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Strategic players for identifying optimal social network intervention subjects

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ABSTRACT

We present a method whereby social network ties are used to identify behavioral leaders who are situated in the network such that these individuals are: 1) able to influence other individuals who are in need of and most receptive to intervention, thereby optimizing the impact of the intervention; and 2) not embedded with ties to individuals that are likely to be behaviorally antagonistic to the intervention or that would compromise the optimal impact of intervention. In this study we developed a method that we call Strategic Players, which is a solution for identifying a set of players who are close to a target subset of the network (i.e., the target group), and far away from the subset we wish to avoid (i.e. the avoid group), where the proximity to either the target or avoid group may be facilitated by network members who are in neither group (i.e. the neutral group). This solution seeks to maximize the diffusion of the behavior to the target group while minimizing contact and influence to the avoid group. We apply this method to two different social networks, and one simulated social network.

Introduction

Social networks provide a way to spread information and the adoption of healthy behaviors. The position of an individual in a social network plays an important role in how influential that individual is within the network. Social network interventions (SNIs) target individuals who, by virtue of their position in the network, are influential in the behavior of others. Such interventions are specifically designed to consider social connections when attempting to change health behaviors, in large part because social networks provide a way to spread information and healthy behavior (Centola, 2010; Latkin et al., 2013b; Latkin et al., 2013c; Pilowsky et al., 2007; Smith and Christakis, 2008; Tobin and Latkin, 2008; Valente, 2012). One common SNI approach involves engaging peer educators or influential individuals (commonly called "opinion leaders") who communicate within their communities and serve as role models, thus conveying behavior change goals to others.

SNIs rely on diffusion of innovation theory (Rogers, 2002). According to this theory, individuals are more likely to adopt innovative methods, products, or ideas when they see them adopted by others with whom they have close, credibility-enhancing relationships. There is evidence that health-enhancing behaviors spread through networks via similar mechanisms, such that individuals are more likely to adopt health-enhancing behaviors when their close associates have adopted similar behaviors (Smith and Christakis, 2008; Valente, 2010). Close connections are therefore typically assumed to be central to the efficacy of network interventions (Fujimoto and Valente, 2012). HIV prevention is one area in which the efficacy of SNIs has been established (Amirkhanian et al., 2005; Broadhead et al., 1998; Latkin et al., 2013a), and there is evidence that greater behavior change occurs among those with closer network proximity to peers who are modeling the desired behavior change (Li et al., 2012).

Borgatti uses social network metrics to identify network members who have the "most important" positions in the network, which he refers to as the set of key players (KPP-Pos; Borgatti, 2006). The approach to identifying a KPP-Pos set differs from, for instance, centrality scores (e.g. Bonacich, 1972; Freeman, 1979) by its focus on the importance of nodes to network *cohesion*, where cohesion is measured by some variant of path length or reachability in the network as a whole. For example, it is easy to construct networks where the most central nodes can be removed without much effect

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on average path lengths. By shifting the criterion from centrality to cohesion, the KPP-Pos approach identifies a minimal set of nodes that serve as the most important members of the network in terms of linking nodes to each other through the shortest average paths (though other definitions of cohesion apply as well).

The KPP-Pos approach is arguably an improvement over centrality measures for identifying sets of influential network members. Influential network members are arbiters of important resources (information, support, etc.) which are assumed to flow through network linkages, for example, by behavioral modeling or interpersonal interaction. However, KPP-Pos does not take into account node characteristics, and only uses the network position to determine membership in the KP-Pos set. An example of such a situation, for purposes of this paper, is a behavioral health intervention, where a primary at-risk subset of the members of some network (e.g., a community or organization) is targeted for the intervention in such a way that other secondary at-risk members will be maximally exposed to the primary at-risk intervention recipients, and thus be helped indirectly. Such contagion effects are of interest because maximizing them can dramatically amplify the effect of the original intervention (e.g., Aral and Walker, 2011).

There exists a need to broaden the goal of methods like KPP-Pos. Not only do we need to identify opinion leaders who optimally reach those individuals in the network who would be targeted for intervention, but we may also want to avoid exposing other individuals to the intervention. For example, an intervention designed to reduce smoking risk among susceptible adolescents (e.g., who have begun an intermittent pattern of smoking) would need to include or exclude potential opinion leaders and secondary targets of the intervention based on whether they show the target behavioral pattern. Another example is an intervention in which one wishes to avoid targeting members who are unlikely to be responsive to the intervention, or could even be openly antagonistic, in order to avoid reducing the overall efficacy of the intervention within the network. Current methods do not address this important objective of avoiding wasting resources on network members who are known *a priori* to be at little or no risk or are not likely to be responsive to the intervention.

An additional circumstance that requires a modification to the methods for identifying key players refers to an intervention design feature (as opposed to a participant characteristic as above) in which an intervention is being tested within a community of smaller networks. For example, consider a social network intervention at an elementary school in which one class is identified as the control group, and another class is identified as the intervention group. While social connections will primarily be formed within the classes, there will also be the potential for cross-class social ties. For optimal internal validity and to provide the best test of an intervention relative to a control, it is important to (a) avoid the transmission of intervention effects to the control group, and (b) avoid suppression of the intervention effects from contact with the (presumably less effective) control condition (called leakage and contamination, respectively in some contexts; Aral and Walker, 2011, 2012). This circumstance requires similar optimization of the identification of key players referred to above, but also requires attending to ties between sub-networks, such that we may avoid transmission or suppression of effects.

In summary, there is a need to extend the Key Player identification whereby social network ties are used to identify individuals who are situated in the network such that these opinion leaders are 1) able to influence those individuals who are part of the target population and are most receptive to intervention; and 2) are not embedded with ties that are likely to be behaviorally antagonistic to the intervention or that would compromise the optimal evaluation of intervention efficacy.

Method: strategic players

The objective of this study is to develop a solution for identifying a set of players who are close to a target subset of the network (i.e., target group), and far away from the non-targeted subset (i.e., avoid group). Under the assumption that when individual *A* reports a relationship with individual *B*, that individual *B* may influence individual *A* (Mundt, 2011; Rosenquist et al., 2010; Valente et al., 2003), this solution should maximize the diffusion of the behavior to the target group while minimizing contact with or influence on the avoid group.

It should be noted, that a third group (which we call the neutral group) consisting of members that are in neither the target or avoid group, may be present. Neutral group members are important in that the shortest distance path between two members of the network may be through a neutral network member. For the purpose of this paper, we focus on the situation in which strategic players are chosen from the target set and where neutral group members can transmit the effect of the intervention.

Rather than simply considering direct connections, in the KPP-Pos method, where there are n members of the network, the set K of key players (with pre-specified size |K|) is identified as the set of network members for which the average of the inverse minimum distance d_{Kj} from any member of the set K to all other network nodes (the distance weighted reach) is maximized. Thus, this method seeks to choose network members as the key player set to maximize:

$$D = \frac{\sum_j \frac{1}{d_{Kj}}}{n} \tag{1}$$

which is equation 14 in the original Key Players paper (KP-Pos; Borgatti, 2006). KPP-Pos is an excellent way to identify a subset of network members to intervene upon in the absence of other covariate information, in the sense that the KPP-Pos set optimally “connects” the network.

Next, we extend the KPP-Pos method (Eq 1), to identify the Strategic Player set or SP set as the set of the members of T to whom we should provide the intervention. We must identify the subset T of the network who are the targets to whom we want *maximum* diffusion, and the subset A of the network to whom we seek to *minimize* diffusion. We now seek to maximize:

$$D = \theta \frac{\sum_j \frac{1}{d_{Tj}}}{t} - (1-\theta) \frac{\sum_j \frac{1}{d_{Aj}}}{a} \tag{2}$$

Where t is the number in the target group, a is the number of individuals in the avoid group, and θ is a user-supplied parameter quantifying the tradeoff between maximizing reachability to the target population, and minimizing reachability to the avoidance population. When $\theta = 1$, reaching all the targets is the only priority, and the avoid group does not affect the selection of players. At the other extreme, setting θ equal to zero would result in the SP algorithm selecting from the target population so as to maximize the distance from the avoid group with no regard to distances to other population members.

The path definition on which the distance metric is calculated is flexible and may be defined to refer to distance across directed or undirected ties. The choice of which path definition to use will depend on the situation at hand. For example, in the case in which the researchers believe influence will only spread through reciprocated relationships (such as close friendships), the path definition should be calculated over the undirected network of reciprocated ties. However, if the intervention will spread from