynamic. Our results highlighting some novel network-based strategies that may be effective in supporting young people to be physically active.
How Physical Activity Shapes, and is Shaped By, Adolescent Friendships

Physical activity (PA) tends to decline in adolescence with few youth, particularly girls, meeting recommended activity guidelines (Aaron, Storti, Robertson, Kriska, & LaPorte, 2002; Gordon-Larsen, Nelson, & Popkin, 2004). From a public health and child development perspective this is problematic, because engagement in PA has been found to have a positive immediate and long-term impact on physical and mental health (Hallal, Victora, Azevedo, & Wells, 2006). Lack of vigorous PA has also been identified as a key risk factor for overweight in adolescents (Patrick et al., 2004). Evidence of a dose-response relationship between adolescent PA and positive health outcomes is lacking, and the required threshold remains unclear. Recommendations for participation in moderate to vigorous PA (MVPA) therefore range widely, from 20 minutes at least three times a week (Sallis & Patrick, 1994), to 60 minutes every day (Biddle, Cavill, & Sallis, 1998). Nonetheless, the positive impact of being active in adolescence is clear, and public health authorities worldwide recognize the importance of initiating and maintaining participation in MVPA in this age cohort. To date, initiatives that have been successful in achieving these aims are characterized as being multicomponent school-based interventions, which also involved family or community settings (van Sluijs, McMinn, & Griffin, 2007).

The success of school-based PA interventions may, in part, be due to the role of school peers in supporting these behaviors. Activities such as sports and active play are typically very social at this age, and a growing body of evidence suggests that young people’s friends are important referents for these behaviors. Perceived social support from friends, by watching or encouraging sporting activities, has been associated with increased PA (Duncan, Duncan, & Strycker, 2005), and participating in PA with friends has been positively associated with activity levels amongst young girls (Voorhees, et al., 2005). As emphasized
in social learning theory (Bandura, 1977), friends modeling and social reinforcement of these activities may be an important determinant of adolescent PA. In a school context, emulating friends’ behaviors may also be a useful strategy in establishing or maintaining friendship relations (Brown, Bakken, Ameringer, & Mahon, 2008).

Friends may also have a direct impact on young people’s attitudes and thoughts about PA. For example, adolescents’ perceptions of peer norms have been found to predict their attitudes towards PA, and also directly predicted intentions to engage in PA amongst boys (Baker, Little, & Brownell, 2003). The theory of planned behavior (Ajzen, 1991), which is commonly employed to predict health behaviors in adults and adolescents (Armitage & Conner, 2001), proposes that the social environment influences individual behavior via perceptions of norms. Subjective norms, as well as attitudes and perceptions of behavioral control, subsequently predict intentions to engage in the behavior, and intentions (moderately) predict future behavior. Support for this proposed cognitive pathway of social influence is sparse however, particularly for adolescents, because subjective norms are often found to be a relatively weak predictor of behavioral intentions (Armitage & Conner, 2001).

These findings would suggest that adolescent friends are likely to be similarly engaged in PA, a phenomenon known as homophily (McPherson, Smith-Lovin, & Cook, 2001). However, studies looking at self-reported behaviors amongst friends have found interesting, albeit conflicting, associations. In Australia, a cross-sectional study found that friends participated in similar amounts of organized PA, such as sports and training (de la Haye, Robins, Mohr, & Wilson, 2010). Yet, a longitudinal study in Scotland found that young people showed a preference for friends with different sporting behaviors (Pearson, Steglich, & Snijders, 2006). Similarities in PA may therefore not always be a characteristic of friendships, and whether behavioral similarities (or in fact differences) arise because youth
form relationships with peers who have similar behaviors (i.e., selection processes) or because they change their behaviors to emulate their friends (i.e., influence processes), is not clear.

The conclusions to be drawn from the current literature are limited by a number of factors. First, many of the studies outlined above are cross-sectional and so cannot tease out the directionality of the effects. Second, few studies account for the role of PA in the initial formation of friendships, which may plausibly account, to some extent, for behavioral similarities (or differences) amongst friends. Third, although the literature has established the importance of adolescents’ perceptions of their friends’ behavior, additional research measuring *self-reported* behavior amongst friends is needed to verify if friends’ actual behaviors are influential. And finally, many studies make assumptions about the independence of individuals or friendship dyads, when they are likely to be embedded in larger, interdependent, social structures (Snijders, Pattison, Robins, & Handcock, 2006). Research that accounts for the patterns of interdependent friendship connections, or *friendship network*, within a group of individuals, as well as individual-level variables, is likely to provide a more precise and rich account of behavioral outcomes (Robins & Kashima, 2008). The implications of these limitations are an inadequate understanding of the processes that lead to associations in PA amongst adolescents and their friends, the magnitude of these effects, and the mechanisms that may be underpinning this.

To address these limitations, this study employed new methods to longitudinally model individual (self-reported) behavior in the context of complex friendship networks. These stochastic actor-oriented models (SAOMs) for the co-evolution of social networks and behavior (Snijders, Steglich, & Schweinberger, 2007) allow us to simultaneously test effects of friendship selection and influence associated with PA, and to explore potential
mechanisms driving these processes. Longitudinal studies of adolescent friendship networks using these methods have found that some health behaviors, particularly risky behaviors like smoking and substance use, are relevant to the formation of adolescent friendships, and are also influenced by friends (e.g., Mercken, Snijders, Steglich, Vartiainen, & de Vries, 2010; Pearson, et al., 2006). This is evidenced by the tendency for adolescents to select friends who engage in particular (often similar) behaviors, and for the behaviors of friends to become increasingly alike over time. Although increasing behavioral similarities amongst socially connected individuals may result from shared environments or opportunities (Cohen-Cole & Fletcher, 2008b), it is typically attributed to social influence, although as we highlight above, the processes that underpin this are not well understood and likely to be complex. Whether or not friends influence adolescent PA, controlling for initial similarities when friendships are formed, will be the primary focus of this study. Whether these processes are mediated through adolescents’ attitudes or cognitions towards PA, such as perceived social norms, will also be explored.

In addition to advancing our understanding of peer influence on adolescent health behaviors, delineating the processes that lead to associations in PA amongst young people and their friends may provide insights into possible intervention strategies. Inhibiting or harnessing social influence processes amongst connected individuals has been identified as a potentially effective approach to health promotion (Valente, 2010). Additionally, recent research looking at the role of social networks in obesity has suggested that obesity tends to “spread” amongst adolescents and their friends, as if it were contagious (Fowler & Christakis, 2008; Halliday & Kwak, 2009). Results of the current study will provide some insights as to whether this phenomenon is likely to be driven by the clustering and/or socialization of PA behaviors amongst adolescent friends.
In the current study, it is expected that participation in PA will play a role in the formation of adolescent friendships, and that adolescents will be influenced by their friends’ behavior, resulting in PA similarities amongst friends growing stronger over time. Potential psychosocial mechanisms underpinning these selection and influence processes will also be explored. Based on social cognition models of behavior (Ajzen, 1991; Bandura, 1977) we anticipate that adolescents will emulate the behaviors of their friends, and that this process will be partially mediated via perceptions of peer norms and intentions.

Method

Sample

Two groups of participants, each defined as a separate friendship network, were recruited from grade 8 cohorts at two public high schools in metropolitan Australia. At both schools, grade 8 is the first year of high school, with students feeding in from numerous primary schools. Information letters were mailed to the homes of all students, inviting them to participate in the study and giving parents/guardians and students the opportunity to opt-out. The letter also stated that participants would be entered into a draw to win a $20 gift voucher for a local sporting goods store. Participation rates at each school were excellent, with 92.9% of students in Group 1 (n = 222, 52.7% male) and 90.2% of students in Group 2 (n = 156, 55.1% male) taking part in the study, resulting in total sample of 378 students. At the start of the study, the mean age of participants was 13.6 years in Group 1 (SD = 0.4; range 12.3 to 14.4), and 13.6 years in Group 2 (SD = 0.4; range 12.3 to 15.6).

Procedure and Measures

Three waves of data were collected over the school year, each involving the completion of a paper-based questionnaire in class under teacher supervision.
Questionnaire items assessed school-based friendship relations, engagement in moderate to vigorous physical activity (MVPA) over the previous month, as well as attitudes and cognitions about regular engagement in MVPA. These measures were part of a larger questionnaire that took 25 minutes to complete. The final questionnaire was developed based on a pilot of a preliminary version, tested with a sample of Australian adolescents.

**Friendship networks.** Friendships amongst school peers were assessed by having participants list the names of their close friends, defined as “friends you hang around with the most”, who were in their grade level at school. Students were then instructed to circle the names of listed friends who they considered to be their “best friends”, and only these best friend nominations were used for this study. There were no limitations on the number or gender of nominated friends.

**Participation in physical activity.** Three items measured participation in MVPA outside of school, over the past month. MVPA was defined as “activities that make your heart beat faster and make you sweat” and did not include walking. Items measured average weekly frequency of participation in PA from 1 (never) to 7 (everyday), and responses to the statement “In the past month, have you done physical activities in your spare time at least 3 times a week” (rated on a 7-point scale, anchored by definitely did not do this - definitely did do this). The third item assessed average weekly hours of MVPA by having participants list specific physical activities they had done in a typical week over the previous month, as well as the average duration (minutes) and weekly frequency of each activity. This information was used to calculate average weekly hours of MVPA, and this was rescaled into 7 categories where 1 = none and 7 = 14 or more hours. The mean of these three items, labeled “behavior”, was calculated for each of the three waves to reflect overall participation in MVPA (Group 1 $\alpha = .79$ to .84, Group 2 $\alpha = .77$ to .84).
**PA-related attitudes and cognitions.** Standard items were used to measure variables derived from the theory of planned behavior (Ajzen, 1991), including attitudes, descriptive peer norms, injunctive peer norms, perceived behavioral control, self-efficacy, and behavioral intentions. All items were rated on 7-point scales anchored by two statements, unless otherwise noted.

Attitudes towards PA were measured by two items: “Would you like to do PA at least three times a week... definitely would not like to do this - definitely would like to do this” and “I think that doing PA at least three times a week would be... unenjoyable - enjoyable”. The mean of the two items was used in all analyses, as Cronbach’s alphas showed good reliability across each wave for both groups (Group 1 $\alpha = .76$ to .84, Group 2 $\alpha = .79$ to .86).

Peer norms were measured by two items focusing on the behavior and expectations of school friends with regards to regular PA. Descriptive peer norms were measured by the item “Of your close friends at school, how many do PA at least three times a week... none of my close friends - all of my close friends”. Injunctive peer norms were measured by the item “Do your close friends at school think that you should do PA at least three times a week... they definitely think I should not - they definitely think I should”. As these are considered to represent different normative constructs (Rivis & Sheeran, 2003), and because Cronbach’s alphas for these two measures were low (Group 1 $\alpha = .46$ to .71, Group 2 $\alpha = .55$ to .68), these items were not combined.

Perceived behavioral control was measured by the item “Whether or not I do PA at least three times a week is entirely up to me... strongly disagree - strongly agree.” Self-efficacy was measured by the item “If I wanted I could do PA at least three times a week... definitely false - definitely true.” These two items were retained as independent constructs
for all analyses due to the low Cronbach’s alpha values (Group 1 $\alpha = .25$ to $\alpha = .48$, Group 2 $\alpha = .48$ to $\alpha = .56$).

Finally, two items measured intentions to do MVPA in the coming month: “In the next month, how often do you plan to do physical activities” (rated on a 7-point Likert scale where 1 = never and 7 = every day) and “In the next month, do you intend to do PA at least 3 times a week... definitely do not intend to do this - definitely intend to do this”. The reliability of these two items was good (Group 1 $\alpha = .80$ to $\alpha = .84$, Group 2 $\alpha = .79$ to $\alpha = .86$), and the mean score was used as a measure of intention to do PA.

*Control attributes.* Participants noted their gender (1 = male, 2 = female) and whether they identified with an ethnicity other than Anglo-Australian (1 = identify with another ethnicity). The amount of pocket money (i.e., allowance) available to them each week was also assessed on a 4-point scale, where 1 = less than $10 and 4 = more than $30. A record of participants’ home group class was also obtained from the school, to identify students who regularly shared classes together.

*Analyses*

*SAOMs for social networks and behavior.* To make statistical inferences about whether changes to friendship ties and to participation in PA were interdependent, SAOMs for the co-evolution of networks and behavior were used (Snijders, et al., 2007). These models are implemented in the SIENA (Simulation Investigation for Empirical Network Analysis) 4.0 software (Ripley & Snijders, 2010). The overall approach of the algorithm is to choose a random individual (or *actor*) in the network, and determine the probabilities associated with the actor making particular changes to their social ties or behavior, given the current state of the network.
In these simulation models, friendship ties and individual’s behavior (i.e., PA) are the dependent variables. Information on these variables, as well as other covariates, are collected at each wave of the study representing the observed state of the network at given points in time. At each wave the network is formally represented as a directed adjacency matrix with $n \times n$ cells, coded as 1 to represent a friendship tie, and 0 the absence of a tie, between each pair of actors. Outgoing ties from non-participants at each wave are coded as missing, with all missing data treated as non-informative in the models, and imputed for the simulation process (Ripley & Snijders, 2010). Changes between the observed panels of data are modeled using continuous time Markov chains, to determine the most likely series of unobserved micro-steps taken by actors when changing their ties or behavior. This is captured in two components of the model; the rate function and the evaluation function. The rate function assesses how quickly these changes occur (i.e., the average number micro-steps between waves), and the evaluation function determines the “rules” that guide these changes. These rules are formalized as specific effects in the model, and the parameter estimates for these effects allow us to infer which were the most likely to have governed the series of unobserved micro changes, that resulted in larger observed changes across the panels of data.

To model the evolution of both the friendship network and individual behavior, two submodels are estimated simultaneously, each with rate and evaluation functions, and each controlling for effects in the other. The network dynamics submodel tests effects predicting changes to friendship ties, and the behavior dynamics submodel tests effects predicting changes to the dependent behavior variable (e.g., PA).

Before describing the model specifications applied in this study, we will briefly outline some of the relevant assumptions (described in greater detail in Snijders, van de
Bunt, & Steglich, 2010). Because we are modeling a continuous-time Markov process, the unobserved micro-changes to friendship ties and behavior are assumed to occur in a step-by-step fashion. Actors can either change a network tie or adjust their behavior, and are assumed to react to each other’s changes. This approach also implies that actors base these changes on the current state of the network, not on previous states. Finally, the network ties are assumed to be states rather than brief events. The models may therefore not be suitable for the study of brief social connections, such as email messages or phone calls, but are more appropriate for the study of relationships that tend to be relatively enduring.

**Model specification.** Two models were estimated to test our hypotheses. The first, labeled the *behavior only model*, examined the evolution of the friendship networks and PA, where friendship ties and PA behavior were the dependent variables of interest. The network dynamics component of this model tested three effects of PA behavior on changes to friendship ties. The first was a main effect of actor PA behavior on outgoing friendship nominations (behavior adolescent), and the second was a main effect of actor PA behavior on friendship nominations received (behavior potential friend). Positive estimates for these two main effects reflect a tendency for individuals with high PA behavior scores to send or receive a higher number of friendship nominations respectively, compared to individuals with low scores. Finally, a third interaction effect tested whether or not similarities on PA behavior between actors and potential friends predicted friendship ties (behavior similarity). A positive parameter estimate would indicate that participants tended to form friendships with peers who had similar PA behavior scores to themselves, and would provide support for our first hypothesis.

Effects of actor-covariates (gender, ethnicity, and pocket money) on changes to friendship ties were also controlled for in the network dynamic submodel. For each
covariate, the two main effects and one interaction effect described for PA behavior above were estimated. Additionally, an effect of sharing the same home group class on friendship ties (represented as a dyad-level covariate for each pair of actors) was included in the model. Social networks are also assumed to be self-organizing, meaning that the likelihood of a friendship tie between two individuals is also dependent on the presence (or absence) of other ties. To control for these structural dependencies commonly found to impact the likelihood of adolescent peers becoming friends (e.g., Mercken, et al., 2010), three effects were included. An outgoing ties effect modeled the overall tendency to form friendship ties, which is typically negative in large groups as people tend to nominate a relatively small number of potential friends. A reciprocating ties effect reflected the tendency for mutual friend nominations, and a transitivity effect (also called transitive ties) the likelihood for friendships to form between friends of friends. The inclusion of these structural effects as predictors of friendship ties, particularly transitivity, is important so that the effect of PA on friendship selection is not overestimated.

The behavior dynamics component of the behavior only model tested effects predicting changes to actors’ PA behavior scores. The hypothesis that friends would influence adolescent PA was tested by an effect of “friend behavior” on actors’ PA behavior. A significant positive effect would indicate a tendency for actors to change their behavior so that it became more similar to the average behavior score of their nominated friends. Covariate effects on changes to PA behavior were also controlled for. Positive covariate effects indicate that actors with high scores on the attribute tend to increase their PA behavior score. To model the overall distribution of PA scores over time, linear and quadratic shape effects were also included (Snijders, et al., 2010).
The second aim of our study was to explore whether friend selection and influence effects associated with PA behaviors were partially mediated by adolescents’ attitudes and cognitions about PA. To do this we specified a second model for the co-evolution of the friendship networks, PA behaviors, and PA-related intentions, attitudes, perceived norms, perceived behavior control, and self-efficacy (behavior and cognitions model). The approach for model specification was the same as for the behavior only model, with PA-related attitudes and cognitions also included as dependent variables. The network dynamics submodel therefore included main and interaction effects of each PA-related variable on changes to friendship ties, thus testing for competing selection effects. The behavior dynamics submodel included rate and evaluation functions for all PA-related dependent variables, and tested effects of friends’ scores on changes to actors’ scores for each measure. Therefore, friends’ influence on PA behavior, indicated by a tendency for scores to assimilate amongst friends, was tested alongside effects for assimilation on attitudes and cognitions.

Additional details. Because each grade-level cohort was treated as a separate social network (i.e., participants could only nominate friends within their school grade level), a multi-group analysis for multiple networks approach was used (Ripley & Snijders, 2010). First, the models described above were estimated for each group independently. Once homogeneity of the PA-related effects across the two networks was confirmed, they were combined into one project with the same model specifications and parameter values, although the rate functions were allowed to differ.

To specify the two final models, we used a forward selection approach (described in Burk, Steglich, & Snijders, 2007; Snijders, et al., 2010). Effects for each covariate (groups of main and interaction effects) were score tested against a null model (Schweinberger, 2010),
and if any were significant the group of effects was retained and estimated in the final model. This approach is recommended due to issues with collinearity amongst the effects. Therefore, covariate effects not listed in results tables were found to be non-significant.

**Results**

**Descriptives**

A summary of descriptive statistics is presented in Table 1. The cohort of students from Group 1 (n = 222) and Group 2 (n = 156) were comparable in their ethnic diversity, and had access to similar amounts of pocket money each week. Changes in the PA variables are also summarized in Table 1. Maximum likelihood mixed effects models were used to test for differences between groups and across waves for each of these measures. A significant group by time interaction was found for PA behavior (p = .003). Post hoc tests showed no significant group differences, but there were significant changes on this measure across time for both groups, highlighting a decline in activity levels. In Group 1, the mean for behavior at Wave 3 was significantly lower than the mean at Wave 1 (p = .003) and Wave 2 (p = .012). In Group 2, the mean for behavior declined significantly from Wave 1 to Wave 2 (p = .044) but was not significantly different at Wave 3. There was also a significant group by time interaction for attitudes (p = .003). Again, there were no significant differences on this measure between groups at each wave, but there was evidence of a shift towards more negative attitudes in Group 1. As was found for the behavior measure in this group, the mean attitude score at Wave 3 was significantly lower than the mean at Wave 1 (p < .001) and Wave 2 (p < .001). For all other PA variables, there were no significant differences between groups, or across waves. As the rate functions for the behavior dynamics are
allowed to differ in the multi-group SIENA analysis, these group differences in changes to mean behavior and attitude scores were not problematic for subsequent analyses.

Correlations between PA variables and PA behavior in the subsequent wave are presented in Table 2. These show that engagement in PA was fairly consistent across time, indicated by the strong positive correlations between the behavior measures. There were also moderate to large positive relationships between the attitudinal and cognitive measures and subsequent PA behavior, with the strongest effects for intentions and attitudes. Generally, perceived behavior control was not associated with subsequent PA behavior.
Table 1. *Individual Descriptive Statistics*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1 (n = 222)</th>
<th></th>
<th></th>
<th>Group 2 (n = 156)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wave 1</td>
<td>Wave 2</td>
<td>Wave 3</td>
<td>Wave 1</td>
<td>Wave 2</td>
<td>Wave 3</td>
</tr>
<tr>
<td>N classes (avg. n per class)</td>
<td>9 (25)</td>
<td></td>
<td></td>
<td>12 (13)</td>
<td></td>
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<tr>
<td>% other ethnicity</td>
<td>31.1</td>
<td></td>
<td></td>
<td>29.5</td>
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<tr>
<td>M (SD) pocket moneya</td>
<td>1.8 (0.9)</td>
<td>1.7 (0.8)</td>
<td>1.9 (0.9)</td>
<td>2.0 (0.9)</td>
<td>2.0 (1.0)</td>
<td>2.0 (0.9)</td>
</tr>
<tr>
<td>M (SD) for PA variables</td>
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<tr>
<td>Behavior</td>
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<td>4.7 (1.4)</td>
<td>4.4 (1.6)</td>
<td>4.8 (1.6)</td>
<td>4.5 (1.6)</td>
<td>4.7 (1.6)</td>
</tr>
<tr>
<td>Intentions</td>
<td>5.1 (1.5)</td>
<td>5.2 (1.4)</td>
<td>5.1 (1.5)</td>
<td>5.3 (1.4)</td>
<td>5.2 (1.6)</td>
<td>5.3 (1.4)</td>
</tr>
<tr>
<td>Attitudes</td>
<td>6.1 (1.2)</td>
<td>6.1 (1.2)</td>
<td>5.7 (1.4)</td>
<td>5.9 (1.3)</td>
<td>5.9 (1.4)</td>
<td>6.0 (1.3)</td>
</tr>
<tr>
<td>Descriptive peer norm</td>
<td>4.7 (1.3)</td>
<td>4.7 (1.2)</td>
<td>4.5 (1.2)</td>
<td>4.5 (1.4)</td>
<td>4.4 (1.4)</td>
<td>4.5 (1.4)</td>
</tr>
<tr>
<td>Injunctive peer norm</td>
<td>4.8 (1.6)</td>
<td>4.9 (1.5)</td>
<td>4.8 (1.8)</td>
<td>4.7 (1.5)</td>
<td>5.0 (1.7)</td>
<td>5.0 (1.8)</td>
</tr>
<tr>
<td>Perceived behavior control</td>
<td>6.0 (1.3)</td>
<td>6.1 (1.1)</td>
<td>5.9 (1.3)</td>
<td>6.1 (1.3)</td>
<td>6.0 (1.3)</td>
<td>6.1 (1.2)</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>6.3 (1.2)</td>
<td>6.4 (1.1)</td>
<td>6.3 (1.3)</td>
<td>6.3 (1.1)</td>
<td>6.4 (1.2)</td>
<td>6.4 (1.1)</td>
</tr>
</tbody>
</table>

*a1 = less than $10, 2 = $10 to $20, 3 = $20 to $30, 4 = more than $30.*
Table 2. *Correlations of PA Variables with Later Behavior*

<table>
<thead>
<tr>
<th>PA variable</th>
<th>Wave 1 variables with Wave 2 behavior</th>
<th>Wave 2 variables with Wave 3 behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1</td>
<td>Group 2</td>
</tr>
<tr>
<td>Behavior</td>
<td>.67* (164)</td>
<td>.64* (121)</td>
</tr>
<tr>
<td>Intentions</td>
<td>.62* (163)</td>
<td>.54* (121)</td>
</tr>
<tr>
<td>Attitudes</td>
<td>.42* (163)</td>
<td>.53* (121)</td>
</tr>
<tr>
<td>Descriptive peer norm</td>
<td>.41* (162)</td>
<td>.26* (119)</td>
</tr>
<tr>
<td>Injunctive peer norm</td>
<td>.33* (162)</td>
<td>.25* (118)</td>
</tr>
<tr>
<td>Perceived behavior control</td>
<td>-.01 (162)</td>
<td>.24* (119)</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>.32* (163)</td>
<td>.35* (119)</td>
</tr>
</tbody>
</table>

*Note. Correlations are based on pairwise deletion with n in parentheses.*

*p < .01.*
Structural characteristics of the two friendship networks are summarized in Table 3. Across each wave, students in Group 1 nominated approximately 4 best friends, and in Group 2 they nominated approximately 3.5 friends. About one third of these friendship nominations were reciprocated (reciprocity index). The transitivity index indicates the proportion of 2-path relations (where friendship ties exist between AB and BC) that are transitive (where friendship ties exist between AB, BC, and AC), and 39% to 44% of friendships that could easily be transitive, actually were. Although these structural characteristics were quite stable across the school year, not all friendships endured. Between each of the three waves of data (Period 1 and Period 2), students, on average, maintained two friendships, but also dissolved one friendship tie and nominated one new friend. Over the course of the year, new students were invited to participate in the study and could join the friendship network, and some students left. These changes in the composition of the network are summarized in Table 3, and were modeled as exogenous events at specified time points (Huisman & Snijders, 2003).

Observed similarities on PA behavior amongst friends, or network autocorrelation, at each wave is also described in Table 3 using Moran’s I, a measure of spatial correlation. Coefficient values close to 0 indicate that connected individuals (i.e., friends) are not more similar on PA behavior scores than would be expected if they were randomly paired, and values close to 1 indicate that connected individuals are very similar. Friend similarities on PA behavior were found to increase over time, and were strongest in Group 2.
Table 3. *Network Descriptive Statistics*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1 (n = 222)</th>
<th></th>
<th>Group 2 (n = 156)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wave 1</td>
<td>Wave 2</td>
<td>Wave 3</td>
<td>Wave 1</td>
</tr>
<tr>
<td>% non-respondents</td>
<td>14.4</td>
<td>14.9</td>
<td>11.7</td>
<td>13.5</td>
</tr>
<tr>
<td>M (SD) friends nominated</td>
<td>3.8 (2.5)</td>
<td>4.0 (2.6)</td>
<td>4.0 (2.8)</td>
<td>3.4 (2.5)</td>
</tr>
<tr>
<td>Reciprocity index</td>
<td>.34</td>
<td>.37</td>
<td>.34</td>
<td>.33</td>
</tr>
<tr>
<td>Transitivity index</td>
<td>.44</td>
<td>.43</td>
<td>.43</td>
<td>.41</td>
</tr>
<tr>
<td>Network autocorrelation for PA behavior(^a)</td>
<td>.09</td>
<td>.15</td>
<td>.21</td>
<td>.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>M new friendship ties</td>
<td>1.4</td>
<td>1.3</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>M stable friendship ties</td>
<td>2.2</td>
<td>2.4</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>M friendship ties dissolved</td>
<td>1.1</td>
<td>1.2</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Composition change (joined, left)</td>
<td>3, 3</td>
<td>3, 1</td>
<td>6, 1</td>
<td>5, 0</td>
</tr>
</tbody>
</table>

*Note.* The % of non-respondents is the proportion of participants who did not complete the questionnaire. The reciprocity index is the proportion of friendship nominations that were reciprocated. The transitivity index is the proportion of 2-paths (friendship ties between AB and BC) that were transitive (friendship ties between AB, BC, and AC).

\(^a\) Network autocorrelation coefficient: Moran's *I.*
The first two aims of this study were to determine if PA played a role in adolescents’ friendship choices, and if friendships influenced adolescent PA. The behavior only model for the co-evolution of PA behavior and friendship networks tested both of these effects simultaneously. The results are presented across two tables, with the network dynamics submodel summarized in the first column of Table 4, and the behavior dynamics submodel summarized in the first column of Table 5.

The network dynamics submodel (Table 4, column 1) tested effects on changes to friendship ties. The results show that behavior similarity positively and significantly predicted the formation of friendship ties, meaning that participants tended to nominate friends who engaged in similar amounts of PA to themselves. The main PA behavior effects were not significant: adolescent PA (behavior adolescent) was not associated with the number of friends nominated, and peer PA (behavior potential friend) was not associated with the number of friendship nominations received. Covariates significantly predicted friendship choices, with participants showing a preference for friends of the same gender, ethnic background, and who had similar amounts of pocket money. There was also a main gender effect (gender potential friend) with girls attracting more friend nominations than boys. Classroom context was also important, with friendships more likely to form amongst students in the same home group class (same classroom friend).

Friendship choices were also governed by the network structure. The negative outgoing ties effect indicates that the overall density (i.e., proportion of actual vs. potential friendship ties) remained low. The positive reciprocity effect reflects the tendency for friendship nominations to be mutual, and the positive transitivity effect indicates that students were likely to become friends with “friends of their current friends”. So, to
summarize, participants were more likely to become friends with a school peer if 1) that peer had nominated them as a friend, or was a friend of their current friend(s), 2) they shared similar demographics and were in the same home group class, and 3) over and above this, if they also engaged in similar amounts of PA.

Table 4. *Results of the Network Dynamics Submodels*

<table>
<thead>
<tr>
<th>Network dynamics</th>
<th>Behavior only</th>
<th>Behavior and cognitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PE (SE)</td>
<td>t-value</td>
</tr>
<tr>
<td>Structural effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outgoing friendship ties</td>
<td>-3.39 (0.07)**</td>
<td>-56.49</td>
</tr>
<tr>
<td>Reciprocating friend ties</td>
<td>1.58 (0.08)**</td>
<td>20.33</td>
</tr>
<tr>
<td>Transitivity</td>
<td>0.45 (0.02)**</td>
<td>24.04</td>
</tr>
<tr>
<td>Covariate effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender adolescent</td>
<td>-0.11 (0.07)</td>
<td>-1.65</td>
</tr>
<tr>
<td>Gender potential friend</td>
<td>0.13 (0.06)*</td>
<td>2.15</td>
</tr>
<tr>
<td>Same gender friend</td>
<td>0.73 (0.06)**</td>
<td>12.54</td>
</tr>
<tr>
<td>Ethnicity adolescent</td>
<td>-0.03 (0.06)</td>
<td>-0.56</td>
</tr>
<tr>
<td>Ethnicity potential friend</td>
<td>0.03 (0.06)</td>
<td>0.59</td>
</tr>
<tr>
<td>Same ethnicity friend</td>
<td>0.17 (0.05)**</td>
<td>3.25</td>
</tr>
<tr>
<td>Money adolescent</td>
<td>0.02 (0.03)</td>
<td>0.69</td>
</tr>
<tr>
<td>Money potential friend</td>
<td>-0.05 (0.03)</td>
<td>-1.87</td>
</tr>
<tr>
<td>Money friend similarity</td>
<td>0.33 (0.09)**</td>
<td>3.55</td>
</tr>
<tr>
<td>Same classroom friend</td>
<td>0.62 (0.06)**</td>
<td>11.07</td>
</tr>
<tr>
<td>Physical activity effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behavior adolescent</td>
<td>0.01 (0.02)</td>
<td>0.50</td>
</tr>
<tr>
<td>Behavior potential friend</td>
<td>-0.01 (0.02)</td>
<td>-0.50</td>
</tr>
<tr>
<td>Behavior similarity</td>
<td>0.66 (0.22)**</td>
<td>3.07</td>
</tr>
<tr>
<td>Intention adolescent</td>
<td>-0.13 (0.05)*</td>
<td>-2.48</td>
</tr>
<tr>
<td>Intention potential friend</td>
<td>-0.03 (0.05)</td>
<td>-0.55</td>
</tr>
<tr>
<td>Intention similarity</td>
<td>0.06 (0.36)</td>
<td>0.16</td>
</tr>
<tr>
<td>Attitude adolescent</td>
<td>0.06 (0.05)</td>
<td>1.26</td>
</tr>
<tr>
<td>Attitude potential friend</td>
<td>-0.05 (0.05)</td>
<td>-1.09</td>
</tr>
<tr>
<td>Attitude similarity</td>
<td>0.86 (0.35)*</td>
<td>2.44</td>
</tr>
</tbody>
</table>

*Note. PE = parameter estimate. Rate parameters for each period of the behavior only model ranged from 6.1 to 8.9, and for the behavior and cognitions model ranged from 6.0 to 8.6.  
*p < .05, two-tailed.  **p < .01, two-tailed.
Table 5. Results of the Behavior Dynamics Submodels

<table>
<thead>
<tr>
<th>PA dynamics</th>
<th>Behavior only</th>
<th>Behavior and cognitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PE (SE) t-value</td>
<td>PE (SE) t-value</td>
</tr>
<tr>
<td>Behavior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shape</td>
<td>0.03 (0.04) 0.71</td>
<td>0.00 (0.04) 0.08</td>
</tr>
<tr>
<td>Quadratic shape</td>
<td>-0.03 (0.03) -1.02</td>
<td>-0.03 (0.03) -0.87</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.20 (0.08)** -2.64</td>
<td>-0.21 (0.08)* -2.57</td>
</tr>
<tr>
<td>Money</td>
<td>0.09 (0.04)* 2.23</td>
<td>0.09 (0.04)* 2.09</td>
</tr>
<tr>
<td>Intentions</td>
<td>0.01 (0.05) 0.18</td>
<td>0.01 (0.06) 0.21</td>
</tr>
<tr>
<td>Attitudes</td>
<td>0.15 (0.05)** 2.85</td>
<td>0.14 (0.05)* 2.49</td>
</tr>
<tr>
<td>Friend behavior</td>
<td>2.86 (0.93)** 3.09</td>
<td>2.77 (0.89)** 3.10</td>
</tr>
<tr>
<td>Intentions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shape</td>
<td>0.23 (0.04)** 5.15</td>
<td></td>
</tr>
<tr>
<td>Quadratic shape</td>
<td>0.02 (0.03) 0.62</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.03 (0.09) -0.31</td>
<td></td>
</tr>
<tr>
<td>Behavior</td>
<td>0.17 (0.05)** 3.17</td>
<td></td>
</tr>
<tr>
<td>Friend intentions</td>
<td>3.93 (1.14)** 3.45</td>
<td></td>
</tr>
<tr>
<td>Descriptive norms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shape</td>
<td>0.02 (0.04) 0.46</td>
<td></td>
</tr>
<tr>
<td>Quadratic shape</td>
<td>-0.06 (0.03) -1.70</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.17 (0.09) -1.92</td>
<td></td>
</tr>
<tr>
<td>Behavior</td>
<td>0.04 (0.04) 1.04</td>
<td></td>
</tr>
<tr>
<td>Friend des. norms</td>
<td>4.04 (1.12)** 3.62</td>
<td></td>
</tr>
<tr>
<td>Injunctive norms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shape</td>
<td>0.17 (0.03)** 5.43</td>
<td></td>
</tr>
<tr>
<td>Quadratic shape</td>
<td>0.05 (0.02)* 2.27</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.02 (0.06) -0.28</td>
<td></td>
</tr>
<tr>
<td>Behavior</td>
<td>0.07 (0.03)* 2.40</td>
<td></td>
</tr>
<tr>
<td>Friend inj. norms</td>
<td>2.54 (0.94)** 2.70</td>
<td></td>
</tr>
</tbody>
</table>

Note. PE = parameter estimate. Rate parameters for each period of the behavior only model ranged from 2.8 to 4.7. In the behavior and cognitions model, rate parameters ranged from 3.0 to 5.5 for behavior, from 3.0 to 3.7 for intentions, from 2.9 to 3.9 for descriptive norms, and from 3.4 to 6.9 for injunctive norms.

*p < .05, two-tailed. ** p < .01, two-tailed.
The hypothesis that adolescents’ engagement in PA would be influenced by the behavior of their friends was tested in the behavior dynamics submodel (Table 5, column 1). The significant positive friend behavior effect indicates that participants tended to change their behavior so that it became more similar to the behavior of their friends. In other words, friends’ PA behaviors tended to assimilate over time. Changes to PA behaviors were also predicted by individual attributes, although these effects were not as strong as the effect of friend behavior. The significant negative gender effect indicates that girls were more likely than boys to maintain or move towards low PA behavior scores. The significant positive money effect indicates that students with more pocket money were likely to maintain or move towards high PA behavior scores. Attitudes towards PA also had a significant effect on behavior change, with positive attitudes predictive of high PA behavior scores. Cognitions towards PA did not significantly predict behavior change. Additionally, the non-significant shape effects imply that changes in PA were adequately explained by the friend and covariate effects, rather than some universal rule of behavior change, such as an overall decline in PA.

Overall, the results of the behavior only model show that similarities in PA amongst friends were explained by two processes: the selection of friends with similar behaviors (i.e., friend selection), and assimilation amongst friends over time (i.e., friend influence). To gain a more detailed understanding of the proportion of friend similarity, or network autocorrelation, that can be attributed to these selection and influence processes, we used a simulation approach described in Steglich, Snijders, and Pearson (In press). The average Moran’s $I$ coefficient was calculated for simulations of five different model specifications, each with particular effects omitted. The differences in the $I$ coefficients across these models were partitioned to determine the amount of network autocorrelation unique to the
following processes: friend selection, friend influence, control effects (e.g., structural or covariate effects that also result in friend similarities on PA), and trends from the previous wave. *Indeterminate effects* represent the proportion of autocorrelation that could not be attributed to any one particular process.

Figure 1 shows the percentage of network autocorrelation on PA behavior allocated to each of these processes. In both groups, across both waves, friend influence accounted for a greater proportion of behavior similarity than friend selection. This was particularly the case for Group 1, where the contribution of influence processes on observed PA similarities amongst friends was more than double that of selection processes. The magnitude of both selection and influence processes on friend similarities also decreased between Wave 2 and Wave 3, as friendship and behavior patterns stabilized and the impact of previous waves (i.e., trend effects) increased. The figure also highlights that control effects (i.e., effects of transitivity, reciprocity, and selection of friends with similar covariates) accounted for approximately one quarter of the network autocorrelation on PA at each wave, further emphasizing the importance of controlling for these processes.

*Statistical Models for the Evolution of Networks, Behaviors, Attitudes, and Cognitions*

The second focus of this study was to explore if the selection and influence processes outlined above were mediated by cognitive mechanisms. We tested whether friendship selection was based on similarities in PA-related attitudes and cognitions, as well as behaviors. We also tested if assimilation on PA behaviors (i.e., friend influence on PA) was mediated via assimilation on attitudes and cognitions amongst friends. A final model was developed using a forward selection process, where effects of PA-related attitudes and cognitions were score tested, one at a time, against the behavior only model.
(Schweinberger, 2010). Only variables with significant effects were retained in the final behavior and cognitions model.

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th></th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>selection</td>
<td>21%</td>
<td>selection</td>
<td>31%</td>
</tr>
<tr>
<td>trend</td>
<td>6%</td>
<td>trend</td>
<td>6%</td>
</tr>
<tr>
<td>control</td>
<td>23%</td>
<td>control</td>
<td>26%</td>
</tr>
<tr>
<td>influence</td>
<td>49%</td>
<td>influence</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>selection</td>
<td>13%</td>
<td>selection</td>
<td>19%</td>
</tr>
<tr>
<td>trend</td>
<td>29%</td>
<td>trend</td>
<td>23%</td>
</tr>
<tr>
<td>control</td>
<td>24%</td>
<td>control</td>
<td>28%</td>
</tr>
<tr>
<td>influence</td>
<td>33%</td>
<td>influence</td>
<td>25%</td>
</tr>
<tr>
<td>indeterminant</td>
<td>1%</td>
<td>indeterminant</td>
<td>0%</td>
</tr>
</tbody>
</table>

*Figure 1. Partitioning network autocorrelation on PA behavior.*
The network dynamic component of the behavior and cognitions model (Table 4, column 2) tested effects of PA behaviors, attitudes, and cognitions on friendship selection. Friendship formation was found to be driven by similarities in attitudes (significant positive attitude similarity effect), rather than by similarities on behavior or cognitive measures. Therefore, although results from the behavior only model suggested that students selected friends with similar PA behaviors, this effect was better explained by a tendency for friendships to form amongst peers with similar attitudes. Additionally, there was a significant negative intention adolescent effect, where students with the strongest intentions to do PA nominated fewer friends. As was found in the behavior only model, friendship selection was also driven by covariate and structural effects, as previously reported.

The behavior dynamics submodel tested effects predicting changes to PA behaviors, attitudes, and cognitions (Table 5, column 2). To determine if friends influenced adolescent PA behavior via these psychological constructs, the effect of friend assimilation on behavior was estimated while controlling for effects of friend assimilation on cognitions. In other words, did friends assimilation on cognitions explain their assimilation on behaviors? The results show that the tendency for behavior assimilation amongst friends (significant positive effect of “friend behavior” on adolescent behavior) remained significant in this model. Over and above this effect, there was also a significant effect of assimilation on intentions amongst friends (positive effect of “friend intentions”) and significant effects of assimilation on descriptive norms and injunctive norms amongst friends (positive effect of “friend injunctive norm” and “friend descriptive norm”). There was no evidence of assimilation on friends’ scores for attitudes, perceptions of behavioral control, or self-efficacy.
Overall, these results indicate that friends’ PA behaviors became increasingly alike, and parallel to this, friends also became increasingly similar in their intentions to do PA, and their perceptions of peer norms regarding PA. However, behavior assimilation amongst friends was not *totally* accounted for by the adoption of similar intentions, nor was it accounted for by shared perceptions of peer norms. Moreover, because the size of the effect of “friend behavior” on adolescent behavior (i.e., behavior assimilation) was not weaker in the behavior and cognitions model ($t = 3.10$), compared to the behavior only model ($t = 3.09$), there was no evidence that friend assimilation on intentions or peer norms *partially* mediated their assimilation on PA behaviors.

Finally, there were also significant individual-level effects predicting changes to PA behaviors, attitudes, and cognitions in the behavior dynamics submodel. As was found in the behavior only model, gender and pocket money remained significant predictors of behavior change. Attitudes also remained a significant positive predictor of behavior; therefore, notwithstanding the influence of friends on behavior, adolescents’ own attitudes continued to guide their engagement in PA. Although other cognitive measures were not found to predict behavior change, adolescents’ behaviors were found to predict changes to some cognitions. PA behavior significantly and positively predicted the evolution of adolescents’ intentions and injunctive norms. Thus, greater participation in PA predicted stronger intentions to do PA over time, and stronger perceptions that “my friends think I should do PA”.

**Discussion**

Involvement in PA was found to play an important role in adolescents’ friendship choices, with participants showing a preference for friends whose activity levels were similar to their own. Friends also influenced changes to adolescent PA over the course of the school
year, evidenced by friends’ engagement in leisure-time PA becoming increasingly similar. These findings were consistent across two cohorts of grade eight students at two Australian high schools. Although selection and influence processes contributed to the observed similarities in PA amongst friends, the tendency for adolescents to adopt the behaviors of their friends accounted for a greater proportion of these correlations than homophilic selection. Nonetheless, the preference for adolescents to form friendships with peers who were similarly active or inactive resulted in a school social environment characterized by clustered friendship groups with differing activity levels. It is in this context that changes to PA, and peer influence, took place.

This study also sought to explore potential psychological mechanisms driving PA-based selection and influence amongst friends. With regards to participants’ friendship choices over their first year of high school, sharing similar attitudes towards engaging in PA was a stronger driver for friendship selection than behavioral similarities. Thus, friendships may have been more strongly based on what students were saying they like to do, rather than their actual behaviors, likely reflecting the school context in which these friendships were formed. Following adolescents’ choice of friends with similar attitudes, they subsequently emulated their friends’ PA behaviors. As friends’ behaviors assimilated, so did their intentions to do PA, and their perceptions of peer norms. But despite assimilation on these cognitive constructs occurring in parallel to behavioral assimilation, it appears to be an epiphenomenon of this process rather than a causal mechanism. The motivation for adolescents to adopt their friends’ behaviors may predominantly stem from a desire to establish and maintain affiliations with peers in a new school setting (Brown, et al., 2008), rather than their own beliefs about PA.
Further, our findings suggest that cognitive assimilation amongst friends may occur in parallel to behavior assimilation because changes in adolescents’ behavior predicted changes to some cognitions, including intentions to do PA and perceived social pressure to engage in PA (i.e., injunctive peer norms). In contrast to the theory of planned behavior that considers internal states to be predictive of intentions and behavior (Ajzen, 1991), these results are more in line with self-perception theory, which argues that “individuals come to ‘know’ their own attitudes, emotions, and other internal states partially by inferring them from observations of their own overt behavior” (Bem, 1972, p. 2).

The above findings point to a number of useful avenues for intervention. Declines in PA were predicted by being female, having little pocket money, and having a negative attitude towards doing regular PA. It was also predicted by having friends who engaged in relatively less PA than the adolescent, bearing in mind that these young people actively selected friends who were similarly engaged in PA. Valente (2010) outlines several approaches to utilizing social network methods and data to encourage health behavior change. Based on our findings, targeting inactive youth, particularly girls, and facilitating participation in PA with their close friends may be one effective strategy to promote increased activity. Providing opportunities for friends to model healthy behaviors might also encourage adolescents to adopt more positive cognitions towards PA, as our results suggest that engagement in PA preceded the internalization of more positive intentions and norms. Because many successful interventions targeting youth inactivity are already school-based (van Sluijs, et al., 2007), identifying ways to harness existing social processes that influence and support PA in these settings could increase program effectiveness. Schools also play an important role in how these friendship networks are structured by assigning students to home group classes. Investigating how friendship ties might be encouraged to form
between active and inactive youth, and the outcome of this, would be valuable. Finally, the continued promotion of positive attitudes towards sports and active play is also recommended, as our findings show that over and above effects of peer influence, positive attitudes towards PA remained a significant predictor of increased participation in PA.

That PA was found to cluster in adolescent friendship networks, largely as a result of socialization, also provides insights into mechanisms likely to be driving the observed “contagion” of obesity amongst adolescent peers (Fowler & Christakis, 2008; Halliday & Kwak, 2009). The spread of health behaviors such as PA, smoking (Mercken, et al., 2010), and alcohol use (Pearson, et al., 2006), between socially connected youth could lead not only to the social spread of obesity, but also a vast range of health outcomes. Understanding how and why these processes occur is essential for identifying strategies that might inhibit or harness interpersonal influence.

Although this study provides valuable insights into the interdependent relationship between friendships and adolescent PA, studies of longer duration are needed. Whether or not school friends influence adolescent activity levels beyond the early high school years, and if this has a lasting impact on their behavior, needs to be determined. The use of objective PA measures, such as accelerometers, would also add to the validity of the study. A further limitation is that we focused only on school-based friendships amongst peers in the same grade. Although past studies have found that adolescents’ friends are predominantly schoolmates (Blyth, Hill, & Thiel, 1982), friends from neighborhood or community contexts are also likely to be important referents for leisure-time PA. The role of parents, siblings, and other significant social contacts on adolescent PA was also not examined in this research.
In conclusion, this study applied novel longitudinal social network models (Snijders, et al., 2007) to investigate the dynamic relationship between adolescent friendship networks and their engagement in PA. Participants actively shaped their social environment, selecting friends with similar behaviors and attitudes towards PA, and their engagement in PA was also influenced by their friendships. The mechanisms through which adolescents’ friends influenced their behavior seemed to be less internalized than some health behavior theories would suggest (e.g., Ajzen, 1991). Although many factors are likely to be associated with declines in PA amongst adolescents (Gordon-Larsen, et al., 2004), this study demonstrates that young people’s close friends are important referents for behavior change. This nuanced look at the role of friendships in PA provides some insights into possible intervention strategies that may be useful in establishing social contexts that support and encourage young people to be physically active.
Supplementary Figure. Distribution of physical activity behavior in two adolescent friendship networks at Wave 3. Nodes, each representing a participant, are colored by physical activity scores. Directed ties between nodes represent friendship relations. The images highlight how the selection of friends with similar behaviors, and assimilation in behaviors amongst friends, resulted in friendship networks clustered around activity levels.
CHAPTER 8. CONCLUSIONS, IMPLICATIONS, AND FUTURE DIRECTIONS

Review of the Thesis Aims

In many developed countries there is an alarming proportion of children and adolescents who are overweight or obese: in Australia this figure is between 20% and 25% (Commonwealth Scientific and Industrial Research Organisation & University of South Australia, 2008; Olds, et al., 2004). Although the rapid increase in obesity prevalence over recent decades seems to have halted (Olds, et al., 2009), efforts to reduce the number of overweight children, and to prevent childhood obesity in future, are still needed.

Families and schools have been the primary targets of obesity interventions, with parents and teachers being charged with implementing changes in young people’s health behaviors to reduce their obesity risk. However, there is increasing evidence to suggest that peers may also have an important role in establishing healthy habits and weights, particularly amongst adolescents. The behaviors of peers and close friends seem to be associated with a number of obesity-related behaviors in adolescents including physical activity (Duncan, Duncan, & Strycker, 2005; Voorhees, et al., 2005) and consumption of snack foods and energy-dense foods (Feunekes, de Graaf, Meyboom, & van Staveren, 1998; Salvy, Howard, Read, & Mele, 2009). Moreover, studies looking at broader networks of adolescent friends found that obesity was not randomly distributed in these social structures, but rather was clustered as a result of friends being alike in the extent to which they had excess weight (e.g., Halliday & Kwak, 2009; Valente, Fujimoto, Chou, & Spruijt-Metz, 2009).

Although this research highlighted the relevance of the peer context to adolescent obesity and related behaviors, the processes underpinning associations between friendships and overweight are not clear. Friendships may be based on similarities in weight status,
because overweight children are marginalized by their non-overweight peers (Strauss & Pollack, 2003), and there are a number of confounding influences that could also contribute to similarities in weight status amongst friends (Cohen-Cole & Fletcher, 2008a, 2008b).

Researchers have also proposed that adolescents are likely to become overweight if they have overweight friends (Fowler & Christakis, 2008; Renna, Grafova, & Thakur, 2008; Trogdon, Nonnemaker, & Pais, 2008) as a result of an interpersonal contagion of obesity spreading through the social networks of adolescents and adults (Christakis & Fowler, 2007; Fowler & Christakis, 2008). Because of the reliance on analytic strategies that have not adequately or explicitly considered each of these competing mechanisms, the extent to which processes of friendship selection, social contagion, or confounding influences cause similarities in weight status amongst adolescent friends has been inconclusive.

To disentangle these causal mechanisms and assess whether or not obesity spreads amongst adolescent friends, newly developed statistical models for social networks for longitudinal network data were applied. Furthermore, based on findings that friends influence obesity-related health behaviors in adolescents, it seemed plausible that obesity contagion could result from friends engaging in similar health behaviors, and influencing each other’s behaviors over time. Whether or not health behaviors cluster and spread in larger friendship structures, again accounting for processes of friendship selection and confounding influences, was a second empirical question addressed in this thesis. Thus, the research aims were twofold:

1. To model obesity in adolescent friendship networks longitudinally, using statistical models for social networks that account for friendship selection, obesity contagion, and confounding influences, to determine the underlying processes that cause friends to have similar amounts of excess weight.
2. To examine obesity-related health behaviors, in the context of adolescent friendship networks, to determine if these behaviors clustered and spread amongst adolescent friends, and evaluate the interpersonal and psychosocial mechanisms underpinning this.

**Review of the Thesis Findings**

*Friendships and Overweight: Associations and Underlying Processes*

The first two papers in this thesis looked at associations between the friendships and weight status of early and middle adolescents. Generally, the results support previous research with friends found to be alike in weight status: overweight youth tended to be friends with overweight peers, and nonoverweight youth tended to be friends with nonoverweight peers. This finding held across two samples that differed in age and ethnicity.

The findings in Paper 1, a longitudinal study of 156 Australian grade 8 students, suggested that weight-related similarities amongst friends were at least partially a result of friendship choices. In particular, similarities resulted from the marginalization of overweight students by their nonoverweight peers. About one in five students were overweight or obese, and there was a trend for these adolescents to receive fewer friendship nominations, despite nominating a greater number of friends. Friendships were also more likely to form between peers of the same weight status, with nonoverweight students especially reluctant to nominate overweight students as a “friend”. However, similarities in weight status were only found to predict unilateral friendships, and had quite a different impact on the process of reciprocating a friendship nomination, whereby a “desired friend” becomes a mutual (i.e., reciprocated) friend. Similarities in weight did not predict the reciprocation of a friendship
offer. In fact, mutual friendships were more likely to form amongst dyads whose weight status differed. Although this was an unexpected result, there are plausible explanations: the social benefits derived from heterophilic relationships, for example increased social status attained by overweight youth who are able to establish mutual relationships with nonoverweight grademates, may be one motivating factor. These mutual friendships may have also been based on other, more relationally meaningful, attributes.

Despite weight status being relevant to adolescents’ friendship choices, there was no evidence of the proposed “contagion” of obesity in this cohort over the 16-month study (Paper 1). Therefore excess weight in friends did not significantly predict excess weight in adolescents. Moreover, by the final wave of the study, when participants were nearing the end of grade 9, there was no evidence of network autocorrelation for BMI (i.e., the extent to which dyads who share a friendship tie are similar), probably as a result of mutual friendships stabilizing amongst peers whose weight status was not alike, and because there was no significant evidence of contagion. There was a non-significant trend for friends’ BMIs to become increasingly similar over the course of the study, and how this trend unfolds over a longer time period is a question for future research.

Contextual Variation in Weight-Based Friendship Selection

Although the marginalization of overweight youth by their peers is a fairly universal phenomenon (Gray, Kahhan, & Janicke, 2009), contexts in which overweight youth have been well integrated into the peer group were identified in Paper 2. Variations in local norms, and in particular the norms endorsed by high status peers, have been found to impact the characteristics that are positively valued in peer settings and that are deemed relevant to the formation of friendships (Dijkstra, Lindenberg, & Veenstra, 2008; Wright, Giammarino, & Parad, 1986). Children and adolescents who deviate from local norms are
commonly subject to peer rejection and marginalization (Wright, et al., 1986). The extent to which healthy body weights, and healthiness more generally, are endorsed by high status youth and subsequently valued by their peers, could also vary contextually. Therefore in Paper 2, differences in classroom health norms were examined, and the hypothesis that overweight children are at greater risk of rejection in contexts where healthiness was associated with high status was tested. As expected, overweight youth were only rejected by their peers in classrooms characterized by strong health norms. In these classes, where healthiness was associated with popularity, overweight children, and especially overweight girls, tended to receive fewer friendship nominations, and the friends they did have were likely to be other overweight students. However, in classrooms where the association between popularity and general healthiness was weak or nonexistent, overweight children were found to be well integrated in their peer network.

These results show how variations in local health norms impact the relevance of weight status in adolescents’ peer relations: when healthiness was associated with high status it appears to have also been a salient and valued characteristic, and overweight children who deviated from this norm were rejected by their peers. These local norms seem to have influenced the formation of friendships amongst dyads, shaping the social processes or “building blocks” of the network, and impacting the structure and distribution of overweight in the larger friendship network. These findings also suggest that weight-based stigma may be reinforced or accentuated through the promotion of healthy behaviors and lifestyles, especially if initiatives associate healthiness, or activities like sports and healthy eating, with social status. Ironically, this may increase the social isolation of overweight youth, making them less receptive to these types of behavioral interventions.
Chapter 8. Conclusions, Implications, and Future Directions. Page 169

*Obesity-Related Behaviors in Adolescent Friendship Networks*

Although Paper 1 found no significant evidence that obesity spread from friend to friend in adolescents’ social networks, there was a trend for friends’ BMIs to become increasingly alike over the relatively short study. Evidence of adults’ weight status being predicted by the weight status of their friends has emerged over several decades (Christakis & Fowler, 2007); therefore it seems plausible that the contagion process of interest may play out over a longer timeframe than was assessed in Paper 1. Investigating shared obesity-related behaviors amongst friends as a plausible mechanism that could result in parallel changes to friends’ BMIs, will provide further insight into the existence and origins of this phenomenon.

The final two papers in this thesis examined obesity-related behaviors in the context of adolescent friendship networks to determine if friends’ behaviors were alike, and if so, whether these similarities were caused by friends influencing adolescents’ behavior over time. The first of these studies (Paper 3) examined a range of behaviors known to be associated with obesity in young people, including physical activity (Han, Lawlor, & Kimm, 2010), sedentary screen-based activities (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998), and consumption of energy-dense foods (Johnson, Mander, Jones, Emmett, & Jebb, 2008). This cross-sectional study looked at the friendship networks of three cohorts of adolescents, and found that friends were alike on some of these behaviors: in particular their engagement in organized physical activities, such as sports and training. Friends’ behavioral similarities were also found to differ by gender and between cohorts, again suggesting that local contexts and norms are important to these social processes.

In two of the three cohorts in Paper 3, adolescent friends tended to participate in similar amounts of organized physical activity, so that inactive youth were likely to be friends
with inactive peers, and active youth tended to be friends with each other. Across all three groups, female friends were alike in the “screen time” they allocated to Internet use and video gaming, and male friends in two of the three groups were alike in the amount of energy-dense foods they consumed. Because friendships were also likely to be reciprocal and transitive, similar friends often clustered together into friendship groups resulting in friendship networks characterized by pockets of youth whose behaviors were obesity-promoting, and clusters whose behaviors were protective against obesity.

Similarities in TV and movie watching, as well as participation in non-organized physical activities (which includes active play and active transportation), were not found to be a basis for friendships amongst these groups of adolescents. These relatively less social behaviors may not have been salient to adolescents’ choice of friends, and the lack of evidence for similarities amongst friends also suggests that these behaviors were not susceptible to peer influence. Family or community contexts, or other individual or environmental factors, may be more predictive of variations in these activities.

Processes Underlying Friend Similarities in Physical Activity

The strongest evidence of behavioral similarity amongst friends in Paper 3 was found for participation in organized physical activities (PA). Therefore the final paper of this thesis focused solely on examining the processes leading to associations between friendships and activity levels, and whether or not there was evidence of social contagion. In Paper 4, engagement in moderate to vigorous PA was measured three times over one school year in two Australian grade 8 cohorts, together with friendship nominations. Again, adolescents were found to engage in similar amounts of PA as their close friends, and in both groups this resulted from processes of homophilic friendship selection and social influence. Participants were likely to befriend peers whose attitudes towards PA and participation in PA were
similar to their own, and over and above this, also emulated their friends’ behaviors so that their PA participation became increasingly alike. In the context of the larger network, adolescents’ adoption of their friends’ behaviors resulted in friendship clusters becoming increasingly polarized by activity levels, a process that could plausibly result in the clustering of obesity in larger social networks and similarities in obesity risk amongst friends.

In both cohorts, changes to PA were predicted by individual factors, with males, and adolescents with the most pocket money, and those with positive attitudes towards PA, being the most likely to adopt or maintain high levels of PA. But the strongest predictor of PA was friends’ engagement in PA: over time, adolescents changed their behavior so that it was more closely aligned to the behaviors of their close friends. The psychological mechanisms through which adolescent PA was influenced by friends’ behavior were of particular interest, in terms of theoretical and practical applications. This influence process was not found to be mediated via adolescents’ perceptions of peer norms regarding PA, or their intentions to do PA, as proposed by the theory of planned behavior (Ajzen, 1991). Rather, adolescents were found to adopt the behaviors of their friends, and subsequently adjusted their beliefs and norms so that they remained consistent with their changing behaviors (as depicted in Figure 1 below). Therefore, although friends’ PA behaviors and beliefs became increasingly alike over time, their cognitions were not a causal mechanisms for changing behaviors, but were predicted by behavior change. This social influence process seemed to be less internalized than some health behavior theories would suggest, and may be better explained by self-perception theory (Bem, 1972) whereby adolescents’ beliefs about PA are deduced by reflecting on their own recent behavior. Adolescents may be primarily motivated to imitate behaviors modeled by their friends to achieve social goals, such as peer acceptance or increased social status (Berndt, 1979; Corsaro & Eder, 1990).
Figure 1. The evolution of adolescent PA, their friends’ PA, and their beliefs and attitudes about PA.

The results of these final two studies suggest that adolescents’ peer environments are likely to be relevant to some obesity-related behaviors, particularly their engagement in physical activity, and that the relationship between friendships and behavior is a dynamic one. With regards to PA, adolescents based their friendships around similarities in attitudes to PA, resulting in friendship dyads whose PA behaviors were similar, and a network stratified by this health behavior. Adolescent PA was also influenced by the behavior of close friends, causing behaviors to assimilate and spread amongst friends and within connected social groups. The social contagion of behaviors such as PA is a plausible mechanism that could underpin network effects on health outcomes such as obesity. Understanding the psychological and social processes driving this behavioral contagion highlights potential avenues for interventions to halt or harness these network effects.

Significance and Implications of the Thesis Findings

The most potentially important insight from this series of studies is the extent to which social networks and health attributes were mutually dependent: not only did friendships predict health attributes, but health attributes predicted friendships. The
evolution of adolescents’ health behaviors, BMIs, and friendship networks was dynamic and complexly interdependent.

The Social Contagion of Health Behaviors and Health Outcomes

The primary aim of this thesis was to test claims that obesity spread through adolescents’ social networks as a result of interpersonal contagion. Although there was no significant evidence that friends’ BMIs predicted changes to adolescent BMI, collectively the studies identified a number of social processes that result in friends sharing a similar behavioral obesity risk. First, friends were found to be alike on a number of obesity-related behaviors, including PA, screen time (for girls), and energy-dense food consumption (for boys). Moreover, similarities amongst friends in PA were strongly explained by processes of social influence, so that an adolescent with inactive friends was likely to adopt, or maintain, an inactive lifestyle. The clustering and spread of behaviors associated with obesity amongst friends implies that obesity risk also clusters and spreads through these social ties.

A second mechanism that could result in friends’ risk of excess weight being comparable arises through the marginalization of overweight youth by their peers. The experience of peer rejection and victimization as a result of weight-based stigma has been associated with changes in BMI (Adams & Bukowski, 2008; Lemeshow, et al., 2008). Because overweight youth tend to befriend one another, they may experience parallel changes in weight not as a result of contagion, but through their shared experience of being excluded by their peers. Moreover, in contexts where being overweight deviated from local norms and valued characteristics, excess weight was found to be highly salient to the formation of friendships. In these contexts, it is also plausible that friends act as important referents for adolescents’ perceptions of weight norms, their ideal weight, and their subsequent weight management.
As a whole, these findings call into question the usefulness of simply focusing on the spread of a health outcome, such as obesity, in social networks. If obesity is “socially contagious” the ability to intervene in this process will depend on having an understanding of the underpinning interpersonal mechanisms. Inquiring into how social networks influence health practices and behaviors—that in turn can impact a myriad of health outcomes—will likely be of greater practical significance.

The psychosocial mechanisms underpinning peer influence on adolescent PA were examined in Paper 4, providing useful insights. Many behavioral and social influence theories propose that the social environment influences behavior via individuals’ normative beliefs: thus, we are influenced by our perceptions of other’s behaviors, more than their actual behaviors. Amongst adolescents, perceptions of peers’ smoking behavior and drug use have been found to predict subsequent usage (Rice, Donohew, & Clayton, 2003), however this was not found to be a mechanism through which friends influenced adolescent PA. Changes in PA behaviors were found to be predicted by friends’ self-reported PA but not by adolescents’ perceptions of their friends’ PA (i.e., descriptive norms), nor was this influence process mediated through adolescents’ descriptive norms. The psychological pathways through which peers influence adolescents may differ according to the behavior in question, perhaps as a function of the social nature and meaning of the behavior. Activities such as sports, training, and active play are typically very public and accepted behaviors, whereas smoking and drug use amongst early to mid adolescents is much more covert. Imitating and adopting behaviors publicly modeled by peers may be a mechanism through which friends’ PA influences changes to adolescent PA, whereas adolescents may have less opportunity to observe their peers engaging in more covert behaviors, and peer influence processes may occur predominantly via adolescents’ perceptions of what their friends are
doing. Moreover, deviant behaviors such as smoking may be more central to group identities and subversive subcultures in adolescence, therefore group norms about smoking may be more integrated into members’ beliefs, compared to behaviors that are less salient to social identities (Abrams & Hogg, 1990).

Identifying the mechanisms through which friends influence specific behaviors has practical, as well as theoretical, relevance. For example, smoking interventions have sought to change young people’s perceptions of social norms in an effort to promote healthy behaviors (Bruvold, 1993). However this approach may not be as effective for visible and socially accepted behaviors such as PA, and strategies that provide opportunities for adolescents to model healthy behaviors amongst their peers may be more successful in encouraging increased activity.

The Role of Adolescents in Shaping Their Peer Environments

Adolescents are not just passive recipients of peer influence, but also actively shape their peer environment in ways that are relevant to their health. Their friendship networks were found to emerge from various interpersonal social processes, such as preferences for friends with similar weight status, health beliefs and behaviors, as well as a range of other salient (and potentially confounding) demographic variables; and preferences to befriend peers with characteristics that were socially valued (e.g., not overweight). Variations in local norms were also found to impact whether or not attributes were valued and salient to peer relationships, and if they predicted friendship choices. Moreover, friendships were not just based on actors’ overt preferences but also external forces that provided opportunities for relationships to develop, such as shared classroom environments and shared common friends. These local processes constrained or facilitated particular relationships and generated networks that were not just randomly connected pairs of friends, but that were
characterized by fairly homogenous clustered social groups and broader social hierarchies based on status-related attributes. It is in these contexts, where health attributes are socially meaningful and provide social capital, that contagion and influence take place.

Weight-based friendship selection, and in particular the manifestation of weight-based stigma as the rejection and exclusion of overweight youth by their peers, has a profound impact on adolescent health and well being (Gray, et al., 2009; Puhl & Latner, 2007). In these thesis studies, the observed associations between friendships and weight status, and thus the non-random distribution of overweight in the friendship networks, was found to be explained by the marginalization of overweight youth. Not only does the experience of weight-related peer rejection and relational aggression have a negative impact on adolescents’ physical and psychological wellbeing (Puhl & Latner, 2007), it may also lead to weight gain (Adams & Bukowski, 2008; Lemeshow, et al., 2008). The importance of addressing this issue alongside obesity-prevention efforts is obvious, and identifying contexts that are protective of weight-based marginalization is therefore of great value. The results of Paper 2 suggest that environments without strong status-based health norms may facilitate the integration of overweight youth into their peer groups and may therefore be protective of some of the social and psychological risk factors associated with childhood obesity.

*Selection and Influence Processes are Interdependent*

When attributes or behaviors are salient or valued in a peer context, they are likely to be relevant to friendship choices, and these friends are also likely to be important referents for these attributes or behaviors. Engagement in PA for example, was found to be a basis for friendships, and friends also influenced changes in this behavior. Longitudinal network studies of adolescent smoking have also found that it is a behavior that both
predicts, and is predicted by, friendships (Mercken, Snijders, Steglich, Vartiainen, & de Vries, 2010; Pearson & Michell, 2000). It follows then, that friends may also be important referents for norms around body weight, given the relevance of this attribute in friendship choices.

The question then becomes, what makes an attribute or behavior salient to peer relationships? The findings from Paper 2 support claims that it is the characteristics endorsed by high status youth that are most valued in peer settings (Dijkstra, et al., 2008), and subsequently shape friendship choices. In Paper 3, friends were often found to be alike on behaviors—implying that the behavior was a basis for friendships, and/or was influenced by friends—when that activity was endorsed by popular (i.e., high in-degree) friends.

Associations between social status and health attributes could arise through several processes: adolescents could become popular or well-liked if they possess valued or desirable traits; the characteristics of popular adolescents may define what is valued; or popular students may feel pressure to adopt behaviors or attributes that are socially valued to maintain their status. Further research is needed to determine which of these processes result in health attributes or behaviors becoming valued in adolescent peer environments and are subsequently shaping the formation of friendship networks and the potential for peer influence. Moreover, whether certain attributes are universally salient to adolescents, or the extent to which local contexts shape these phenomena, also needs to be considered.

*From Dyads, to Groups, to Networks: The Value of a Social Network Framework*

This series of studies also draws attention to the value of looking beyond friendship dyads, and considering interpersonal processes such as friendship selection and social influence in the context of larger social structures. Collecting and analyzing network data are substantially more demanding tasks than traditional random sampling designs:
additional time and resources are needed to recruit complete populations and to capture
individual as well as relational data, and the modeling approaches are also computationally
intensive. However, for the research questions at hand, the advantages of applying a social
network framework clearly justified the additional effort.

The significant contribution of endogenous structural processes in the formation of
friendships, and thus overall network structure, implies that these are important processes
to control when modeling associations between friendships and health attributes. In
particular, the tendency for (often similar) friends to befriend each other’s (also similar)
friends is a potential confounding influence when testing homophily, and should be
controlled so that attribute-based friendship selection is not overestimated. A social
network framework also allows us to look beyond dyadic similarities, and to explore more
global aspects of network structure, such as popularity (in-degree) and the clustering of
friendships, providing insight into how these wider friendship patterns relate to health
outcomes and behavior, and how interpersonal processes play out in larger social contexts.
In the studies reported here, friendship selection and influence was found to result in
networks characterized by segmented friendship cliques with obesity-promoting and
obesity-protective behaviors. And social status within these friendship clusters and wider
network was also associated with obesity-related behaviors and weight status. Finally, the
statistical models applied in these studies—exponential random graph models and
stochastic actor-oriented models—provided a means to account realistically for the
dependencies found in relational data, and a framework to account for both selection and
influence processes simultaneously.
Practical Implications

**Opportunities for Network-Based Behavioral Interventions**

Collectively, the findings from these studies suggest that adolescents’ peer environment is relevant to addressing particular obesity-related behaviors, including physical activity, sedentary screen activities, and energy-dense food consumption. Because friends were found to engage in similar behaviors, and friendships were also likely to cluster into densely connected peer groups, mapping the distribution of these behaviors within friendship networks could be useful in identifying naturally-occurring friendship clusters that do little physical activity, who are high screen-users, or who are high consumers of energy-dense foods, and who can be targeted in school-based interventions.

Insights into the social and psychological mechanisms that underpin associations between friendships and health behaviors also highlight how network-based health interventions might be effective in supporting young people to have healthier lifestyles. Although peer influence can result in adolescents adopting their friends’ unhealthy habits, there is also the potential for positive influence when peers model healthy behaviors. As reported in Paper 4, adolescents whose friends were very active were likely to adopt or maintain active lifestyles as well. And in studies of adolescent smoking, non-smoking youth have been found to discourage their friends from smoking (Kobus, 2003). Peer-led behavioral interventions are one approach that might be successful in encouraging healthy social influence. This was applied in a school-based smoking intervention called ASSIST, which mapped friendship networks to identify students who occupied high-status positions within their naturally occurring friendship groups (Campbell, et al., 2008). These peer leaders were trained to disseminate non-smoking norms amongst their friends via discussion, and were found to be more effective at preventing smoking uptake over two
years compared to traditional teacher-led interventions in control schools. Moreover, because the ASSIST intervention was only targeted at peer leaders, who made up approximately 15% of the total student population, it was also more cost effective than the control condition that targeted all students.

Peer-led behavioral interventions could also be effective in encouraging physical activity, decreased screen time, and healthier eating habits, although the mechanisms of social influence may differ depending on the behavior. Because peer influence on PA was not found to be mediated via adolescents’ perceptions of peer norms (Paper 4), providing opportunities for peer leaders to model healthy behaviors, and for friends to engage in these activities together, may be more effective than having peer leaders discuss healthy norms about PA. The opportunity for adolescents to engage in physical activities with their friends may even encourage the internalization of more positive beliefs about PA, as suggested by the findings in Paper 4, potentially heightening the maintenance of these behaviors in future.

Schools may also be in a position to manipulate the structure of friendship networks by providing students with opportunities for interaction to facilitate the formation of friendships (Moody, 2001). In Paper 1 and Paper 4, students were more likely to become friends if they shared a home group class: an effect which contributed to the overall structuring of the friendship network. Organizing classrooms, extra-curricular groups, or even buddy systems in ways that encourage relationships that have the potential to be conduits for positive social influence and the spread of healthy behaviors amongst students should be explored. How to encourage youth with obesity-promoting behaviors to adopt the habits of healthier peers, without these “healthy” students being negatively influenced, is likely to be a challenge. To overcome this, future research could test whether these
influence processes are moderated by social status, and how healthy behaviors modeled by popular youth might influence, but not be influenced by, less healthy peers.

**Addressing Weight-Based Stigma Amongst Adolescent Friends**

Obesity prevention efforts should also ensure that their programs are in line with a “do no harm” policy, and that in the promotion of healthy weights and healthy lifestyles they are not worsening the stigma experienced by overweight youth. If healthiness is touted as a desirable and valued characteristic, are overweight children likely to be further stigmatized as a result of deviating from this norm, as suggested by the findings in Paper 2? Overweight children’s quality of life and social and emotional development should be prioritized as much as their physical health.

To date, interventions that have sought to change young people’s negative perceptions of their overweight peers, and the expression of this stigma, have been generally unsuccessful (Gray, et al., 2009). The findings from Paper 2 suggest that high status peers could play an important role in efforts to reduce weight-based stigma, and could be a useful target in future interventions. How different qualities of friendship develop and emerge so that they are more inclusive of overweight youth could also be an area for future research.

**Limitations**

Some aspects of the study designs, including the sampling framework and the measurement and analytic tools used, limit the interpretations, generalizability, and conclusions that can be drawn from the thesis results. Because many of these constraints have been outlined in each of the four papers, only a brief summary will be reviewed here.
Limitations Arising From the Sampling Framework

A complete network study design involves taking a census rather than a random sample of all individuals in a population of interest, and mapping the network of relationships amongst all members. This allows the researcher to make inferential statements about social processes within that particular group, however to determine if effects generalize more widely, many social networks need to be sampled. The adolescent populations studied in this thesis included a small number of school grade-level cohorts from Australia, and 28 school classes from the Netherlands. Three of these papers looked at similarity, selection, or influence effects in one, two or three groups of adolescents. Some of the findings supported the hypotheses, were consistent across two or three groups, and were in line with evidence from larger bodies of literature: thus, their generalizability to wider adolescent populations is fairly convincing. However, whether some of the novel and unexpected results generalize beyond the populations that were sampled needs to be determined by further research. Additionally, differences in effects across groups suggest that contextual factors may be important to some selection and influence processes, and sampling a larger number of social networks to test potential moderating factors is required. This approach was applied in Paper 2, where a larger number ($N = 28$) of classroom-based friendship networks were sampled to assess the moderating effect of health norms on weight-based marginalization in early adolescents.

These studies also focused exclusively on friendships amongst classmates or grademates. Although adolescents’ friends are predominantly school-based (Blyth, Hill, & Thiel, 1982), they are likely to have significant relationships with students outside their classroom and grade-level, as well as with youth from family, neighborhood, or wider community contexts (Blyth, et al., 1982; Dolcini, Harper, Watson, Catania, & Ellen, 2005).
The results summarized in this chapter are therefore limited in that they only consider how same-age, school-based friends impact obesity and related behaviors. In particular, out-of-school friends may be influential in adolescents’ evening and weekend leisure activities, such as physical activities and screen time, which could be investigated in future research. As highlighted in Chapter 2, measuring young people’s complete friendship networks, including non-school based friends, requires substantial time and resources to identify and recruit participants. Whole-of-community studies in small towns and cities may be the most practical means of investigating these broader social network measures.

**Limitations Arising from Data Measurement**

Although the use of objective anthropometric measures was a key strength of this thesis, the behavioral and relational measures were all self-report and thus subject to respondent bias. The choice of behavioral measures was a compromise between utilizing the most valid and reliable items, and minimizing missing data by ensuring the questions could be easily and quickly completed. Although more rigorous measures such as accelerometers, food diaries, and daily activity diaries would have been ideal, the demand on respondents and potential for missing data was deemed to be too great. Physical activity, food consumption, and screen time were therefore assessed using brief, validated, self-report measures and where possible included multiple items to assess reliability. An approach used in the ASSIST smoking trial (Campbell, et al., 2008) to ensure reporting bias was minimal, was to validate self-reported smoking by collecting objective measures (in this case saliva samples) from a small subsample of the population. This design could be feasible in many complete network studies, and would enable researchers to assess whether reporting bias is a significant confounding influence on selection and influence effects. For example, it seems plausible that if adolescents’ behaviors are influenced by their peers, they
may also be inclined to bias their responses so that they are more socially desirable (from their friends’ perspective), causing homophily and influence effects to be overestimated.

Relational data were also self-report, captured using peer nomination measures whereby participants listed the names of their friends. Although this is a quick and reliable way to measure friendships in young people, it is also susceptible to respondent fatigue, bias, and missing data if participants simply forget to nominate a friend. A missing tie has consequences for how a particular dyad is represented (e.g., not friends, unilateral friends, or mutual friends), and it can also impact the representation of broader network structures such as triads, or bridging relationships between segmented friendship groups. Utilizing directed relational information in the analysis of network data overcomes some of these issues, and enables some level of confirmation in the form of reciprocity. Multi-informant methods, such as social cognitive mapping (SCM), are also being increasingly used to obtain more reliable and complete measures of young people’s social networks and social groups (e.g., Gest, Davidson, Rulison, Moody, & Welsh, 2007). Here, participants are not only required to report on their own relationships, but also on the relationships and/or social group membership of their peers (e.g., “Which kids at your school hang around together a lot?”), with responses combined into composite scores. SCM can overcome issues of missing data, respondent bias or misreporting, and has the potential to identify broader social groupings, although there is also a great deal of overlap in SCM and self-reported friendship methods (Cairns, Leung, Buchanan, & Cairns, 1995), and approaches to statistically analyze this data are highly complex and not well advanced..

The relational measures used in these thesis studies also assumed that friendship was a binary construct: participants’ peers were either friends, or they were not. However friendship could also be conceptualized as a continuous construct (Hartup, 1996), and
relationships could be assessed in terms of strength, intimacy, liking, or frequency of interaction. The degree of closeness in a friendship may be important in explaining some of these effects of interest in these studies, particularly the weight-based selection processes, where similarities in weight status predicted desired versus mutual friendships in very different ways. Although the statistical models applied in these papers are able to account for ordinal relational data, this option is typically not implemented in the software because it creates many more parameters and excessive complexity. Relationship strength or quality could also be incorporated as a dyadic covariate in these models, and may be useful to consider in future research.

**Future Research Directions**

*Mechanisms Underpinning the Spread of Obesity and Related Behaviors*

Whether or not obesity “spreads” amongst adolescent friends has not been substantiated or refuted by the results of this thesis, and long-term studies that adequately model selection, contagion, and confounding influences would be needed to draw any firm conclusions. However, should we find evidence that obesity is socially contagious, we would want to determine exactly what it is that is spreading amongst friends. As emphasized already in this chapter, investing research efforts into the study of health practices and behaviors in social networks, rather than health outcomes, is likely to provide more practical insights into mechanisms that could be addressed in health interventions.

The results summarized here do suggest that friends share similar obesity risk: they engage in similar obesity-related behaviors, and their participation in PA assimilates over time. Future research should investigate whether friends also influence adolescent screen time and consumption of energy-dense foods, and if this accounts for the behavioral
similarities observed in Paper 3. Moreover, because some of these health behaviors have been found to correlate (e.g., Gorely, Marshall, & Biddle, 2004), studies of multiple behaviors would be valuable to determine the extent to which numerous obesity-promoting behaviors cluster together in friendships and friendship groups. Whether adolescents’ friends influence their perceptions of weight norms, indirectly influencing their weight management over time, would also be a useful issue to examine in future studies.

Developmental, social influence, and social network theory identify a number of factors that are likely to mediate or moderate processes of social selection and influence amongst adolescent friends. The nature of these social processes is likely to depend on individual characteristics, the context in which the social group is situated, and importantly the behavior or outcome in question. Many of these factors were not a focus of this thesis, and would be relevant to consider in future research looking at obesity-related behaviors amongst adolescent peers.

Individual level factors. A range of individual factors are likely to impact both selection and influence effects relating to health behaviors and weight status. The salience of some behaviors to adolescent friendships may differ by gender, as was the case for screen time and energy-dense food consumption in Paper 3. Gender was also found to moderate the impact of weight status on friendship selection, and could also be relevant to “obesity contagion”. These social processes may also change as adolescents age and their peers become increasingly salient (Peterson, 1989), and future studies should test for differences in effects across developmental stages.

If adolescents’ motivation to adopt their friends’ behaviors is largely driven by goals for peer acceptance and social status, there are also likely to be individual differences in social goals that mediate friendship selection and influence effects. Youth who occupy low
status positions amongst their peers may select friends with particular attributes to attain status and may be more susceptible to peer influence, while high status youth may be the most influential, although they are also likely to be under the most pressure to conform to peer norms to maintain their status (Kobus, 2003). Future research on obesity and related behaviors in adolescents could begin to explore how these various individual-level factors interact with friendship selection and influence.

**Contextual factors.** Although the relevance of some behaviors in adolescent peer environments may be fairly universal (e.g., physical activity), local contextual factors may also determine which health attributes and behaviors are salient in peer groups, and whether these traits are a basis for friendship formation, or if peers are important referents for these attributes. Light & Dishion (2007) describe this contextual variation as “unique social ecologies” that shape the interpersonal processes that arise within particular peer groups, classrooms, and school cohorts. Differences in local ecologies could arise through variations in local norms, cultures, school policies, or even physical environments. For example, status-based health norms were found to impact the marginalization of overweight youth across different classrooms (Paper 2). Large studies that sample multiple friendship networks are needed to assess the impact of various contextual factors on these processes, especially because some of these group-level variables may be more amenable to intervention than individual or network-level factors.

The social network literature also provides strong evidence that characteristics of the network structure impact how information, resources, and behaviors flow through social groups. Behaviors have been found to be more homogenous, and are more strongly influenced and reinforced, in networks that are cohesive and centralized (e.g., Centola, 2010; Haynie, 2001). Even at a local level, pressure to conform to other’s behavior can be
stronger in a friendship triad than a dyad: when one person’s behavior differs from two alters in a friendship triad, they experience more pressure to resolve this dissonance than an individual whose behavior differs from one alter in a friendship dyad (Davis, 1963).

Finally, school environments may vary in the degree to which they are obesogenic, with opportunities for physical activity influenced by the physical environment, and the consumption of snack foods and soft drinks shaped by school policy. The norms, beliefs, and assumptions supported within the broad cultural and community environment in which the schools are embedded, as well as the more local family and peer contexts, may also differ from school to school.

Temporal factors. The relevance of friends to health behaviors and outcomes may vary over time, at different stages of development, and during different stages of transition. For example, pre-adolescents have been found to be more susceptible to peer influence on smoking than late-adolescents (Urberg, Cheng, & Shyu, 1991). These thesis studies intentionally focused on adolescents commencing their first year of high school, when friendships were being established and were likely to change. The relevance of attributes such as weight status and leisure activities in the formation of friendships, and the pressure to adopt behaviors to fit in with new peer groups, may be heightened during this time. Once friendships and peer groups stabilize, the strength of these selection and influence effects may subside. How these processes differ over time is a further question that could be addressed in future research. Identifying these moments of friendship transition, that may be a window of opportunity to shape adolescents’ adoption of new behaviors and establishment of behavioral patterns, will be useful in planning intervention approaches.
**Trialing Network-Based Interventions**

Rather than solely focusing on identifying processes through which friends impact adolescent health behaviors and outcomes, we should also begin to trial viable network-based interventions. Not only have a number of potential intervention approaches been outlined in this chapter, but there is also a growing literature looking at adolescent health risk behaviors in the context of their social networks that could also inform program designs (e.g., Valente, 2010).

**Final comments**

In conclusion, the series of studies presented in this thesis provide further evidence that the peer context is relevant to understanding and addressing adolescent overweight and obesity. In these adolescent friendship networks, friends were found to be alike in weight status and on some behaviors associated with overweight, as a result of various social mechanisms.

These peer environments were found to be shaped by adolescents’ preferences for friends whose characteristics were similar to their own, including their attitudes towards and engagement in physical activity, and the extent to which they were overweight. Endogenous structural processes also predicted friendship choices, resulting in networks that were characterized by segmented and homogenous friendship groups.

Adolescents were also shaped by the friendship networks that they actively created. Although there was no evidence that friendships predicted excess weight in these studies, participation in physical activity, a behavior strongly associated with obesity risk (Han, et al., 2010), was influenced by adolescents’ friends. The assimilation of obesity-related behaviors such as physical activity amongst friends is a possible mechanism through which obesity, and many other health outcomes, might “spread” through social networks.
Adolescents are therefore not just passive recipients of influence in their social environment, but are also agents who structure their peer context in ways that may have important implications for their health. This final chapter has outlined some of the important implications of these findings, and suggested a number of ways in which network structures and network processes—including processes of selection and influence—might be harnessed to foster peer contexts that support healthy relationships, healthy behaviors, and ultimately reduce adolescents’ risk of obesity.

We shall not cease from exploration
   And the end of all our exploring
Will be to arrive where we started
   And know the place for the first time
-T. S. Eliot
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