Social Network Structures in African American Churches: Implications for Health Promotion Programs

Soohyun Nam · Sunyoung Jung · Robin Whittemore ·
Carl Latkin · Trace Kershaw · Nancy S. Redeker ·
Sangchoon Jeon · David Vlahov

Published online: 11 February 2019
© The New York Academy of Medicine 2019

Abstract The prevalence of obesity among African Americans is higher than among other racial/ethnic groups. African American churches hold a central role in promoting health in the community; yet, church-based interventions have had limited impact on obesity. While recent studies have described the influence of social networks on health behaviors, obesity interventions informed by social network analysis have been limited. We conducted a cross-sectional study with 281 African American men and women from three churches in northeast urban cities in the USA. Data were collected on sociodemographic and clinical factors and anthropometrics. Using a social network survey applying a name generator, we computed network level metrics. Exponential random graph models (ERGM) were performed to examine whether each structural property found in the empirical (observed) networks occurred more frequently than expected by chance by comparing the empirical networks to the randomly simulated networks. Overall, church friendship networks were sparse (low density). We also found that while friendship ties were more reciprocated between dyads in church networks, and there were more tendencies for clustering of friendships (significant positive transitive closure) than in random networks, other characteristics such as expansiveness (number of actors with a great number of friends) did not differ from what would be expected by chance in

random networks. These data suggest that interventions with African American churches should not assume a unitary network through which a single intervention should be used.

Keywords Social network analysis · Social network structure · African American · Church-based intervention · Community-based health intervention · Obesity

Introduction

African Americans have the highest rates of overweight or obesity compared to other groups in the USA and disproportionately suffer from obesity-related problems such as cardiovascular disease, type 2 diabetes, and some types of cancer [1–3]. However, current behavioral interventions to address obesity that often focus on an individual's behaviors in this high-risk, underserved population have not been successful [4–7].

Church-based health promotion interventions have the potential to reach large, hard-to-reach groups and may reduce health disparities. Among African Americans, the church has been a central community resource and a key setting for intervention recruitment and participation [7]. Church-based health interventions that incorporate spiritual and cultural contextualization have been effective. For example, church-based interventions had a significant impact on one-time health behavior adoption such as screenings for prostate, colorectal, and breast cancers, as well as short-term health behavior

S. Nam (✉) · S. Jung · R. Whittemore · C. Latkin ·
T. Kershaw · N. S. Redeker · S. Jeon · D. Vlahov
Yale University, School of Nursing, 400 West Campus Drive,
Orange, CT 06477, USA
e-mail: soohyun.nam@yale.edu

changes for weight reduction such as physical activity and healthy eating [7–11].

Despite this evidence, sustainable risk reduction for African Americans who have the highest obesity rate has not occurred [12–15]. In a recent review of 27 church-based obesity studies [7] among African Americans, most randomized controlled trials (RCTs) (7 out of 12 RCTs) showed improvement in at least one outcome (e.g., body mass index, physical activity, or diet) during a short-term period (e.g., 8 weeks to 4 months among RCTs). Despite the well-documented beneficial effects of social support provided in group-based interventions for health behaviors and weight loss, individual- and group-level approaches showed similar results in obesity outcomes [16, 17]. In addition, contrary to most of the current literature, multi-level interventions (e.g., a combination of individual, church-level, and community coalitions) did not have a greater impact on weight-related outcomes than those targeting only one level [7].

These findings suggest that the effect of group-based interventions conducted within a church setting may be more complex and nuanced than assuming that a congregation is a unitary structure. For example, the effect of interventions in the church setting may be overestimated or underestimated because of the unmeasured networking effect, the group dynamic based on hidden group structures [18, 19]. Therefore, examining social network structures within the church may suggest more effective strategies to improve church-based interventions and to deliver health promotion programs.

Social networks—the webs of social relations and interactions among social actors [20]—influence various health behaviors through social influences, social identity, social learning, and social diffusion [21]. Recent work regarding the potential role of social network analysis in health programs suggested that measures of social network analysis (e.g., degree, density, reciprocity) can be used at each of the four stages of program implementation—exploration, adoption, implementation, and sustainment [22]. A systematic review on social network analysis to obesity that included eight studies ($n = 7$ adolescents, $n = 1$ adults) with entire networks at the level of bounded communities (aka., sociocentric networks) showed significant associations between structural network features and obesity, and strong network influences on diet, physical activity, and weight-related social norms; these suggest that social network-informed intervention may be an effective

strategy to improve adoption and maintenance of obesity-risk behaviors [18, 23–26]. Although churches are viewed as the center of life for many African Americans and venues for community-based health intervention [7, 27], data are sparse on network structures based on social network analysis in this setting.

Methods to analyze social network data need to address the complexity of data that are captured on groups of individuals who are asked to report about their relationships with others and then tie all of the relationships to each other. One approach to analyze such data is by using Exponential Random Graph Models (ERGMs) [28, 29]. ERGMs identify the particular configuration of ties—for example, reciprocity (the extent to which ties are reciprocated) and transitivity (shared friendship; ‘friends of my friends are also my friends’)—that occur more or less than would be expected at chance level given the number of people (actors) and how many are connected (density) of the networks. In an ERGM, networks are treated as an endogenous process and actor attributes (e.g., sociodemographic variables) are treated as exogenous or explanatory variables that affect the presence of social ties [30]. Therefore, ERGMs can be used to (1) describe a network structure, (2) determine if individual attributes (=actor level characteristics, e.g., sociodemographics) are associated with network structural properties, and (3) determine whether individual attributes are associated with behaviors controlling for a network structure and the association between network structure and individual attributes [31]. In this paper, we focused on examining structures of church-based friendship networks. The purpose of this paper is to characterize church-based networks using ERGMs from three African American church congregations. We also discuss churches as potential sites for health promotion programs using social network-informed interventions.

Methods

Design, Participants, and Procedures

Using a cross-sectional study design, we examined church network structure within three African American church congregations in the Greater New Haven urban area. Eligibility criteria for participants included the following: (1) men or women over 21 years of age, (2) self-reported Black or African American, and (3) able to speak and read English. We excluded individuals who

reported disabilities or acute/terminal conditions (e.g., terminal cancer, dialysis) that affect daily physical activity, active psychiatric illnesses such as thought disorders in the past 6 months. Eligible and consenting participants completed the surveys and anthropometric measurements and received a \$30 gift card. All study protocols were reviewed by the Yale University Institutional Review Board prior to study implementation.

In order to engage the community, we first met with the Associate Director of the Yale Center for Clinical Investigation (Yale's Clinical and Translational Science Awards program [CTSA]) who was responsible for the "cultural ambassadors," composed of local ministers and church leadership groups. The cultural ambassadors, and Black community leaders from the New Haven Chapter of the National Association for the Advancement of Colored People provided guidance for a recruitment plan. Church leaders who expressed interest in the study invited the research team to visit small group meetings in the churches (e.g., Bible studies, prayer meetings, women's ministry meetings, choir group practice) to present the study purpose, describe study-related activities, and to discuss effective recruitment strategies. These included kick-off events such as providing marketing gifts (e.g., hand sanitizers) with the study logo on them, health fairs, posting flyers in church buildings, and weekly newsletters. Pastors and the study's principal investigator announced the study at a Sunday service to initiate recruitment and then every 3–4 weeks to encourage participation. We continued enrollment and data collection from May 2015 to June 2016. We visited every Sunday consecutively for 4–6 months per church and also visited each small group meeting such as Bible studies, prayer meetings, women's ministry meetings, choir group practice during weekdays until we achieved saturation, i.e., identified people who either had already participated or declined to participate. The total seating capacity for Sunday worship of the three churches was approximately 150, 170, and 230 people. We also kept track of our recruitment/enrollment logs and stopped the recruitment when the monthly enrollment numbers continued to decrease and was approximately < 5 people per month.

Variables and Measures

Sociodemographic Characteristics and Chronic Comorbid Conditions Sociodemographic data included age, gender, race/ethnicity, marital status, educational

level, employment status, and annual household income. Chronic comorbid conditions were self-reported about past or current medical diagnosis of the following chronic condition: hypertension, hear failure, heart attack, angina, stroke, diabetes, arthritis, asthma, chronic obstructive pulmonary disease, and depression.

Anthropometric Characteristics We weighed each participant on a calibrated digital scale while they wore light clothing without shoes. Height was measured using a portable stadiometer. Body mass index (BMI) was calculated as weight (kg)/height squared (m^2). Percent body fat was estimated using the same digital scale that measures foot-to-foot bioelectric impedance. Waist circumference was taken at the narrowest part of the torso, at the end of a normal expiration. Hip circumference was taken around the buttocks in a horizontal plane at the level of maximal extension of the buttocks. The average of three measurements was calculated, and inter- and intra-observer reliability were checked [32].

Social Networks A name generator network survey was used to elicit index person's friendship networks. A name generator [31] survey included the total number of individuals (i.e., social network members), then asked about social support (social network members who provided emotional, financial, and informational support); socialized with (social network members with whom the individual got together to socialize, eat out, have physical activity together, have fun doing things or talk about importance of physical activity, healthy eating and sleep); type and frequency of shared activities per week or month; amount of time (in months) that the index participant has known each network member. Participants were then asked to list their close friends in the church, the bounded network. Participants also responded to types of the relationship (friend, family) with the listed network members.

Statistical Analysis

Descriptive statistics were conducted to summarize sample characteristics and study variables. Differences among participants of the three churches regarding sociodemographics, clinical factors, and anthropometric characteristics were examined with one-way analysis of variance (ANOVA) for continuous variables and with χ^2 tests for nominal variables. For all analyses, an alpha of .05 was used as the significance level (two-tailed). Each

network characteristic was computed with UCINET 6 for Windows [33]: *density* (number of ties among people in the network expressed as a percentage of all possible ties), *degree* (number of ties coming from each person and going to each person, *in-degree*, *out-degree*), *geodesic distance* (the number of ties in the shortest possible walk from one person to another), reciprocity (extent to which ties are reciprocated between actors), *transitivity* (extent to which two of a person's friends are friends with each other), *clustering coefficient* (a measure of the degree to which nodes in a graph tend to cluster together), *centralization* (extent to which the network is focused on one or a few people), and *isolates* (a person not connected to anyone). We conducted ERGMs with Markov Chain Monte Carlo (MCMC) maximum likelihood estimates to determine whether structural properties in the observed (empirical) network occur greater than expected by chance, based on a fixed number of nodes and graph density [28, 34]. To compare with each church's network and randomly generated ones, structural parameters and standard errors were estimated and simulated using PNet software [34].

To illustrate, Table 1 shows the structural parameters for the directed network used in this study and their corresponding graph configurations [30]. Parameter estimates of zero indicate that the effect being modeled occurs at a rate consistent with chance, whereas a positive parameter suggests that the effect is more prevalent and a negative parameter that the effect is less prevalent than chance, given the other effects in the model [23]. The parameter estimate that is greater than twice its standard error (parameter estimate divided by the

standard error > 2) was considered significantly different from zero [29]. Convergence of the estimation algorithm was assessed by a t-ratio (parameter observation-sample mean/standard deviation), which was considered to get convergence when the absolute value of this indicated less than 0.1. Once convergent estimates were achieved, goodness of fit was assessed with simulation of the estimates in PNet. A t-ratio for parameters less than 2 in absolute value was not regarded as bad fit, although preferably t-ratios should lie between -1 and 1 [28, 36].

Results

Of 281 African American men and women from the three churches, the mean age was 52.8 years ($SD = 14.8$); 77% were women, 32.4% were currently married, and 44.2% had a college degree or higher. Overall, 45.9% were employed full-time, and 49.1% had an annual household income over \$40,000. Mean BMI was 32.0 kg/m^2 ($SD 7.0$) and mean total body fat was 40.5% ($SD 10.2$). About 12% had normal BMI; 27.0% were overweight (BMI 25–29.99 kg/m^2); and 61.6% were obese (BMI $\geq 30 \text{ kg/m}^2$).

Table 2. shows the sociodemographic and clinical characteristics among the three churches. There were significant differences among participants across the three churches in the following: gender, marital status, employment status, some of the clinical factors, BMI, and body fat.

Table 1 Structural parameters, tie configuration, and description used in this study

Parameter	Tie configuration	Description
Reciprocity		Models the tendency for ties to be reciprocated.
Popularity: alternating k-instar (AinS)		Models the in-degree distribution and tendency for popularity.
Expansiveness: alternating k-outstar (AoutS)		Models the out-degree distribution and reflects social activity or expansiveness.
Transitivity: alternating k-triangle effect (AT-T)		Models the tendency for 2-paths to close, meaning for 'a friend of a friend to become a friend' (i.e., shared friendship).
Multiple connectivity: alternating 2-path effect (A2P-T)		Models nodes that are connected by many 2-paths; a pre-cursor to transitivity.

Note: Based on Lusher, Koskinen, and Robins [30]; De la Haye, Robins, Mohr, and Wilson [35]

Table 2 Sociodemographics and clinical characteristics of the participants from the three church networks ($n = 281$).

Category	Mean (SD) or N (%)				F or χ^2	p
	Total ($n = 281$)	Network A ($n = 113$)	Network B ($n = 95$)	Network C ($n = 73$)		
Age ^a (years)	52.8 (14.8)	53.7 (16.8)	52.9 (12.2)	51.3 (14.8)	0.58	.562
Gender ^b					9.17	.010*
Woman	216 (76.9)	94 (83.2)	75 (78.9)	47 (64.4)		
Marital status ^b					25.28	.014*
Married	91 (32.4)	51 (45.1)	19 (20.0)	21 (28.8)		
Widowed	25 (8.9)	11 (9.7)	8 (8.4)	6 (8.2)		
Separated	12 (4.3)	2 (1.8)	8 (8.4)	2 (2.7)		
Never married	74 (26.3)	25 (22.1)	30 (31.6)	19 (26.0)		
Divorced	64 (22.8)	18 (15.9)	26 (27.4)	20 (27.4)		
Other	15 (5.4)	6 (5.3)	4 (4.3)	5 (6.8)		
Education level ^b					7.81	.099
High school graduate or below	157 (55.9)	59 (52.2)	51 (53.7)	47 (64.4)		
College graduate	62 (22.1)	21 (18.6)	25 (26.3)	16 (21.9)		
Graduate school or higher	62 (22.1)	33 (29.2)	19 (20.0)	10 (13.7)		
Employment status ^b					20.20	.010*
Full time	129 (45.9)	53 (46.9)	44 (46.3)	32 (43.8)		
Part time	33 (11.7)	11 (9.7)	9 (9.5)	13 (17.8)		
Retired	55 (19.6)	30 (26.5)	17 (17.9)	8 (11.0)		
Unemployed	35 (12.5)	5 (4.4)	18 (18.9)	12 (16.4)		
Others	29 (10.3)	14 (12.4)	7 (7.4)	8 (11.0)		
Annual household income					15.07	.020*
0–\$39,999	108 (38.4)	35 (31.0)	38 (40.0)	35 (47.9)		
\$40,000–\$79,999	76 (27.0)	37 (32.7)	24 (25.3)	15 (20.5)		
\$80,000 or higher	62 (22.1)	33 (29.2)	18 (18.9)	11 (15.1)		
Refused to answer	35 (12.5)	8 (7.1)	15 (15.8)	12 (16.4)		
Clinical factors ^b						
CVD	126 (44.8)	59 (52.2)	33 (34.7)	34 (46.6)	6.49	.039*
Asthma or COPD	39 (13.9)	11 (9.7)	17 (17.9)	11 (15.1)	2.99	.224
Diabetes	50 (17.8)	22 (19.5)	18 (18.9)	10 (13.7)	1.14	.565
Arthritis	98 (34.9)	37 (32.7)	34 (35.8)	27 (37.0)	0.40	.817
Depression	35 (12.5)	7 (6.2)	18 (18.9)	10 (13.7)	7.84	.020*
Anthropometrics characteristics						
BMI (kg/m^2) ^a	32.0 (7.0)	32.3 (7.2)	33.1 (7.5)	30.0 (5.5)	4.36	.014*
< 25	32 (11.4)	9 (8.0)	11 (11.6)	12 (16.4)		
25–29	76 (27.0)	30 (26.5)	21 (22.1)	25 (34.2)		
30–39	136 (48.4)	60 (53.1)	44 (46.3)	32 (43.8)		
40 or higher	37 (13.2)	14 (12.4)	19 (20.0)	4 (5.5)		
Waist-hip ratio ^a	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)	0.95	.390
Body fat (%) ^a	40.5 (10.2)	41.1 (8.7)	42.4 (10.2)	37.1 (11.5)	6.32	.002*

Note: Network A (=Church A), * $P < 0.05$ significance; CVD cardiovascular disease (angina, heart attack, stroke, and hypertension), COPD chronic obstructive pulmonary disease, BMI body mass index

^aContinuous variables

^bNominal variables

Table 3 shows network compositions. Overall, 61% of participants among the three churches reported that their social network members were friends.

Network Structure and Characteristics

The range of Sunday worship attendance was from 80 to 170 per church including children. Per the mean of Sunday worship attendance rate (97.3, 126, and 151.3 people), approximately 75% of church congregations from each church ($n = 281$) participated in the study. Common reported reasons for refusal of participation were as follows: lack of time for survey participation; no interest in participating in the study; not wanting to check body weight, body fat, or waist circumference.

Table 1 shows definitions of terms, and Table 4 shows descriptions of structural properties from the friendship networks from the three churches, and recommended thresholds for well-connected networks for behavior transmission in group health intervention [38]. Network *density*—the extent to which members are connected (number of ties present divided by number of possible ties)—for three churches was all less than 0.1. *Degree*, the number of ties coming from each person (actor) and going to each person, for three churches was 1.4, 0.6, and 1.2, respectively. A long *geodesic distance* which implies a long time before something (e.g., resources, information) gets from one actor to the other actor [37] ranged from 1.9 to 4.3 in our three observed networks. *Reciprocity*, the extent to which ties are reciprocated, for three churches was 0.21, 0.14, and 0.23, respectively. *Transitivity* for three churches was 0.08, 0.08, and 0.14, respectively. *Components*, the presence

of disconnected groups in the networks ranged from 57 to 88. *Isolates*, the number of people not connected to anyone, ranged from 18 to 39.

Exponential Random Graph Model Parameter Estimates for the Friendship Networks

Table 5 shows structural parameter estimates and standard errors in each of the friendship networks from the three churches. Models of three networks (i.e., friendship networks from three churches) showed a good convergence (maximum likelihood estimates), which is indicated by t-ratio that all the parameters estimated in the model were less than 0.1 in absolute value. In addition, the models generally had a good fit, reproducing well a set of features of the observed networks, by absolute values of t-ratio for all configurations, less than 2. The reciprocity of all three networks was statistically significant (estimate ranged from 3.58 to 4.06), indicating that friendship ties tended to be reciprocated between dyads. Also, the three networks had significant positive popularity values (estimate ranged from 0.48 to 1.02), indicating that there were actors who were very popular and received more nominations than we would have expected by chance. However, the expansiveness of all three friendship networks was not significant. This indicates that there was no difference in the number of actors who had a large number of friends between the observed networks and randomly generated networks. All three networks had significant positive transitivity (estimate ranged from 0.95 to 1.10), indicating that there was a higher number of transitivity in observed networks than in random networks. This means that the

Table 3 Network compositions.

Type of relationship	N (%)			
	Total ($n = 960$)	Network A ($n = 419$)	Network B ($n = 287$)	Network C ($n = 254$)
Friends	586 ((61.0))	254 ((60.6))	193 ((67.2))	139 ((54.7))
Family				
Parents	40 ((4.2))	17 ((4.1))	13 ((4.5))	10 ((3.9))
Spouse	30 ((3.1))	12 ((2.9))	8 ((2.8))	10 ((3.9))
Children	41 ((4.3))	16 ((3.8))	14 ((4.9))	11 ((4.3))
Siblings	82 ((8.5))	29 ((6.9))	29 ((10.1))	24 ((9.4))
Others	69 ((7.2))	36 ((8.6))	5 ((1.7))	28 ((11.0))
No response	112 ((11.7))	55 ((13.1))	25 ((8.7))	32 ((12.6))

Note: Network A (=Church A)

Table 4 Network characteristics of the friendship networks from three African American churches ($n = 281$)

Category	Network A	Network B	Network C
Size	113	95	73
Density (recommended threshold: between 0.15 and 0.50) [31]	0.01	0.01	0.02
Average degree (recommended threshold > 1)	1.40	0.60	1.16
Average geodesic distance (SD) [37]	4.3 (1.9)	1.9 (1.1)	2.9 (1.7)
Reciprocity (recommended threshold > 0.50) [38]	0.21	0.14	0.23
Transitivity (recommended threshold > 0.3) [38]	0.08	0.08	0.14
Clustering coefficient (overall/weighted)	0.21/0.13	0.17/0.10	0.20/0.17
Centralization (in/out) (recommended threshold < 0.25) [38]	0.13/0.03	0.05/0.03	0.05/0.04
Number of component [38]	80	88	57
Number of isolates [38]	19	39	18

Note: Network A (=Church A), *SD* standard deviation

Density: the number of ties present divided by number of possible ties. Degree: the number of links to and from a person, *in-degree* is the number of ties received and *out-degree* is the number of ties sent. Geodesic distance: Shortest path between two people. Reciprocity: Tendency to have reciprocated ties. Transitivity: The extent to which two of a person's friends are friends with each other. Clustering coefficient: The average personal network density for all the nodes in a network. Centralization: The extent to which the network is focused on one or a few people. Component: Set of individuals who are connected with another, but not with others in the community (all non-isolates). Isolates: People not connected to anyone

networks had a tendency for 'a friend of a friend to become a friend' and that the networks were characterized by clustered friendship groups. Significant positive values for popularity and transitivity parameters indicate the existence of a core in the church networks created by both popularity and transitivity effects.

Discussion

The structural properties found in friendship networks in each of three urban African American churches in the northeast showed that the overall density of the networks was low, a finding that suggests that it should not be

assumed that social relationships are well-connected enough for a group health intervention in which the church is considered as one big social network. Optimal density in networks may depend on the types of networks: biological, friendship, organizational [31]. The recommended density threshold for behavioral transmission in a group intervention ranges from 0.15 to 0.50 [31]. If density is too low, intervention strategies may be needed to build connections within the intervention groups by including networking activities [38]. Along the same lines, in the recent study by Marks et al., they described the network structure of 19 community organizations prior to implementation of a community-based obesity prevention intervention [39]. Contrary to their

Table 5 Structural parameter estimates of the three networks by exponential random graph models (ERGMs) ($n = 281$)

Network Parameter	Network A			Network B			Network C		
	Estimate	SE	t-ratio	Estimate	SE	t-ratio	Estimate	SE	t-ratio
Reciprocity	3.63*	0.32	-0.01	4.06*	0.59	0.09	3.58*	0.44	-0.04
Popularity (AinS)	0.82*	0.16	0.05	1.02*	0.25	0.02	0.48*	0.23	0.05
Expansiveness (AoutS)	-0.35	0.20	0.04	0.02	0.34	0.09	-0.16	0.26	0.01
Transitive closure (AT-T)	0.95*	0.12	0.03	0.95*	0.29	0.07	1.10*	0.17	-0.03
Multiple connectivity (A2P-T)	-0.06	0.05	0.02	-0.11	0.14	0.04	-0.18	0.10	-0.04

Note: * parameter estimate/the standard error > 2

SE standard error, *AinS* alternating k-instar, *AoutS* alternating k-outstar, *AT-T* alternating k-triangle effect, *A2P-T* alternating 2-path effect

hypothesis, they found that networks were sparse (low density) and not well connected, which may have negatively influenced the success of community level efforts to prevent obesity [39]. They emphasized that in planning of community-based obesity interventions, we cannot assume the pre-existence of strong networks and deliberate fostering to increase connections is required to improve information flow and group cohesion [39].

Centralization in the church networks was low which met recommended threshold for group health intervention (< 0.25) [38]. To date, data are sparse on the effect of centralization on group health intervention. Centralized networks may have different patterns of decision-making processes and diffusion of ideas compared to decentralized networks [40]. For example, highly centralized networks such as hierarchical networks in corporations have the potential for efficient decision making and fast diffusion when the central people reach many people quickly [31]. Conversely, centralized networks may also have slow diffusion if the central people are resistant or do not embrace new ideas [31]. Reciprocity in our church networks indicated low mutual relationships (recommended value is > 0.50). Transitivity, a cohesion measure in a network, was also relatively low (recommended value is > 0.3) in the church networks [41]. If social relationships are transitive ('friends of my friends are also my friends') within intervention groups, the group becomes cohesive, which may create more positive social interactions including social support [31].

We also performed ERGM to estimate model parameters and standard errors, based on a fixed number of nodes (same network size and fixed density) by comparing each of the three observed church networks to randomly generated networks. All three observed networks showed significant structural properties in reciprocity, popularity, and transitivity.

Reciprocity, which indicates that a nomination between two actors is mutually reciprocated, was significantly present in our adult friendship networks. To date, limited data available to compare our estimates of reciprocity in other adult friendship networks. However, in a study of adolescent friendship, there were more tendencies in reciprocity in girl's friendships than in boys' friendships [35]. The parameter estimates of reciprocity in our sample of mostly women were significantly positive and greater than adolescent girls' friendships, a finding that suggests that adult female friendships in the church may be more reciprocated than in girls' friendships in school. The significant reciprocity may be explained by

their long-term relationships among peer women within church. It indicates stable social relationships and balanced social exchange ("give and take") [42], which may predict positive mental health outcomes [42].

Although parameter estimates of transitivity in our adult friendship networks were slightly smaller than those found in adolescents' friendships in the de la Haye et al. study [23], the significant and positive effects of transitivity suggests that a tendency to transitive clustering of networks exists in the adult friendships in African American churches. Popularity estimates were also significant and positive, indicating that there were popular church members who received more nominations (higher in-degrees) than their peers, which suggests the potential for social network intervention using peer leaders.

Some limitations in the present study should be noted. We included three churches in urban areas where 34–37% of the population was African American/Black. It may not represent friendship networks in African American churches. Although we asked about their significant social relationship with different name generator questions (friendship, kinship, economic exchange etc.) within the church, the findings were not mutually exclusive. That is, some participants nominated the same people for other relationship questions, or nominated their adult family member as friends. Multiplexity—a connection between two actors is multiplex when those actors interact in multiple different contexts (e.g., the spouse is your best friend)—may exist in our observed networks. The potential multiplexity may have influenced the structure of our observed networks. Last, as commonly occurs in sociocentric network studies, there was a challenge to examine adult friendship networks. Planning for recruitment and study procedures with our community partners and church leadership groups, we decided to use only in-person data collection rather than telephone interviews or using a roaster, the method used in school- or organization-based network studies. This may influence our study findings; for example, individuals who do not have a connection (i.e., isolates) with other church members and do not attend Sunday worship regularly for 4–6 months would have been missed.

Implications for Church-Based Network Interventions

The significant reciprocity and transitivity we found in the friendship networks in churches suggest that leveraging on existing mutual relationships (dyad- and triad) may be effective strategies to promote health behaviors via social

influence, and to sustain the health behavior change based on the continuity of social relations. Social norms that influence adoption of health behaviors could also be improved by network interventions, particularly within the church where people share social identities and there are in-person social interactions.

Peer leaders for health interventions could be identified from opinion leaders who receive many incoming ties (e.g., central people) or based on other individual network position (bridge, isolates) to reach out to people within the networks and outside of the network boundary (e.g., outside of the church). For example, in a study of network structure using agent-based models, the computer simulations of synthetic agents, the network intervention that targeted opinion leaders increased the average level of physical activity across the entire network [43]. However, the intervention that targeted the most sedentary children was the most effective at increasing the targeted high-risk group's physical activity levels [43]. Therefore, in developing network interventions, there is a need for specific attention to the following: specific behaviors targeted within the networks, the goals of network interventions, whether the goal is reaching out to a large number of people to adopt healthy behaviors or to targeting high-risk people who may also not be well connected with others (e.g., isolates) within the networks.

As in many social relationships, unhealthy behaviors, for example, high-risk sexual practices, smoking, and illicit drug use are also shared through networks. Negative interaction within social networks, often not measured in studies, could influence the effect of group intervention, and may require rewiring networks or building new networks. Future efforts for church-based or group-based interventions should consider examining the underlying network structures that may influence adoption and maintenance of targeted health behaviors; and how network structures evolve during and after the interventions and how the change in network structures have impact on network function. Also, examining network analysis at the individual level is needed—whether individual's network characteristics (e.g., position in networks: central, periphery, bridge) are associated with his/her health outcomes including health behaviors.

In summary, the application of social network analysis to group- and community level-health interventions is an emerging field and many opportunities remain open [22, 39, 44, 45]. Understanding social network structure based on sociocentric network analysis in African American churches may be important to develop

health promotion programs and improve the effect of the interventions by allocating resources efficiently and targeting health problems and behaviors.

Acknowledgments This research was supported by grants from the National Institute of Nursing Research and National Research Foundation of Korea (K23NR014661 and NRF-2017R1D1A1B03033380).

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

1. Flegal KM, Carroll MD, Kit BK, Ogden CL. Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999–2010. *JAMA*. 2012;307(5):491–7. <https://doi.org/10.1001/jama.2012.39>.
2. Wang Y, Beydoun MA, Liang L, Caballero B, Kumanyika SK. Will all Americans become overweight or obese? Estimating the progression and cost of the US obesity epidemic. *Obesity (Silver Spring)*. 2008;16(10):2323–30. <https://doi.org/10.1038/oby.2008.351>.
3. Centers for Disease Control and Prevention. *Health data interactive*. Atlanta, GA: Centers for disease control and prevention, national center for health statistics. <http://www.cdc.gov/nchs/hdi.htm>. Updated 2014. Accessed May/1, 2017
4. Tussing-Humphreys LM, Fitzgibbon ML, Kong A, Odoms-Young A. Weight loss maintenance in African American women: A systematic review of the behavioral lifestyle intervention literature. *J Obes*. 2013;2013:437369. <https://doi.org/10.1155/2013/437369>.
5. Young DR, Stewart KJ. A church-based physical activity intervention for African American women. *Fam Commun Health*. 2006;29(2):103–17. Accessed 15 April 2018. <https://doi.org/10.1097/00003727-200604000-00006>.
6. West DS, Elaine Prewitt T, Bursac Z, Felix HC. Weight loss of Black, White, and Hispanic men and women in the diabetes prevention program. *Obesity (Silver Spring)*. 2008;16(6):1413–20. <https://doi.org/10.1038/oby.2008.224>.
7. Lancaster KJ, Carter-Edwards L, Grilo S, Shen C, Schoenthaler AM. Obesity interventions in African American faith-based organizations: a systematic review. *Obes Rev*. 2014;15:159–76. Accessed 15 April 2018. <https://doi.org/10.1111/obr.12207>.
8. Holt CL, Litaker MS, Scarinci IC, et al. Spiritually based intervention to increase colorectal cancer screening among African Americans: screening and theory-based outcomes from a randomized trial. *Health Educ Behav*. 2013;40(4): 458–68. Accessed 15 April 2018. <https://doi.org/10.1177/1090198112459651>.
9. Matthews AK, Berrios N, Darnell JS, Calhoun E. A qualitative evaluation of a faith-based breast and cervical cancer screening intervention for African American women. *Health*

- Educ Behav.* 2006;33(5):643–63. Accessed 15 April 2018. <https://doi.org/10.1177/1090198106288498>.
10. Wilcox S, Parrott A, Baruth M, et al. The faith, activity, and nutrition program: A randomized controlled trial in African-American churches. *Am J Prev Med.* 2013;44(2):122–31. Accessed 15 April 2018. <https://doi.org/10.1016/j.amepre.2012.09.062>.
11. Vidrine DJ, Fletcher FE, Danysh HE, et al. A randomized controlled trial to assess the efficacy of an interactive mobile messaging intervention for underserved smokers: project ACTION. *BMC Public Health.* 2012;12(1):696. Accessed 15 April 2018. <https://doi.org/10.1186/1471-2458-12-696>.
12. Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999–2002. *JAMA.* 2004;291(23):2847–50. <https://doi.org/10.1001/jama.291.23.2847>.
13. Williamson DF, Kahn HS, Remington PL, Anda RF. The 10-year incidence of overweight and major weight gain in US adults. *Arch Intern Med.* 1990;150(3):665–72.
14. Mokdad AH, Ford ES, Bowman BA, Dietz WH, Vinicor F, Bales VS, et al. Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001. *JAMA.* 2003;289(1):76–9.
15. Lewis CE, Smith DE, Wallace DD, Williams OD, Bild DE, Jacobs DRJ. Seven-year trends in body weight and associations with lifestyle and behavioral characteristics in black and white young adults: the CARDIA study. *Am J Public Health.* 1997;87(4):635–42.
16. Faridi Z, Shuval K, Njike VY, et al. Partners reducing effects of diabetes (PREDICT): a diabetes prevention physical activity and dietary intervention through African-American churches. *Health Educ Res.* 2010;25(2):306–15. Accessed 15 April 2018. <https://doi.org/10.1093/her/cyp005>.
17. Allicock M, Campbell MK, Valle CG, Carr C, Resnicow K, Gizlice Z. Evaluating the dissemination of body & soul, an evidence-based fruit and vegetable intake intervention: challenges for dissemination and implementation research. *J Nutr Educ Behav.* 2012;44(6):530–8. Accessed 15 April 2018. <https://doi.org/10.1016/j.jneb.2011.09.002>.
18. Gesell SB, Bess KD, Barkin SL. Understanding the social networks that form within the context of an obesity prevention intervention. *J Obes.* 2012. Accessed 15 April 2018;2012:1–10. <https://doi.org/10.1155/2012/749832>.
19. Hunter RF, McAnaney H, Davis M, Tully MA, Valente TW, Kee F. "hidden" social networks in behavior change interventions. *Am J Public Health.* 2015;105(3):513–6. Accessed 6 October 2016. <https://doi.org/10.2105/AJPH.2014.302399>.
20. Smith KP, Christakis NA, eds. Social networks and health. *Annu Rev Sociol.* 2008;34:405–29. <https://doi.org/10.1146/annurev.soc.34.040507.134601>.
21. Berkman LF, Glass T, Eds. *Social epidemiology*. New York: Oxford; 2000. Berkman L. F. and Kawachi I., eds. Social integration, Social Networks and Social Support and Health
22. Valente TW, Palinkas LA, Czaja S, Chu K, Hendricks Brown C. Social network analysis for program implementation. *PLoS One.* 2015;10(6). Accessed 12 November 2018): e0131712. <https://doi.org/10.1371/journal.pone.0131712>.
23. de la Haye K, Robins G, Mohr P, Wilson C. Obesity-related behaviors in adolescent friendship networks. *Soc Networks* 2010;32(3):161–167. Accessed 15 April 2018. doi: <https://doi.org/10.1016/j.socnet.2009.09.001>.
24. Nam S, Redeker N, Whittemore R. Social networks and future direction for obesity research: a scoping review. *Nurs Outlook.* 2015;63(3):299–317. Accessed 15 April 2018. <https://doi.org/10.1016/j.outlook.2014.11.001>.
25. Christakis NA, Fowler JH. The spread of obesity in a large social network over 32 years. *New Engl J Med.* 2007;357(4): 370–9. Accessed 30 August 2018. <https://doi.org/10.1056/NEJMsa066082>.
26. Zhang S, de la Haye K, Ji M, An R. Applications of social network analysis to obesity: a systematic review. *Obes Rev.* 2018;19(7):976–88. Accessed 12 November 2018. <https://doi.org/10.1111/obr.12684>.
27. Taylor RJ, Mouzon DM, Nguyen AW, Chatters LM. Reciprocal family, friendship and church support networks of African Americans: findings from the national survey of American life. *Race Soc Probl.* 2016;8(4):326–39. Accessed 15 April 2018. <https://doi.org/10.1007/s12552-016-9186-5>.
28. Robins G, Pattison P, Kalish Y, Lusher D. An introduction to exponential random graph (p*) models for social networks. *Soc Networks.* 2007;29(2):173–91. Accessed 15 April 2018. <https://doi.org/10.1016/j.socnet.2006.08.002>.
29. Snijders TAB, Pattison PE, Robins GL, Handcock MS. New specifications for exponential random graph models. *Sociol Methodol.* 2006;36(1):99–153. Accessed 15 April 2018. <https://doi.org/10.1111/j.1467-9531.2006.00176.x>.
30. Lusher D, Koskinen J, Robins G, editors. *Exponential random graph models for social networks: theory, methods, and applications*. New York, NY: Cambridge University; 2012.
31. Valente TW. Social networks and health: models, methods, and applications. In: Social networks and health: Models, methods, and applications ; 2010:1–296. Accessed 30 November 2015. <https://doi.org/10.1093/acprof:oso/9780195301014.001.0001>.
32. Chen MM, Lear SA, Gao M, Frohlich JJ, Birmingham CL. Intraobserver and interobserver reliability of waist circumference and the waist-to-hip ratio. *Obes Res.* 2001;9(10): 651. Accessed 15 April 2018
33. Borgatti S, Everett M, Freeman L. *UCINET for windows: software for social network analysis*. Harvard, MA: Analytic Technologies; 2002.
34. Wang P, Robins GL, Pattison PE. PNet: A program for the simulation and estimation of exponential random graph models. 2006.
35. de la Haye K, Robins G, Mohr P, Wilson C. Obesity-related behaviors in adolescent friendship networks. *Soc Networks.* 2010;32(3):161–7. Accessed 9 October 2013. <https://doi.org/10.1016/j.socnet.2009.09.001>.
36. Robins G, Pattison P, Wang P. Closure, connectivity and degree distributions: exponential random graph (p*) models for directed social networks. *Soc Networks.* 2009;31(2):105–17. Accessed 15 April 2018. <https://doi.org/10.1016/j.socnet.2008.10.006>.
37. Borgatti SP, Everett MG, Johnson JC. *Analyzing social networks*. London: Sage; 2013.
38. Gesell SB, Barkin SL, Valente TW. Social network diagnostics: a tool for monitoring group interventions. *Implement Sci.* 2013;8(1):116. <https://doi.org/10.1186/1748-5908-8-116>.
39. Marks J, Sanigorski A, Owen B, McGlashan J, Millar L, Nichols M, et al. Networks for prevention in 19 communities at the start of a large-scale community-based obesity prevention initiative. *Transl Behav Med.* 2018;8(4):575–84. Accessed 12 November 2018. <https://doi.org/10.1093/tbm/iby026>.

40. Sueur C, Deneubourg J, Petit O. From social network (centralized vs. decentralized) to collective decision-making (un-shared vs. shared consensus). *PLoS One*. 2012;7(2). Accessed 15 April 2018);e32566. <https://doi.org/10.1371/journal.pone.0032566>.
41. Snijders T Transitivity and triads. http://www.stats.ox.ac.uk/~snijders/Trans_Triads_ha.pdf; accessed 9/12/2013. Updated 20122018.
42. Fyrand L. Reciprocity: A predictor of mental health and continuity in elderly people's relationships? A review. *Curr Gerontol Geriatr Res*. 2010;2010:14. <https://doi.org/10.1155/2010/340161>.
43. Zhang J, Shoham DA, Tesdahl E, Gesell SB. Network interventions on physical activity in an afterschool program: An agent-based social network study. *Am J Public Health*. 2015;105:S236–43. Accessed 15 April 2018. <https://doi.org/10.2105/AJPH.2014.302277>.
44. Luke DA, Stamatakis KA. Systems science methods in public health: Dynamics, networks, and agents. *Annu Rev Public Health*. 2012;33:357–76. <https://doi.org/10.1146/annurev-publhealth-031210-101222>.
45. Sabot K, Wickremasinghe D, Blanchet K, Avan B, Schellenberg J. Use of social network analysis methods to study professional advice and performance among healthcare providers: A systematic review. *Syst Rev*. 2017;6(1):208–017 –0597-1. <https://doi.org/10.1186/s13643-017-0597-1>.