Social Network Structure of a Large Online Community for Smoking Cessation

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Objectives. We evaluated the social network structure of QuitNet, one of the largest online communities for behavior change, and compared its characteristics to other known social networks.

Methods. Using modern network analysis methods, we identified QuitNet members who were active during a 60-day period, along with their ties. We then derived multiple subgroups, such as key players and integrators, from connections and communication patterns.

Results. Among 7569 participants, we identified 103592 connections to other members. Metrics of social network integration were associated with increased likelihood of being female, being older, having been in the system longer, and not smoking.

Conclusions. The QuitNet community is a large-scale social network with the characteristics required for sustainability of social support and social influence to promote smoking cessation and abstinence. These characteristics include persistence of members over time, heterogeneity of smoking status, and evidence of rich, bidirectional communications. Some of the influential subgroups we identified may provide targets for future network-level interventions. (*Am J Public Health.* 2010;100:1282–1289. doi:10.2105/AJPH.2009.165449)

Despite decades of research, tobacco use remains the most deadly of behaviors, causing 5 million deaths worldwide annually[1] and projected to cause 10 million per year by 2030.[2] The United States has an estimated 44.5 million smokers, leading to 430000 premature deaths annually.[3] Evidence-based cessation interventions exist but are vastly underutilized by smokers.[4] There is a pressing need to maximize the population impact of cessation with innovations that are attractive and accessible to consumers.[3] One method is to leverage social network effects, which play a prominent role in the induction of smoking cessation and the perpetuation of abstinence.[5]

Observational studies support a robust relationship between social support and positive outcomes for smoking, other health behaviors, and health status.[6,7] Higher levels of connectedness and positive social support are associated with smoking cessation and relapse prevention.[8–11] Negative social support (e.g., a spouse who smokes or is critical of attempts at cessation) are barriers to cessation.[11] After these associations were established, intervention studies manipulated supportive interactions outside the context of cessation treatment as a means to improve outcomes, with disappointing results.[8,10–15] Consequently, enthusiasm for social support interventions waned,[16] and the focus shifted to delivering the briefer treatments preferred by smokers.[17]

Online social networks, which have proliferated in the past decade, offer a novel way to address the gap between observational data and lackluster intervention effects. Social network interventions may work through multiple mechanisms, including social support, information transfer, social influence, modeling, and the transmission of social norms. Despite the growth of online communities and networks, few published reports describe their characteristics.[18–21] Moreover, health behavior studies containing social network features have not documented the characteristics of the social network itself.[22–25] Before network effects are studied, it is critical to determine whether a true social network has developed. Otherwise, efforts to evaluate the efficacy of a social network intervention may fail if researchers unwittingly study a system that has not yet developed into a functional, sufficiently heterogeneous, large, and stable network or in which the ties between participants are weak or insufficient. Finally, no social network studies to our knowledge have examined the mechanisms that might underlie their effectiveness in changing behavior.

We used formal network methods and analytic techniques to explore key structural and functional characteristics of a large, known online community for smoking cessation. Specifically, we sought to (1) characterize the social network and participants of this community, (2) describe its structure and establish that it shared characteristics with other known online networks, and (3) identify subgroups whose existence and characteristics might inform the design of cessation interventions. Our intent was to establish the necessary foundation for subsequent investigations into the effectiveness of online social networks in influencing cessation outcomes as well as to advance understanding of social network effects in tobacco treatment.

METHODS

QuitNet (http://www.quitnet.com) is one of the most popular, long-lived, and successful continuously operating online social networks focused on smoking cessation. For over 10 years it has enrolled individuals into a network of current and former smokers seeking to quit or stay abstinent and has provided multiple mechanisms of social support and influence. Characteristics of QuitNet's users and details regarding its development and evolution are published elsewhere.[25–27] Since the inception of its social network features in 1997, more than 800000 individuals have registered. In 2007, QuitNet had approximately 1.2 million unique visitors, of whom 123927 registered as new members (L. Severtson, Healthways QuitNet, personal communication, March 7, 2008).

QuitNet's community features allow for multiple forms of social support. Communication can occur through asynchronous channels (e.g., private internal e-mail [Qmail] or

one-to-many messaging in the threaded forums) or through synchronous channels (such as chat rooms). Users can self-affiliate into clubs (user-initiated minisites, complete with dedicated forums), and buddy lists allow individuals to keep track of their friends. Social influence regarding cessation is conveyed through profile pages, journals (similar to a blog), anniversary lists, and testimonials. Users are encouraged to publicly share their quit dates, which are set through a wizard tool, and users are prompted for updates at each login.

QuitNet maintains a complete transactional history of all events, including communications that occur throughout the site. Active events (e.g., sending internal e-mail, posting a public message) and passive actions (e.g., reading messages, viewing another individual's profile) are logged into a relational database. This database provides a rich source of information about social network ties (a connection between 2 actors, such as a communication or friendship; also called an edge or a link)—literal evidence of communications and links between participants.

Data Extraction

We compiled data on registered QuitNet members in the United States who indicated during registration that they were looking for smoking cessation help for themselves and who logged in to the Web site during the 60-day study period (March 1, 2007–April 30, 2007) and completed 1 or more of the following actions: (1) exchanged an internal message with another participant, (2) posted a message within the online forums, and (3) added, or was added by, another QuitNet participant to a buddy list. This data set included both new users and QuitNet members who registered before the study period. Individuals who met the inclusion criteria formed the weakly connected core. We delineated subsets of the online community in this core.

We collected anonymized registration data for all members of our core sample. We also collected Web site utilization data, including records of logins, message exchange time stamps (internal e-mail sent and received, forum posts), additions to buddy lists, initial motivation to quit according to the stages of change algorithm,[28] and subsequent recording and changes to quit dates that occurred during the 60-day window. We extrapolated smoking status by carrying forward status at registration and adjusting it according to user-provided quit dates. Individuals who provided a quit date that fell within or after the observation period (or failed to provide a quit date) were coded as smoking; individuals whose last known quit date was prior to the observation period were coded as abstinent. At the end of the 60-day period, we calculated duration of participation (time on site) by the number of days since registration.

Because our initial data set (the weakly connected core) was large and the number of participants within this core who had few ties was also large, we delineated 5 subsets of participants. We first identified additional network cores, subsets of the graph that were connected with a relatively small diameter (the longest path through the network when the shortest possible path is selected for any 2 participants).[29] This is equivalent to the widely disseminated concept of 6 degrees of separation, where the maximum shortest pathway through the theoretical world is 6 degrees. We defined a strongly connected core of actors (individuals having connections to other individuals; also referred to as a node or a vertex) as individuals connected by buddy nominations plus observed communications and a densely connected core as actors connected by symmetric buddy nominations plus a minimum of 5 communications with at least 1 buddy during the observation period. We chose symmetric buddy nominations to differentiate the strongly connected core from the densely connected core because previous research in real-world networks indicated that behavior change may be more likely when nominations are symmetric.[30]

We then delineated 3 additional subgroups directly from the weakly connected core: a group of new registrants from the initial 4-week period (newcomers), their alters (integrators; alters are actors with a tie to another actor of interest, known as an ego), and key players, a set of actors with high levels of connection to the entire community.

Data Analysis

We examined demographic, smoking history, and Web site utilization characteristics for the entire community and each subgroup (Table 1). We used parametric and nonparametric tests to determine the statistical significance level. Members of the subgroup were removed from the larger group (e.g., the strongly connected core from the weakly connected core) prior to analysis so that comparisons were between nonoverlapping groups. We performed logistic regressions with centrality measures (degree, the number of alters to which an ego is connected, and Freeman's betweenness, the number of shortest paths that include a given ego) as categorical data, zero as the referent, smoking status as the dependent value, and controls for age, gender, time since registration, and number of logins. We used SPSS for Windows version 17.0 for these analyses.[31]

We examined the community structure to see whether it displayed common characteristics of social networks. For network manipulation, characterization, and statistical analyses, we used the software program ORA,[32] with the exception of Freeman's betweenness and the core–periphery correlation, for which we used UCINet 6.[33] We created static graphs and time-lapse animations with an iterative spring-embedded algorithm to minimize overlapping ties.[34] For static graphs we used the Pajek program[35] and for animations, SoNIA 1.2.[36]

Although individuals with high degrees (high numbers of alters—ties may link in one direction but not the other [such as e-mail]; this is referred to as the in-degree for ties to an actor and the out-degree for ties emanating from an actor) were easily identified, these individuals often had significant overlap with other well-connected individuals. A group of actors that could reach the maximum proportion of the rest of the network within a set maximum path length was termed a key player set. We derived key player sets from the weakly connected core with the software program KeyPlayer 1.4.[37] To derive the key player set, we used diffusion measures, minimization of reciprocal distance, and the greedy algorithm as software settings, with internal e-mail as the primary tie.

RESULTS

The weakly connected core comprised 7569 QuitNet participants who met the inclusion criteria; these members had 103 592

TABLE 1—Characteristics of and Web Site Utilization Data for Participants in the QuitNet Online Social Network for Smoking Cessation: March 1, 2007–April 30, 2007

	Weakly Connected Core[a] (n = 7569)	Strongly Connected Core[b] (n = 4407)	Densely Connected Core[c] (n = 554)	Key Players[d] (n = 50)	Newcomers[e] (n = 792)	Integrators[f] (n = 756)
Age, y, mean (SD)	42.3 (11.2)	43.8*** (11.1)	46.3*** (10.2)	49.3*** (10.7)	38.9*** (11.3)	45.1*** (10.4)
Female, %	72.0	72.5	78.5***	80.0	74.0	76.6**
Smoking at baseline, %	65.7	64.7*	66.7	77.6	100.0***	60.6**
Smoking at last observation point, %	44.3	39.4***	35.1***	28.0*	85.5***	29.3***
Abstinent for entire study period, %	45.5	54.7***	61.7***	64.0**	1.0***	64.1***
Median no. d since registration (interquartile range)	175 (54–640)	351*** (96–785)	432*** (162–797)	546*** (187–865)	47*** (41–54)	269*** (95–750)
Time since registration, %						
<3 mo	36.3	23.4	14.4	6.0	100.0	23.0
3 mo to 1 y	24.4	27.6	28.0	24.0	. . .	32.8
>1 y	39.3	48.9	57.6	70.0	. . .	44.2
Logins, median no. (interquartile range)	8 (3–32)	17*** (5–62)	127.5*** (41–249)	268*** (164–416)	5*** (1–15)	96*** (31–210)
Forum posts, median no. (interquartile range)	0 (0–3)	1*** (0–7)	11*** (0–82)	135*** (17–456)	0** (0–2)	27*** (6–110)
Forum partners, median no. (interquartile range)	1 (0–9)	3*** (0–21)	50*** (14–102)	143*** (50–305)	0*** (0–5)	53*** (17–110)
Forum partners who reciprocated, %	31.4	42.6***	84.1***	92.0***	26.0***	87.8***
Buddies set, median no. (interquartile range)	0 (0–2)	1*** (0–4)	13*** (7–23)	19*** (6–48)	0*** (0–0)	3*** (0–10)
Buddies who reciprocated, %	23.3	40.0***	84.7***	86.0***	9.7***	52.6***
Chat partners, median no. (interquartile range)	0 (0–1)	0*** (0–1)	0* (0–2)	0** (0–4)	0*** (0–2)	0*** (0–2)
QMail messages, median no. (interquartile range)						
Sent	0 (0–3)	1*** (0–8)	39*** (8–135)	209*** (78–633)	0*** (0–1)	14*** (2–57)
Received	1 (1–4)	2*** (1–10)	46*** (11–132)	169*** (63–320)	2** (1–3)	16*** (3–60)
QMail partners						
People sent to, median no. (interquartile range)	1 (1–3)	2*** (1–5)	12*** (5–25)	57*** (32–114)	1*** (1–3)	7*** (3–19)
People who reciprocated, %	41.5	58.5***	91.7***	98.0***	30.9***	83.5***
Club memberships, median no. (SD)	0.6 (2.7)	0.8*** (3.5)	2.1*** (6.4)	3.6*** (5.9)	0.6 (1.6)	1.8*** (5.5)

Note. Actor = an individual with connections to others in the network; QMail = private e-mail messages on the QuitNet network. The weakly connected core minus subgroup N (strongly connected core or densely connected core) served as comparison group for all subsequent subgroups. Ellipses indicate not applicable (these individuals were excluded by definition of the group).
[a]Participants who completed 1 or more of the following actions during the observation period: (1) exchanged an internal message with another participant, (2) posted a message in the online forums, or (3) added, or was added by, another QuitNet participant to a buddy list.
[b]Limited to participants connected by buddy nominations and observed communications.
[c]Limited to participants connected by symmetric buddy nominations plus a minimum of 5 communications with at least 1 buddy.
[d]Actors with high levels of connection to the entire community.
[e]New registrants to the site in the first 4 weeks of the study.
[f]Participants who were registered on the site before the study began and who initiated and formed ties (through Qmail or forum message) with newcomers.
*P < .05; **P > .01; ***P < .001.

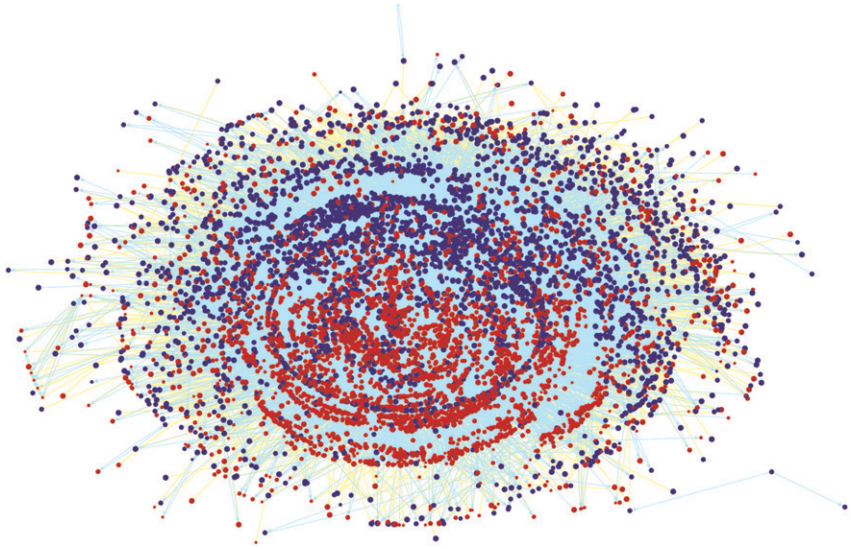
ties. Most participants (72.0%) were female, and 34.3% reported that they had already quit smoking at the time of registration (action or maintenance in the stages of change algorithm; Table 1). Almost half the members of the weakly connected core (45.4%) were abstinent throughout the course of the observation period, as determined by quit date.

Network Participation

The network is presented visually in Figure 1. Consistent with the core–periphery structure, we identified a clear core of actors centrally who were well connected and a more weakly connected rim of actors; this visual finding was supported by a core–periphery coefficient of 0.332, a fit index that indicated a modest correlation between the observed structure and a hypothetical ideal core–periphery structure.[38] Visually, a large cluster of smokers appears in the inferior portion of the graph, and nonsmokers cluster more in the superior aspect.

The majority of weakly connected core members were long-standing members of QuitNet; 63.7% had been members for 3 months or longer. Consistent with other studies,[25,39,40] we observed significant variability in Web site utilization patterns for both visits and communications. A small percentage of participants used the Web site extensively, creating large standard deviations. We also reported median and interquartile range to better represent use patterns among the majority of participants.

Participants made an average of 38.2 visits during the 60-day study period (SD = 83.7; median = 8; interquartile range = 3–32), and 45.8% posted 1 or more messages in the



Note. Red dots indicate individuals presumed to be smoking and blue dots indicate abstinent members; the size of the dot is proportional to the time since joining the network. Blue lines connect buddies and yellow lines represent communications in Qmail, the Web site's internal, private messaging system.

FIGURE 1—Weakly connected core of the QuitNet network plotted with a spring-embedded algorithm: March 1, 2007–April 30, 2007.

forums, with an average of 14.2 posts per person (SD=67.2; median=0; interquartile range=0–3). Close to half (44.1%) of members sent at least 1 message, and 78.7% received at least 1 message from a community member. On average, members sent 18.4 messages (SD=123.7; median=0; interquartile range=0–3), received 18.4 messages (SD=115.5; median=1; interquartile range=1–4), and exchanged messages with 4.2 other members (SD=32.9; median=0; interquartile range=0–1).

Club participation was less common, with 18.9% of members belonging to 1 or more clubs (median=0.55; SD=2.7). After adjustment for age, gender, and utilization, measures of centrality were negatively correlated with active smoking, including Freeman's betweenness centrality (χ^2=16.35; *df*=4; *P*<.003), buddy out-degree (χ^2=29.08; *df*=3; *P*<.001), and Qmail out-degree (χ^2=14.01; *df*=3; *P*=.003). However when an ego's degree was limited to ties to smokers, the correlation reversed, showing a positive correlation between number of contacts and active smoking for both Qmail (χ^2=33.66; *df*=3; *P*<.001) and buddies (χ^2=16.12; *df*=3; *P*=.001.)

Characteristics of Strongly Connected and Densely Connected Cores

We removed the isolates (an actor having no ties to other actors) and pendants (an actor connected only to 1 other actor) recursively from the strongly connected core, yielding a smaller core of 4407 individuals, and from the densely connected core, yielding a very dense subnetwork of 554 participants. Characteristics of the groups are presented in Table 1. We conducted statistical comparisons between unique members of each of the subgroups and the residual members of the weakly connected core.

When compared with the residual members of the weakly connected core, members of the strongly connected and densely connected cores were increasingly likely to be female (for strongly connected cores, 71.3% vs 72.5%; χ^2=1.37; *P*=.243; for densely connected cores, 71.4% vs 78.5%; χ^2=12.73; *P*<.001), older (for strongly connected cores, 40.10 vs 43.8 years; 2-sample *t* test=14.41; *df*=7567; *P*<.001; for densely connected cores, 41.94 vs 46.3 years; 2-sample *t* test=4.46; *df*=7567; *P*<.001), and abstinent during the observation period (for strongly connected cores, 32.5% vs 54.7%; χ^2=365.43; *P*<.001; for densely connected cores, 44.2% vs 61.7%; χ^2=63.77; *P*<.001). They were also significantly more active (for strongly connected cores, 8 vs 17 logins; *z* score=–10.56; *P*<.001; for densely connected cores, 8 vs 127.5 logins; *z* score=–10.56; *P*<.001) and more likely to have been site members for more than a year (for strongly connected cores, 25.9% vs 48.9%; χ^2=410.16; *P*<.001; for densely connected cores, 37.8% vs 57.6%; χ^2=83.82; *P*<.001) compared with residual members of the weakly connected cores.

Characteristics of Subgroups

We delineated multiple, sequential key player groups of varying sizes, along with their corresponding reach into the network, according to their e-mail ties. Increasing group size only marginally increased reach beyond sets of 20 actors (Figure A, available as a supplement to the online version of this article at http://www.ajph.org). Key player groups larger than 20 members were still only able to reach approximately 64% of the network in 2 degrees. As with the other subnetworks, when compared with the residual weakly connected core, these individuals were more likely to be female (80.0% vs 71.9%; χ^2=1.61; *P*=.204) and older (49.3 vs 42.3 years; 2-sample *t* test=4.46; *df*=7567; *P*<.001).

In the first 4 weeks of the study, 792 active smokers registered and were designated as egos (newcomers). Participants who were already registered on the site before the study began and who initiated and formed ties (through Qmail or forum message) with newcomers were identified as integrators (n=756). Newcomers were slightly younger than were the residual weakly connected core members (38.9 vs 42.7 years; 2-sample *t* test =–9.05; *df*=7567; *P*<.001) and slightly more likely to be female (74.0% vs 72.0%; χ^2=1.80; *P*<.001). Compared with the residual weakly connected core, integrators were more likely to be female (76.6% vs 71.5%; χ^2=8.896; *P*=.003) and older (45.1 vs 41.95 years; 2-sample *t* test =7.27; *df*=7567; *P*<.001). (Appendix A, available as a supplement to the online version of this article at http://www.ajph.org, shows a pair of graphical time-lapse animations demonstrating the integration process.)

Network Characteristics and Structure

Characteristics of the full network are presented in Table 2, with myriad ties (buddies, forums, and Qmail) between 2 actors consolidated into a single metric.

The frequency distribution of interpersonal connections has, in general, demonstrated characteristic patterns in previously studied online networks,[20] where the degree distribution approximates a power law. This is popularly referred to as the 90–9–1 rule, indicating that 90% of the members of an online population have no ties, 9% have a few ties, and the remaining 1% have the bulk of the ties.[42] We plotted the in-degree and out-degree versus cumulative distribution for QMail communications on a logarithmic scale (Figure 2).

DISCUSSION

To our knowledge, this is the first formal analysis of a stable therapeutic online social network designed to assist health behavior change (smoking cessation and relapse prevention). We analyzed core characteristics of the entire network as well as subgroup composition. Critically, QuitNet's metrics were similar to those of other known, characterized online networks,[18–20,29,43] including characteristic graphical representations, a small number of well-connected actors with a power-law distribution of ties (i.e., a scale-free network), and identifiable subgroups. Because no standard criteria exist to validate the emergence of online social networks, this characterization derived from a persistent, stable network is a first step in the determination of the necessary and sufficient elements for future interventions and studies. These metrics represent a critical foundation for future basic and applied research to harness the full potential of social networks for population-level health behavior change. That these networks can be characterized has additional implications for advancing theory and informing interventions for behavior change in general.

TABLE 2—Consolidated Properties of the QuitNet Online Social Network for Smoking Cessation: March 1, 2007–April 30, 2007

	Weakly Connected Core
Size	7569
Ties[a]	103 592
Clustering coefficient[b]	0.173
Average shortest path length[c]	3.320
Mean degree[d]	13.686
Tie reciprocity[e]	0.309
Diameter[f]	12

Note. Analyis included buddies, forums, and private internal e-mail messages.
[a]Connections between 2 participants, such as a communication or friendship.
[b]Quantifies the likelihood that the neighbors of any given actor (an individual with connections to others in the network) are also connected[41] and indicates the level of local clustering within the network.
[c]Average of the shortest number of ties required to connect any 2 participants.
[d]Average number of connections per participants.
[e]Percentage of ties that were reciprocated between participants in the network.
[f]Maximum path length (as measured by the number of ties between actors) to connect participants in the network, when the shortest path is selected for any 2 individuals.

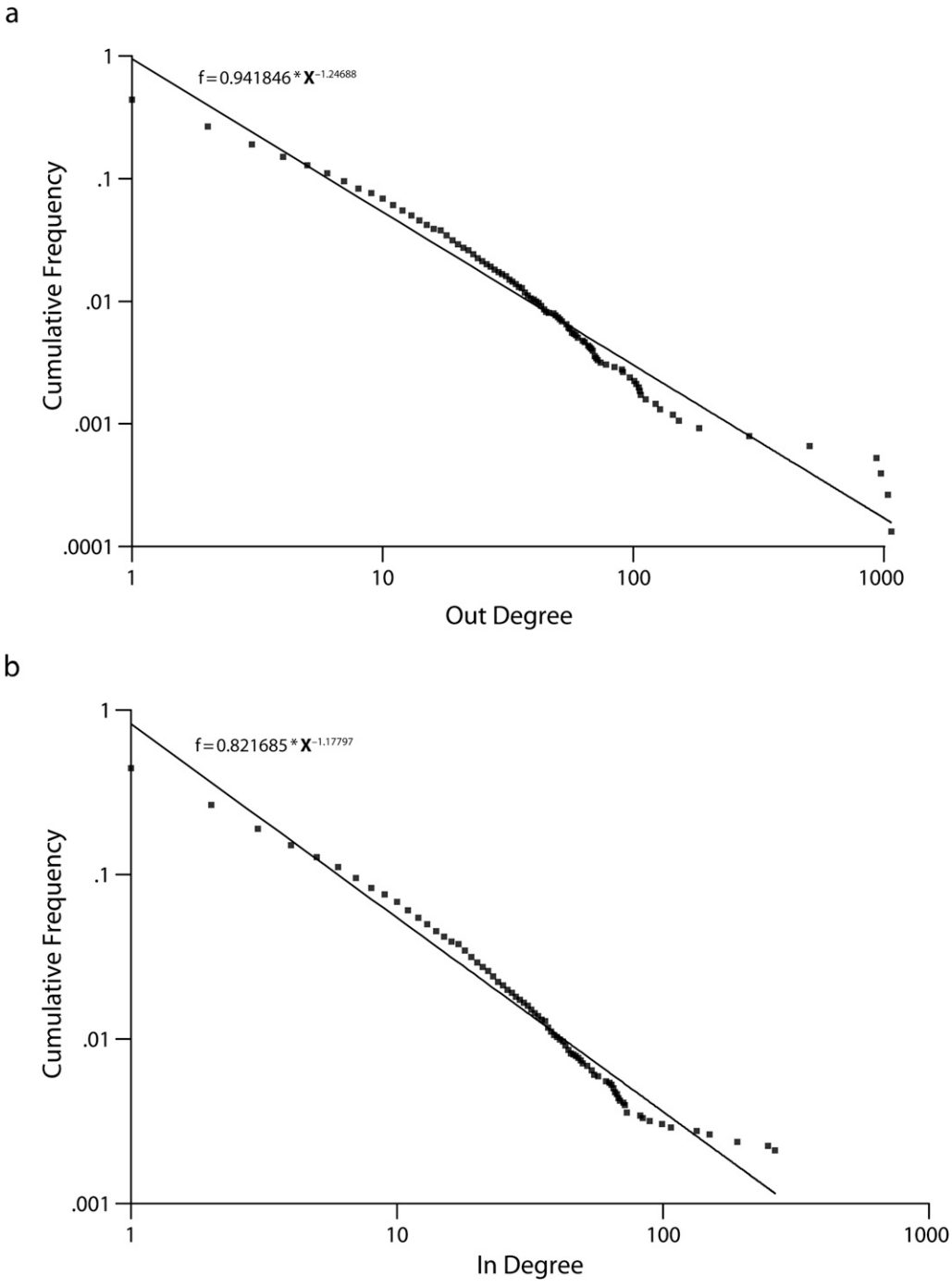
We observed important similarities and differences among QuitNet's core characteristics and those of other known networks. QuitNet's clustering coefficient of 0.173 was within the range of other systems, including electronic messaging (0.13–0.33[20]) and social network sites (0.16–0.28[29]). Although the diameter of the network was similar to that of other systems, the mean degree was significantly lower at 13.69, indicating that on average QuitNet members formed fewer connections than users of other systems, whose average number of connections have been reported to range from 31 to 137.[18,20] The mean can be deceptive because the distribution of tie counts did not follow a normal curve; many participants had only 1 tie, and a few had more than 1000. This scale-free pattern has been observed in many online networks,[18,19,29,43] but not in all real-world networks (e.g., the Framingham Heart Study).[30]

In the case of QuitNet, the conformance was not perfect, the curves for Qmail and buddy lists (data not shown) displayed artifacts in their tails at between 100 and 150 ties. This is likely attributable to limited data at the higher degrees but is curiously close to Dunbar's number, the hypothesized limit of relationships an individual can manage.[44] On the other hand, the Qmail in-degree curve abruptly tailed off at 150 ties; the out-degree curve had an inflection at this point and continued with a small number with up to 1000 ties. The out-degree curve might have reflected a small number of individuals who spent large amounts of time on the site and served as unofficial welcomers and town criers, announcing events such as the anniversaries of members' quit dates. Why certain individuals amass so many connections and spend such concentrated time within the community has not been explored thoroughly but may be attributable to status seeking,[45] similar to the phenomenon that drives unpaid labor in open source software development networks.[46] These similarities and differences add to our growing understanding of the nature of online social networks and highlight potential theoretical mechanisms for future study.

Participation of more women in smoking cessation programs is common. In our analysis, all subgroups of the network were predominantly female, with an increasing likelihood as ties and network density grew stronger. Similarly, age increased as ties grew stronger and network density increased: the mean age of the weakest subgroup was 42 years, and the average age of the most active participants (the key players) was 49 years. This tendency of network members to be female and older is noteworthy in light of the conventional wisdom that the population of Internet users skews in the opposite direction.

The maintenance of behavior change is as crucial—and as difficult—as the induction of the change. Other investigators have hypothesized that recent quitters may be the most likely to participate in social support systems,[47] but we found a fairly equal representation within the network of abstinent smokers and those in the early stages of quitting, as well as marked heterogeneity of time on site within the network, with many who had been members for a year or longer. This is particularly important because our study found that although overall degree was negatively correlated with smoking, increasing numbers of smokers in an ego's local network were positively correlated with smoking. Because maintaining abstinence after cessation is so difficult and because successful quitters provide valuable information and normative influence within a social network, these findings of heterophily and persistence are reassuring and suggest that evolving networks can become more effective over time.

Our key player analysis illustrated one mechanism of identifying subgroups within



Note. The slope of the solid line is represented by the f equation. In degree refers to the total number of individuals connected to an actor (someone with connections to others in the network) by incoming ties, and out degree to the number of individuals tied to an actor by outgoing ties. Although both plots approximate a straight line beyond approximately 150 degrees, the in-degree frequency sharply drops at that point, and the out degree trails in the opposite direction.

FIGURE 2—Cumulative frequency of connections between individuals derived from Qmail exchanges on QuitNet for (a) out-degree log plot distribution and (b) in-degree log plot distribution: March 1, 2007–April 30, 2007.

large networks for dissemination of information. In theory, identification of core groups such as key players could allow for more rapid and efficient dissemination of information.[48] Other groups could be used to enhance network stability, growth, or density. In our QuitNet study, despite the presence of more than 7500 active members in the network, only a few (the highly active integrators) came into contact with new participants. Future research is needed to characterize network integrators and determine whether increasing their numbers or strengthening their role can effect more efficient behavior change.

Limitations

We adhered to a traditional view of social networks, in which a relationship that is inferred from communications data is considered to be present throughout the observation period. In reality, the network was dynamic, and traditional network metrics may have overestimated the diffusion capacity of the network.[36] We also derived information regarding smoking abstinence from participant-provided quit dates of unknown validity.

We used a limited selection of ties to define the network. Many participants appeared to be lurkers, who did not actively communicate but may have been exposed passively to normative influences such as blog postings or the profile information of other members. Finally, we know little about communications and ties between individuals that did not occur through the QuitNet system (e.g., regular e-mail, preexisting friendships, the use of other social networking systems), which may have resulted in underestimation of the strength of some ties or the omission of others.

Conclusions

More research is needed to determine the mechanisms and the effectiveness of persistent therapeutic networks. Our analysis provides a starting point, pointing to the challenges and potential opportunities to improve understanding of the ways social networks can be harnessed to facilitate health behavior change. Studies are needed to elucidate the determinants of network growth, stability, and effect, including age and gender proportions, the predictors of participation and dropping out,[49] and the effect of long-term superusers and key players.

Social support theory suggests that the mechanisms that induce behavior change are broad and include various forms of social influence by observation, modeling, and adjustment to community norms—mechanisms that do not necessarily require explicit communications and will particularly benefit from future dynamic analysis. Our findings illustrate the potential that future research has for the development and implementation of innovative social network interventions to enhance behavior changes that can dramatically improve our nation's health and the health of the world in the Internet age. ■

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Contributors

N.K. Cobb originated the study and performed the social network analyses. A.L. Graham was responsible for the traditional statistical analyses. All authors helped to conceptualize ideas, interpret findings, and review drafts of the article.

Human Participant Protection

No protocol approval was required because the study used preexisting, anonymized data collected for quality improvement purposes. All work was consistent with the APHA Public Health Code of Ethics.

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References

1. *World Health Report 2002: Reducing Risks, Promoting Healthy Life.* Geneva, Switzerland: World Health Organization; 2002.

2. World Health Organization. *World Health Report 1999: Making a Difference.* Geneva, Switzerland: World Health Organization; 1999.

3. National Institutes of Health State-of-the-Science Panel. National Institutes of Health State-of-the-Science conference statement: tobacco use: prevention, cessation, and control. *Ann Intern Med.* 2006;145(11):839–844.

4. Orleans CT. Increasing the demand for and use of effective smoking-cessation treatments reaping the full health benefits of tobacco-control science and policy gains—in our lifetime. *Am J Prev Med.* 2007;33(6 Suppl):S340–S348.

5. Christakis NA, Fowler JH. The collective dynamics of smoking in a large social network. *N Engl J Med.* 2008; 358(21):2249–2258.

6. Berkman LF, Syme SL. Social networks, host resistance, and mortality: a nine-year follow-up study of Alameda County residents. *Am J Epidemiol.* 1979; 109(2):186–204.

7. Cobb S. Presidential Address–1976. Social support as a moderator of life stress. *Psychosom Med.* 1976;38(5): 300–314.

8. Cohen S, Lichtenstein E, Mermelstein R, Kingsolver K, Baer JS, Karmark TW. Social support interventions for smoking cessation. In: Gottlieb BH, ed. *Marshaling Social Support: Formats, Processes, and Effects.* Newbury Park, CA: Sage Publications; 1988:211–240.

9. Cohen S, Lichtenstein E. Perceived stress, quitting smoking, and smoking relapse. *Health Psychol.* 1990; 9(4):466–478.

10. Coppotelli HC, Orleans CT. Partner support and other determinants of smoking cessation maintenance among women. *J Consult Clin Psychol.* 1985;53(4):455–460.

11. Mermelstein R, Cohen S, Lichtenstein E, Baer JS, Karmark T. Social support and smoking cessation and maintenance. *J Consult Clin Psychol.* 1986;54(4):447–453.

12. May S, West R, Hajek P, McEwen A, McRobbie H. Randomized controlled trial of a social support ('buddy') intervention for smoking cessation. *Patient Educ Couns.* 2006;64(1–3):235–241.

13. Lichtenstein E, Glasgow RE, Abrams DB. Social support in smoking cessation: in search of effective interventions. *Behav Ther.* 1986;17(5):607–619.

14. Park EW, Tudiver F, Schultz JK, Campbell T. Does enhancing partner support and interaction improve smoking cessation? A meta-analysis. *Ann Fam Med.* 2004;2(2):170–174.

15. Orleans CT, Schoenbach VJ, Wagner EH, et al. Self-help quit smoking interventions: effects of self-help materials, social support instructions, and telephone counseling. *J Consult Clin Psychol.* 1991;59(3):439–448.

16. Piasecki TM, Baker TB. Any further progress in smoking cessation treatment? *Nicotine Tob Res.* 2001; 3(4):311–323.

17. Lichtenstein E, Hollis J. Patient referral to a smoking cessation program: who follows through? *J Fam Pract.* 1992;34(6):739–744.

18. Ahn YY, Han S, Kwak H, Moon S, Jeong H. Analysis of Topological Characteristics of Huge Online Social Networking Services. In: *Proceedings of the 16th International Conference on the World Wide Web.* New York, NY: Association for Computing Machinery; 2007:835–844.

19. Adamic LA, Buyukkokten O, Adar E. A social network caught in the web. Available at: http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/1057/977. Accessed October 27, 2008.

20. Newman MEJ. The structure and function of complex networks. *SIAM Rev.* 2003;45(2):167–256.

21. Kossinets G, Watts DJ. Empirical analysis of an evolving social network. *Science.* 2006;311(5757):88–90.

22. Womble LG, Wadden TA, McGuckin BG, Sargent SL, Rothman RA, Krauthamer-Ewing ES. A randomized controlled trial of a commercial internet weight loss program. *Obes Res.* 2004;12(6):1011–1018.

23. Barrera M Jr, Glasgow RE, McKay HG, Boles SM, Feil EG. Do Internet-based support interventions change perceptions of social support?: An experimental trial of approaches for supporting diabetes self-management. *Am J Community Psychol.* 2002;30(5):637–654.

24. Tate DF, Wing RR, Winett RA. Using Internet technology to deliver a behavioral weight loss program. *JAMA.* 2001;285(9):1172–1177.

25. Cobb NK, Graham AL, Bock BC, Papandonatos G, Abrams DB. Initial evaluation of a real-world Internet smoking cessation system. *Nicotine Tob Res.* 2005;7(2):207–216.

26. Graham AL, Bock BC, Cobb NK, Niaura R, Abrams DB. Characteristics of smokers reached and recruited to an Internet smoking cessation trial: a case of denominators. *Nicotine Tob Res.* 2006;8(Suppl 1):S43–S48.

27. Graham AL, Cobb NK, Raymond L, Sill S, Young J. Effectiveness of an Internet-based worksite smoking cessation intervention at 12 months. *J Occup Environ Med.* 2007;49(8):821–828.

28. Prochaska JO. Assessing how people change. *Cancer.* 1991;67(3 Suppl):805–807.

29. Mislove A, Marcon M, Gummadi KP, Druschel P, Bhattacharjee B. Measurement and analysis of online social networks. In: *Proceedings of the 7th ACM SIGCOMM Conference on Internet Measurement.* New York, NY: Association for Computing Machinery; 2007:29–42.

30. Christakis NA, Fowler JH. The spread of obesity in a large social network over 32 years. *N Engl J Med.* 2007;357(4):370–379.

31. *SPSS 17.0* [computer program]. Chicago, IL: SPSS Inc; 2008.

32. *Organizational Risk Analyzer 1.9* [computer program]. Pittsburgh, PA: Carnegie Mellon University; 2009.

33. *UCINET 6.* [computer program]. Harvard, MA: Analytic Technologies; 2009.

34. Kamada T, Kawai S. An algorithm for drawing general undirected graphs. *Inf Process Lett.* 1989;31(1):7–15.

35. Batagelj V, Mrvar A. Pajek—program for large network analysis. *Connections.* 1998;21(2):45–47.

36. Moody J, McFarland D, Bender-deMoll S. Dynamic network visualization. *Am J Sociol.* 2005;110(4):1206–1241.

37. Borgatti SP. Identifying sets of key players in a social network. *Comput Math Organ Theory.* 2006;12(1):21–34.

38. Borgatti SP, Everett MG. Models of core/periphery structures. *Soc Networks.* 2000;21(4):375–395.

39. Feil EG, Noell J, Lichtenstein E, Boles SM, McKay HG. Evaluation of an Internet-based smoking cessation program: lessons learned from a pilot study. *Nicotine Tob Res.* 2003;5(2):189–194.

40. Zbikowski SM, Hapgood J, Smucker Barnwell S, McAfee T. Phone and web-based tobacco cessation treatment: real-world utilization patterns and outcomes for 11,000 tobacco users. *J Med Internet Res.* 2008;10(5):e41.

41. Watts DJ, Strogatz SH. Collective dynamics of small-world networks. *Nature.* 1998;393(6684):440–442.

42. Nielsen J. Participation inequality: lurkers vs. contributors in internet communities. Jakob Nielsen's Alertbox. 2006 Available at: http://www.useit.com/alertbox/participation_inequality.html. Accessed February 13, 2009.

43. Holme P, Edling CR, Liljeros F. Structure and time evolution of an Internet dating community. *Soc Networks.* 2004;26(2):155–174.

44. Dunbar RIM. Neocortex size as a constraint on group size in primates. *J Hum Evol.* 1992;22(6):469–493.

45. Lampel J, Bhalla A. The role of status seeking in online communities: giving the gift of experience. *J Comput Mediated Commun.* 2007;12(2):434–455.

46. Raymond ES. *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary.* Cambridge, MA: O'Reilly; 2001.

47. Etter JF. The Internet and the industrial revolution in smoking cessation counselling. *Drug Alcohol Rev.* 2006;25(1):79–84.

48. US Food and Drug Administration. Early communication about an ongoing safety review of Varenicline (marketed as Chantix). 2007. Available at: http://www.fda.gov/cder/drug/early_comm/varenicline.htm. Accessed March 12, 2009.

49. Eysenbach G. The law of attrition. *J Med Internet Res.* 2005;7(1):e11.