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RESEARCH ARTICLE

Community Social Network Pattern Analysis: Development of a Novel Methodology Using a Complex, Multi-Level Health Intervention

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Abstract

Community social networks (CSN) include both individuals and groups, and those with strong partnerships and relationships are well positioned to implement community-based interventions. However, information on the nature of CSN relationships, which is required for multi-level community-based interventions, is not present in the literature. Using data from the multi-level Children's Healthy Living (CHL) trial to reduce child obesity in nine Pacific communities, this study aimed to develop a methodology based on Social Network Analysis (SNA) to understand how CSN evolved over the course of a two-year trial, as well as the characteristics of CSN most successful in impacting indicators of childhood obesity. The two-year trial was conducted over four six-month intervals. Within each interval, implemented activities, as recorded in CHL monthly reports, were coded by activity implementer(s), e.g. government agency, school, or community-based group, as well

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as for collective efficacy impact of the activity, e.g. to leverage resources from outside the CSN or to facilitate civic engagement. Coded data were used to create CSN maps for the four time intervals, and SNA techniques examined the CSN characteristics. CSN density increased over time, as measured by the number of ties within the network. Schools, community-based groups and large organisations were identified as the primary implementers of the CHL intervention and formed a community implementer backbone. Social leveraging, i.e. linking local groups to people with authority over outside resources, was shown to be a central component in intervention success. It took time to develop strong CSN, and stronger (denser) CSN were more successful in building social cohesion and enacting community change. Findings illustrate a methodology that can be useful for tracking the development and impact of CSN.

Keywords

Social Networks; Community Intervention; Childhood Obesity; Collective Efficacy; Multi-Level Intervention; Native Hawaiian and Other Pacific Islanders

Introduction

Making changes to improve health in low-income communities is a challenging task requiring community partners to work together at the local level. To implement complex community interventions, a 'place-based' organising framework involving collaboration among community-based partners is recommended (Singh et al. 2017). Coalitions of diverse organisations that work towards strengthening communities offer opportunities to leverage resources, expand reach and develop skills to impact the health of communities (Butterfoss 2007). By working towards a common goal, community coalitions can mobilise resources, coordinate activities, join together to limit the duplication of activities, and ultimately improve outcomes (Gibbons & Weiss 2012; Scanlon et al. 2012). In addition, the broad reach of diverse groups offers opportunities to increase public support for policies and community action, creating a potential for larger collective impact (Kendall et al. 2012).

Social Network Analysis (SNA) is a systems approach to understanding the dynamics of multi-level interventions that identifies the networks of social relationships that make up the system and the variety of roles that exist and can be created within networks (Hawe, Shiell & Riley 2009). Theorists have used SNA to look at how interventions may transform the structure of Community Social Networks (CSN) through the creation of new events that differ by activity setting (Hawe, Shiell & Riley 2009). SNA has also been used to explore workplace change processes and resource sharing networks (Callon 1984; Orlikowski & Robey 1991). Valente, Chou & Pentz 2007 examined the density of community coalition networks and the uptake of evidence-based interventions; however, the use of SNA with multi-level, community-based interventions is still in the early stages.

The lack of methodology to demonstrate relationships between activities and outcomes has been cited as a potential reason for under-appreciating the impact of community collaborations on community health (Kreuter, Lezin & Young 2000). Interventions affect CSN, change relationships, displace existing activities, and redistribute and transform resources (Hawe, Shiell & Riley 2009). Therefore, understanding the dynamic relationships involved with the implementation of community-based interventions is necessary.

Collaborations and coalitions occur within CSN. CSN can be informal relationships between individuals and groups, with various relationship strengths and degrees of trust (Gilchrist 2004). These individuals and groups may also be connected through a formal network of organisations, such as the Land Grant college system. CSN can be described according to the amount and quality of social interactions within communities and between people with similar behavioural norms that allow for mutually beneficial cooperation (Forrest & Kearns 2001). Communities include a complex system of social networks that have

strong and weak social ties. Strong social networks can bring social cohesion to communities, creating a capacity for social action (Frantz 2016).

Social network structure primarily focuses on the number and frequency of connections among members, without examining the type of connection, such as friendship or shared goals (Moody & Paxton 2009). However, social capital theorists focus on the 'content' of social networks, referring to the resources that are exchanged. Networks where all members know each other amplify actions (Coleman 1988). However, the strength of the connection varies. Strong connections occur between members who are more socially involved (i.e. close friends), and weak connections occur between members with less social involvement (i.e. acquaintances) (Granovetter 1985). However, there are benefits in having both strong and weak connections within networks (Burt 2000). Networks comprised of mainly strong connections have denser networks, and this amplifies actions (Coleman 1988), while weak interactions allow for a broader range of information sharing (Granovetter 1985).

The foundational work of social capital and network theorists provides the basis for examining CSN. Using data from the multi-level Children's Healthy Living (CHL) trial, the aim of which was to reduce child obesity in nine Pacific communities, our study's purpose was to illustrate a methodology based in SNA that could be useful for tracking the development and impact of CSN working to improve health. We incorporated precise measures of social structure from social network theorists. Measures that distinguish trust, support, empowerment were drawn from social capital research, to add dimension to the dyadic models, providing a better way to examine and understand CSN (Moody & Paxton 2009).

Theoretical Framework

This study examined CSN engaged in the CHL trial using the Collective Efficacy (CE) Mechanism of Action Model (CE MAM). As defined by Sampson (1997), CE signifies social cohesion combined with willingness to act/intervene for the common good (Sampson, Raudenbush & Earls 1997). Collaboration and social networks are central to CE (Kleinhans & Bolt 2014). The CE MAM (Figure 1) shows how intervention activities, such as hands-on training, leadership development, peer mentorship, community events, directed projects, and advocacy, can strengthen the five CE building blocks, social bonding, social bridging, social leveraging, empowerment and civic engagement (explained in more detail below). Strengthening the five CE building blocks can improve overall CE (social cohesion and willingness to act), which in turn can improve community health outcomes (Butel & Braun 2019). However, the various

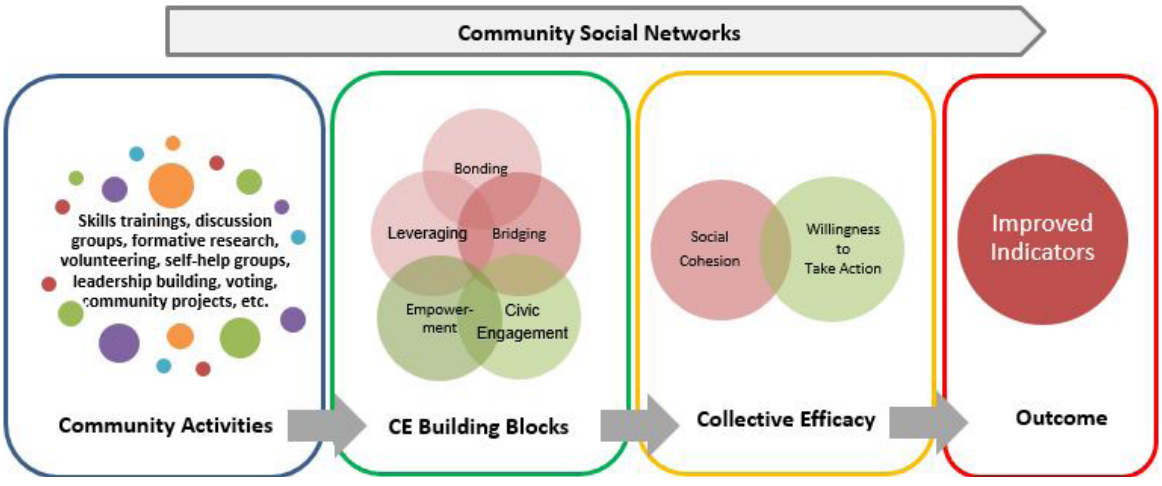


Figure 1. Community Social Networks across the Collective Efficacy Mechanism of Action Model (CE MAM).

types of CSN that are needed to conduct the community activities are not identified in the CE MAM. Furthermore, the literature does not provide a description of the types and density of analysis needed to build CSN so as to achieve their common goals.

CE is composed of five building blocks: (1) social bonding; (2) social bridging; and (3) social leveraging – which make up the social cohesion component of CE; (4) empowerment; and (5) civic engagement – which make up the willingness to act/intervene component (Butel & Braun 2019; Collins, Neal & Neal 2014). Thus, CE looks at how different types of relationships work together, with some being closer than others. The 'reciprocated exchanges that promote CE or trust and cohesion among residents combined with expectations for informal social control related action' (Browning, Feinberg & Dietz 2004) can be examined within CSN. These interactions can then be categorised as low frequency exchanges or high frequency exchanges and can be found in the social cohesion building blocks of social bonding, social bridging and social leveraging (Domínguez & Arford 2010).

Although Sampson uses the term social cohesion (Sampson, Raudenbush & Earls 1997), the sub-concepts of social bonding, social bridging and social leveraging are also identified as social capital (Domínguez & Arford 2010; Larsen et al. 2004; Larson, Story & Nelson 2009), and understanding social capital is central to examining the interactions between individuals and groups in communities (Moody & Paxton 2009). *Social capital* is defined as 'the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalised relationships of mutual acquaintance or recognition' (Bourdieu 1986). To put it another way, it is social connections between people with similar behavioural norms that allow for mutually beneficial cooperation.

Looking further at the sub-concepts of social capital, *social bonding* can be defined as self-efficacy and esteem in peer groups (Domínguez & Arford 2010). Social bonding at the neighbourhood/community level requires trust and association (Larsen et al. 2004). Larsen et al. (2004, p. 65) further states that 'trust refers to passive emotional sentiments, and association refers to the behaviors that produce familiarity, such as informal socialising or lending a tool or assistance to complete a household task'.

Social bridging refers to more distant ties to other groups, such as loose friendships and co-workers. Compared to social bonding, it is more inclusive of other races, ethnicities and other cultural dividers (Babaei 2012). It is based on generalised trust and is more reciprocal in nature. Social bridging brings in more resources, connections and opportunities (Babaei 2012; Domínguez & Arford 2010). By reaching out to other groups, social bridging is akin to 'getting ahead', whereas social bonding is akin to 'getting by' (Putnam 2002).

Social leveraging is the linking of community to people and/or groups in positions of authority and power (Woolcock 2001). The linking to groups outside the community, such as government institutions, policy makers, businesses and funders, can provide key resources to develop capacity and resources in the community (Babaei 2012). The combination of social bonding, bridging and leveraging can vary as a community changes and evolves (Woolcock 2005). Together, bonding, bridging and leveraging within CSN perform important functions in everyday life and are the building blocks of social capital and social cohesion (Forrest & Kearns 2001).

Research suggests that social cohesion and the willingness to act/intervene (key components of collective efficacy) are affected by building social capital in communities (Collins, Neal & Neal 2014). Thus, increasing social capital is a critical step in the process of increasing collective efficacy, which can in turn improve health outcomes.

The other component of CE is the willingness to act/intervene. The willingness to act/intervene embraces the CE building blocks of empowerment and civic engagement. Empowerment involves building capacity in social networks, and civic engagement is political or civic activity that is intended or designed to address

an issue of common concern (Collins, Neal & Neal 2014; Cramb 2006; Forrest & Kearns 2001; Harknett 2006; Henly, Danziger & Offer 2005; Lin 2001).

CHL Intervention Study Design

The CHL trial was funded for five years (2011–2016) to develop and test a community-driven, multi-level, multi-jurisdiction intervention. Funding was obtained from the US Department of Agriculture (USDA) Agriculture and Food Research Initiative to address the growing prevalence of obesity in the United States Affiliated Pacific (USAP) region. The CHL trial was based at the University of Hawai'i at Mānoa. The CHL coordinating centre subcontracted with four other Land Grant institutions in the USAP (University of Alaska at Fairbanks, American Samoa Community College, Northern Marianas College and University of Guam) to carry out the objectives of CHL in their respective jurisdictions. Participating institutions in each jurisdiction obtained Institutional Review Board (IRB) approval themselves or ceded approval to the University of Hawai'i at Mānoa.

The CHL intervention's effect was tested through a community randomised controlled trial (CRCT) in five jurisdictions, where nine communities received the intervention, and nine matched communities served as delayed intervention controls (Wilken et al. 2013). Another nine communities served as temporal controls. The CRCT aimed to evaluate the intervention's impact on anthropometric indicators, including body mass index (BMI) and waist circumference, acanthosis nigricans, and six behavioural objectives, among children aged 2–8 years. Behavioural objectives included increasing fruit and vegetable intake, water consumption, physical activity and sleep duration, and reducing recreational screen time and sugar-sweetened beverage consumption (Wilken et al. 2013). The intervention had a significant positive effect on decreasing prevalence of overweight/obesity status and acanthosis nigricans, and was protective of increase in waist circumference (Novotny et al. 2018).

Prior to the development of the CHL intervention, a 14-month long community engagement process was conducted with over 900 community members from the five CHL intervention jurisdictions (Fialkowski et al. 2014). This community engagement process sought to identify and build on what was working in communities by engaging community partners and members in ways that were sensitive to their cultures and placed the health and wellbeing of young children at the forefront of community decisions and actions. In addition to informing the CHL intervention, the engagement process identified potential community partners, began establishing trusting relationships between diverse community partners and CHL staff, and created a balanced partnership between CHL staff and community partners (Fialkowski et al. 2014).

As recommended by the Analysis Grid for Environments Linked to Obesity (ANGELO) framework, the team designed the multi-level intervention by merging community input and evidence-based strategies identified in the literature (Braun et al. 2014; Fialkowski et al. 2014; Nigg et al. 2016). The resulting intervention required sites to implement 19 activities categorised into four cross-cutting functions: (1) improving preschool policy; (2) advocating and partnering for environmental changes; (3) promoting CHL messages related to healthy behaviours; and (4) training trainers (Braun et al. 2014). The CHL intervention worked with community partners to implement activities. Due to the diversity of CHL communities, the CHL intervention template guided the communities on 'what' activities to implement and allowed the communities to determine specifically 'how' to implement the activities (Table 1). For example, one required activity was to 'work with coalitions to advocate for better access to parks that are safe and inviting'. However, it was up to the community to decide exactly how parks could be improved and which resources to leverage.

Table 1. CHL Trial Cross Cutting Functions (CCF) and Activities

CCF1. Assess Pre-School Policy and Community Environment related to the six CHL behaviors*
1a. Assess existence and quality of preschool wellness policy
1b. Assess community physical environment for policy change
CCF2. Environmental Change
2a. Work with organisations/coalitions to advocate for:
2ai Better access to parks that are safe and inviting
2aii Better access to clean water
2aiii Safer environments for walking, biking, etc. (e.g., bike lanes/racks, sidewalks, greenways)
2aiv Better food placement/availability
2av Gardens and hydroponics
2b Partner with existing entities to purchase or obtain sponsorship for:
2bi Water in the preschools and childcare centers
2bii Gardening supplies for preschool kids
2biii Sports equipment for preschool kids
2biv Campaigns and messages
CCF3. Promote the CHL Message
3a Support Role Models to deliver CHL messages in various ways
3b Enhance exiting social marketing campaigns in the intervention communities, and/or develop low-cost local social marking campaigns related to the six CHL behaviors
3c Advertise CHL or other activities that promote six CHL target behaviors*
CCF4. Train the Trainers
4a Train individuals to promote gardening in preschools and communities
4b Train individuals to lead interactive, hands-on sessions to promote the six CHL behaviors*
4c Train individuals to organize and lead family-based activities that support the six CHL behaviors (park clean-ups, hikes, cooking sessions, etc.)
4d Provide technical assistance to preschool and childcare staff on wellness policies
4e Train childcare providers and preschool teachers in curricula related to six CHL behaviors*
4f Train role models (community champions, role celebrities, role models) to promote and provide curricula related to the six CHL behaviors*

*** The six CHL target behaviors are: increasing fruit/vegetable consumption; water consumption; physical activity; and sleep time; and decreasing sugar-sweetened beverage consumption and screen time.**

Working with partners was central to the CHL trial (Braun et al. 2014; Fialkowski et al. 2014). Various community partners at different levels of influence were engaged to expand the reach of the CHL trial. For example, schools were approached to implement physical activity training for teachers, while community groups were approached to clean up parks and make them safer for play. *In essence, the CHL trial relied on CSN and promoted CE among community members, groups and CHL implementing staff.*

Below we describe the methodology by which CHL attempted to measure CSN development over time.

Over the two-year intervention period (January 2013 through to December 2014), each of the nine CHL trial communities submitted monthly intervention process reports to the CHL coordinating centre. Of the nine communities, two communities filed 24 reports each, while seven communities filed an average of 20 reports over 24 months. For the missing reports, CHL staff communicated with community leaders to request completion of the reports or to confirm that no activities had been conducted.

We used cross-case analysis of the nine CHL intervention communities to examine CSN and how the intervention developed over the course of the project. Specifically, this article illustrates how, through CSN Pattern Analysis, we examined the density and patterns of CSN throughout the CHL intervention by exploring the evolution over time of: (1) different types of community implementers who implemented activities that impacted the various CE building blocks; (2) relationships among community implementers; and (3) interactions between CE building blocks.

Analytic Methods

For analytical purposes, the CSN was conceptualised as a non-directional mapping of relationships or ties to depict CSN that developed in the CHL intervention communities. To examine social structures, this study visualised CSN through maps and utilised graph theory (Rosen 2012) to model pairwise relationships between community partners and CE building blocks. Social network maps characterise networked structures as nodes, and edges are the relationships or interactions that connect them. Community partners and CE building blocks were nodes in the CSN social network maps, and the edges identified the connections between the nodes. To eliminate the visual bias of the maps, descriptive statistics, graph density (connectedness of the graph), and average weighted degree (average number of connections between nodes) were estimated in the analysis.

To understand the evolution of CSN during the implementation of the CHL trial, three separate social network analyses were undertaken. The first two social network analyses identified the networks that assisted the implementation of activities. The third social network analysis identified interactions between the CE building blocks. These three social network analyses allowed for the mapping and exploration of community partners who assisted in implementing the CHL intervention over the two-year period, grouped into six-month intervals. A total of 12 maps, 4 for each CSN, were developed. This allowed for description of the CSN that was central to CHL. The exploratory analysis compared CSN patterns over time. Social network maps developed for each of the five CE building blocks were examined for similarities and differences over time.

The data for social network maps were developed using a multi-step process. *Step One*: For each six-month interval, the CHL intervention monthly progress reports were tallied to estimate a dose for each CHL activity: *the number of events conducted 'times' the activity effectiveness score 'times' the total number of participants 'divided' by the intended number of participants* (Butel et al. 2019). Effectiveness scores were assigned by consensus of two investigators, based on work by Cheadle et al. 2012, 2013), who examined the effectiveness of various activities in reducing obesity. These ranged from 0.33 for low to 1.00 for high. For example, two home-gardening training workshops were conducted, each with 8 participants, although 10 had said they would attend. The number of activities would be two (2), the efficacy score would be 0.67 (moderate), the total number of participants would be 8, and the intended number of participants would be

10. The activity dose equation would be 2 x [0.67 x (8/10)], resulting in an activity dose of 1.07. The activity dose scores in the six-month intervals of time were then summed.

Step Two. The CHL monthly process reports were re-examined to determine which CE building block(s) – social bonding, social bridging, social leveraging, empowerment, and civic engagement – had been addressed by each implemented activity. A community gardening activity, for example, may have brought community members together (social bonding) with extension workers (social bridging) and secured free gardening materials and supplies for the community (social leveraging). A CE building block weighted value of 0, 0.25, 0.5, 0.75, or 1 was based on the degree to which the activity addressed each respective building block. CE building block(s) that were assigned a CE building block weighted value of 0.75 or 1 were considered to be 'meaningfully addressed' and were given a code of '1'. If the score was less than or equal to 0.5, the activity was given a code of '0'. The activity dose from Step 1 was multiplied by 0 if the CE building block was not addressed or not meaningfully addressed, or multiplied by 1 if it was meaningfully addressed. Scores were checked by a second reviewer, with 96 per cent agreement between the two reviewers being essential; agreement was reached on the remaining 4 per cent of codes following discussion. Scores were summed for each of four six-month intervals and overall for the two-year intervention.

Step Three. The CHL intervention monthly process reports were again re-examined to identify the community implementers of each activity. These identified implementers were assigned a nominal code based on their characteristics, for example, school or church (Table 2).

Step Four. The first stage in creating the CSN maps involved developing tables with the CE building blocks as columns and the community implementers as rows for each intervention activity. Social network mapping nodes were generated from the CE building blocks and the community implementers. Next, a two-node CSN map (or bipartite CSN map) examined the ties occurring between the CE building blocks and the community implementers. Gephi, an open-source network mapping visualisation software (Bastian, Heymann & Jacomy 2009), was used to create a bipartite network map for each community implementer for the four six-month intervals of the trial. Additional unimodal maps, used to examine ties existing between a set of nodes, were created to look at relationships between community implementers and

Table 2. Community Implementer Types, Definitions and Assigned Code

Community Implementer Type and Definition	Code
Churches: places of worship and/or clergy (e.g. priest, minister, Catholic church)	1
Community-based groups: non-profit groups that work at a local level (e.g. community-based organisations)	2
Role models: community members who received CHL role model training	3
Large organisations: entities outside the community that employ over 50 people (e.g. colleges, departments of health)	4
Preschools/schools: institutions for educating children	5
Elected: Individuals or groups who hold public office (e.g. mayors, community/neighbourhood boards)	6
Coalitions: Group of people and organisations who join together for a common cause (e.g. Non-communicable Disease Coalition)	7
Cooperative extension: Land Grant college personnel who educate communities in a variety of family, health and agricultural programs (referred to as 'extension')	8

CE building blocks. The node sizes were based on the number of community implementers in the coded category, and the thickness of edges (lines) were determined by the number of times assistance was given to implement the activity related to the CE building block.

As noted above, data were grouped into four intervention time intervals: the first six months of the intervention (0 to 6 months (T1), 6 to 12 months (T2), 12 to 18 months (T3) and 18 to 24 months (T4). Bipartite CSN maps were generated for each of the four intervention time intervals. Thus, a total of four (one for each time interval) bipartite maps were generated. Bipartite CSN maps characterised the community social networks that helped to implement the CHL trial in terms of nodes of community implementers and their link to the CE building blocks. The CSN were interpreted via maps and compared for patterns of relationship between community implementers of the CE building blocks and the nine communities. Descriptive statistics of the number of nodes and edges (lines) present in the maps were reported, along with the graph density (number of ties in the social network as a proportion of total possible ties), and the average weighted degree (how much of the implementation was due to that particular community implementer code) was calculated for each map. Line thickness was based on the number of times the community implementers assisted in applying the same CE building blocks. In the maps, the weight of each edge was '1' and the weights of each edge were summed. The average weighted degree was the average of the sum of weights of the edges of the nodes, which was used to identify which community implementers played a central role in implementing CE building blocks during the CHL intervention. The edge weight was used to identify how closely community implementers worked together.

Each bipartite CSN map generated two unimodal network maps: one identified relationships between community implementers; and the other identified relationships between the CE building blocks. A total of eight unimodal, unidirectional maps were generated. The size of the text reflects the average weighted degree between community implementers.

The second map used the same descriptive statistics to identify the CE building blocks most important to the CHL intervention and CE building block clusters. The size of the text reflects the average weighted degree between CE building blocks. Line thickness was based on the number of times the same building blocks were addressed by community implementers. Comparisons were made over time to determine which CSN were present in communities as the CHL trial was implemented. *Differences in graph density (number of ties in the social network as a proportion of the total number of ties), edge weights (number of ties between nodes), and average weighted degree between the nodes were examined at six-month intervals for the duration of the trial* (Frantz 2016).

Results

COMMUNITY IMPLEMENTERS' RELATIONSHIP TO CE BUILDING BLOCKS

The CSN maps provide a visual representation of the community implementers, shown on the left of each set of maps, and their relationship to each of the CE building blocks, shown on the right side of each set (Figure 2).

Table 3 displays the descriptive statistics of graph density and average weighted degree by time interval. The graph density increased between T2 and T3. The average weighted degree increased between T1, T2 and T3 intervals with a slight decrease between T3 and T4.

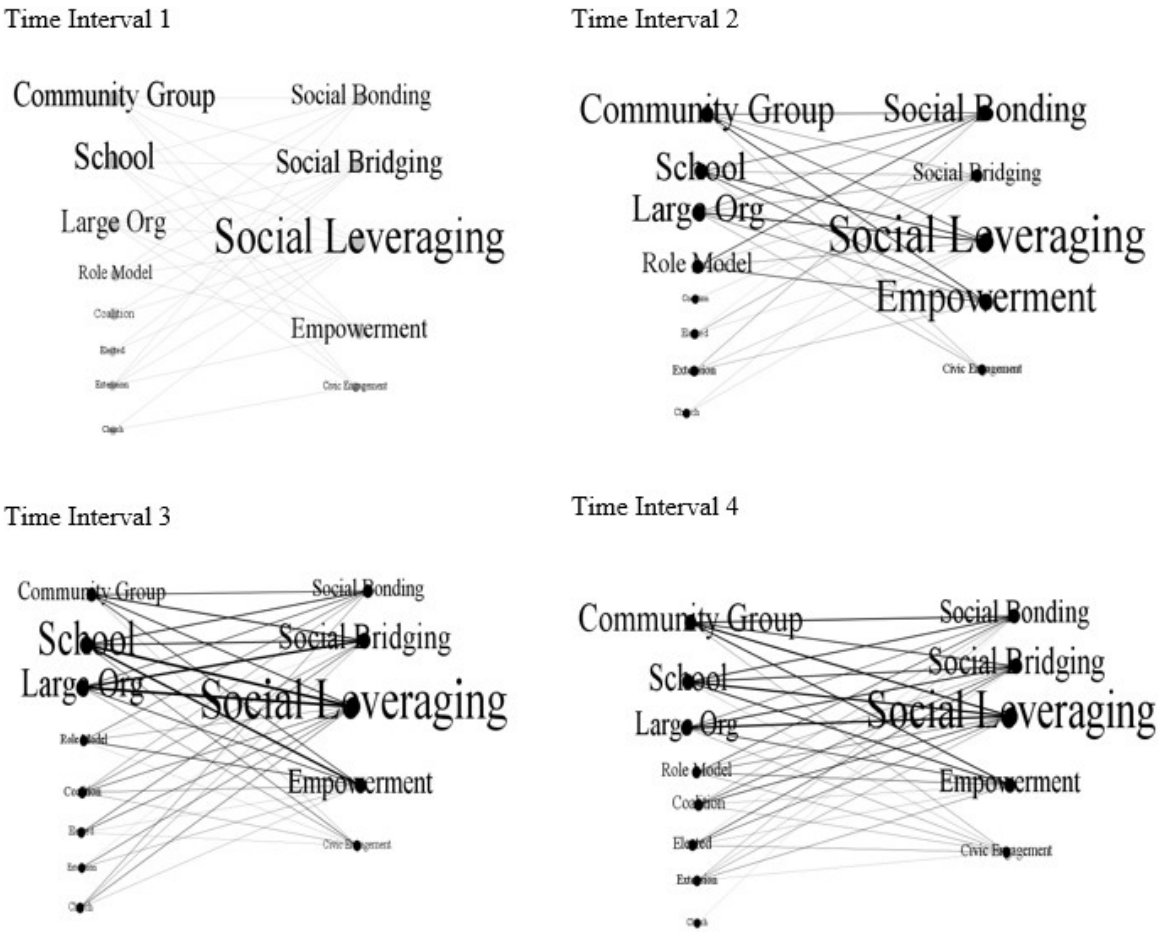


Figure 2. Community Social Network Maps at four six-month intervals of the CHL Trial.

Table 3. Community Social Network Graph Density and Average Weighted Degree by six-month time interval of the CHL Trial

	Six-month time interval			
	1	2	3	4
Graph Density	0.37	0.37	0.46	0.46
Average Weighted Degree	16.92	31.39	59.23	57.01

The number of times each type of community implementer assisted with an intervention activity was tabulated. Schools most frequently assisted in total CHL activities (n=269) followed by community-based groups and large organisations, 244 and 240, respectively (Figure 3).

Figure 4 examines the distribution by percentage of intervention assistance provided by each community implementer for each CE building block. Community-based groups, large organisations and schools had the largest percentage of CHL trial activities for all building blocks, with the exception of social bonding. The top three community implementers for social bonding were schools (26%), community-based groups (25%), and role models (18%).

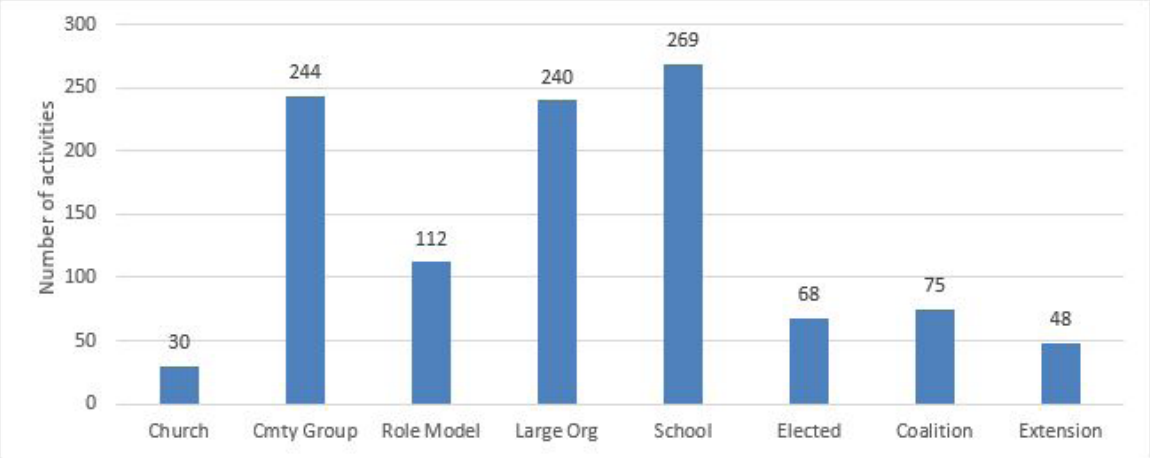
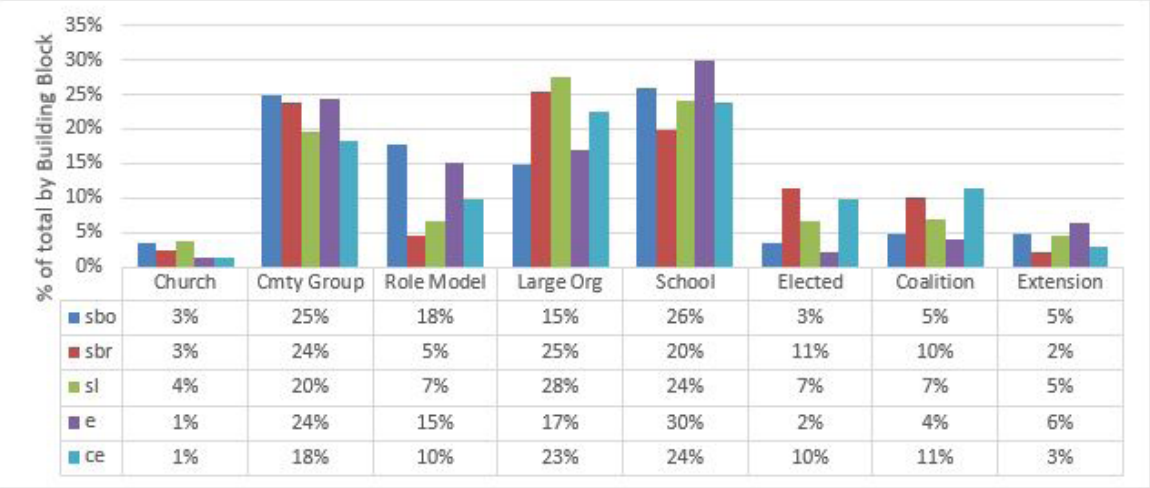


Figure 3. Number of CHL Trial Activities by Type of Community Implementer.



	Church	Cmty Group	Role Model	Large Org	School	Elected	Coalition	Extension
sbo	3%	25%	18%	15%	26%	3%	5%	5%
sbr	3%	24%	5%	25%	20%	11%	10%	2%
sl	4%	20%	7%	28%	24%	7%	7%	5%
e	1%	24%	15%	17%	30%	2%	4%	6%
ce	1%	18%	10%	23%	24%	10%	11%	3%

Figure 4. Percentage of CHL Trial Implementation Assistance Provided by Type of Community Implementer and by CE Building Block. sbo = social bonding; sbr = social bridging; sl = social leveraging; e = empowerment; ce = civic engagement.

RELATIONSHIPS AMONG COMMUNITY IMPLEMENTERS

The unimodal maps provide a visual indication of the relationships among community implementers (Figure 5). The maps also show the progression of the relationships over time. The pattern of the relationship between large organisations, community-based groups, and schools emerged in time interval 1 and continued to strengthen over time. The connections between all community implementer groups were most evident at time interval 3, with churches not being as connected in time interval 4.

The edge weight (number of connections between nodes) between large organisations, schools, and community-based groups formed a strong triad at time interval 2 and continued to increase at time interval 3 and time interval 4. Graph density increased 2.5 times from time interval 1 and time interval 3, and it reached one (indicating the maximum number of ties possible for the network) during time interval 3. The average weighted degree (average number of connections between nodes) was highest at time interval 3 (Table 4).

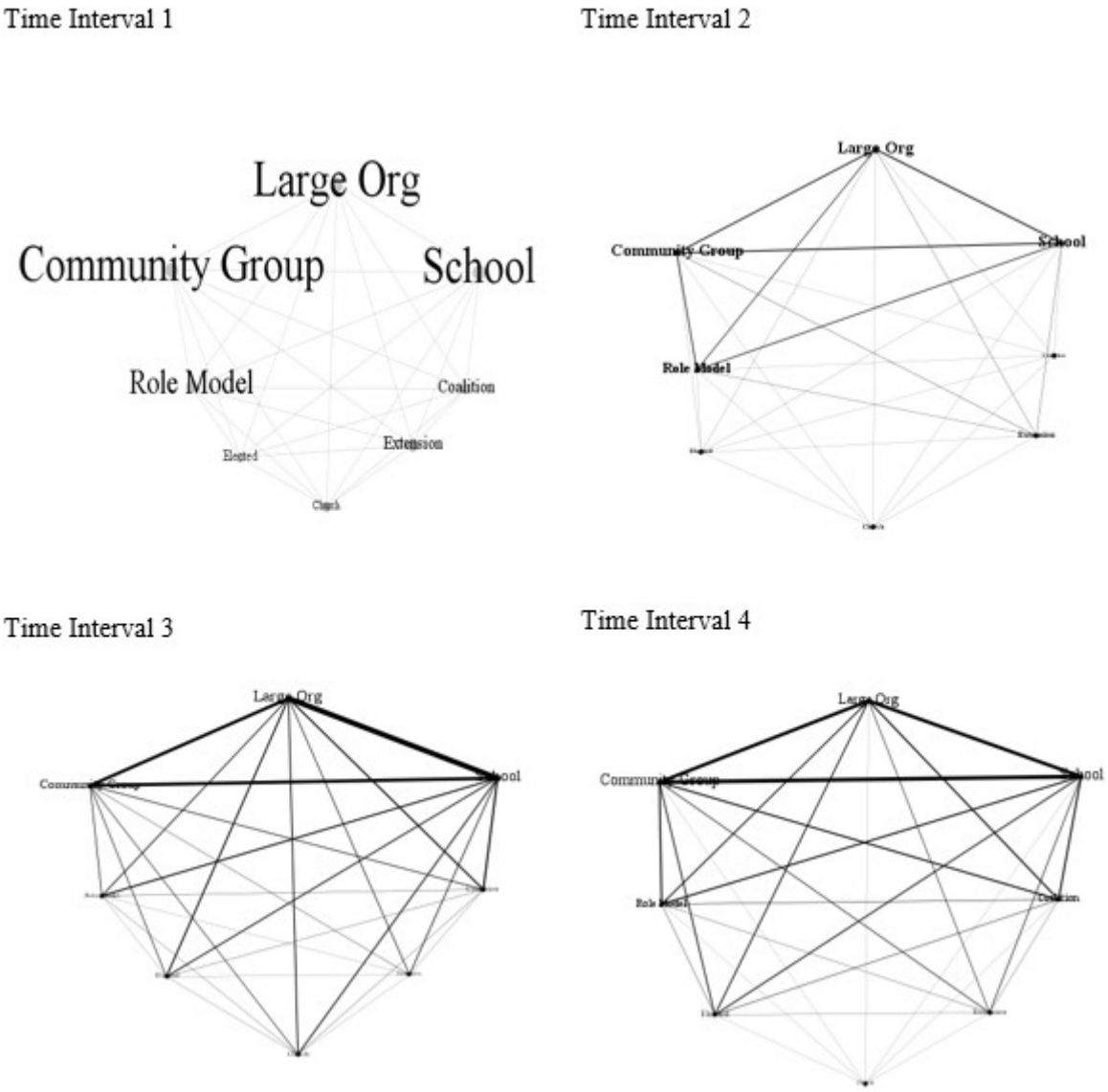


Figure 5. Unimodel Community Social Network Map of Relationships between Community Implementers.

Table 4. Community Implementer CSN Graph Density and Average Weighted Degree by Time Intervals

	Six-month Time Interval			
	1	2	3	4
Graph Density	0.37	0.96	1.0	1.0
Average Weighted Degree	284.75	968	3504.75	3182.25

INTERACTIONS BETWEEN CE BUILDING BLOCKS

The unimodal maps provide a visual representation of the interactions between CE building blocks. The maps show the progression of the interactions between CE building blocks over time. CE building block unimodal maps showed social leveraging was implemented with the other building blocks most frequently, at all four time intervals (Figure 6). Civic engagement was leveraged the least among the CE building blocks. The maximum graph density (graph density =1) is achieved when each node is connected to all other nodes. All CE building blocks were connected, as seen by the graph density =1, at all four time intervals (Table 5). The average weighted degree increased during time interval 1, 2 and 3, with slight decrease during time interval 4 (Table 5).

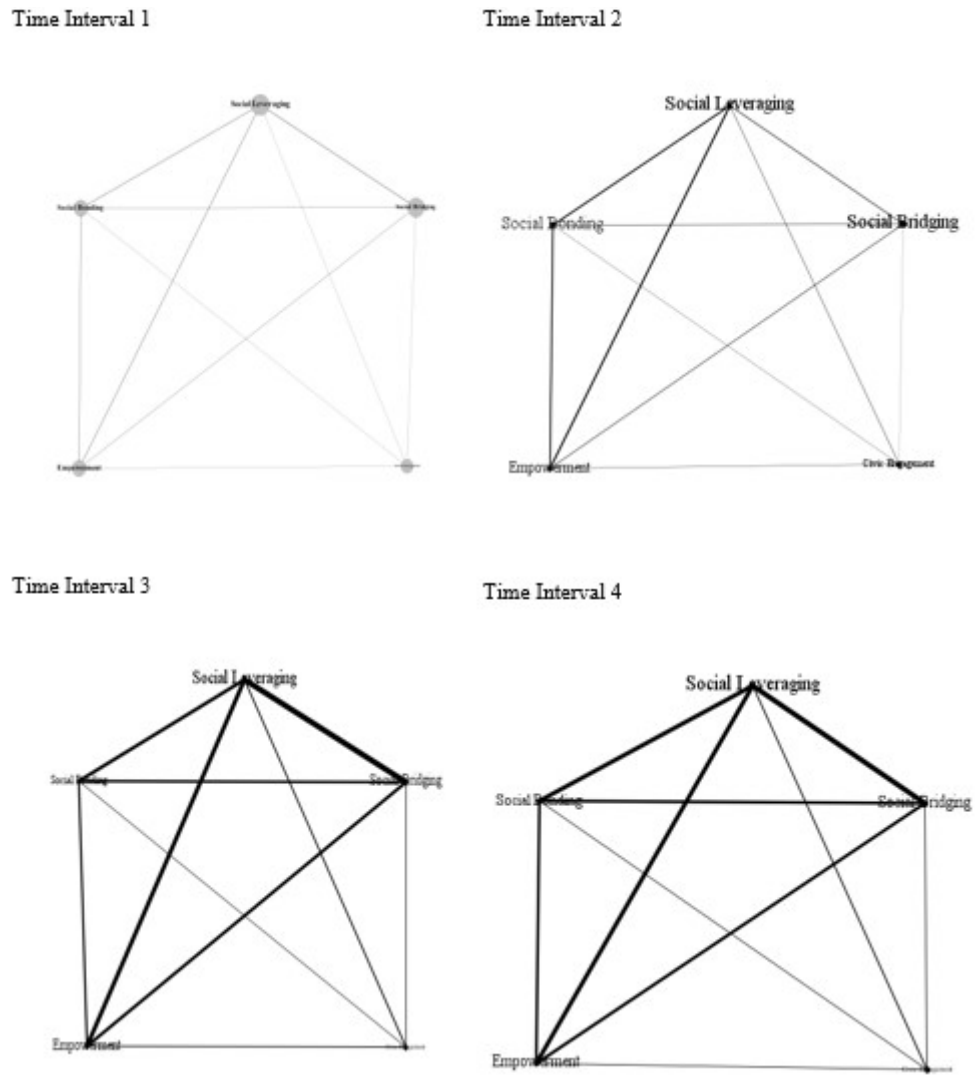


Figure 6. Unimodal Community Social Network Map of Interactions between CE Building Blocks.

Table 5. CE Building Block CSN Density and Average Weighted Degree by Time Interval

	Six-month Time Interval			
	1	2	3	4
Graph Density	1.0	1.0	1.0	1.0
Average Weighted Degree	339.2	1223.2	4214.8	3683.6

Discussion

This study developed a novel methodology to understand connections and interactions between CSN and CE building blocks across time. The four-step method provided a means to assess the strength of connections, applied social network mapping to visualise community change across time, and enabled through SNA to draw inferences about the CSN as a whole and about the relationships between members and CE building blocks.

The analysis of the social network maps showed the development of CSN during the CHL trial. By coding the data in six-month intervals, we were able to track the development of the CSN over time. This methodological approach revealed that the CSN took at least six months to develop. As the intervention progressed over time, the maps showed increased community partner engagement and increased implementation of activities. Supporting the maps' visual display, SNA showed increases in graph density and average weighted degree quantified that relationships were forming during time interval 1 and progressing through the subsequent time intervals (Tuckman 1965). In time interval 1, the graph density and the average weighted degree were low, indicating that the relationships were still forming and the roles of the partners were still being determined. During the second time interval (6 to 12 months), CE building block activities and interactions between the community implementers became stronger. During the third time interval (12 to 18 months), the relationships continued to develop, communities became more empowered, and civic engagement activities increased. There was a slight decrease in activities during the last time interval (T4) when CHL funding was ending. However, CHL staff worked to transition backbone functions to the community as one of the goals of the CHL intervention was sustainability. It is possible that implemented activities were not known to the CHL staff and were therefore not recorded in the reports. The CHL program sought to support implementation of activities that could be continued after the trial period, and the last six months focused on supporting ongoing community efforts. The long-term success of the intervention is currently being evaluated. These findings indicate that the method of mapping the CSN in six-month blocks was sufficient to show the evolution of the CSN in the CHL trial.

By assigning identified implementers by a nominal code based on their characteristics, insight was gained on relationships between the CSN. The unimodal maps showed a pattern emerging between large organisations, community-based groups and schools, suggesting a strong relationship between these types of community implementers, creating a CSN backbone. This infers substantial implementation assistance by the three community implementers in the CHL intervention. These three implementer types (large organisations, community-based groups and schools) represent multiple types and levels of influence. For example, large organisations provided skills development training, community-based groups provided cultural context and community structures, and schools provided community-based locations and access to the target population (2–8 year olds). This supports the recommendation by the U.S. Department of Health and Human Services (Singh et al. 2017) that a collaboration of community-based partners engaged in multi-factorial approaches is necessary for the implementation of complex community interventions to effect community change, and that cross-sector efforts need to be aligned (Sandel et al. 2016).

In coding CHL trial activities by their CE building block, we were able to identify that building capacity and social capital within the CSN was key to trial implementation. One study (Slater et al. 2005) found that the lack of local support, leadership and/or resources can create significant challenges in implementing complex interventions. The implementation of complex interventions that address health disparities in a comprehensive manner requires building collaborative capacity to take collective action (Kendall et al. 2012). In addition, the central role of social leveraging in the CHL trial was identified. Examining the connections (edge weights) to the other building blocks suggests that social leveraging of resources, such as providing skills training and building on activities of similar programs, was central to: (1) developing community trust, e.g. by providing playground painting supplies (social bonding); (2) establishing connections between community implementers, e.g. local non-profit bringing program to Head Start classrooms (social bridging); (3) building community capacity, e.g. training families and teachers how to grow food (empowerment); and (4) providing opportunities for civic engagement, e.g. getting permission from park department and officials to improve park facilities.

This study had identifiable limitations. First, the retrospective nature of this study limited the ability to obtain clarity when questions arose regarding community implementers. However, the system of monthly reporting on paper, followed by confirmation by phone, helped assure that reports were robust. Second, this method examined the actions of the community implementers but did not measure behavioural concepts behind the actions, and therefore did not capture the behaviours (i.e. willingness) that preceded the actions. Third, the CE building blocks were binary coded (yes/no) as to whether or not they were addressed, potentially losing insightful information. Fourth, the small sample size (n=9 communities) and lack of comparable data in the control communities limited the types of quantitative analysis that could be conducted and thus the conclusions that could be drawn. Consequently, the analysis was limited to descriptive methods for identifying and depicting CSN that were present in the CHL intervention.

Conclusion

The social network maps showed the development of CSN during the CHL intervention. The systematic approach to developing and analysing the maps indicates the methodological potential of applying SNA to multi-level community-based interventions. By analysing the development and strength of the connections in CSN, we were able to draw inferences about the CSN as a whole and about the relationships between members and the CE building blocks.

This novel approach provides a visual way to understand CSN and capture the evolution of CSN over the course of a two-year trial. By applying SNA we were able to quantify select important characteristics of the CSN and the CE building blocks. The emergence of a CSN backbone, the increasing density of the CSN over time, and the central role of social leveraging provide insight for conducting successful multi-level community interventions. These findings support the development of a method to systematically assign an activity dose to implemented activities in a community intervention, relate the dose to CE building blocks, and examine community partners who assisted with activity implementation over time. This methodology allows for CSN maps to be developed and CSN patterns to be analysed to examine relationships with and between multiple types of community implementers, to understand the nature and characteristics of these relationships, and to provide guidance on the evolution of CSN during community-based interventions.

This evolution of CSN engaged in the CHL intervention sheds light on the dynamics of CSN. Since community interventions thrive through collaborative partnerships, it is prudent to understand the dynamics of the partnership. By applying this study's methodology, we can begin to develop and cultivate CSN to improve health in communities.

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