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Analysis of Friendship Network and its Role in Explaining Obesity

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Abstract

We employ Add Health data to show that friendship networks, constructed from mutual friendship nominations, are important in building weight perception, setting weight goals and measuring social marginalization among adolescents and young adults. We study the relationship between individuals' perceived weight status, actual weight status, weight status relative to friends' weight status and weight goals. This analysis helps us understand how individual weight perceptions might be formed, what these perceptions do to the weight goals, and how does friends' relative weight affect weight perception and weight goals. Combining this information with individuals' friendship network helps determine the influence of social relationships on weight related variables. Multinomial logistic regression results indicate that relative status is indeed a significant predictor of perceived status, and perceived status is a significant predictor of weight goals. We also address the issue of causality between actual weight status and social marginalization (as measured by the number of friends) and show that obesity precedes social marginalization in time rather than the other way around. This lends credence to the hypothesis that obesity leads to social marginalization not vice versa. Attributes of friendship network can provide new insights into effective interventions for combating obesity since adolescent friendships provide an important social context for weight related behaviors.

General Terms

Economics

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Additional Key Words and Phrases

Add Health; causality; friendship network; obesity; perceived weight; relative weight

1. INTRODUCTION

The prevalence of obesity has more than tripled among children in the US in the last three decades. This has become a major public health concern because studies have shown a positive relationship between childhood weight, adult weight, diseases, and mortality [Dietz 1998; Zametkin et al. 2004; Crossman et al. 2006; Jeffery et al. 2000].

The spread of infectious diseases such as Influenza and Small Pox requires physical proximity, but no relationship with the transmitter [Chen et al. 2010; Longini et al. 2005]. However, the spread of obesity requires no physical proximity, but may be influenced by a close relationship with the transmitter [Cohen-Cole and Fletcher 2008; Fowler and Christakis 2008; Valente et al. 2009; Eisenberg et al. 2005]. This paper aims to study the influence of such close relationships by analyzing the friendship network of adolescents and young adults on their weight status.

The work is based on data from the National Longitudinal Study of Adolescents Health (Add Health) [Udry 1998; Harris 2009]. The information on friendship nomination is used to construct the friendship network. Under the survey, each participant was asked to nominate 5 male and 5 female friends which ensures that the total number of links incident on a node can be at the most 10. The nodes of this friendship network are the survey participants and the links represent the friendship ties between participants. In this network, a link is created between two individuals when each one nominates the other as a friend. In other words, for two individuals to be called friends, two-way nomination of friendship must be made.

The friendship network, thus created, is used to study the relationship between individuals' perceived weight status, actual weight status, relative weight status (i.e. relative to one's friends' weight status) and weight goals.¹ This analysis helps us understand how individual weight perceptions might be formed, what these perceptions do to the weight goals, and how relative weight status affects weight perception and weight goals. These questions when studied in the context of friendship network help determine the influence of social ties on weight related variables. The longitudinal data on friendships and the actual weight status can help explain the relationship between social marginalization and obesity. In this research, we study the following hypotheses:

1. Obesity leads to social marginalization and not vice versa.
2. People misperceive their weight status. These perceptions are influenced by their weight status in relation to their friends' weight status. The following subhypotheses are studied:

¹Definitions of these variables can be found in Section 3.

- a. When an individual is heavier than his/her peers, he/she will exaggerate his/her weight status to be heavier (e.g., an overweight person might consider herself obese).
 - b. when an individual is lighter than his/her peers, he/she will exaggerate his/her weight status in the opposite direction (e.g., an overweight person might consider herself normal weight if most of her peers are more overweight than she is).
3. Perception of the weight status is more important than the actual weight status in determining weight goals because it is the perception that drives people's weight goals.

To better understand the relationship between overweight/obesity and social marginalization in adolescents we analyzed existing longitudinal network data from Add Health. The BMI was calculated from the height and weight as measured by the survey conductors for all the three Waves. We first categorize the respondents into weight status groups based on their BMI where 1 = underweight (BMI < 18.5); 2 = normal weight (18.5 ≤ BMI < 24.9); 3 = overweight (25 ≤ BMI < 29.9); and 4 = obese (BMI ≥ 30). The weight status groups are further categorized based on race/ethnicity (White, Black, Asian and Native American) and gender. Next, the social marginalization is measured by the share of friendship links each category of individuals has. The greater the number of reciprocal friendship links a person has the less socially marginalized he/she is. People with no reciprocal friendship links are considered to be the most socially marginalized.

The relationship between social marginalization and obesity has been studied in the past [Strauss and Pollack 2003], and the effect has been shown both ways i.e. social marginalization and peer rejection tend to increase sedentary behavior, reduce active leisure activities and encourage eating out of boredom. At the same time, overweight and obese individuals, especially adolescents, are more likely to be socially isolated [Valente et al. 2005]. However, what is needed is a better understanding of the relationship between social marginalization and obesity. If one precedes the other in time, we have some evidence for a causal relationship in which the prior phenomenon causes the latter. Under hypothesis 1, our aim is to understand which factor precedes the other so appropriate interventions can be designed to address both these factors.

For hypotheses 2 and 3 we run multinomial logistic regressions and the results indicate that relative weight status is a significant predictor of the perceived weight status even when actual weight status is present as a control variable; and the weight goal is more aligned with the perceived weight status rather than the actual weight status.

This paper is organized as follows. Section 2 gives a brief overview of the related work and compares it with the contributions of this study. Section 3 explains the data and concepts used in the study. Section 4 analyzes the relationship between obesity and social marginalization. Section 5 examines the influence of relative weight and friendship network on perceived weight and weight goals. The final section provides the summary and conclusions.

2. RELATED WORK

Researchers have shown that peer groups are formed around shared behavior [Valente 2010] and adolescent friendships provide an important social context for many health related behaviors to take place [De La Haye et al. 2010]. For example Voorhees et al. report that adolescent girls are more physically active when their close friends are physically active [Voorhees et al. 2005]. Valente et al. find that adolescent weight is associated with the friends' weight cross sectionally and longitudinally [Valente et al. 2009]. Peers affect perceptions of acceptable weight [Crawford and Campbell 1999] and their social influences impact norms for perceived obesity. As a result peer behavior and peer involvement in weight loss programs have been found to be very effective [Paxton et al. 1999; Wing and Jeffery 1999; Jelalian and Mehlenbeck 2002; Eisenberg et al. 2005]. In general, the attributes of adolescents peers are important determinants of health behaviors [Duncan et al. 2005].

To identify close relationships between peers, past researchers have used unidirectional and bi-directional friendship nominations. The uni-directional nominations are measured by the in-degree, or out-degree of the individuals. Studies have found that the in-degree does not provide a fair representation of friendship because adolescents nominated by overweight and obese individuals as friends are less likely to reciprocate the nomination as compared to the friends of the normal weight adolescents [Strauss and Pollack 2003].

Similarly, out-degree measures the self-reported friendship ties which is known to provide inaccurate number of friends [Bondonio 1998]. This means both in-degree and out-degree measures of friendship provide a biased view of the friendships given that reciprocity is often missing among the friends of the obese individuals. In order to avoid these biases, this study creates friendship links only when both individuals nominate the other person as a friend. The mutual friendship has been shown to have a big influence on one becoming obese [Christakis and Fowler 2007]. The odds of becoming obese were shown to increase by 171% for people greater than 21 years of age if their friends became obese. However, most of the existing literature on friendship networks is based on one-way nominations of friends [Bondonio 1998; Cohen-Cole and Fletcher 2008; Bearman and Moody 2004].

The friendship network also provides the social context to study the role of social ties on distorted self perceptions of weight and consequently on misguided weight goals. Previous research shows that distorted self perception can have a negative effect both ways. Individuals who are overweight and obese but do not perceive it are not likely to use any interventions to fight the weight issue. On the other hand, individuals who are normal weight or underweight and perceive themselves to be overweight or obese can unduly be suffering with low self-esteem and psychosocial distress [Linder et al. 2010; Tang et al. 2010; Kurth and E. 2008]. Work by [Jaworowska and Bazylak 2009] finds a distorted self perception of body weight in both males and females. The females tend to overestimate their body weight and the males tend to underestimate it. Others [Linder et al. 2010] find that women tend to be more accurate than men in identifying themselves to be overweight.

A study on Chinese adolescents [Tang et al. 2010] shows that perceived weight status, rather than the actual weight status, is associated with depression and anxiety. A German adolescents study shows that genuinely obese adolescents are less likely to accept interventions and have a better quality of life than those who perceive themselves to be overweight [Kurth and E. 2008] whereas adolescents of normal weight can have a marked deterioration in quality of life from perceived obesity.

Given the results of these studies it is important to understand the factors that are responsible for the perception of weight status. Aligning perception with the actual weight status is necessary for bringing awareness and implementing effective interventions. To understand the cause of perception, this research examines the role of friend's relative weight as a possible source. It calculates each participant's relative status and checks if the relative status influences the perceived weight status and if the perceived status, in turn, affects the weight goals.

3. SAMPLE DESCRIPTION

This research uses the National Longitudinal Study of Adolescents Health (Add Health) data [Udry 1998; Harris 2009]. This survey started in 1994-95 and followed the same cohort from adolescence into young adulthood. Wave I and II data were collected in 1994-1996 and Wave III data were collected in 2001-2002. This study uses longitudinal data on 20,502 survey respondents who were present in all the three Waves. Details on the sample size of each Wave, demographics of the respondents, response rate, geographical area covered etc. are available at <http://www.cpc.unc.edu/projects/addhealth>.

The survey collects data on respondents' friendship network. In each Wave, each respondent was asked to nominate 5 male and 5 female friends. Each nomination creates a directional link in the friendship network between ego and the nominated person. This study considers only those links that are bi-directional between respondents. This mutual-nomination measure of friendship differs from other notable research on this topic where friends are measured as the number of friendship nominations or the in-degree measure [Strauss and Pollack 2003].

Figures 1 and 2 show the friendship networks generated using bidirectional links for Wave I and Wave III respectively. The size of the nodes represent the weight status, links represent the friendships, and the color of the node represents the race. The structural properties of all three friendship networks, corresponding to the 3 Waves are described in detail in the Appendix.

Other variables used in this study are BMI (calculated from the measured height and weight in Wave I, II and III)², perceived weight status, weight goal, race and gender. BMI is defined as the weight in kilograms divided by the square of height in meters. We perform paired t-test on BMIs, as shown in Table I to check the trend over the 3 Waves.

²BMI and actual BMI is used synonymously.

We convert BMI into a categorical variable, weight status category where 1 = underweight (BMI < 18.5); 2 = normal weight (18.5 ≤ BMI < 24.9); 3 = overweight (25 ≤ BMI < 29.9); and 4 = obese (BMI ≥ 30) [Dietz and Bellizzi 1999].

For the perceived weight status, the Add Health survey participants were asked about self-perception of their weight status. They were asked to choose from 5 categories: severely underweight, slightly underweight, normal weight, overweight and obese. We combine the first two categories (severely underweight and slightly underweight) into one (underweight) category, in order to match the four weight status categories described above.³ The perceived weight status is an important variable since it provides an individual's perception of his/her weight status. People's perception of their weight status is known to be frequently inaccurate [Jaworowska and Bazylak 2009]. Deviation between the perceived weight and the actual weight show the extent to which people mis-estimate their weight. People who are overweight, obese or at risk of being obese must realize their true weight status in order to accept interventions to reduce weight.

Survey participants also provided answers regarding their weight goals. They were asked if they would aim at "losing weight", "gaining weight", "staying the same" or "do nothing". When perceived weight is studied in conjunction with the weight goal one can begin to understand why some people with the wrong perception continue to have inconsistent weight goals. We also consider relative weight status which is calculated as the ratio of one's BMI to the average of his/her friends' BMIs. This is used to measure the effect of social ties on perceived weight status.

4. SOCIAL MARGINALIZATION

In this section, we examine the issue of social marginalization of overweight and obese individuals through friendship networks. We first examine if a lower friend count from the overweight and obese group may be attributed to the lower size of the group. Second, we investigate whether obesity precedes social marginalization in time, or vice versa. An earlier version of this work appeared in [Apolloni et al. 2011]. In contrast, in the current paper, we extend this work by studying the relationship between individuals perceived weight status, actual weight status, weight status relative to friends' weight status and weight goals.

4.1. Friends vs. Weight Status

In order to understand social marginalization, we examine the distribution of weight status and compare it with the distribution of friends' weight status. The goal is to see if the number of friends in any weight group are higher or lower than what would be consistent with the population size of that weight group.

First, we build a friendship matrix based on the mutual friendship nominations. In this matrix, each row shows the distribution of friends across various groups for the row index, where the index represents a group.

³Note that the perception is about the weight status rather than the actual weight.

As an example, Table II shows a row for the underweight group and we suppose this group makes 100 friends total. Then the numbers in the row imply that 25 of these friends are underweight, or of actual weight status 1; 50 are normal weight; 15 are overweight; and 10 are obese.

In order to examine the racial and gender differences, we take the friendship data and split it by race, gender and the actual weight status. We use a 3-digit system to categorize individuals. The first of the 3-digits shows the race of the individual which ranges from 1 to 5: 1 = White; 2 = Black; 3 = Asian; 4 = Native American; 5 = Other. The second digit shows the gender and takes value 1 for male and 2 for female. The third digit is the person's actual weight status which ranges from 1 to 4: 1 = Underweight; 2 = Normal Weight; 3 = Overweight; 4 = Obese. For instance, a category of 314 refers to the group of Asian boys who are obese, and 422 refers to the group of Native American girls who are normal weight.

A complete friendship matrix has 40 rows and 40 columns for each of the 40 race-gender-weight categories. We use an example of 3×3 matrix as shown in Table III, to explain the race-gender-weight status group and the friendships. This example considers only white boys who are underweight (111), normal weight (112) and overweight (113). Note that the percentage shown in the table are for illustration purposes only and are not the actual value for those categories in the data. In this particular example, we assume that there are a total of 3 race $\times$ gender $\times$ weight categories in the population. The fraction represented by row i and column j shows the percentage of people in row i that are friends with the percentage of people in column j . For example, row 1 and column 1 show that 35% of White underweight boys' friends are White underweight boys; row 2 and column 1 show that 15% of White, normal weight, boys' friends are White, underweight boys and so on. The column average shows the average popularity of the category, given by the column header e.g. White, normal weight, boys are the most popular and White, overweight, boys (113) are the least popular.

However, this friendship matrix can provide a biased view if we do not account for the size of each group in the population. In other words, certain groups may have lower friendship percentage because there are fewer of them in the population. We calculate the distribution race-gender-weight status categories as a reference, see Table IV. If there is no discrimination, then the average share of friendship of each category should be equal to the distribution of that category. For instance, assume that in the example shown above, there are 20% boys in category 111, 60% in category 112, and 20% in category 113. In this case both underweight and overweight white boys are not favored as friends (i.e., average < distribution), the overweight boys, even more so.

Figures 3, 4 and 5 show the average share of friends and the size of the group in each category split by race, gender and actual weight status for Waves I, II and III. The plots show the following:⁴

⁴Note that the fraction of Asians and Native Americans is small among the Add Health respondents, which causes low to zero friendship share in some cases.

1. Being overweight does not necessarily imply lower popularity for all race groups: Black and Native American are more popular in general (average exceeds the distribution) and this popularity holds even for overweight and sometimes obese individuals. In Wave III, all sub-categories of Black except obese (i.e. 214 and 224) are slightly favored as friends.
2. The group with the least number of friends is the White obese male category in Wave III where the average number of friends is only one third of the distribution. This is noteworthy given that the obese group as a whole exhibits a number of friendship ties that is close to that of other groups in Wave III.
3. The difference in patterns between Wave I and II is minor.

Overall, these results show that obese, white males, face the highest risk of social marginalization among all the categories however in case of obese Native Americans, both males and females are still popular as friends. These results highlight the cultural differences in the stigma associated with being overweight. Among Native Americans and Black adolescents, the stigma of being overweight and obese is not as socially isolating as it is for Whites.

Next, instead of analyzing correlations between friendships and weight status, we focus on studying causality in order to understand whether the lack of friends is causing the person to be overweight or it is the overweight that causes the person to be unable to make friends. A causality test developed by Granger [Granger 1969] will be used. The results of this test will demonstrate the likelihood of a causation, between friendship and weight status, or the lack of it, more forcefully than a simple correlation. However, note that there still remains a possibility of a confounding factor which may be driving both the dependent and the independent variable and causing spurious correlation to occur between these variables.

4.2. Temporal Relationship between Obesity and Social Marginalization

We use friendship ties as a proxy for social marginalization or lack of social relations. Specifically, we test to see whether social isolation precedes the presence of obesity or vice versa using the Granger causality test. We measure social isolation or marginalization by the number of friends a person has and, obesity by the actual weight status. The following model was estimated:

$$Friends_3 = c + a_1 Friends_1 + a_2 Friends_2 + b_1 BMI_1 + b_2 BMI_2 + u_t, \quad (1)$$

$$Friends_3 = c + a_1 Friends_1 + a_2 Friends_2 + v_t, \quad (2)$$

where $Friends_1$ represents the number of friends in Wave 1, $Friends_2$ is the number of friends in Wave II and $Friends_3$ is the number of friends in Wave III. The definition of friend is as defined before, i.e. two individuals have to be mutually nominated to be called friends. Similarly, BMI_1 represents the actual weight status in Wave 1, BMI_2 and BMI_3 represent the actual weight status in Wave II and III respectively. To examine the influence of past values of weight status on the future values of the number of friends, the regression uses the number of friends from Wave III and regresses it on the number of friends from

Wave I and II, and weight status of Wave I and II. If the coefficients of BMI_1 and BMI_2 are significant and the variance of the error term of this regression is less than the variance of the error term of a similar equation where the lagged values of BMI are dropped, we can say that the lagged values of actual weight status cause future values of social marginalization.

The results of the tests are shown in Table V. The p values of the estimated coefficients in Table V show that all coefficients in both equations are statistically significant at 5% level or less, and the variance of $(\hat{u}_t) < \text{variance of } (v_t)$. The coefficients of the lagged values of BMI show that the actual weight status in Waves I and II negatively impacts the number of friends in Wave III in a statistically significant way. We also tested the counter model where the actual weight status and the friends were swapped in the above model to see if the lagged number of friends caused the future weight status to change. The results are shown in VI. The estimated coefficients were not significant and the variance of (u_t) was exactly the same as the variance of (v_t) which means adding friendship variable to the regression did not improve its ability to predict the future values of weight status. These results show that it is obesity that precedes social marginalization, and lends credence to the notion that obesity precedes social isolation rather than the other way around. Note that the issue of race/ethnicity and gender interacting with social marginalization to influence obesity is important too but authors plan to address that in future work.

5. INFLUENCE OF FRIENDSHIP NETWORK

The role of social networks on obesity among children and young adults has been established in the past [De La Haye et al. 2010; Valente et al. 2009]. This section specifically addresses how the friendship network affects individuals' perception of weight and their weight goals.

The effect of friendship networks is captured through relative weight status, i.e., the ratio between ego's BMI and the average of ego's friends' BMI, and its relationship with the perceived weight status.

$$\text{Relative weight status} = \frac{\text{Ego's BMI}}{\text{Average of ego's friends' BMI}}. \quad (3)$$

Our hypothesis is that relative weight status affects one's perception about his/her weight status, which consequently impacts the weight goals. Relative status is likely to explain discrepancies between one's weight perception and actual weight status because perceptions are often formed by what one observes in its social network and considers as a social norm.

Our previous results have shown consistent similarity between Wave I and II results so to avoid redundancy, we focus on only Wave I and III, for this part of the analysis,

5.1. Perceived and Actual Weight Status

Results in Table VII and Table VIII show that people often misperceive their weight status. This fact holds no matter what the person's race, gender, and the actual weight status is.⁵ The obese individuals are often the least accurate about their weight perception. Only 26%

of the obese individuals in Wave I perceived themselves as obese; in Wave III, this percentage dropped to 21%.

The drop in correct perception is even bigger for the overweight individuals. Only 62% of the overweight in Wave I perceive themselves to be overweight, and in Wave III, this dropped to 47%. Among the overweight individuals 30% perceived themselves as normal weight in Wave I and 48% perceived themselves as normal weight in Wave III. This shift in perception mirrors the shift in body weight. That is, as the population gets heavier, people perceive themselves to be “normal weight” at heavier weights. They are “normal weight” as defined by a weight that is shared by a large proportion of the population. This is a troubling observation because unless there is an accurate self perception of the weight and the risks involved, the individuals will not be motivated to intervene to reduce the risk.

Not all weight groups show a decline in percentage of right perceptions from Wave I to Wave III. Underweight and normal weight status individuals actually show an increase in having the correct weight perception. Fewer underweight individuals see themselves as normal weight over time (from 48% to 36%). Among the normal weight status individuals, more perceived themselves as underweight (from 15% to 19%) and fewer perceived themselves as overweight (from 21% to 12%) in Wave III compared to Wave I.

These results show that social norms may be changing between Wave I and Wave III. As the society became heavier in Wave III, the social acceptance of obesity appears to have gone up. More of the overweight and obese individuals perceive themselves as normal weight in Wave III.

Figure 6 and 7 show box plots of the variance in actual BMI for each perceived weight group in Wave I and III. The box plots for the perceived status underweight (value=1) show the least noticeable change. We see that the box height defined by lines of lower and upper quantile of actual BMIs of those who perceive themselves as normal weight has enlarged from Wave I to Wave III and so does the distance between minimum and maximum for the group over that time period. This implies that people of a wider range of BMIs are perceiving themselves as normal weight as the population gets heavier overall. For example, in Wave I, some people with BMI 30 perceive themselves as normal weight. In Wave III, people with BMI 40 and above perceive themselves as normal weight. As for perceived status 3 and 4 (overweight and obese), we observe an upward shift as well, which also coincides with the weight increase in Wave III.

5.2. Relative and Perceived Weight Status

As shown above, there is rather high discrepancy between actual weight status and the perceived weight status. To understand the source of this discrepancy, we analyze the relationship between perceived status and the relative weight status. Specifically, we use multinomial logistic regression to examine the explanatory power of relative weight on perceived weight and see if it is a significant predictor of the perceived weight.

⁵Additional summary tables of perceived vs actual weight for each race and gender sub-category are available upon request.

The explanatory variables used in the multinomial logistic regression are relative weight, race (1=White, 2=Black, 3=Asian, 4=Native American), gender, and actual weight status. Here we use the largest race (1=White) as the reference group. Gender takes value 0 for male and 1 for female with female being the reference group. For perceived weight status, the normal weight status group is the reference group.

The regression results in Tables IX show that in Wave I, relative status, actual status and gender are significant with p-value less than 0.001. Relative weight status is significant in explaining perceived weight status even when the model is controlled for actual weight status. The magnitude of effect of relative weight status is larger than that of actual status for those who perceive themselves as underweight or overweight. For obese individuals, the effect of the relative and actual weight status is close but the actual status has slightly more impact.

Table X shows that in Wave III, relative status and gender are still significant factors for perceived weight status. The overall patterns are similar compared with the results from Wave I, but the magnitude of effect of relative status is less than that of actual status in Wave III. This could be interpreted as an increase in the social acceptance of heavier people and setting of new social norms in Wave III.

The results indicate that being relatively heavier than friends makes one more likely to feel overweight or obese, and less likely to feel as underweight. The females are more likely to perceive themselves as overweight and obese. The cultural difference is also reflected by race. Being Black has significant impact on perception in both Waves, except for individuals with underweight status in Wave III. And in Wave III, being Native American has significant positive effect on perception of being underweight.

5.3. Perceived Weight Status and Weight Goals

We hypothesize that weight goals are more aligned with the perceived weight status rather than the actual status. Multinomial logistic regression is used to analyze the effect of perceived weight status, race, actual weight status and gender on the weight goals. Weight goal of 4, i.e. “Do Nothing” is used as the base to examine what makes an individual want to do something to change his weight. Note that the difference between “Do nothing” and “Stay the same” is that the latter requires effort, and is a clear goal.

Similar to the analysis on the weight status perception, results for both Waves I and III shown in Tables XI and XII indicate that the perceived weight status and gender are significant in predicting weight goals. The only exception is case of “stay the same” goal, which is a more complex situation than the goals of losing or gaining weight.

In case of the goal to gain or lose weight, the sign and magnitude of the relative weight and gender are consistent with our hypothesis. In case of the goals of losing and gaining weight, the magnitude of impact by perceived weight is larger than that of the actual weight status. In Wave I, for the goal of gaining weight, the actual status is not a significant factor.

6. SUMMARY AND CONCLUSIONS

The results of this research have implications for designing interventions for reducing obesity among adolescents and young adults. For example effective interventions should take into account the friendship networks, since the weight status of the close social network determines the social norms and the level of social acceptance of obesity, which consequently affect the individuals' awareness of their weight status, and their willingness to make efforts towards a healthier weight.

Granger causality test results confirm that the likelihood of causation runs from obesity to social marginalization and not vice versa. However this analysis does not rule out that there may be a third confounding factor that drives both obesity and social marginalization which may be responsible for causing spurious correlation between them. We also find a declining trend in the magnitude of social marginalization among overweight and obese individuals, partially due to the fact that the whole population is getting heavier over time.

Analysis of perceived weight status and weight goal reveals that the perceived status and weight goal are closely aligned. The inaccuracy in perception grows from Wave I to Wave III. This research tries to determine the cause of mis-perception by understanding its relationship with respect to the friends' weight. Relative weight is used as a proxy for measuring the influence of social network on perceived weight status and hence weight goal. Multinomial logistic regression results show that relative weight is a significant predictor of the perceived weight status, and the perceived weight status is a significant predictor of weight goal. Hence, individuals who are heavier than their friends are more likely to have the goal of losing weight and vice versa. This is an important finding as it suggests novel modifiable social and behavioral factors that can be intervened to combat obesity among adolescents and young adults.

This research lays the groundwork for future analysis of social networks in explaining obesity. Our future work will focus on understanding whether the causality relationship between social marginalization and obesity is coincidental or not; also whether confounding factors such as the socio-economic status and built environment, which are likely to be associated with both the weight status and the social marginalization, are responsible for causing spurious correlation between them.

In this paper the race categories are considered to be non-overlapping and discrete groups but in reality people are multi-racial. Hence by-race aspect of the results may change depending upon how the race questions are asked and the context in which the questions are asked [Harris and Sim 2002; Fryer Jr. et al. 2012]. Future work will look deeper into this issue.

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APPENDIX

Structural Analysis of Friendship Networks

In this section we analyze the structural properties of the friendship networks generated from Wave I, II and III data. The structural measures include degree distribution, clustering coefficients, clique counts, clique size, s -metric, number of components, largest connected component, and common neighbors. Table XIII provides an overview of the various structural attributes for Waves I, II and III which can provide further insights into effective interventions.

Common Neighbors

This function finds the average number of common neighbors that pairs of nodes at distance d have. In other words, for a given distance, we first find all the pairs of nodes that have distance d between them and then determine the average number of common neighbors between the nodes in such pairs.

Largest Component

The largest component of the network is the largest connected subgraph where every node in the subgraph can be reached from any other node. Wave I friendship network has 416 nodes in its largest component, whereas Wave II and Wave III have only 38 and 55 nodes respectively. The size of the largest component plays a big role in the diffusion of information, ideas as well as diseases.

Number of Components

This measures the total number of disconnected components in the network. Each vertex and edge belongs to only one of the components. Wave I friendship network has 1,013 components, Wave II has 525 and Wave III has 217 components. Given that Wave I has only 3,097 nodes, each component is quite small whereas Wave III has 2,448 nodes, and 217 components, so the average size of the component is much larger in Wave III. This is also reflected in the average degree of the Wave III network.

Likelihood

The likelihood of a graph $G(V,E)$ is given by the s -metric, $s(g) = \sum_{(u,v) \in E} d_u d_v$ as defined in [Li et al. 2005] where d_u and d_v represent the degree of nodes u and v respectively. s -metric is maximized when the high degree nodes are connected to other high degree nodes. Low

$s(g)$ values are obtained when the high degree nodes are connected to the low degree nodes. In terms of the friendship network, this means that $s(g)$ values are high when popular people are connected to other popular people and $s(g)$ values are low when popular people are connected to more isolated people. It is reflective of the degree of segregation between the high degree nodes and the low degree nodes.

Cliques

Next, we count the number of maximal cliques of various sizes in the network. As shown in Table XIV, most of the cliques in Wave I and II are of size 2 and 3. Cliques of size 4 are rare, and size 5 and higher are almost non-existent. In contrast, in Wave III, the clique size goes as high as 9, although there are only 3 cliques with size 9; there are 19 of size 7 and 75 of size 6. The cliques in Wave III are bigger in size and occur much more frequently. This shows fundamental differences in the connectivity of the friendship network in Wave III, and the friendship networks of Wave I & II.

Clustering Coefficient

The local clustering coefficient of a node [Watts and Strogatz 1998] measures how close its neighbors are to being a clique. It is measured by the proportion of edges present between a node's neighbors to the possible number of edges between them. We calculate the clustering coefficients for each of the nodes in each of the three Waves.

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Fig. 1.

Friendship Network, Wave I: The colors of the nodes represent participants' race and the size of the node represents their weight status. The bigger the circle, higher is the weight status. The links between the nodes represent mutual nominations of friendship. Representation obtained using OSLOM software [Fortunato et al.].

Fig. 2.

Friendship Network, Wave III: The colors of the nodes represent participants' race and the size of the node represents their weight status. The bigger the circle, higher is the weight status. The links between the nodes represent mutual nominations of friendship.

Representation obtained using OSLOM software [Fortunato et al.].

Fig. 3.

Distribution versus average percentage of friends by each category split by race, gender and actual weight status for Wave I

Fig. 4.

Distribution versus average percentage of friends by each category split by race, gender and actual weight status for Wave II

Fig. 5.

Distribution versus average percentage of friends by each category split by race, gender and actual weight status for Wave III

Fig. 6.
BMI vs. perceived weight status, Wave I

Fig. 7.
BMI vs. perceived weight status, Wave III

Table I

BMI trend: results of paired t-test

(a) Wave I to Wave II				
Degree of freedom	Mean of differences	Standard error	t value	P > t
4584	-0.54	0.06	-9.95	0.000

(b) Wave II to Wave III				
Degree of freedom	Mean of differences	Standard error	t value	P > t
4014	-3.54	0.07	-47.27	0.000

(c) Wave I to Wave III				
Degree of freedom	Mean of differences	Standard error	t value	P > t
4775	-4.13	0.08	-56.48	0.000

Table II

Friendship matrix example

	1	2	3	4
1	0.25	0.50	0.15	0.10

Table III

Friendship matrix with 3-digit categories example

	111 (white, boys, underwt.)	112 (white, boys, normalwt.)	113 (white, boys, overwt.)
111	0.35	0.60	0.05
112	0.15	0.75	0.10
113	0.05	0.65	0.30
Column average	$(0.35+0.15+0.05)/3 = 0.183$	$(0.60+0.75+0.65)/3 = 0.667$	$(0.05+0.10+0.30)/3 = 0.15$

Table IV

Popularity Measure: This table explains that if the average percentage of friends from a group is larger than the representation of that group in the sample, then that group is considered to be popular or favored.

	111	112	113
average (avg)	0.183	0.667	0.15
distribution (distri)	0.20	0.60	0.20
comparison	distri > avg	distri < avg	distri > avg
implication	not favored	favored	not favored

Table V

This table presents results of the Granger causality regression tests which checks if the past BMI values are causing changes in the current number of friends. This combined with the variance test determines if the causality is present. In this case, we find that all the coefficients of BMI are statistically significant at 5% level or less and the variance of $(u_t) < \text{variance of } (v_t)$ which means the presence of previous values of BMI helps increase the explanatory power of the regression.

(a) $Friends_3 = c + a_1Friends_1 + a_2Friends_2 + b_1BMI_1 + b_2BMI_2 + u_t$				
Regressor	Coefficient	Standard Error	t value	P > t
Intercept	1.45	0.06	23.31	0.000
Friends ₁	-0.25	0.03	-8.03	0.000
Friends ₂	0.24	0.03	6.99	0.000
BMI ₁	-0.22	0.03	-6.17	0.000
BMI ₂	-0.06	0.03	-1.90	0.05

(b) $Friends_3 = c + a_1Friends_1 + a_2Friends_2 + v_t$				
Regressor	Coefficient	Standard Error	t value	P > t
Intercept	0.82	0.02	39.06	0.000
Friends ₁	-0.24	0.03	-7.68	0.000
Friends ₂	0.25	0.03	7.02	0.000

Table VI

This table presents results of the Granger causality regression tests which checks if the past friendship values are causing changes in the current values of BMI. This combined with the variance test determines if the causality is present. In this case, we find that the coefficients of friendship are either not significant or marginally significant, and the variance of $(u_t) = \text{variance of } (v_t)$ which means the presence of previous values of friendship did not improve the explanatory power of the regression.

(a) $BMI_3 = c + a_1BMI_1 + a_2BMI_2 + b_1Friends_1 + b_2Friends_2 + u_t$				
Regressor	Coefficient	Standard Error	t value	P > t
Intercept	1.09	0.02	51.08	0.000
BMI ₁	0.32	0.01	26.54	0.000
BMI ₂	0.42	0.01	34.18	0.00
Friends ₁	-0.02	0.01	-1.91	0.06
Friends ₂	-0.003	0.01	-0.25	0.08

(b) $BMI_3 = c + a_1BMI_1 + a_2BMI_2 + v_t$				
Regressor	Coefficient	Standard Error	t value	P > t
Intercept	1.08	0.02	51.33	0.000
Friends ₁	0.33	0.01	26.57	0.000
Friends ₂	0.42	0.01	34.23	0.000

Table VII

Actual and perceived weight status, Wave I

Perceived	Underweight	Normal Wt.	Overweight	Obese
Actual				
Underweight	0.49	0.48	0.03	0.00
Normal Wt.	0.15	0.63	0.21	0.01
Overweight	0.03	0.30	0.62	0.06
Obese	0.05	0.12	0.57	0.26

Table VIII

Actual and perceived weight status, Wave III

Perceived	Underweight	Normal Wt.	Overweight	Obese
Actual				
Underweight	0.60	0.36	0.03	0.01
Normal Wt.	0.19	0.68	0.12	0.00
Overweight	0.03	0.48	0.47	0.02
Obese	0.04	0.15	0.61	0.21

Table IX

Multinomial logistic regression outputs, Wave I. Here perceived represents perceived weight status (perceived = 2 is used as the reference group); relative is the relative weight status; actual status is actual weight status (ordinal from 1 to 4); gender is a dummy variable for gender with values 0 = Male and 1 = Female; and race takes values of 2 = Black, 3 = Asian, and 4 = Native American (race = 1 is White and used as the reference group).

Observations = 2686	LR $\chi^2(15) = 1476.99$
Log likelihood = -2186.32	Prob > $\chi^2 = 0.0000$
Pseudo $R^2 = 0.25$	

(b) perceived = 1				
Regressor	Coefficient	Standard error	z	P > z
relative	-3.33	0.40	-8.28	0.000
actual status	-1.48	0.14	-10.84	0.000
gender	-1.01	0.13	-8.37	0.000
race2	0.42	0.16	2.54	0.011
race3	0.37	0.37	1.02	0.308
race4	0.25	0.17	1.49	0.136
Intercept	4.93	0.42	11.80	0.000

(c) perceived = 3				
Regressor	Coefficient	Standard error	z	P > z
relative	2.02	0.33	6.17	0.000
actual status	1.90	0.12	15.51	0.000
gender	1.49	0.12	12.17	0.000
race2	-0.49	0.16	-2.99	0.003
race3	0.12	0.32	0.37	0.713
race4	-0.01	0.15	0.08	0.936
Intercept	-7.79	0.40	-19.27	0.000

(d) perceived = 4				
Regressor	Coefficient	Standard error	z	P > z
relative	3.08	0.58	5.34	0.000
actual status	3.48	0.24	14.42	0.000
gender	3.01	0.34	8.74	0.000
race2	-1.45	0.44	-3.32	0.001
race3	0.23	0.76	0.30	0.761
race4	-0.39	0.47	-0.84	0.403
Intercept	-17.04	0.91	-18.79	0.000

Table X

Multinomial logistic regression outputs, Wave III. Here perceived represents perceived weight status (perceived = 2 is used as the reference group); relative is the relative weight status; actual status is the actual weight status (ordinal from 1 to 4); gender is a dummy variable for gender with values 0 = Male and 1 = Female; and race takes values of 2 = Black, 3 = Asian, and 4 = Native American (race 1 is White and used as the reference group).

Observations = 1904	LR $\chi^2(15) = 1085.26$
Log likelihood = -1566.89	Prob > $\chi^2 = 0.0000$
Pseudo $R^2 = 0.26$	

(b) perceived = 1				
Regressor	Coefficient	Standard error	z	P > z
relative	-0.90	0.39	-2.33	0.020
actual status	-1.05	0.16	-6.55	0.000
gender	-1.02	0.16	-6.55	0.000
race2	0.05	0.19	0.26	0.799
race3	0.40	0.35	1.14	0.235
race4	0.52	0.25	2.10	0.035
Intercept	2.05	0.41	4.99	0.000

(c) perceived = 3				
Regressor	Coefficient	Standard error	z	P > z
relative	0.62	0.27	2.32	0.020
actual status	1.76	0.11	16.37	0.000
gender	1.19	0.14	8.35	0.000
race2	-0.86	0.17	-5.19	0.000
race3	0.52	0.33	-1.59	0.113
race4	0.00	0.26	0.01	0.989
Intercept	-6.42	0.34	-18.83	0.000

(d) perceived = 4				
Regressor	Coefficient	Standard error	z	P > z
relative	0.98	0.42	2.31	0.021
actual status	3.51	0.32	11.12	0.000
gender	2.96	0.41	7.29	0.000
race2	-1.12	0.33	-3.45	0.001
race3	0.74	0.60	1.24	0.216
race4	0.42	0.64	0.66	0.509
Intercept	-16.49	1.21	-13.60	0.000

Table XI

Multinomial logistic regression outputs, Wave I. Here goal represents weight goal (goal = 4 is used as the reference group); perceived is the weight perception (ordinal 1 to 4); actual status is the actual weight status (ordinal 1 to 4); gender is a dummy variable for gender with values 0 = Male and 1 = Female; and race takes values of 2 = Black, 3 = Asian, and 4 = Native American (race 1 is White and used as the reference group).

Observations = 2686 LR $\chi^2(15) = 1815.01$

Log likelihood = -2598.59 Prob > $\chi^2 = 0.0000$

Pseudo $R^2 = 0.26$

(b) goal = 1				
	Coefficient	Standard error	z	P > z
perceived	1.70	0.15	11.13	0.000
actual status	0.98	0.15	6.49	0.000
gender	1.46	0.16	9.07	0.000
race2	0.06	0.24	0.27	0.785
race3	-0.25	0.47	-0.54	0.592
race4	0.36	0.23	1.59	0.112
Intercept	-5.99	0.39	-15.19	0.000

(c) goal = 2				
	Coefficient	Standard error	z	P > z
perceived	-2.09	0.17	-12.39	0.000
actual status	0.19	0.17	1.12	0.263
gender	-1.56	0.18	-8.75	0.000
race2	1.16	0.23	4.98	0.000
race3	0.11	0.51	0.21	0.833
race4	0.65	0.24	2.71	0.007
Intercept	4.16	0.37	11.19	0.000

(d) goal = 3				
	Coefficient	Standard error	z	P > z
perceived	-0.13	0.14	-0.96	0.336
actual status	0.37	0.14	2.64	0.008
gender	0.30	0.14	2.15	0.031
race2	0.30	0.21	1.41	0.159
race3	0.20	0.41	0.50	0.617
race4	0.28	0.21	1.33	0.183
Intercept	0.42	0.32	1.31	0.190

Table XII

Multinomial logistic regression outputs, Wave III. Here goal represents weight goal (goal = 4 is used as the reference group); perceived is the weight perception (ordinal 1 to 4); actual status is the actual weight status (ordinal 1 to 4); gender is a dummy variable for gender with values 0 = Male and 1 = Female; and race takes values of 2 = Black, 3 = Asian, and 4 = Native American (race 1 is White and used as the reference group).

Observations = 1904 LR $\chi^2(15) = 934.51$

Log likelihood = -2031.10 Prob > $\chi^2 = 0.0000$

Pseudo $R^2 = 0.19$

(b) goal = 1				
	Coefficient	Standard error	z	P > z
perceived	1.24	0.12	10.32	0.000
actual status	0.51	0.09	5.48	0.000
gender	0.84	0.14	5.97	0.000
race2	-0.34	0.16	-2.15	0.032
race3	-0.39	0.30	-1.29	0.196
race4	-0.28	0.26	-1.09	0.275
Intercept	-4.93	0.31	-15.91	0.000

(c) goal = 2				
	Coefficient	Standard error	z	P > z
perceived	-1.11	0.15	-7.38	0.000
actual status	-0.52	0.13	-3.98	0.000
gender	-1.66	0.17	-9.89	0.000
race2	0.36	0.18	2.02	0.044
race3	0.22	0.35	0.64	0.523
race4	0.04	0.27	0.16	0.876
Intercept	3.09	0.34	9.07	0.000

(d) goal = 3				
	Coefficient	Standard error	z	P > z
perceived	0.02	0.14	0.18	0.857
actual status	-0.07	0.11	-0.59	0.558
gender	0.21	0.15	1.39	0.165
race2	0.22	0.17	1.30	0.194
race3	-0.47	0.41	-1.16	0.244
race4	-0.15	0.28	-0.53	0.593
Intercept	-0.93	0.32	-2.90	0.004

Table XIII

An overview of the structural attributes of the bi-directional friendship networks derived from Wave I, II and III of the Add Health data.

Attribute	Wave I	Wave II	Wave III
Number of Vertex	3097	1452	2448
Number of Edges	2330	989	5277
Minimum Degree	0	1	1
Maximum Degree	8	5	10
Average Degree	1.51	1.36	4.31
Avg.Common.Neigh.d1	0.16	0.1	1.95
Avg.Common.Neigh.d2	1.08	1.03	1.81
Largest Component	416	38	55
Number of Components	1013	525	217
S-Metric/Likelihood	12284	3296	188979

Table XIV

Clique count of various size for bi-directional friendship networks from Wave I, II and III of the Add Health data

Clique Size	Wave I	Wave II	Wave III
2	1854	900	813
3	146	106	518
4	14	11	367
5	2	1	144
6	0	0	75
7	0	0	19
8	0	0	4
9	0	0	3