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Some friends matter more than others: BMI clustering among adolescents in four European countries

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Abstract

Previous research stresses the importance of social networks for obesity. We draw on friendship data from 18,133 adolescents in four European countries to investigate the relationship between individuals' body mass index (BMI) and the BMI of their friends. Our study reveals strong evidence for BMI clustering in England, Germany, the Netherlands, and Sweden; adolescents tend to be friends with others who have a similar BMI. Furthermore, we extend current debate and explore friendship characteristics that moderate the relationship between social networks and BMI. We demonstrate that BMI clustering is more pronounced in (1) strong compared to weak friendships and (2) between adolescents of the same biological sex. These findings indicate that more research on social networks and health is needed which distinguishes between different kinds of relationships.

Keywords: BMI; homophily; adolescents; Europe; public health; sociology; social clustering

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1. Introduction

Obesity is related to cardiovascular diseases, cancer, diabetes, psychological problems, and social marginalization (Kopelman, 2007; Puhl & Brownell, 2001) and remains a major threat to public health (World Health Organization, 2000). Previous research stresses the importance of social relationships for health outcomes (Haas et al., 2010; Koehly & Loscalzo, 2009; Smith & Christakis, 2008; Valente, 2010) and situates obesity within network contexts (see Cunningham et al., 2012; Salvy et al., 2012; Shoham et al., 2015; Zhang et al., 2018). Adolescents are particularly affected by networks because of increased vulnerability to socialization, peer pressure, and heightened perception of body norms (Brechwald & Prinstein, 2011; Cotterell, 2007).

Notwithstanding an increasing amount of evidence for BMI clustering among adolescents (Bruening et al., 2015; Centola & van de Rijt, 2015; de la Haye et al., 2011a; Halliday & Kwak, 2009; Leatherdale & Papadakis, 2011; Loh & Li, 2013; Nie et al., 2015; Renna et al., 2008; Schaefer & Simpkins, 2014; Shoham et al., 2012; Simpkins et al., 2013; Trogdon et al., 2008; Valente et al., 2009), only a small number of studies investigate such clustering in European countries (de la Haye et al., 2017; Gwozdz et al., 2015; Mora & Gil, 2013). As noted by Bruening et al. (2015), more research is needed that validates findings on the prevalence of BMI clustering with a contemporary sample of diverse middle and high school students outside the United States.

Over the last decade, much progress has been made concerning the underlying mechanisms of BMI clustering (de la Haye et al., 2011a, 2013; Shoham et al., 2012; Simpkins et al., 2013), partly driven by methodological innovations that allow separation of selection from influence effects (Steglich et al., 2010). Furthermore, scholars increasingly study obesity-related behaviors as conduits for weight similarities (Ali et al., 2012; de la Haye et al., 2010, 2011b, 2013; Frank et al., 2004; Shoham et al., 2012, 2015). While the wider literature on peer pressure and adolescents moved beyond the juxtaposition of parents and peers (see e.g. Brittain, 1963; Floyd & South, 1972), studies on BMI and social networks in adolescents almost exclusively focus on within-classroom relationships. Furthermore, research remains negligent toward different kinds of friendships within the classroom. Analyzing characteristics that moderate BMI clustering provides a more nuanced view of BMI clustering in classroom settings and may point to potentially underlying mechanisms that link social networks with health outcomes.

Our study offers a validation of previous findings on the prevalence of BMI clustering among adolescents with a large dataset from Europe and reveals that some friends matter more than others. BMI clustering is more pronounced in (1) strong compared to weak friendships and (2) between adolescents of the same sex.

2. Theoretical considerations and hypotheses

2.1 Social networks, social clustering and adolescence

Social clustering is one of the most persistent findings in social network analysis (McPherson et al., 2001; Brechwald & Prinstein, 2011), and a plethora of evidence suggests that individuals are more likely to be friends with other individuals who are similar on diverse characteristics, such as race and ethnicity (Blau et al., 1984; Goodreau et al., 2009; Quillian & Campbell, 2003; Marsden, 1987; Shrum et al., 1988), age (Fischer, 1977; Feld, 1982; Marsden, 1987), religion (Laumann, 1973; Verbrugge, 1977), education (Marsden, 1987; Louch, 2000), occupation (Laumann, 1973; Kalmijn, 1998), sex (Marsden, 1987; Smith-Lovin & McPherson, 1993), values (Huston & Levinger, 1978), drug consumption (Kandel, 1978), and other types of behavior (Knecht et al., 2010; Cohen, 1977).

Selection and influence (see Kandel, 1978) are the main explanations for such social clustering. Actors may choose to form relationships with similar counterparts (McPherson & Smith-Lovin, 1987) because similarity of attributes simplifies the process of evaluating, communicating, and predicting the behavior of others (see also Festinger & Hutte, 1954; Hamm, 2000; Werner & Parmelee, 1979; Ibarra, 1992). Having something in common makes it easier to establish trust and solidarity and also reduces tie maintenance costs (Felmlee et al., 1990; Leenders, 1996). Contrasting such choice homophily, Feld (1981) suggests that similar people occupy positions in social space that are proximate to each other, and in consequence, similar people are more likely to meet (Blau et al., 1984; Feld, 1981, 1982). Opportunities for meeting and interacting with others are pivotal for social relationships. Foci, defined as “social, psychological, legal or physical objects around which joint activities are organized” (Feld, 1981, p. 1016), are seen as social structures that systematically constrain the formation and maintenance of social relationships. Examples of such foci are sports teams, political parties, swimming pools, or restaurants. In Feld’s (1982, p. 798) view, social clustering is a likely outcome to the extent that “people draw their friends from foci, and foci bring homogeneous sets of people together.”

Alternatively, actors may adopt behaviors and attributes from others (see e.g. Friedkin, 1998; Brechwald & Prinstein, 2011). Different theoretical traditions are used to substantiate such social influence more generally (see also Burgess & Akers, 1966; Festinger, 1954; Warr, 2002; Zajonc, 1968). For example, social learning theory (Bandura, 1977) suggests that people learn in social contexts; they directly observe and imitate the behaviors of others. Modeling, social reward, punishment, and reinforcement of valued peers change behavior. In contrast, observing others may influence perceptions of social norms, which shapes (together with beliefs and behavior control) intentions and subsequent behaviors (Ajzen, 1991). The theory of normative influence suggests that individuals desire to align with others’ expectations and preferences (Asch, 1955). Individuals experience normative standards expressed by parents or peers and adhere to these standards (Kandel & Lesser, 1969; Simpson, 1962), which assist in generating a favorable sense of self (Abrams & Hogg, 1990).

Both selection and influence processes are especially important for young people (Brown et al., 1986; Cotterell, 2007; Giordano, 2003) and a large amount of studies investigate peer influence processes in adolescence (Brechwald & Prinstein, 2011; Prinstein & Dodge, 2008; Veenstra et al., 2013). Peer group affiliations have been associated with identity development (Erikson, 1994) and organization of status structures (Coleman, 1961). Often, the need for peer acceptance is a central concern in adolescents' lives (Aloise-Young et al., 1994). Such a desire to "fit in" makes adolescents particularly vulnerable to selection and influence processes. Scholars extend attachment theory (Bowlby, 1969) to adolescence (Smith et al., 1999) and highlight the sense of belonging and continuity within a group of friends. Peer groups influence the socialization and identity of adolescents by allowing individuals to explore different interests and uncertainties while providing group membership. In turn, group identity forms when young people seek connections and supportive relationships (Newman & Newman, 2001).

2.2 BMI and social networks

While most studies on BMI clustering among adolescents build on data from the United States (Bruening et al., 2015; Centola & van de Rijt, 2015; Halliday & Kwak, 2009; Renna et al., 2008; Schaefer & Simpkins, 2014; Shoham et al., 2012; Simpkins et al., 2013; Trogdon et al., 2008; Valente et al., 2009), a growing amount of research shows BMI clustering elsewhere, such as Australia (de la Haye et al., 2011*a*), Canada (Leatherdale & Papadakis, 2011), China (Loh & Li, 2013; Nie et al., 2015), Spain (Mora & Gil, 2013), and the Netherlands (de la Haye et al., 2017). Gwozdz et al. (2015) investigate several European countries at once and find BMI clustering in Italy, Cyprus, Hungary, and Estonia. No evidence for BMI clustering was found in Spain, Belgium, Sweden, and Germany; however, these results are based on school-class BMI averages, which is problematic as they ignore relationship structure within school-classes.

The empirical and theoretical literature on the origins of weight similarities between friends (Cunningham et al., 2012; de la Haye et al., 2011a, 2013; Salvy et al., 2012; Simpkins et al., 2013; Shoham et al., 2012) has been growing since its inception with Christakis and Fowler's (2007) widely disputed study on obesity and networks. Christakis and Fowler argued that obesity spreads through social networks like a disease by changing individuals' general perceptions of norms regarding the acceptability of obesity (see also Herman et al., 2003). These findings have been criticized for relying on partial network information (Cohen-Cole & Fletcher, 2008) and for not considering that individuals may preferentially associate with others who are similar. Others contend BMI clustering has more to do with behavior modeling (Birch, 1980; de la Haye et al., 2013; Greenhalgh et al., 2009) and impression management, than it does with norms (see for a systematic review Salvy et al., 2012). Since then, studies have both supported (Yakusheva et al., 2014; Renna et al., 2008; Trogdon et al., 2008) and contested (Cohen-Cole & Fletcher, 2008; Halliday & Kwak, 2009) the notion that obesity is contagious.

For example, findings from a study of Australian middle school students indicate that weight similarities are mostly driven by marginalization and selection processes and less by influence from friends (de la Haye et al., 2011*a*). Previous research also suggests that overweight children are marginalized by their peers and are less likely to be selected as friends (Strauss & Pollack, 2003). According to Schaefer & Simpkins (2014), selection processes are mostly driven by non-overweight adolescents selecting non-overweight friends, whereas overweight adolescents are indifferent in their friendship choice. O'Malley & Christakis (2011) demonstrate that BMI similarity matters both for maintaining existing ties, as well as for forming new ones, and de la Haye et al. (2017) show that overweight children are less likely to receive friendship nominations and more likely to receive antipathy nominations.

Only a small number of studies exist that isolate selection from influence in relation to adolescents' BMI. Whereas de la Haye et al. (2011*a*) find evidence mostly supporting selection, others (de la Haye et al., 2013; Shoham et al., 2012; Simpkins et al., 2013) provide evidence in favor

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of both selection and influence effects. In attempts to untangle the relationship between social networks and BMI even further, a growing body of literature examines the importance of obesity-related behaviors—such as food intake, screen time, playing sports, and other physical activities (Ali et al., 2012; de la Haye et al., 2010, 2011b, 2013; Frank et al., 2004; Feunekes et al., 1998; Salvy et al., 2012; Shoham et al., 2012, 2015)—as immediate precursors of BMI (Spruijt-Metz, 2011) and conduits for weight similarities. For example, de la Haye et al. (2013) suggest that imitation, rather than belief change, drives social influence with respect to food intake. Building on these theoretical considerations and previous empirical studies, our first hypothesis is as follows:

> H1: Adolescents' BMI in England, Germany, the Netherlands and Sweden is positively predicted by the average BMI of their friends.

2.3 Some friends matter more than others

The peer influence literature identifies moderators for social influence as one important area for further research (Brechwald & Prinstein, 2011). Not all pathways for social influence are equally effective. Dyadic characteristics, or target-influencer characteristics, which delineate strong and weak conduits for social influence, receive attention alongside characteristics related to susceptibility and influencing capabilities. On the other hand, social selection can be affected when individuals have multiple attributes in common (Block & Grund, 2014). Extending the debate on BMI clustering, we are interested in portraying a more nuanced understanding of adolescents' BMI clustering. Do all friendships matter the same or are some friendships associated with greater BMI clustering?

2.3.1 BMI clustering and friendship strength

Several studies examine relationship strength and quality as moderators for peer influence. Social clustering has been found to be more pronounced in strong friendships compared to weak friendships with regard to drinking behavior (Bot et al., 2005), depressive symptoms (Stevens & Prinstein, 2005; Prinstein, 2007), substance use (Urberg et al., 2003), smoking (Mercken et al., 2010), prosocial behavior (Barry & Wentzel, 2006), and obesity (Christakis & Fowler, 2007). One can argue that strong relationships are characterized by greater exposure and repeated interaction with friends, which in turn may promote social learning and imitation. Additionally, norms and peer pressure might be more pronounced in tight friendship groups. Notwithstanding the obvious shortcomings in Christakis & Fowler (2007) (see e.g. Lyons, 2011 and Cohen-Cole & Fletcher, 2008), subsequent studies did not reinvestigate their finding that reciprocal friendships are associated with greater obesity clustering. According to Christakis & Fowler (2007), mutual dyads reflect stronger relationships in which social influence operates with greater strength. In contrast, non-reciprocal friendships reflect weaker relationships and are less effective conduits for influence (see also Mueller et al., 2010).

However, social selection may also lead to greater clustering among close friends. Individuals may become closer with friends who share similar body norms (Hruschka et al., 2011). Status associated with physical fitness may lead to stronger friendships between athletic individuals and marginalization of the overweight. A subsequent lack of friendship opportunities may cause those socially marginalized to strengthen ties with other marginalized youth (Valente et al., 2009; de la Haye et al., 2017; Schaefer & Simpkins, 2014). Overweight adolescents may also feel less judged by other overweight peers, which could subsequently increase friendship strength. Feelings of acceptance can motivate friendships as well and foster an environment of comfort, support, and reinforcement of identity, further enhancing friendship development (Simpkins et al., 2013). Following these considerations, our second hypothesis is as follows:

> H2: BMI clustering among adolescents in England, Germany, the Netherlands and Sweden is greater in strong friendships, smaller in weak-outgoing friendships and smallest in weak-incoming friendships.

2.3.2 BMI clustering among same-sex friends

Previous studies mainly investigate the importance of sex differences for BMI clustering in adult populations (Christakis & Fowler, 2007; Cohen-Cole & Fletcher, 2008; Trogdon et al., 2008; Renna et al., 2008; Loh & Li, 2013). Christakis & Fowler (2007) reveal that individuals of the same sex are more likely to be similarly obese (see also Renna et al., 2008). Loh & Li (2013) and Bruening et al. (2015) find this effect as well, but for females only. In contrast, Trogdon et al. (2008) find no statistically significant difference between BMI similarities among same-sex compared to opposite-sex friends. Surprisingly, we are aware of only one study that investigates moderation of BMI clustering or obesity-related behavior by sex similarity in adolescents: De la Haye et al. (2010) find that same-sex friends are more similar with regard to physical activity; female friends engage in similar screen-based behaviors; and male friends are similar in high-calorie foods consumption. The lack of research in this area is especially alarming because adolescence is a crucial period for defining gender roles (Havighurst, 1948; Crouter et al., 1995). While children use gender-based inferences to make choices and predict others' preferences and established norms from early childhood (Martin et al., 1995), gender is particularly salient during adolescence (Kessels, 2005). Social norms are often gendered and it is plausible that norms around eating and fitness (Kanter & Caballero, 2012; Mueller et al., 2010) as well as perceptions of ideal body weight (Fallon & Rozin, 1985; Yakusheva et al., 2011) vary between boys and girls. Same-sex friends often spend more time with each other (Mehta & Strough, 2009), and increased exposure to weight-related behaviors provides a pathway for weight change. Our third hypothesis is as follows:

> H3: BMI clustering of adolescents in England, Germany, the Netherlands and Sweden is greater among friends of the same sex than among friends of the opposite sex.

3. Data and method

We use data from the Children of Immigrants Longitudinal Survey in Four European Countries (CILS4EU) (Kalter et al., 2016; CILS4EU, 2016) to investigate BMI clustering among adolescents in Europe. Data were collected in 2010 and include information on 18,133 adolescents from 958 school-classes (which are nested in 480 schools) in England, Germany, the Netherlands, and Sweden, with a roughly equal representation of boys and girls in each country. There is an overrepresentation of schools with children of immigrants (see CILS4EU, 2016). Data contain extensive information on adolescents from questionnaires including demographic details, beliefs, attitudes, leisure time activities, academic performance, and friends (Kalter et al., 2016). Students were asked to name up to six friends among their classmates. Hence, network boundaries are defined by the school-class in which the survey was conducted, i.e. there are no between-school-class ties. On average, adolescents were 14.99 years old (std = 0.81) (more than 95% of individuals are between 14 and 17 years old). For more technical details on the surveys, see CILS4EU (2016). Adolescents nominated 3.60 classmates as friends on average (std = 1.51) (see Table 1). In total, there are 86,515 pairs of individuals connected by a friendship nomination; 41,086 were strong and 45,429 were weak (see our definition further below). Figure 1 shows one example network for Germany. Node size corresponds to individuals' body mass index (BMI) and node color to biological sex (grey = boys, white = girls).

3.1 Body mass index

BMI is calculated as body mass (in kilograms) divided by height (in meters) squared (for other measures of adolescent fatness used, see Gwozdz et al., 2015). Height and weight are self-reported in our data; we calculated BMI for 15,357 individuals only, due to missing data on either weight or height, or both. The average BMI for all students is 20.58 (std = 3.19) (see Table 1). English adolescents have an average BMI of 20.27 (std = 3.55), Germans 21.20 (std = 3.24), Dutch 20.28 (std = 2.93), and the Swedish 20.81 (std = 3.04). Furthermore, we calculated BMI-for-age scores using z-score transformation (World Health Organization, 2017) which correct for age and sex. Our analyses use this adjusted BMI score.

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Table 1. Descriptive statistics

	Mean	Std	*N*
BMI	20.58	3.19	15,357
Obese	6.81%		1,046
Overweight	11.22%	–	1,723
Female	49.70%	–	18,119
Age	14.99	0.81	17,769
School performance	3.63	0.71	18,025
Exercise (≥once/week)	66.55%	–	15,487
Born in the country	89.06%	–	18,067
Support from family	73.25%	–	17,487
Support from friends	67.20%	–	18,133
Outgoing nominations	3.61	1.51	18,133
Incoming nominations	3.43	1.96	18,133
Friends' average BMI	20.58	2.06	17,636
Strong friends' average BMI	20.54	2.42	14,897
Weak friends' average BMI	20.64	2.57	14,686
Female friends' average BMI	20.37	2.33	11,442
Male friends' average BMI	20.80	2.38	11,850

Notes: Obese and overweight calculated based on age- and sex-group-specific percentiles for BMI provided by WHO; obese defined as BMI $\geq$ 95 percentile; overweight defined as 85 percentile $\leq$ BMI $<$ 95 percentile.

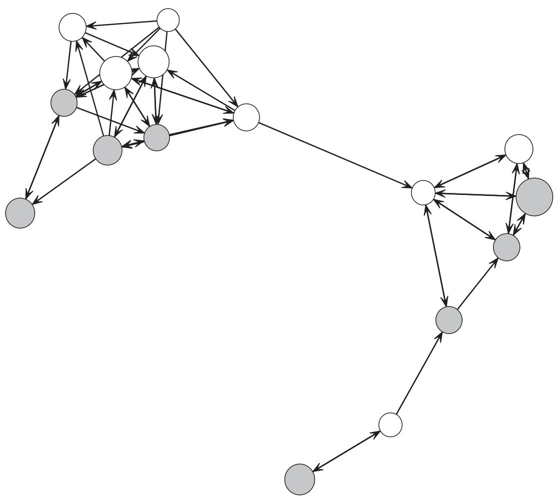

Figure 1. Example plot of a classroom in Germany.

3.2 Strong and weak friendships

In the context of BMI and networks, several studies have used broad friendship definitions, such as everyone in the same grade, school, or community (Asirvatham et al., 2014; Gwozdz et al., 2015; Loh & Li, 2013). Trogdon et al. (2008) argue that such broad definitions have particular use in capturing relationships that facilitate social norms. However, they render fine-grained analyses impossible (e.g. dyadic level). As our hypotheses relate to actual friendships, rather than grade- or school-level association, we draw on CILS4EU's complete school-class network data. Individual students were asked to nominate their "best friend" and up to five other members of their own school-class as "friends." Individuals who both made and received no within-school-class friendship nominations were excluded from our analyses. We exploit the directionality in friendship nominations to distinguish "strong" from "weak" friends; we consider mutual nomination a strong friendship and asymmetric nomination a weak friendship. Furthermore, like Christakis & Fowler (2007), we distinguish between weak-outgoing (ego nominates alter, but not vice versa) from weak-incoming (alter nominates ego, but not vice versa) friendships.

3.3 Covariates

Our analyses include several covariates that are known predictors of BMI and adolescent friendships. Higher BMI may be related to popularity (Strauss & Pollack, 2003); we therefore include the number of friendship nominations ego makes and the number of friendship nominations ego receives. Others have outlined various mechanisms that link obesity with school performance (Taras & Potts-Datema, 2005)); we include school performance as an average of math and language scores (language of the country where ego lives). Both math and language scores are self-reported and range from 1 (worst) to 5 (best). A lack of physical activity has been repeatedly confirmed as a precursor for obesity (Frank et al., 2004; Spruijt-Metz, 2011). We therefore include a direct measure for level of exercise, drawing on a question in which adolescents were asked to indicate how often they "do sports or go to the gym." Possible answers range from "never" (value 1) to "everyday" (value 5). Furthermore, since social capital may protect against obesity (Kawachi & Berkman, 2000; Holtgrave & Crosby, 2006), we include measures for support from family and friends. Concerning family support, we generate a variable that takes the value 1 (and 0 otherwise) when adolescents respond with "often" or "always" when asked about whether they feel close to their family at home. Concerning friend support, we generate a variable that takes the value 1 (and 0 otherwise) when adolescents report that they "go to a friend" when they have a worry or concern. Lastly, ethnic differences in obesity have been highlighted (see Saxena et al., 2004), which could be driven by cultural differences in diets or norms around eating and physical activity. We include a measure that takes the value of 1 when individuals were born in the country of residence (and 0 otherwise). Summary statistics for all variables included in our analyses are presented in Table 1.

3.4 Method

The main variable of interest in our study is adolescents' BMI (adjusted for sex and age group), which is approximately normally distributed in our data. We follow Valente et al. (2009) and use ordinary least-squares (OLS) regression to predict adolescents' BMI from the average BMI of various friends while controlling for a variety of other individual-level characteristics. The students in our dataset are based in 958 different school-classes in 480 different schools. We use hierarchical linear models (HLMs) to account for this nested data structure and control for unobserved heterogeneity at the school-class level (Snijders & Bosker, 2012). Since students who are part of the same school-class often live in geographic proximity, this strategy also controls for unobserved regional and cultural differences. We only include random effects for school-classes (and not for schools or countries, due to their small numbers).

Let j denote the index for school-classes and i denote the index for individuals. Y_{ij} is the dependent variable representing the BMI of individual i from school-class j; x_{ki} indicates the attribute of individual i on variable k, and β_k are parameters to be estimated. The error of the model is partitioned into a school-class specific error u_j and the residual error ϵ_{ij}. Both u_j and ϵ_{ij} are assumed to be independent of one another and normally distributed with means of zero and variances of σ_u^2 and σ_ϵ^2, respectively. The variance of Y_{ij} is therefore decomposed into the variance at the school-class level and the variance at the individual level. The general form of our statistical model is given as follows:

$$Y_{ij} = \beta_0 + \sum_k \beta_k x_{ki} + u_j + \epsilon_{ij} \tag{1}$$

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Due to the large sample size of $N = 18,133$, we chose against using a network autocorrelation or spatial model, which would explicitly account for dependencies between observations (Leenders, 2002). Instead, in line with previous research on BMI clustering (see Valente et al., 2009; Mora & Gil, 2013), we generate independent variables based on the average BMI over certain friends. An alternative modeling strategy would have been to focus on the presence/absence of friendship ties between similar actors using exponential random graph models (ERGMs), which explicitly take dyadic dependence into account (Lusher et al., 2012; Schaefer & Simpkins, 2014). Fitting ERGMs on 958 separate networks, however, is challenging due to stringent goodness-of-fit requirements and model degeneracy. Furthermore, the kind of interaction effects we are interested in cannot be included in a straightforward manner, and school-class-, school-, or country-level effects could only be modeled in meta-analyses. Nevertheless, we conducted additional ERGM analyses on a subset of 96 networks (see Appendix) and results confirm our findings.

4. Results

In all our models, using adjusted BMI-for-age scores (World Health Organization, 2017) yielded substantively similar results compared to non-transformed scores. Since age and sex differences in BMI are crucial during adolescence, we report results for adjusted BMI scores. Our first hypothesis suggests that adolescents' BMI is positively predicted by the BMI of their friends. Table 2 shows estimation results for all students as well as separate results for England, Germany, the Netherlands, and Sweden. Model 1 uses OLS regression and Model 2 adds random intercepts for school-classes. A likelihood-ratio test suggests the inclusion of these random effects (p value < 0.001).

Model 2 shows a positive effect for sex ($\beta = 0.225$, CI [0.185, 0.266]) and a negative effect for age ($\beta = -0.142$, CI [−0.166, −0.117]); younger or male adolescents tend to have a higher adjusted BMI.[1] In contrast, adolescents who perform well in school ($\beta = -0.033$, CI [−0.061, −0.005]) and who exercise at least once per week ($\beta = -0.042$, CI [−0.083, 0.000]) have lower adjusted BMIs. Similarly, adolescents who receive support from their family ($\beta = -0.066$, CI [−0.109, −0.022]) or support from their friends ($\beta = -0.059$, CI [−0.101, −0.022]) have lower adjusted BMIs. There are no significant effects for being born in the country, nominating more friends, or for having more incoming friendship nominations. Most importantly, there is a positive and significant effect for friends' average BMI (adj.) ($\beta = 0.171$, CI [0.143, 0.201]). European adolescents are clustered in friendships by weight. In separate analyses for each country (Models 3–6), this effect remains. Initial ERGM analyses confirm this effect (see Appendix). In sum, we find clear evidence in favor of our first hypothesis: *Adolescents' BMI in England, Germany, the Netherlands and Sweden is positively predicted by the average BMI of their friends.*

Looking at different kinds of friendships, Model 7 in Table 3 shows results for adolescents who have both strong and weak friends (adolescents who had only strong friendships or only weak friendships were excluded from the analysis).[2] We calculated the average BMI (adj.) over strong friends, weak-outgoing and weak-incoming friends. Estimates for control variables remain similar. As hypothesized, the effect for strong friends' average BMI (adj.) ($\beta = 0.137$, CI [0.109, 0.165]) is larger than the effect for weak friends' average BMI (adj.) ($\beta = 0.091$, CI [0.065, 0.116]); although confidence intervals overlap, a t-test shows that coefficients are significantly different from each other ($\chi^2 = 5.27$, df $= 1$, $p = 0.022$). Further distinction within weak friends (see Model 8) indicates that the effect is more pronounced for weak-outgoing friends ($\beta = 0.101$, CI [0.062, 0.139]) than for weak-incoming friends ($\beta = 0.042$, CI [0.008, 0.076]); again, confidence intervals overlap, but a t-test shows that coefficients are significantly different from each other ($\chi^2 = 4.74$, df $= 1$, $p = 0.030$). Additional regression models (not reported here) which contrast (a) strong with weak-outgoing friends only and (b) strong with weak-incoming friends only confirm this pattern. In sum, we find support for our second hypothesis. BMI clustering among adolescents in England, Germany, the Netherlands and Sweden is greater in strong friendships, smaller in weak-outgoing friendships, and smallest in weak-incoming friendships.

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Table 2. Multilevel regression for BMI (adjusted for age and sex) in four European countries

	All countries		England	Germany	Netherlands	Sweden
	(1)	(2)	(3)	(4)	(5)	(6)
Male	0.216 (0.020)***	0.225 (0.021)***	0.119 (0.059)*	0.375 (0.039)***	0.106 (0.036)**	0.282 (0.037)***
Age	−0.135 (0.012)***	−0.142 (0.012)***	−0.241 (0.038)***	−0.145 (0.021)***	−0.096 (0.020)***	−0.348 (0.042)***
School performance	−0.036 (0.014)*	−0.033 (0.014)*	0.023 (0.044)	−0.051 (0.031)	0.045 (0.025)	−0.068 (0.025)**
Exercise (=once/week)	−0.049 (0.021)*	−0.042 (0.021)*	−0.025 (0.062)	−0.029 (0.039)	−0.141 (0.042)***	0.069 (0.036)
Born in the country	−0.026 (0.033)	−0.017 (0.033)	−0.060 (0.086)	−0.017 (0.063)	−0.068 (0.067)	0.019 (0.054)
Support from family	−0.066 (0.022)**	−0.066 (0.022)**	−0.073 (0.062)	−0.049 (0.039)	−0.025 (0.040)	−0.083 (0.042)*
Support from friends	−0.061 (0.022)**	−0.059 (0.022)**	−0.067 (0.074)	−0.057 (0.040)	−0.034 (0.038)	−0.052 (0.038)
Outgoing nominations	0.000 (0.007)	−0.001 (0.007)	0.015 (0.020)	−0.001 (0.010)	0.017 (0.012)	−0.035 (0.011)**
Incoming nominations	0.000 (0.005)	0.000 (0.005)	−0.007 (0.014)	−0.024 (0.030)	−0.008 (0.009)	−0.009 (0.009)
Friends' average BMI (adj.)	0.217 (0.014)***	0.171 (0.015)***	0.116 (0.031)***	0.133 (0.034)***	0.153 (0.028)***	0.223 (0.027)***
School-class random effect	NO	YES	YES	YES	YES	YES
Groups		862	197	196	220	249
N	12,425	12,425	2,143	2,983	3,745	3,554
Log-likelihood	−18443.06	−18436.87	−3610.18	−4273.49	−5317.82	−8919.54

Dependent variable: BMI (adjusted for age and sex); standard errors in parenthesis; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Table 3. Multilevel regression for BMI (adjusted for age and sex) and types of friends

	All (7)	All (8)	Boys (9)	Girls (10)
Male	0.238 (0.024)***	0.248 (0.039)***		
Age	−0.136 (0.014)***	−0.136 (0.023)***	−0.149 (0.038)***	−0.058 (0.034)
School performance	−0.034 (0.016)*	−0.052 (0.027)*	−0.028 (0.046)	−0.047 (0.038)
Exercise	−0.039 (0.025)	−0.047 (0.040)	−0.046 (0.075)	−0.003 (0.056)
Born in the country	−0.007 (0.040)	0.030 (0.064)	0.141 (0.117)	0.115 (0.091)
Support from family	−0.089 (0.026)***	−0.070 (0.042)	−0.087 (0.076)	−0.054 (0.059)
Support from friends	−0.052 (0.025)*	−0.072 (0.040)	−0.058 (0.069)	−0.089 (0.073)
Outgoing nominations	0.000 (0.010)	−0.012 (0.019)	−0.036 (0.031)	0.018 (0.023)
Incoming nominations	−0.004 (0.006)	−0.010 (0.011)	0.005 (0.017)	−0.031 (0.015)*
Strong friends' average BMI (adj.)	0.137 (0.014)***			
Weak friends' average BMI (adj.)	0.091 (0.013)***			
Weak friends' average BMI (adj., outgoing ties)		0.101 (0.020)***		
Weak friends' average BMI (adj., incoming ties)		0.042 (0.017)*		
Female friends' average BMI (adj.)			0.113 (0.037)**	0.193 (0.038)***
Male friends' average BMI (adj.)			0.196 (0.042)***	0.037 (0.025)
School-class random effect	YES	YES	YES	YES
Groups	824	723	552	557
N	8,670	3,566	1,230	1,309
Percentage *N* (compared to Model 1)	0.70	0.29	0.10	0.11
Log-likelihood	−12629.59	−5297.19	−1904.15	−1791.40

Dependent variable: BMI (adjusted for age and sex); standard errors in parenthesis; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.
(7) coeff. different $p = 0.0217$, $\chi^2 = 5.27$.
(8) coeff. different $p = 0.0295$, $\chi^2 = 4.74$.
(9) coeff. different $p = 0.1559$, $\chi^2 = 2.01$; for unadjusted BMI: $p = 0.0233$, $\chi^2 = 5.14$.
(10) coeff. differnet $p = 0.0009$, $\chi^2 = 11.08$; for unadjusted BMI: $p = 0.0033$, $\chi^2 = 8.63$.

Testing our third hypothesis, we performed separate regressions for boys (Model 9) and girls (Model 10). Notice that these analyses only include adolescents who have both male and female friends. For boys (Model 9), the effect for male friends' average BMI (adj.) is positive and significant ($\beta = 0.196$, CI [0.113, 0.279]). In contrast, the effect for female friends' average BMI (adj.) ($\beta = 0.114$, CI [0.041, 0.187]) is less pronounced. Although the difference between coefficients is as hypothesized, confidence intervals overlap and the difference is not statistically significant ($\chi^2 = 2.01$, df = 1, $p = 0.156$). For girls (see Model 10), the effect for female friends' average BMI (adj.) ($\beta = 0.192$, CI [0.117, 0.268]) is greater than male friends' average BMI (adj.) ($\beta = 0.037$, CI [−0.013, 0.086]). In this case, the difference between coefficients is significant ($\chi^2 = 11.08$, df = 1, $p < 0.000$). Even though differences in coefficients are only significant for girls, overall results for Models 9 and 10 provide evidence for our third hypothesis: *BMI clustering of adolescents in England, Germany, the Netherlands and Sweden is greater among friends of the same sex than among friends of the opposite sex.*

5. Conclusion and limitations

Social clustering—the similarity of friends on individual attributes—is one of the most persistent empirical regularities in social life and has been documented for a variety of socially relevant characteristics (McPherson et al., 2001). Concerning obesity and social networks, it has been disputed whether similarities in BMI among friends are the outcome of selection or influence processes (see Christakis & Fowler, 2007; Cohen-Cole & Fletcher, 2008). Notwithstanding this debate, the empirical pattern of BMI clustering is striking (Cunningham et al., 2012; Salvy et al., 2012). Adolescents tend to have a similar BMI as their friends (Bruening et al., 2015; Centola & van de Rijt, 2015; de la Haye et al., 2011a; Halliday & Kwak, 2009; Leatherdale & Papadakis, 2011; Loh & Li, 2013; Nie et al., 2015; Renna et al., 2008; Schaefer & Simpkins, 2014; Shoham et al., 2012; Simpkins et al., 2013; Trogdon et al., 2008; Valente et al., 2009), but evidence for European countries still remains scarce (de la Haye et al., 2017; Gwozdz et al., 2015; Mora & Gil, 2013), and scholars caution that validation outside the United States is needed (Bruening et al., 2015). Drawing on a large dataset with friendship data from 18,133 adolescents in four European countries collected in 2010, we validate previous findings and contribute to the burgeoning literature that establishes BMI clustering among adolescents as a universal phenomenon.

We find no association between number of friends (incoming and outgoing) and BMI. Classroom networks might be limited in size and status distinctions might matter more in larger groups. Similarly, social status penalties might be connected with excess weight and relate with BMI in a non-linear way. We included migration status of individuals in our analyses due to an overrepresentation of schools with migrants in the data, but find no effect in this regard. We encourage more research that investigates the relationship between migration status, ethnic background, and BMI clustering. For example, adolescent membership in a particular ethnic group may represent differing cultural norms and practices compared with interethnic friends. And even more, ethnic differences established by families might be amplified by friendship networks that are often clustered by ethnicity as well. The literature is largely quiet with regard to ethnicity and BMI clustering. At a school level, meta-analyses could examine whether BMI clustering is greater in schools with a high proportion of children of migrants. Such school-level analyses could also take other characteristics of schools into account. Shoham et al. (2012) and Simpkins et al. (2013) find differing effects among different schools, and Gordon-Larsen et al. (2006) suggest that environment differences may be responsible for heterogeneity of effects. So far, few studies have examined which ecological factors may contribute to BMI clustering.

Besides validating previous findings with a large dataset from Europe, we were interested in whether some friends matter more than others. Previous research overwhelmingly treats friendships as homogenous and rarely analyses moderators of BMI clustering at the dyadic level, such as friendship strength (Christakis & Fowler, 2007) or friendships between adolescents of the same sex (Bruening et al., 2015; Christakis & Fowler, 2007; Cohen-Cole & Fletcher, 2008;

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Trogdon et al., 2008; Renna et al., 2008; Loh & Li, 2013). Identifying such moderators can assist in understanding underlying mechanisms and portray a more nuanced picture of BMI clustering. Our finding that BMI clustering is more pronounced for same-sex compared to opposite-sex friends could indicate that gender differences in body image, eating, and fitness norms are important. If only modeling and imitation mattered, we would not expect to find such a gradient. In that case, different kinds of friends would matter the same. On the contrary, it appears that same-sex peers may be more important for establishing acceptable behavior around eating and physical activities (Christakis & Fowler, 2007). The finding that BMI clustering is more prevalent for strong compared to weak friends is less easily reconciled with existing theories. Friendships between adolescents with similar BMI may become stronger over time due to lack of judgment from similar others, or simply a lack of other friendship opportunities. At the same time, peer influence might operate more profoundly through close friends. As of yet, the literature remains silent regarding which mechanisms may lead to these gradients in BMI clustering. Additional longitudinal research should attempt to disentangle whether gradients operate through selection or influence processes (de la Haye et al., 2010).

Understanding how BMI and social networks are related is of critical importance for effective health interventions, since obesity and obesity-related behaviors may spread through social networks (Christakis & Fowler, 2007; de la Haye et al., 2011a, 2013). For example, knowing the level of BMI clustering in a school-class informs intervention strategies regarding whether friendships should be considered in school-level strategies which aim to promote healthier lifestyles (e.g. through diet recommendations for parents, school menus, or sports activities). There is evidence that the social context which has contributed to the rise of the obesity epidemic can also be used to combat it. Koehly & Loscalzo (2009) offer recommendations as to how this could be achieved according to the communal coping process, which purports that interpersonal relationships are the conduits to behavior change (e.g. increased physical activity). From this point of view, interventions are more successful achieving behavioral change when they do not regard individuals as isolates, but as embedded in families and peer networks. Prominent individuals in networks can be targeted, thus functioning as positive influencers toward healthy behaviors. Our research adds that interventions might be even more effective when they operate through friends of the same sex or through tight friendship groups. Despite an increasing amount of research into the mechanisms that link friendship and BMI (de la Haye et al., 2011a, 2013; Shoham et al., 2012; Simpkins et al., 2013), more research on obesity-related behaviors is needed (Ali et al., 2012; de la Haye et al., 2010, 2011b, 2013; Frank et al., 2004; Shoham et al., 2012; Shoham et al., 2015), in particular in the light of our findings that identify sex and friendship strength as moderators.

Our study is not without limitations. Foremost, we only have cross-sectional data, preventing us from separating underlying mechanisms. Do adolescents select friends based on BMI or are they influenced by existing friends and subsequently become similar on BMI? Distinguishing these pathways is difficult (Shalizi & Thomas, 2011), but important for the development of effective intervention strategies. An increasing amount of longitudinal studies suggest that both selection and influence are important for BMI (de la Haye et al., 2013; Shoham et al., 2012; Simpkins et al., 2013), but more research is needed, especially in relation to different kinds of network ties. This includes not only strong and same-sex ties but also more generally network relations outside the classroom. While friendships among adolescents are almost exclusively studied within schools, admittedly one of the most relevant settings in which friendships emerge and manifest, this practice fails to acknowledge the importance of e.g. parents, teachers, or other adolescents outside the classroom. In order to overcome restrictions of current datasets, future research on BMI clustering should employ broader view of relevant networks and investigate different types of relationships.

Other limitations concern the statistical model and measurements used. Due to our sample size of 18,133 individuals in 958 school-classes, we decided against a network autocorrelation model, which explicitly accounts for dependencies between observations. Instead, we generated new independent variables based on the average BMI of friends. An alternative strategy would be to run separate network autocorrelation models for school-classes and aggregate results (see Achen, 2005 and Lewis & Linzer, 2005). At the same time, our choice of statistical model is in line with previous research on BMI clustering (see Valente et al., 2009; Mora & Gil, 2013) and, hence, results are comparable. Shifting focus from actors to relationships, ERGMs also provide a useful framework (Schaefer & Simpkins, 2014; de la Haye et al., 2017) to account for dyadic dependencies and would be a natural next step. Running ERGM analyses on so many networks, however, is challenging, especially because of goodness-of-fit requirements and issues with missing data. So far, methodological recommendations for model specification and for the aggregation of results from several networks are limited (Handcock & Gile, 2010; Snijders & Baerveldt, 2003), mostly due to the fact that network data on so many school-classes have only recently been made available. Recent advancements in ERGM analyses, however, point toward exciting developments, which allow fitting ERGMs on networks with a large number of nodes (Stivala et al., 2016). Finally, our BMI calculations are based on self-reported height and weight. While such measures are widely used in the literature, Gosse (2014) identifies problems with self-reported BMI, but also that no correction method has been found yet.

Conflict of interest. The authors have nothing to disclose.

Notes

1 All confidence intervals refer to the 95% level. Keep in mind that BMI scores have been adjusted according to tables provided by WHO to correct for age and sex.

2 An average BMI score over weak friends cannot be calculated for individuals who only have strong friends. An imputation does not seem to be appropriate in this case because there is no data missing. In order to say something substantial about the differences between types of friendships, we decided to focus our analyses on individuals who exhibit all types of friendships in question. While this procedure reduces the sample sizes in Models 7, 8, 9, and 10, it makes the resulting coefficients more meaningful. Since we are interested in whether the same individual is closer in BMI to friends who do have a certain characteristic compared to friends who do not have a certain characteristic, list-wise deletion seems appropriate.

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Appendix

We conducted ERGM analyses for a subset of 96 networks. In order to obtain more conservative results, we limited our analyses to those networks where more than 90% of individuals both participated in the friendship survey and for whom BMI-for-age scores could be calculated. BMI-for-age scores were calculated based on BMI and L, M, T scores provided by the World Health Organization (2017). Our ERGM specification includes effects for edges, reciprocity, clustering (GWESP, with alpha fixed at 0.25), BMI-for-age popularity (NODEICOV), BMI-for-age activity (NODEOCOV), and BMI-for-age similarity (ABSDIFF). Models were fit separately for each network. After that we followed common practice (see Handcock & Gile, 2010; Snijders & Baerveldt, 2003; Welles & Contractor, 2015) and used WLS to aggregate results. These analyses confirm the BMI clustering effect found using the OLS models (Table A1).

Table A1. Aggregated average effects for 96 networks

	b_WLS	se_WLS	*N*
Edges	−3.716	0.034	96
Mutual	2.904	0.051	96
GWESP (alpha = 0.25)	0.888	0.023	96
BMI-for-age (incoming)	−0.024	0.016	96
BMI-for-age (outgoing)	0.020	0.016	96
Absolute difference in BMI-for-age	−0.036	0.011	96

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