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Social Networks and Health: A Systematic Review of Sociocentric Network Studies in Low- and Middle-Income Countries

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Abstract

In low- and middle-income countries (LMICs), naturally occurring social networks may be particularly vital to health outcomes as extended webs of social ties often are the principal source of various resources. Understanding how social network structure, and influential individuals within the network, may amplify the effects of interventions in LMICs, by creating, for example, cascade effects to non-targeted participants, presents an opportunity to improve the efficiency and effectiveness of public health interventions in such settings. We conducted a systematic review of PubMed, Econlit, Sociological Abstracts, and PsycINFO to identify a sample of 17 sociocentric network papers (arising from 10 studies) that specifically examined health issues in LMICs. We also separately selected to review 19 sociocentric network papers (arising from 10 other studies) on development topics related to wellbeing in LMICs. First, to provide a methodological resource, we discuss the sociocentric network study designs employed in the selected papers, and then provide a catalog of 105 name generator questions used to measure social ties across all the LMIC network papers (including both ego- and sociocentric network papers) cited in this review. Second, we show that network composition, individual network centrality, and network structure are associated with important health behaviors and health and development outcomes in different contexts across multiple levels of analysis and across distinct network types. Lastly, we highlight the opportunities for health researchers and practitioners in LMICs to 1) design effective studies and interventions in LMICs that account for the sociocentric network positions of certain individuals and overall network structure, 2) measure the spread of outcomes or intervention externalities, and 3) enhance the effectiveness and efficiency of aid based on knowledge of social structure. In summary, human health and wellbeing are connected through complex webs of

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dynamic social relationships. Harnessing such information may be especially important in contexts where resources are limited and people depend on their direct and indirect connections for support.

Keywords

Networks; sociocentric; name generators; network type; centrality; social structure; network position; systematic review

INTRODUCTION

Measuring the role of social networks in low- and middle-income countries (LMICs) may be particularly critical for interpreting health outcomes in these contexts. As there are often limited social protection schemes in LMICs, and significant geographic and infrastructural barriers in accessing those that do exist, many sources of formal support are simply not available when needed. Instead, direct or indirect connections up to several degrees of separation (e.g., friends of friends) may be one's only source of assistance (e.g. Apicella et al., 2012; Comola, 2012; De Weerdt and Dercon, 2006; Ware et al., 2009) or of relevant influence. Critically, individuals with few informal social connections and no access to other sources of formal support in resource-limited contexts may suffer serious consequences. Indeed, Tsai et al. (2013) reviewed a number of qualitative studies describing how the "social death" from HIV stigma, and the resulting loss of instrumental support, is often feared more than HIV itself.

Many network studies related to health and health behaviors in LMICs have measured specific social ties representing actors' personal networks (e.g. Adams et al., 2002; Avogo and Agadjanian, 2008; Bignami-Van Assche, 2005; Edmonds et al., 2012; Fonseca-Becker and Valente, 2006; Green et al., 2011; Kohler et al., 2007; Miguel and Kremer, 2003; Moore, 2014; Moser and Mosler, 2008; Ruiz-Casares, 2010; Sandberg, 2012; White and Watkins, 2000; Wutich and McCarty, 2008; Zhang et al., 2012). Although these studies typically collect data about an actor's immediate contacts and the actor's perceptions of ties between those contacts, they cannot fully reveal structural aspects of the larger network in which actors are embedded nor explore the diffusion of behaviors, resources, technologies, and diseases through a larger set of people. In contrast, sociocentric network studies attempt to depict the entire network by collecting data on the social ties between all targeted individuals within a defined population (Marsden, 1990). Such data permit calculation of network structure and function, and increase our understanding of the mechanisms through which social networks may affect health-related attitudes, behaviors, and outcomes (or vice versa). Relevant network effects may include provision of perceived or actual social support, social influence and learning, social engagement, person-to-person transmission of diverse sorts, and/or access to resources (Berkman et al., 2000). Crucially, networks create pathways for the spread of attitudes, behaviors, and emotions, as well as financial, physical, informational, labor, and social resources.

Understanding the formation of social ties, sociocentric network structure and function, and the associated mechanisms linking these to health or health behaviors, may be extremely relevant in the context of allocating limited resources or targeting public health and

economic development interventions in LMICs (Christakis, 2004; Honeycutt, 2009; Rasul and Hernandez, 2012; Valente, 2012). For example, the most efficient allocation of budgetary resources for a given intervention may depend on how the network structure affects health behaviors or how it affects the flow of diverse phenomena through the network. Importantly, information about network structure and function might be exploited in two broad ways. First, interventions could manipulate the topology of the network or rewire social ties (e.g., by directly introducing people to each other or by indirectly causing people to become more connected). Second, interventions may try to facilitate the contagion of phenomena within an extant network – for example, by encouraging adoption of vaccines, clean water methods, contraception, neonatal assistance, or other public health interventions. Both types of interventions can, in turn, have two effects. Manipulating peer reinforcement might increase the probability that the treated will respond to the treatment. In addition, network effects can also be exploited to enhance the response to treatment among the untreated as treatment effects may ripple outward from targeted individuals, affecting others to whom they are connected (Philipson, 2002). Thus, measuring social networks -- and studying contagion in a network and how it may be amplified across individuals indirectly connected to the targeted recipients (Christakis and Fowler, 2013) -- is critical for determining both intervention efficiency and effectiveness, particularly in LMICs.

AIMS

To summarize existing knowledge about network structure and function in relation to health in LMICs, we conducted a systematic review of sociocentric network studies exploring health-related issues in LMICs. The goals of this review were to provide a resource for the design and analysis of sociocentric network research in LMICs; summarize extant evidence regarding social network associations with health and health-related issues in varying cultural, political, and economic contexts in LMICs; and provide a framework for thinking about the role of social network analysis in research, intervention design and evaluation, and creation of public health policy. We were guided by three main questions:

1. How are sociocentric social networks quantitatively measured in LMICs for health-related research?
2. What common observations can we make about how network composition, network position, and network structure are associated with health and health behaviors in these settings?
3. How can sociocentric network data collection be improved in LMICs and what directions might future research on social networks and health in LMICs take?

We begin this review by outlining some conceptual considerations relevant to social networks and health. This is followed by a description of the methods used to conduct the review and then a summary of findings extracted from the studies reviewed.

CONCEPTUAL FRAMEWORK

Numerous studies have shown that social relationships in general matter for health and health-related outcomes (e.g. House et al., 1988; Seeman 1996; Umberson et al., 2010), and

that the quantity, quality, and type of social ties are associated with wellbeing (e.g. Berkman and Krishna, 2014; Cornwell et al., 2009; O'Malley and Christakis, 2011; Wellman, 1992). In addition, specific arrangements of social ties into social networks, and certain positions within social networks, may be associated with health-related outcomes (e.g. Ali and Dwyer, 2010; Christakis and Fowler, 2009; Ennett and Baumann, 1994; Haas et al., 2010; Luke and Harris, 2007; Pollard et al., 2010; Smith and Christakis, 2008; Valente, 2010). Furthermore, social network structure may affect health and development by providing a basis for phenomena as diverse as cooperation (Apicella et al., 2012; Fowler and Christakis, 2010; Rand et al., 2011), generosity (D'Exelle and Riedl, 2010), altruism (De Weerdt and Fafchamps, 2011), social norms (Coleman, 1988) and social capital (Lin, 1999; Moore et al., 2013). Indeed, research has shown that social networks are a fundamental aspect of human sociality (Apicella et al., 2012; Henrich and Broesch, 2011).

Measuring Social Structure

While some researchers use the term ‘social networks’ to refer to an individual's general subset of social relationships, such as family members, friends, or religion-based contacts, other researchers discuss social networks in relation to the structural arrangement of social relationships in which people are embedded (Berkman et al., 2000; Smith and Christakis, 2008). This social structure is typically assessed by identifying specific social ties, measuring characteristics of those social ties, and linking them together in an extended web of interaction. Therefore, the tie is the important unit of measurement (Freeman, 1979; Marsden, 1990, 2002; Scott and Carrington, 2011; Wasserman and Faust, 1994). Name generators (NGs) are survey questions used to elicit social ties between pairs of people (or households). Such questions request respondents to name specific people with whom respondents have a certain type of connection (Marin, 2004; Marsden, 1990). Thus, the NG often determines the type of network measured. A ‘name roster’ of all the names is typically created and follow-up questions (name interpreters) may be asked about perceived attributes of the named people or of ties.

In general, NGs may elicit how a tie exists (e.g., the tie is realized through participation in shared activity, conversation, exchange of physical resources, sharing of feelings, having the same bloodline, being in the same neighborhood) or by what is given or received across a tie. Some studies refer to four approaches to measuring ties, such as the role-relation, interaction, affective or exchange approaches (Marin and Hampton, 2007; van der Poel, 1993; Sandberg, 2012), and other studies discuss the type of support that is provided through a tie (e.g., emotional support, financial and instrumental support, or informational support (Cohen and Wills, 1985)). Frequently, NGs will refer to multiple characteristics of a tie. Alternatively, some studies may employ a general NG that simply requests people to name whom one knows (McCarty et al., 2007).

Figure 1 depicts four separate egocentric networks (A, B, C, D) within one sociocentric network. By convention, the index actors are referred to as “egos” and the actors’ immediate contacts are referred to as “alters.” This image shows that an egocentric study would simply measure the immediate network around A, B, C, and D and, for example, could only provide information about ego-perceived social support from proximal alters. However, a

sociocentric study can provide information about how support might arise from more distal alters or how the overall structure of the larger network might influence outcomes. Typically, to collect sociocentric network data, a census-like survey must be first conducted on the targeted population in order to identify all eligible respondents, who may then be referred to as potential “nodes” in the network. This census then allows linkage of nodes and ties into a complete social network after data on participants' social connections are collected.

In general, sociocentric network data permit calculation of (a) actual network composition of egos’ immediate alters, by which we mean the identity and attributes of the alters a person is directly connected to (as opposed to ego-perceived alter characteristics, which are sometimes collected in egocentric network studies though the information may be often inaccurate (White and Watkins, 2000; Valente et al., 1997)); (b) network composition up to various degrees of separation from an individual, e.g. actual characteristics of alters’ alters; (c) the extent of an ego's embeddedness (or prominence) in the network, a construct otherwise known as individual centrality or network position; (d) structural characteristics of the whole network, also known as macrostructure; and, (e) social contagion (for example, how health and health behaviors may spread across the network), in particular when longitudinal data are available.

METHODS

Paper selection criteria

We selected papers that met the following network-related criteria: (a) used quantitative data collected via census-based inclusion of participants (i.e., not just respondent-driven sampling); (b) enumerated a sociocentric social network within a circumscribed boundary by identifying specific person-to-person or household-to-household ties through a name-generation method in a defined population; and (c) provided a description of sociocentric network data collection methods, calculated some sort of network measure (either at the level of the individual, such as centrality, or at the level of the whole network, such as the number of components), or provided a map of a complete social network. We excluded studies of contact-tracing networks, which did not attempt to enumerate a full population sociocentrically. In addition, only papers that were focused on health and health behaviors in an LMIC and written in English were included. Studies of mobile communication networks, school-based networks, networks of institutional or corporate entities, or ‘dark’ networks (terrorism, corruption, drug, or sex-trade networks) were excluded.

Systematic Search

Systematic searches of public health, social science, and medical peer-reviewed journals using PubMed, Econlit, Sociological Abstracts, and PsychINFO search databases were conducted prior to December, 2013. The following search terms were used: (network[ti] or networks[ti]), and (an LMIC country name[anywhere] or “developing country”[anywhere] or “Sub-Saharan Africa”[anywhere]), and health[anywhere]. A total of 2379 records (including duplicates) were identified with 1724 from PubMed, 92 from EconLit, 176 from Sociological Abstracts and 387 from PsychINFO. After eliminating duplicates, and sequentially screening titles and then abstracts for relevance, 166 articles were selected for

full-text review (see Figure 2). Twelve articles met the criteria from the systematic search. Five more articles were identified by a careful hand search of citation lists, Google Scholar, and the databases from the Social Science Research Network (SSRN) and the National Bureau of Economic Research (NBER).Thus, a total of 17 papers providing information on quantitative, sociocentric network analyses in relation to health and health behaviors were included in this review. These 17 "health-focused" papers describe data derived from 10 unique studies.

Additional Papers

Although discussing health-focused sociocentric network studies in LMICs was the primary motivation for this review, other studies on more general aspects of wellbeing may offer additional insights for sociocentric network measurement in LMICs, especially given the extent of connection between health and development. Thus, our review also examined 19 "development-related" papers (based on data collected from 10 unique sociocentric network studies). This additional set of papers was selected via a thorough, but not systematic, search of the same online databases and bibliographies as well as authors' familiarity with certain studies. Although these 19 papers should not be understood as an exhaustive presentation of sociocentric network research on development topics (e.g., studies on conservation, agriculture, or migration were not included), they likely reflect a substantial portion of the literature that can be identified when conducting an interdisciplinary social science search for studies measuring sociocentric network structure in LMICs.

Style of Analytical Review

The 17 health-focused papers covered an array of contexts, populations, study designs, network types, and network analyses. Given the diversity of methodological and analytical designs, we did not conduct a meta-analysis although we were able to identify common themes in relation to network composition, individual network centrality, and network structure. Thus, we first offer a synthesis of the methodological choices made in the selected studies. We then describe how (a) individual network composition was related to family planning, (b) individual network centrality was associated with potential for behavior change, and (c) macro network characteristics were associated with disease transmission. Information from the 19 development-related papers is incorporated. Finally, we focus our discussion on challenges and future directions for network-based research in LMICs.

RESULTS

Study Characteristics

Among the 10 health-focused studies, nine countries were represented: Ethiopia, Nepal, Bangladesh, Madagascar, Mali, Brazil, China, Malawi, and Ecuador. These studies generally focused on the possible diffusion of behaviors and diseases, with seven papers on contraception use and family planning, two on mercury consumption, five on HIV transmission, and three on diarrheal disease transmission (Table 1). Among the 10 development-related studies, eight countries were represented: Tanzania, Nicaragua, Gambia, Indonesia, Thailand, Nepal, China, and India. These studies covered a wide range of topics, including risk-sharing and insurance, generosity, gender issues, economic

development, food-sharing, cooperation, kinship and dwelling proximity, poverty identification, microfinance, favor exchange, and latrine ownership (Table 2). These papers, however, generally either focused on the formation of social ties and network structure or on the adoption of a new 'technology' (loosely defined).

Given that 17 out of the 20 studies were cross-sectional in nature, very little could be determined about actual diffusion. Therefore, most of these studies interpreted evidence regarding network characteristics and outcomes as possible predictors of behavioral change, diffusion, and network formation. A few health-focused studies used outcome or predictor data representing multiple time points, but only collected network data at one time point (Alvergne et al., 2011; Comola, 2008; Sandberg, 2005, 2006). Also, only one health study (Helleringer et al., 2013) and two development studies (Comola and Prina, 2013; De Weerdt, 2004) collected network data at more than one time point. No interventions were conducted or evaluated in any of the health-focused studies, nor were any experiments conducted. Among the development-related studies, two discussed randomized intervention experiments (Cai et al., 2012; Comola and Prina, 2013), one discussed results in relation to an intervention (Banerjee et al., 2013), two discussed manipulated games (Apicella et al., 2012; D'Exelle and Riedl, 2010), and one discussed simulations as compared to real world data (Alatas et al., 2012).

Sociocentric Network Study Design

All of the health-focused studies collected data on person-centric networks where each specific individual within the defined target population could represent an ego as a node in a network. Fifteen out of the 17 health-focused papers presented data on person-centric networks while two papers actually presented data on household-centric networks where households represented the egos as nodes in the network (Table 1). To do so, one paper merged individual-based ties at the household level (Bates et al., 2007), and another paper only counted ties for the most well-connected person in the household (Zelner et al., 2012). In contrast, 16 out of the 19 development-related papers described household-centric networks (Table 2). Several of these papers arose from studies where only household heads (and sometimes their spouses) were included in the surveyed population. Likely related, the number of network units included in the development-focused studies was notably greater than the number included in the health-focused studies (median = 31 and 3.5 respectively) (Tables 1 and 2).

Name Generators and Network Types

Table 3 presents a catalog of 105 NGs used among all of the ego- and sociocentric network studies conducted in LMICs that were cited in this review. The exact text (or as close as possible) for all NGs from 37 out of 38 studies (including the 20 sociocentric network health and development studies) are provided, and organized according to network type. (NGs were not available for one study). We provide this catalog because it is often requested by people wishing to design a network-based study or intervention, and it provides a context for assessing the NGs used in the 20 studies discussed in this review. Further, the NGs used in egocentric studies were included because social ties, as previously described, are measured

in the same way regardless of design. Supplemental Table 1 provides the same NGs, but it is organized according to study and includes the paper references and country of use.

In general, some NGs focused on specific characteristics, such as types of people, feelings towards a person, advice topics, supports, or interactions, and usually a combination of characteristics while others asked about more general ties (Table 3). Moreover, the vast majority of NGs elicited seemingly positive social ties. Only one NG explicitly stipulated a negative type of social tie. NGs were frequently oriented such that the ego was the origin of the tie-defining activity (e.g., To whom did one go for advice) and not in the other direction (e.g., Who came to you for advice). In addition, some NGs stipulated that alters be residents of the target population (so as to also be included in the study), and some NGs included a time boundary (i.e. in the past six months). Frequently, the number of nominations was limited to a maximum amount, with a few studies requesting an exact number of nominations. Among all studies except for one (D'Exelle and Riedl, 2010), responses to NGs were based on free recall of names and collected during in-person interviews. Finally, a few NGs were used as follow-up questions to elicit any important social ties that may have been missed by other NGs employed.

The number of NGs used in data collection among the 20 studies in this review ranged from 1 to 12 (Tables 1 and 2), with the health-focused studies including slightly fewer NGs (median = 1 NG) than the development-related studies (median = 2 NGs). Two studies also elicited ties by asking about participation in community groups and then the studies assumed ties between people who participated in the same community group (Alatas et al., 2012; Helleringer and Kohler, 2007). Some papers with multiple network types available combined the ties into one synthesized network for analysis (see the India development-related papers for an example). In contrast, a few papers used other information collected about the ties to allocate ties into separate network types for analysis (D'Exelle and Riedl, 2010; Comola and Prina, 2013). Most papers with multiple NGs, however, either analysed the network types separately or analysed just one or two of the network types out of the total number available (Table 1 and Table 2). Interestingly, out of 23 papers included in this review with access to data on multiple network types, only a few examined the extent of overlap between different types of networks (D'Exelle and Riedl, 2010; Entwisle et al., 2007; Stoebenau and Valente, 2003).

Among the 20 reviewed studies, the health behavior studies commonly measured advice networks and friendship networks while the disease transmission studies typically measured sexual networks, spending-time networks, and food-sharing/preparation networks (Table 1). Kinship and instrumental support networks were most typically measured among the development-related studies (Table 2). Very few of the reviewed studies discussed why certain network types were measured (as compared to others) though some chosen network types were obviously related to the study topic.

Social Networks, Health Behaviors, Health Outcomes, and Development

Network Composition and Family Planning—Six studies examined immediate network composition in relation to family planning/fertility-related issues (Alvergne et al., 2011; Comola, 2008; Gayen and Raeside, 2010; Sandberg, 2005; Sandberg, 2006;

Stoebenau and Valente, 2003). Together, these studies demonstrate mixed results regarding the relationship between attributes of immediate alters and ego outcomes. For example, a study of family planning advice networks in Madagascar showed that personal knowledge of family planning methods was associated with the average level of knowledge among directly connected advice-network members (Stoebenau and Valente, 2003). However, actual contraception use was not associated with knowledge of, nor use of, contraception among directly connected network members. This latter finding was consistent with those obtained in a study of friendship networks in Ethiopia (Alvergne et al., 2011). In contrast, among friendship networks in Bangladesh, women using similar contraceptive methods were more likely to be connected to each other than women using dissimilar methods (Gayen and Raeside, 2010).

Only one study examined the relevance of indirectly connected alter composition to egos' family planning outcomes. Among contraception discussion networks in Nepal, exposure to a family planning radio show among both immediate alters and alters' alters (i.e. "friends of friends") predicted contraception adoption decisions among egos (Comola, 2008). Moreover, this study demonstrated that exposure to the radio show spread across the network through peers and determined contraception adoption.

Individual Network Centrality and Potential for Behavior Change—Three studies demonstrated a positive relationship between centrality and positive outcomes, including contraception use (Gayen and Raeside, 2010), dietary changes (Mertens et al., 2008), and latrine ownership (Shakya et al., 2014a). For example, three measures of egos' centrality in a Bangladesh friendship network were associated with perceptions of alters' approval of contraception use and encouragement of family planning discussion, as well as with frequency of discussion with friends (Gayen and Raeside, 2010). This study provided some evidence that women who were centrally located in the network were more likely to use contraception than women located on the periphery of the network. However, this finding was not consistent with those obtained in a contraception network study from Ethiopia (Alvergne et al., 2011)). In contrast, the association between ego latrine ownership and the portion of alters with latrines was greater for people on the periphery of a network in India than for more centrally-located individuals (Shakya et al., 2014a). Similarly, actual contraception use among women in Bangladesh was associated with having a tie to someone outside the village network (though this does not necessarily indicate location within the overall network) (Stoebenau and Valente, 2003).

Three studies showed that 'change agents' were central to the community network. For example, the local intervention collaborator dominated a mercury discussion network in a village in Brazil (Mertens et al., 2012). Likewise, midwives were centrally located in a friendship network in Mali (Hurley et al., 2013), and community-based family planning distribution agents were central in family planning discussion networks (Stoebenau and Valente, 2003). None of these papers, however, indicated the extent to which these persons were central to their networks before they participated in the intervention roles, nor did they indicate how these individuals were chosen as 'change agents.'

Finally, two development-focused network studies showed that behavior change was associated with centrality of the first person to adopt. For example, among villages in China, take-up of weather insurance by rice-farming households was greater in villages where the first people to receive information about insurance were central to rice/finance discussion networks (Cai et al., 2012). Similarly, a study from India showed that participation in a microfinance program was greater across a village when the first person to be informed of the program was more central than others in a network synthesized from multiple tie types (Banerjee et al., 2013). Interestingly, both of these studies showed that neither the decision to take up insurance nor the decision to participate in a microfinance program was associated with the decisions of participants' immediate social contacts. Instead, the decisions were associated with diffusion of knowledge about these issues from contacts to participants. This is similar to some of the contraception studies linking composition and knowledge, but not composition and use, as previously described.

Network Structure and Disease Transmission—All of the health-focused papers assessing network structure analyzed structural characteristics in relation to risk of disease transmission. In particular, the Likoma Network Study (LNS) in Malawi has significantly contributed to the literature on sexual network structure and HIV-related outcomes (Helleringer and Kohler, 2007; Helleringer et al., 2007; Helleringer et al., 2009; Helleringer et al., 2013). For example, even though individuals typically had less than 3 or 4 sexual partners during a three-year period, half of the Likoma population was connected together in a giant network component with evidence of substantial cyclical structures in the network (Helleringer and Kohler, 2007). Moreover, several individuals had multiple partners in common and more than one-quarter were connected through multiple chains. The authors suggested that the high connectivity could support broad diffusion of pathogens despite the overall low number of partners and low rate of partner change. Notably, the LNS' structural findings differed from a study examining sociocentric sexual networks in rural China where neither large components nor cycles existed within the overall network (Fu et al., 2011).

Furthermore, in the LNS, the relative risk of HIV was higher among people who were involved in bridge relationships with in-coming visitors, and use of condoms was lower in such relationships (Helleringer et al., 2007). The authors argued that these bridge relationships may play a critical role in increasing the spread of HIV across the network. The prevalence of HIV was higher in sparser regions of the network, which tended to be populated with older respondents, widows, and women, than in more dense areas of the network (Helleringer and Kohler, 2007).

A group of papers from Ecuador assessed the relationship between network structure and diarrheal transmission in food-sharing, spending time, and discussing-important-matters networks while including information on road access, housing density, and distance to main town (Bates et al., 2007; Trostle et al., 2008; Zelner et al., 2012). Bates et al. (2007) showed that households in villages with road access and greater housing density had a greater total number of ties and that the number of ties was inversely associated with risk of diarrheal transmission. A second study from Ecuador showed that estimates of disease transmissibility through food-sharing networks varied considerably from village to village due to variation in average personal network size per village, which, in turn, was inversely associated with

village distance to the nearest town (Trostle et al., 2008). The threshold for disease transmissibility was higher in ‘closer’ villages. Finally, a third study demonstrated that a greater density of spending time and discussion networks among households in more remote villages facilitated the spread of, and adherence to, sanitation practices, which reduced the risk of disease transmission (Zelner et al., 2012).

Development Outcomes and Community Social Cohesion—Community-level social connectedness, as measured by several network structure characteristics, may exert different effects on various outcomes across different network types (Alatas et al., 2012; Cai et al., 2012; Entwisle et al., 2007; Shakya et al., 2014b; Zelner et al., 2012). For example, one study in China showed that take-up of weather insurance among rice-farming households was much greater in villages where households were clustered together. Similarly, another study of 51 villages in Thailand showed that more cohesive villages tended to exhibit lower out-migration and greater involvement in agricultural cultivation (Entwisle et al., 2007). In contrast, the same study showed that villages with less internal cohesion displayed more connections to outside villages and exhibited lower fertility and greater affluence. Likewise, a study of latrine ownership in India demonstrated that households were more likely to own a latrine in less cohesive network communities (Shakya et al., 2014b). Finally, a study in Indonesia showed that people in more networked villages were better at identifying which community members were poor than people in less networked villages (Alatas et al., 2012). Likely related to social cohesion, several studies demonstrated clustering of kin within close proximity in sociocentric networks (i.e. Nolin, 2010; Verdery et al., 2012).

DISCUSSION

This systematic review summarizes the relatively small body of work on social networks and health derived from sociocentric network studies conducted in LMICs. Logistically, it highlights the heterogeneous methods and designs that may be used to measure sociocentric networks, the importance of multiple levels of analysis, and the relevance of distinct network types. In addition, we show that network composition, individual network centrality, and network structure are associated with individual and community health and development outcomes in different contexts, and that geography and spatial context may interact with both network characteristics and outcomes.

Specifically, we offer three main findings from this review. First, behavioral change among people in a network may be more likely to occur and diffuse through a network if the first people to change their behaviors are central to the community network at least for certain behaviors. Second, both the structural arrangement of ties and the spatial context within which the ties occur have important implications for the way that various diseases (and other outcomes) may pass from person to person. Third, the collective assessment of the studies in this review raises several issues that may be more challenging to address for sociocentric network data collection in LMICs than in higher-income countries. These challenges include methodological decisions regarding level of analysis and boundary specification (of network units, actor eligibility and network type) (Marsden, 1990), as well as data collection

feasibility and accuracy. Importantly, this body of work and these general findings suggest a number of ways to improve future sociocentric network research in LMICs.

Addressing Sociocentric Network Data Collection Challenges in LMICs

First, several papers mention the issue of 'level' (such as the person, household, community, or village level) in their methodological and analytical decisions and interpretations. For example, Jaimovich (2011) showed that indicators of economic development were differently related to network information at the dyadic-, household-, and macro levels. Likewise, Shakya et al. (2014b) demonstrated that the proportion of latrine ownership among an ego's immediate contacts, network-based community contacts, and village contacts were each differently related to the ego's likelihood of owning a latrine. (See Bannerjee et al., 2013 for a further example). Also relevant is a study conducted in Thailand by Faust et al. (1999), which showed that the spatial arrangement of villages and various geographic features determined village-level social and economic ties between villages. Thus, decisions about the level of data collection and analysis are relevant to the potential use of network information for conducting and evaluating future interventions.

Unfortunately, the ability to collect multilevel sociocentric network data may be limited given the substantial effort required to collect sociocentric network data (considering extant methods) in LMICs. One solution, particularly for studies wishing to include several villages, may be to measure household-level ties (i.e. by only interviewing one household head) instead of individual-level ties. The cost of such a study design is that important micro-level information may be lost. For example, if the node of choice represents a single gender, then a study may fail to uncover important gender differences in access to support (D'Exelle and Holvoet, 2011), particularly in gender-separated societies. Thus, choices regarding what a node should represent and the number of network units to measure require serious consideration in relation to study aims.

Second, to collect sociocentric network data, information on the boundary of the target area is needed so that a population of potentially eligible actors can be defined and ties within the population can be established (Laumann et al., 1983). Although villages almost exclusively represented the network unit of choice in the studies reviewed, village boundaries were heterogeneously specified, and few studies described significant qualitative data or formative research on actors' understanding of the boundaries within which they were supposed to make nomination choices in response to NGs. If the network unit is geographically based, network boundary specification can be challenging in LMICs (compared to high-resource settings) as legal or physical boundaries are not always clearly documented, and can be very fluid (Entwisle et al., 2007; Entwisle et al., 1998). Indeed, community boundaries may be subjectively understood rather than legally defined, or they may differ markedly from existing documentation, particularly if the legal boundaries tend to change over time. Participatory community mapping, combined with use of geographic information systems and any available official information, may yield useful data on community boundaries.

In addition, the network boundaries chosen for a specific sociocentric network study should be sufficient to support the study aims though they may not always be obvious at the outset. For example, consider a hypothetical study consisting of a single index village. Actors in

this village may regularly interact in-person with alters in a nearby village (see Koster, 2011 for an example), or they may be strongly influenced by alters whose main households are in the index village, but who spend most of their nights outside of the village (such as partners who work away for significant periods of the year). Such alters may represent important 'bridge' positions in a larger network, bringing significant influence or disease into the network from beyond the boundaries of the index village (Helleringer et al., 2007; Helleringer et al., 2009). Expanding the definition to permit inclusion of such 'bridge' people, and attempting to engage them in the study, perhaps by conducting work during nights, weekends or holidays, may provide more accurate network data.

Third, selecting appropriate NG questions (and therefore network types) is a critical consideration, and depends on the topic of the study, the theory supporting evidence of ties in relation to that topic, and the culture and context in which the research is conducted. Indeed, there is substantial diversity in the NGs that have been employed in network studies in terms of specificity versus globality, function, target, and overlap (Table 3). Although using functionally specific NGs may produce more reliable information on network characteristics (Marin and Hampton, 2007) and on the association between networks and health (Perry and Pescosolido, 2010), deciding which NGs to use may be quite complex in LMICs where the meaning of words and relationships can change across cultures and languages. Likewise, including multiple NGs to describe various network types may be better than using a single NG (Marin and Hampton, 2007). However, if resources are scarce or data are collected via in-person interviews requiring significant coordination, care is needed to choose one or two of the most relevant network types. To that end, NGs focused on identifying close kin, friends, important-matters discussion partners, or instrumental support partners seemed common and widely applicable in the studies covered by this review. Alternatively, there may be other viable methods for reducing question burden (McCarty et al., 2007).

Importantly, NG choice matters for research outcomes because network characteristics and the associations between network characteristics and outcomes may differ across network types (Bates et al., 2007; D'Exelle and Riedl, 2010; Jackson et al., 2012; Jaimovich, 2011; Stoebenau and Valente, 2003). For example, generosity exhibited different associations with network characteris- tics when comparing several types of village networks in Nicaragua (D'Exelle and Riedl, 2010), and a structural network measure of support was greater in favor networks than in hedonic (visiting) networks across multiple villages in India (Jackson et al., 2012). In addition, critical reflection on NGs may be even more important in LMICs where reduced access to formal support (or even informal support) may cause overlap of social ties across different forms of interaction and support. Indeed, a recent review discussed the implications of relationships between network types on outcomes (Kivela et al., 2014).

Fourth, feasibility of network data collection, in terms of time and resources, may be more difficult in LMICs than in higher-income countries. Often, accurate and recent census data about who resides within the targeted network boundaries are not easily available although such information is needed in order to know whom to interview and who is an eligible response to NGs. If complete census data cannot be obtained prior to NG-based data collection, then an understanding of what percentage of the network is needed for relatively

accurate network descriptions should be taken into careful consideration, as some studies have done (e.g. Alatas et al., 2012; Banerjee et al., 2013). Moreover, if a longitudinal outcomes study is planned, then both census and network data may need to be collected multiple times as part of an open-cohort research design. Critically, people may fluidly move in and out of eligibility, e.g. by becoming ‘of age’ to be named as an alter, by marrying a resident and moving into a targeted village, by leaving the household for two years and then returning after a divorce, or by being a migrant worker whose main household is in the targeted village and who may be an important alter, but who may not often be physically available. To address some of these complexities, a recent paper offers methodological insight to collecting multiple rounds of sociocentric network data (Helleringer et al., 2013). Indeed, it may be necessary to account for changes in network structure over time when measuring health outcomes, especially for examining the impact of interventions. One study of 19 slums in Nepal demonstrated that an intervention providing access to savings accounts changed the network of financial transactions between two waves of data collection (Comola and Prina, 2013). This study also showed that accounting for these network changes improved estimation of peer-effect estimates.

In addition, as shown by some of the studies included in this review, physical distance to infrastructure and distance between nodes may be related to formation of network ties, network characteristics, and health outcomes. Thus, distance is an additional factor to account for that may be important in LMICs where infrastructure and technology have not reduced the relevance of this factor in ways that have changed for higher-income countries. Indeed, a group of studies not included in this review demonstrated that risk of diarrheal disease was associated with spatial clustering but not with kinship clustering of related-households (Emch et al., 2012; Giebultowicz et al., 2011; Perez-Heydrich et al., 2013). Thus, collecting spatial information via GPS devices and information on actual geographic characteristics, such as the existence of mountains or swamps within the targeted area, seems important to incorporate in sociocentric network studies where environmental challenges might affect certain properties of social networks and thus determine the flow of resources or influence (Matous et al., 2013).

Finally, very few of the reviewed studies discussed methods to ensure accuracy of tie identification. There are many scenarios in LMICs that may delay or block the ability of the research staff to link an ego to a specific alter. For example, alters may have the same names or be informally identified as ‘my friend's mother's neighbor's brother’ or as ‘the older woman who stays by the water tap.’ In these cases, accurate identification of alters may involve time-consuming, iterative processes. A few sociocentric network studies, however, have used photographic confirmation of named alters during the interview process to improve accuracy of tie identification (Apicella et al., 2012; Ensminger et al., 2011; Stafford et al., 2010). In addition, accurate entry of social ties into a data collection system may be quite complex (again due to the possibility of name overlap), which may prove difficult to address in resource-limited settings. Combining photographic search systems with computer-assisted, mobile data collection, however, may help increase the speed and accuracy at which network data can be collected. Assessing local connectivity may then become increasingly important (Seidner et al., 2012).

Advancing Research on Social Networks and Health in LMICs

Sociocentric network studies involving health in LMICs are still uncommon. Although it is possible we may have missed some articles, inclusion of a few additional studies is unlikely to have permitted robust comparisons of results between countries or the conduct of a formal meta-analysis on the importance of network centrality, composition, or structure in relation to outcomes. Thus, there is a strong need for more in-depth sociocentric network and health studies in LMICs, particularly in relation to intervention and evaluation, using standardized metrics. Indeed, our review identifies a number of gaps in the literature. Many of the reviewed studies calculated few network characteristics, despite having sociocentric network data that could be used to study network structure, composition, and function in depth. Similarly, few studies provided visually rich network maps or looked at overlap in social ties across network types. Moreover, many of the health-related studies did not measure enough village networks to permit conclusions about how differences in macrostructure are related to outcomes. Thus, despite the potential richness of sociocentric network data, analyses have not progressed beyond basic calculations, particularly for studies conducted in LMICs.

Critically, little is known in these settings about the importance of network characteristics for certain sub-populations (e.g. youth and older adults or urban residents), how networks influence outcomes over time and vice versa, and the extent of network-related intervention effects (i.e. spillovers or externalities). Moreover, network comparisons across cultures are needed. In addition, the potentially negative influence of social networks on health was not discussed in the reviewed studies. In high-income countries, social ties have been associated with harms ranging from substance use (Ennett et al., 2006) to suicidal behaviors (Bearman and Moody, 2004). Certainly networks may involve antagonism as well as friendship (Christakis and Fowler, 2009), particularly in LMICs where people may not have as much of a choice regarding to whom they are connected.

These gaps, however, present opportunities for future research to explain how networks affect health outcomes (and vice versa) and how network information can be used to improve health outcomes in LMICs. In particular, longitudinal data and experiments are needed to increase understanding of pathways and causality. The associations between network characteristics and individual outcomes demonstrated by many extant studies using observational data are subject to all the usual sorts of constraints affecting observational studies (e.g. the observed association not necessarily reflecting causal effects), plus other limitations that are distinctive to network data settings (Aral et al., 2009; Christakis and Fowler, 2007, 2013; Manski, 1993; Shalizi and Thomas, 2011). Ongoing development of tools for faster and more accurate network data collection, testing of non-census-based network data collection methods to determine whether such information can provide reliable estimates of sociocentric network measures, and advances in analytical techniques for use with sociocentric, longitudinal network data or with randomized experiments or instrumental variable methods will facilitate these endeavors (Aral and Walker, 2011; Bond et al., 2012; Christakis and Fowler, 2013; Fowler and Christakis 2009; O'Malley, 2013; O'Malley et al., 2014; VanderWeele, 2013).

Conclusion

Individuals in communities around the world are linked together through strong and weak ties representing many types of relationships. Collectively, these ties lead to extended webs of interaction and connect people to others whom they may not even know exist. The evidence presented in this review suggests that research and applications should account for the networks in which individuals are embedded. If this recommendation is followed, then, based on the findings, global health policymakers and practitioners could potentially plan for more efficient and effective use of limited development aid to improve health outcomes across a larger number of people or to reach those who are more isolated. Crucially, experimenting with how to use sociocentric network knowledge to improve health outcomes through innovative intervention design and evaluation may be a worthy endeavor in resource-limited contexts, particularly in areas with substantial competition for development funds. Moreover, findings from the development-related studies provide an impetus for cross-disciplinary collaboration in the design and interpretation of network studies. This is particularly important in LMICs given the need for social change across highly related sectors, especially in rural and/or resource-limited settings where the social network may be the only reliable source of multiple types of support. In sum, this review provides a foundation on which studies, interventions, and policies may begin to more systematically capitalize on social ties that assist the spread of positive outcomes (and to stop the spread of negative outcomes) among individuals and communities in LMICs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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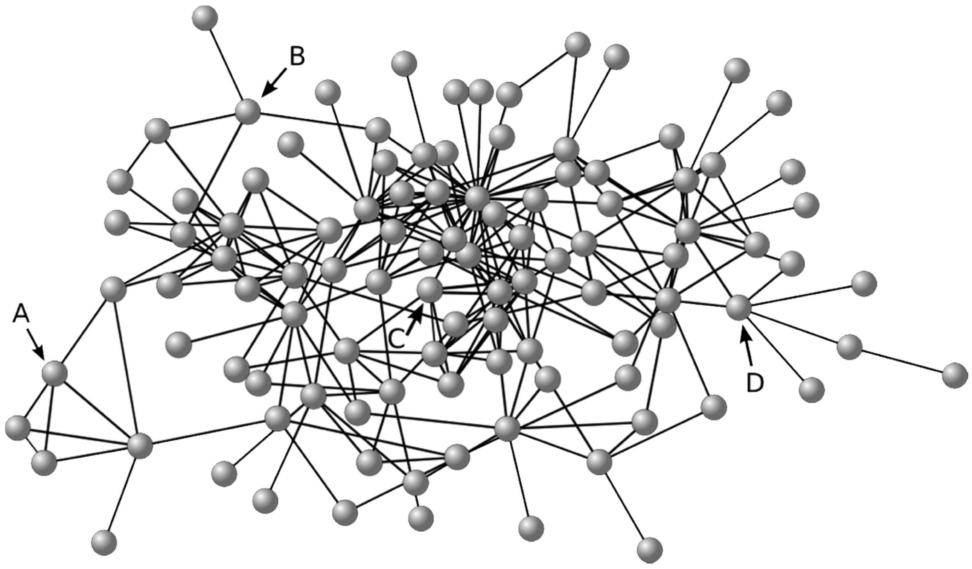
RESEARCH HIGHLIGHTS

- A systematic review of sociocentric network papers on health and wellbeing in LMICs
- A catalog of name generators organized by network type is provided
- Network composition, position and structure were related to outcomes and behaviors
- Future whole network studies in LMICs require significant attention to design
- Accounting for network structure may improve intervention effectiveness and efficiency



Note: In this natural network of close friendships among 105 college students living in the same dorm, each circle ("node") represents a student and each line ("tie") a mutual friendship. Even though persons A and B both have four friends, A's four friends are more likely to know one another (there are ties between them) whereas none of B's friends know each other. A has greater "transitivity" than B. Also, even though persons C and D both have six friends, they have very different "locations" in the social network. C is much more "central" than D, and C's friends have many friends themselves, whereas D's friends tend to have few or no friends.

Figure 1.
Depiction of example egocentric networks (A, B, C, and D) within a sociocentric network.

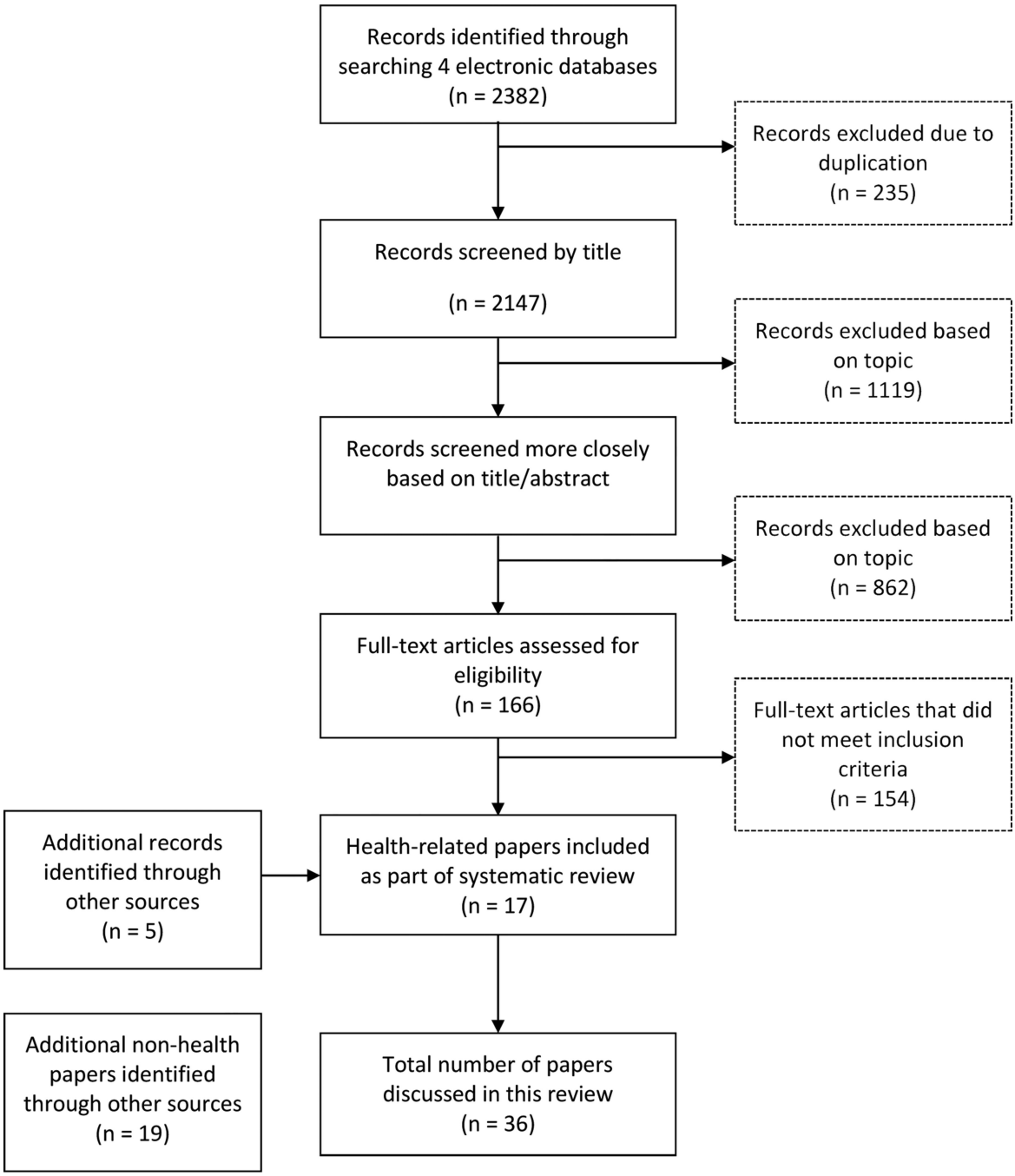


Figure 2.
QUOROM flow chart of paper search and selection process for a systematic review of studies on sociocentric networks and health conducted in low- and middle-income countries.

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Table 1

Sociocentric network studies of health and health behaviors in low- and middle-income countries (N=17 unique papers from 10 studies).

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
Alvergne et al., 2011	The spread of contraception use	All ever married women of reproductive age and their husbands across four rural villages in Ethiopia	Cross-sectional study of person-centric networks with current and self-reported historical data	1 type: same-sex friendships	Direct and indirect composition; Individual centrality	The mean out-going nominations was 2.7 for women and 3.8 for men.	No
Comola, 2008	Communication and adoption of contraception use	All married women of reproductive age in three rural villages in Nepal	Cross-sectional study of person-centric networks with two waves of outcome data	1 type: same-sex contraception advice	Direct and indirect composition	The average number of links per woman was 1.8 and the shortest distance between women was 4.5 links. The number of isolates was 71 out of 337.	Yes
Gayen & Raeside, 2010	Perceived peer encouragement and contraception use	One married woman of reproductive age with children for every household from seven rural villages in Bangladesh	Cross-sectional study of person-centric networks, but only one person per household was included	1 type: same-sex friendships	Direct composition; Individual centrality; Macrostructure	None available.	Yes
Sandberg, 2005	Expected family size and uncertainty about local infant mortality	All women of reproductive age in one rural village in Nepal	Cross-sectional study of person-centric networks with current and self-reported historical data	3 types: receiving assistance when sick, giving assistance to someone, and work-colleagues (types combined for analysis)	Direct composition	The average out-going nominations was 5.4.	No
Sandberg, 2006	Fertility tempo and local infant mortality	Same as above	Same as above	Same as above	Direct composition	Same as above.	No
Stoebenau & Valente, 2003	Contraception use and connection to family planning distribution agents	All adults of reproductive age in	Cross-sectional study of	2 types: general advice; family planning advice	Direct composition; Individual centrality	There were 46 out 159 isolates in a general	Available from authors

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
		one rural village in Madagascar	person-centric networks	(analyzed separately)		advice network and 117 in the family planning advice network. Density was 0.25 and 0.11 in each respective network. Only 20% of the ties were the same across the two network types.	
Hurley et al., 2013	Midwives as potential change agents	All adult women from two rural villages in Mali	Cross-sectional study of person-centric networks	1 type: friendship	Individual centrality; Macrostructure	The average out-going nominations was 1.2 and 0.4 in Village A and B, respectively.	Yes
Mertens et al., 2008	Communication about mercury consumption and health	All heads of household (usually a couple) in one rural village in Brazil	Cross-sectional study of a person-centric network	1 type: health discussion	Macrostructure	There were 25 isolates out of 158 nodes with 130 linked in one dense component. The average distance between people in the main component was 3.4 links.	Yes
Mertens et al., 2012	Adoption of new fish consumption behavior and participatory research	Same as above	Same as above	Same as above	Direct composition; Individual centrality	The average out-going nominations was 3.5 for women and 2.6 for men and the average in-coming nominations was 2.1 for women and 2.0 for men.	Yes
Fu et al., 2011	HIV transmission	All adults in ten villages clustered within one rural community in China	Cross-sectional study of person-centric networks	1 type: sexual	Dyadic characteristics; Macrostructure	Among 628 sexual ties, there were 336 components with 80% representing dyads. Sixty components	Yes

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
						contained partners outside of the defined network.	
Helleringer & Kohler, 2007[b]	HIV transmission	All people aged 18 to 35 (and older spouses) in seven villages on one island in Malawi	Cross-sectional study of person-centric networks	4 types: sexual; friendship; assistance during unexpected hardship; shared group (only analyzed the sexual network)	Macrostructure	There were 256 components with 86% of size five or smaller representing 34% of sexually active respondents during the recall period. Two-thirds of respondents were part of 35 components of size six or larger. 56% of males and 46% of females constituted a single giant component, with a high prevalence of paths that begin and end at the same person.	Yes
Helleringer et al., 2007[b]	HIV transmission	Same as above	Same as above	Same as above	Dyadic characteristics	Among ongoing relationships, 22.5% were with external partners.	No
Helleringer et al., 2009[b]	HIV transmission	Same as above	Same as above	Same as above	Individual centrality; Dyadic characteristics; Direct and indirect composition; Macrostructure	The mean out-going nomination was 2.4 among men and 1.8 among women during the three years prior to survey. The mode incoming nomination for the same period was 1 with a large number of	No

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
						people with no sexual contacts.	
Helleringer et al., 2013[b]	HIV transmission	All people aged 18 through 49 in more than the seven original villages on the same island in Malawi (see above)	Longitudinal study of person-centric networks	2 types: sexual; friendship (only analyzed the sexual network)	Focused on describing study design and data collection methods	None available.	Yes (repeated from prior paper)
Bates et al., 2007[c]	Diarrheal disease transmission	All men and women aged 13 and older across 9 rural villages in Ecuador	Cross-sectional study of household-centric networks that were calculated from person-centric network information by combining responses from everyone in the household	7 types: spend time; one food-sharing/prepping; five more that were not described (separately analyzed only the first two types)	Household centrality; Macrostructure	The village-average number of contacts per household ranged from 4.8 to 18.7 for the spend time network and from 0.4 to 10.4 for the food-sharing network.	No
Trostle et al., 2008[c]	Diarrheal disease transmission	All individuals aged 13 and older across 21 rural villages in Ecuador	Cross-sectional study of person-centric network	7 types: food-sharing/prepping; six more that were not described (only analyzed first network)	Individual centrality; Macrostructure	The village-average number of contacts per person ranged from 0.02 to 4.8. The most remote villages had, on average, two more connections per person than villages close to the main town.	Yes
Zelner et al., 2012[c]	Diarrheal disease transmission	All men and women aged 13 years and older across 18 rural villages in Ecuador	Cross-sectional study of household-centric networks that were calculated from person-	7 types: spend time; general advice; and five more that were not described (separately analyzed only the first two types)	Direct composition; Household centrality; Macrostructure	The village-average number of contacts per household ranged from 0.8 to 4.5 for the important matters network and from 2.6 to	No

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
			centric network information, by only counting the social ties for the person in the household with the most connections			7.8 for the passing time network. The global village-level extent to which households clustered together ranged from 0.12 to 0.37, and from 0.15 to 0.46, for the important matters and passing time networks, respectively.	

Notes:

[a] Presentation of measures was contingent upon availability.

[b] Data for the four Malawi-based papers come from the same long-term study, called the Likoma Network Study.

[c] Data for the three Ecuador-based papers come from the same long-term study, called EcoDess

Table 2

Sociocentric network studies of development-related issues in low- and middle-income countries (N = 19 unique papers from 10 studies).

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
De Weerdt, 2004	Risk-sharing and network formation	All adults in one rural village in Tanzania	Longitudinal study of household-centric networks created from person-centric network information (with ties calculated in different ways)	2 types: kinship; general assistance (only the assistance network is analyzed)	Dyadic characteristics	Among all mentioned network members, 34% of contacts lived outside of the study population. Out of 7021 possible household dyads, 93% had no relationship, and 33% of the existing dyads had a friend in common.	Yes
De Weerdt & Dercon, 2006	Risk-sharing and formation of insurance networks (in response to past health shocks)	Same as above	Same as above with ties aggregated from person-centric network information	Same as above	Direct composition; Dyadic characteristics	The mean number of links between individuals was 3.5 and the mean number of links between households was 6.3.	No
De Weerdt & Fafchamps, 2011	Risk-Sharing and formation of insurance networks (in response to current health shocks)	Same as above	Same as above	Same as 2004 paper, but created 4 types: kinship; general assistance broken into three separate types - transfers/gifts, loans, and labor	Dyadic characteristics	None available.	No
Comola, 2012	Network externalities and formation of social ties	Same as above	Same as above	Same as the 2004 paper	Direct and indirection composition	The mean average shortest distance between households was 2.5 links with a maximum of 5 links. All households were connected in one component.	Yes
D'Exelle & Riedl, 2010	Generosity, differences across network types and network formation	All household heads in one rural village in Nicaragua	Cross-sectional study of person-centric networks	1 type that was separated into 6 types: any-type of relation, then split into friendship; general support; activities; economic exchanges; neighbors; family (analyzed separately)	Individual centrality; Macrostructure	Across five network types (excluding family), the proportion of all possible ties that were present ranged from 0.032 (support network) to 0.186 (friendship network), and the extent to	Yes

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
						which individuals were clustered ranged from 0.040/0.041 (support/economic network) to 0.133 (friendship network). There were no isolates in the combined network.	
D'Exelle & Holvoet, 2011	Gender and network formation	Same as above	Same as above	Same as above	Dyadic regressions; Individual centrality	The average ego-network size for both men and women, separately, was greatest in the friendship network and least in the support network (excluding the family network).	Yes
Jaimovich, 2011	Economic predictors of social tie formation and macrostructure	Household heads across 60 rural villages in Gambia	Cross-sectional study of household-centric networks	6 types: labor support; land use; agricultural input support; economic support; two more types (each type analyzed separately and also separately analyzed two combined types of economic and family ties)	Dyadic characteristics; Household centrality; Macrostructure	The average number of links per household was around 1-2% of the total possible links for all network types except for kinship with 10%. In the economic network, less than 10% of households have at least one outside-village tie. The village average percentage of actual ties observed between households ranged from 2-5% except for the kinship network (14%). At the village level, the inputs network showed the greatest average number of links (39.8) apart from the kinship network (147.7).	Yes
Nolin, 2010; 2012	Formation of food-sharing ties	At least one or more adult(s) per household in one rural village in Indonesia	Cross-sectional study of a household-centric network	1 type: food-sharing	Household centrality; Exponential random graph modeling	The mean out-going nominations and incoming nominations were both 9.8 though the standard deviation	Yes

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
						was greater for out-going than in-coming links. 96% of ties were within village. 67% of ties were reciprocated.	
Apicella et al., 2012	Cooperation and social proximity	All adults in 17 Hadza hunter-gatherer camps in rural areas in Tanzania	Cross-sectional study of person-centric networks combined with a public goods game	2 types: desired same-sex campmates; gifts (analyzed separately)	Individual centrality; Direct and indirect composition; Dyadic characteristics; Macrostructure	The mean in-coming and out- going nominations for the gift network were 1.9 (s.d. = 1.6) and 2.2 (s.d. = 0.8), respectively, while the mean in-coming and out-going nominations for the campmate network were 3.4 (s.d. = 2.8) and 6.5 (s.d. = 2.1), respectively.	Yes
Entwisle et al., 2007	Variation in the structure of social ties	All people aged 18-35 in all households in 51 villages in one district in Thailand	Cross-sectional study of household-centric networks	2 types: siblings; labor support (analyzed separately)	Macrostructure	Across villages, the mean percentage of households reached directly was about 11% for both network types, and the mean percentage of isolates was 26% and 58% for the sibling and labor networks, respectively. The correlation between sibling ties and labor ties was 0.1, on average.	Yes
Verdery et al., 2012	Kinship and dwelling proximity	Same as above	Same as above	2 types: siblings; labor support (only analyzed sibling network)	Dyadic characteristics; Macrostructure	None available.	Yes
Comola & Prina, 2013	Intervention driven network changes in social ties and network spillover effects on household outcomes	All female heads of households in 19 slums in Nepal	Longitudinal study of household-centric networks in relation to an exogenous intervention	2 types: gifts and loans with regular partners; gifts and loans with occasional partners (the two types were combined and analyzed, and then split as gifts and loans)	Direct composition; Household centrality; Dyadic characteristics	On average, households had 1.7 financial partners with 0.7 within the village and 0.8 among relatives (regardless of location).	No

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
Alatas et al., 2012	Information accuracy, network structure, and community-based targeting	15% of household heads (which provided complete data on 65% of all households) in each of 631 neighborhoods in Indonesia	Cross-sectional study of household-centric networks compared with simulations	2 types: kinship; shared group (analyzed as one network)	Household centrality; Macrostructure	Across the villages, the average number of ties per household was 8.3, with households reporting being related to an average of 3.1 households in the village. The average path length between households was 2, and 41% of a household's contacts were themselves linked to each other, on average.	No
Cai et al., 2012	Take-up of weather insurance and diffusion of knowledge	All household heads from rice-farming households in 185 rural villages in China	Cross-sectional study of household-centric networks combined with a randomized experiment	1 type: friendship-economic advice	Direct and indirect composition; Household centrality; Macrostructure	The average number of out-going and in-coming nominations per household were 4.9 and 3.3, respectively, with an average path length of 3.6 between households. On average across villages, 18% of a household's contacts were also connected to each other, 17% of social ties were reciprocated, and 99% of households were connected to a main giant component.	No
Banerjee et al., 2013	Diffusion of participation in a microfinance intervention program	50% of households with a woman of about reproductive age (where both the household head and spouse were included) in 43 rural villages in India	Cross-sectional study of household-centric networks	12 types: frequent communication; spends time (both directions); borrow rice/kerosene (both directions); borrow money (both directions); advice (both directions); transport assistance; kinship; attend temple together (one network synthesized from all types)	Household centrality; Macrostructure	The average number of ties per household was almost 15, with an average path length of 2.2 between households, and 26% of a household's contacts were also connected to each other..	No

Papers	Topic	Targeted Population	Study and Paper Design	Network Types Measured and Analyzed	Focus of Network Analysis	Sample of Basic Network Position and Structural Characteristics[a]	Network Map
Jackson et al., 2012	Network patterns of favor exchange and support	Same as above, but in 75 rural villages in India	Same as above	Same as above, but some networks analyzed separately and other analyses used partial synthetic networks	Dyadic characteristics; Macrostructure	None available.	No
Shakya et al., 2014a	Latrine ownership	Same as above	Same as above	Same as the Banerjee et al., 2013 paper.	Direct composition; Strength of ties; Household centrality	The average total number of household ties was 9.1. The average path length between households per village across all villages was 3.2 and the average proportion of observed ties out of the total possible per village was 0.04. The average number of components per village was 1.1.	Yes
Shakya et al., 2014b	Latrine ownership	Same as above	Same as above	Same as the Banerjee et al., 2013 paper.	Direct composition; Network community composition; Macrostructure of network communities and villages	None available.	Yes

Notes:

[a]Presentation of measures was contingent upon availability.

Table 3

A catalog of 105 ‘Name Generators’ (survey questions employed to elicit social ties) sorted by network type, which were collected from 37 social network studies conducted in low- and middle-income countries.

Network Type	Text of Name Generators
Kinship	1. Asked to name all other households in the hamlet to whom they were related (either through blood or marriage).
	2. “Does this person have other siblings besides the ones [living in the household] that are still living?” If so, then name and contact's location were recorded.
	3. “With which households do your family members have kinship relationships?”
	4. “Can you tell me about people who are close to you and are kin or faux kin?”
	5. Asked to name five relatives respondent speaks with most frequently.
	6. “Name any close relatives, aside from those in this household, who also live in this village. Plus people in those same households.”
	7. “Have any of your household members married members of other households?” [Direction was indicated and Names given as response].
	8. Asked to name siblings (no other criteria).
	9. Asked to name spouse (no other criteria).
Sex Partners	10. Asked to name with sexual partners within the past five years.
	11. Asked to name five most recent sexual partners in the past three years.
Friends: General	12. “Name up to five other women/men [same-sex as respondent] with whom you talk most and perceive as among your best friends.”
	13. Asked to name up to five women in the village with whom they talked most and perceived as their best friends.
	14. Asked to name five friends speak with most frequently.
	15. Asked to name four closest friends on the island.
	16. “Who are your closest friends in the village?”
	17. Asked to name best friends.
	18. Who are the people that you really enjoy socializing with?
	19. Ask to name all people perceived as available for recreation and companionship (e.g. have fun or relax).
Affective Support: General	20. Asked to name people who provide emotional support.
	21. Asked to name the people perceived as available for emotional or affective support (e.g. share secrets and discuss feelings)
	22. “Can you tell me about people who you share your secrets with?”
	23. “Can you tell me about people who are closest to your heart?”
	24. “Can you tell me about people who are close but don't live in area?”
	25. “Can you tell me about people who are in your age grade who you are close to?”
	26. Asked to name all people available for validation or positive feedback (e.g. tell good things about yourself)
Spend-Time: General	27. “In your free time, whose house do you visit (up to 8 people)?”
	28. “Who visits your house in his or her free time (up to 8 people)?”
	29. “In general, with whom do you spend time [outside your household, but in your community]?”
	30. Asked to name with whom outside the household the subject spent time in the last week.
	31. “Can you tell me about people who you gather with regularly in your free time?”

Network Type	Text of Name Generators
	32. “Can you tell me about people who you pass your days with in the dry season?”
Communication: General	33. “Whom have you talked to in the past week (besides family members living in the same household)?”
	34. “Name the 5 non-relatives whom you speak to the most.”
	35. “With whom do you talk most often (up to four people other than spouse or kin)?”
	36. “Can you tell me about people who you talk with on the telephone?”
	37. Asked to name 20 people with whom they had communicated in the last 6 months by e-mail, phone, person, or any other means, starting with those most important first.
	38. Asked to name 40 people that respondent knew. Knowing was defined as “you know them and they know you by sight or by name, you could contact them, and that there has been some contact (in person, by telephone, by mail or email) in the last two years’”.
Advice: General	39. Asked to name to whom outside the household the subject talks about important matters.
	40. Who are the people with whom you discuss matters that are important to you?
	41. Asked to name (up to five) people to whom respondents go for advice or to discuss personal topics.
	42. “If you had to make a difficult personal decision, whom would you ask for advice (up to 8 people)?”
	43. Asked to name people perceived as available for advice and information (e.g. useful information on how to care for a sick sibling).
	44. Asked to name people who provide cognitive support.
	45. “Who do you talk to, here in the village of [name], when you have a big decision to make in your life, or when you need advice about a problem? Can you name four people?”
	46. “In this packet, you will find a photograph of all/most of the adults in this village. Pick out the photographs of all the people you usually talk to about any kind of problem in this village.”
	47. “Are there any other people outside this village you usually talk to about any kind of problem in this village? Please list all of them.”
	48. “Who comes to you for advice (up to 8 people)?”
Advice: Specific	49. Asked to name five close friends (not including parents or children), either within or outside the village, with whom he/she most frequently discusses rice production or financial related problems.
	50. Asked to name the individuals with whom they usually discussed mercury issues, whether in the context of health, dieting, or fishing.
	51. Asked to name five close friends (not including parents or children), either within or outside the village, with whom he/she most frequently discusses rice production or financial related problems.
	52. “Have you spoken to anyone here in [name of village] about ways to avoid pregnancy? Can you name four people you have spoken with?”
	53. “Have you spoken to anyone about ways to avoid pregnancy outside of the village of X? Can you name four people you have spoken with?”
	54. “How many people have you chatted with about modern methods of child spacing/family planning? I mean people other than your husband/wife. [If Yes,] Could you please give me the names of (up to) four of these?”
	55. “How many people have you chatted with about AIDS? I mean people other than your husband/wife. [If Yes,] Could you please give me the names of (up to) four of these?”
	56. Asked to name the people to whom respondents had spoken about place of delivery during pregnancy. Probing continued until 20 names were given.
	57. “Who would you go to for advice if you had a question about fish or fishing?”
	58. “Who would you go to for advice if you had a question about planting or growing yams?”
	59. “Who would you go to for advice if you had a question about using a plant as a medicine?”
	60. Asked to name individuals with whom the respondent specifically speaks about child health issues.
	61. “Who had respondent talked to about the forthcoming referendum?”

Network Type	Text of Name Generators
Instrumental Support: General	62. Asked to name people outside the subject's immediate household whom the subject had helped. 63. Asked to name people who provide material support. 64. Asked to name people who provide practical support. 65. Asked to name five people to turn to for help in case of unexpected hardship. 66. Asked to name people perceived as available for instrumental or tangible aid (e.g. food, transportation, or help thatching a roof). 67. “Can you tell me about people whom you can ask for help in a crisis?” 68. “Can you tell me about people whom you would ask to be responsible for your family when you travel?”
Instrumental Support: Specific	*Food* 69. “In the past week, outside your household, with whom did you participate in activities having to do with food, like preparing or sharing it?’ 70. Asked to name individuals to whom the subject had given gifts of food, usually more than once, during the preceding hunting season. 71. Asked to name individuals from whom the subject had received gifts of food, usually more than once, during the preceding hunting season. 72. Asked to name the person from whom food was acquired outside the household. 73. “If you need to kerosene or rice, to whom would you go?” 74. “Who would come to you if he or she needed to borrow kerosene or rice”? *Health (likely related to transport or money)* 75. “If you had a medical emergency and were alone at home, whom would you ask for help in getting to a hospital (up to 8 people)?” 76. Suppose you suddenly become seriously ill at night, who will you call for help? 77. Asked to name people outside the subject's immediate household to whom the subject had turned for help when sick. 78. “Who had helped respondent the last time they had drinking water or health problems?” *Money* 79. “If you suddenly needed to borrow Rs. 50 (a small amount) for a day, whom would you ask (up to 8 people)?” 80. “Whom do you trust enough that if he or she needed to borrow Rs. 50 (a small amount) for a day you would lend it to him or her (up to 8 people)?” 81. Suppose you need to borrow a large sum of money, say 250,000 FCFA (about $500), whom would you ask for help? 82. “Did you lend out or borrow in money from other households in the last year?” [Direction was indicated] 83. Asked to name people inside or outside the village that a participant could rely on most and with whom the participant or members of the participant's household regularly exchanged gifts and/or loans. 84. “Can you give a list of people from inside or outside of [this village], who you can personally rely on for help and/or that can rely on you for help in cash, kind or labour?” *Labor* 85. “Did anyone from this village help [the participant] to harvest rice?” If so, then name and contact's location were recorded. 86. “Did anyone from another village come to help [the participant] harvest rice?” If so, then name and contact's location were recorded. 87. “Did you, or any members of your household, work for other households during the last year?” [Names and direction was indicated] 88. Asked to name people outside the subject's immediate household to with whom the subject had worked in the previous year.

Network Type	Text of Name Generators
	Other
	89. “Of the land you cultivated last year, did you lend out or borrow in land from other villagers?” [Names and direction was indicated]
	90. “Did you lend out or borrow in any means of production (such as tools or fertilizer) from other households in the last year?” [Direction was indicated]
Shared Group: General	91. “Can you tell me about people who you talk to in associations or committees you belong to?
Shared Group: Specific	92. “Whom do you go to temple with (up to 8 people)?”
	93. “Can you tell me about people who you talk to in religious group you belong to?”
	94. Asked to name social contacts whose children attend local primary schools.
	95. “Please tell me the complete names of five people in your [voluntary association] group that you talked to most often in the past six months?”
	96. “Can you tell me about people who you talk to in your work or work association?”
Other Ties: Specific	97. “With whom would you like to live after this camp ends?” [choosing from among the entire same-sex adult Hadza population].
	98. Asked to name up to six people to whom they would like to give an actual gift of honey from among members of their particular camp.
	99. “Can you tell me about people who have a style of living which pleases you?”
Negative Ties	100. Asked to name all people who sometimes make the respondent feel bad or upset.
Follow-up	101. Asked to name husband, mother-in-law or co-wife, if conspicuously absent from the list generated from the previous questions.
	102. “Who are the people that you are close to, but did not mention earlier?”
	103. “Can you tell me about people who you may have forgotten among those you have cited?”
	104. Asked to name the five most important people among the people already listed from the previous questions.
Not free re-call	105. Asked whether the interviewed person knew the household [a card with the name for every household was displayed] and whether the subject had a social relation of any kind with one of the household members. Then, asked about the content of the relation: friendship, support, social-public, economic, neighbor, or family.

Notes: Exact wording, and the number of responses permitted, are provided if available. Supplemental Table 1 lists the same name generators, but organizes them according to the study in which they were used.