A Comparison of Network Sampling Designs for a Hidden Population of Drug Users: Random Walk vs. Respondent-Driven Sampling

David C. Bell[a], Elizabeth B. Erbaugh[b], Tabitha Serrano[c], Cheryl A. Dayton-Shotts[d], Isaac D. Montoya
a Department of Sociology, Indiana University-Purdue University Indianapolis, 425 University Blvd, Indianapolis, IN 46202, USA
b Sociology and Anthropology, Stockton University, School of Social and Behavioral Sciences, 101 Vera King Farris Drive, Galloway, NJ 08205, USA
c Shell Oil Company, Houston, TX, USA
d University of Texas M.D. Anderson Cancer Center, USA

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ABSTRACT

Both random walk and respondent-driven sampling (RDS) exploit social networks and may reduce biases introduced by earlier methods for sampling from hidden populations. Although RDS has become much more widely used by social researchers than random walk (RW), there has been little discussion of the tradeoffs in choosing RDS over RW. This paper compares experiences of implementing RW and RDS to recruit drug users to a network-based study in Houston, Texas. Both recruitment methods were implemented over comparable periods of time, with the same population, by the same research staff. RDS methods recruited more participants with less strain on staff. However, participants recruited through RW were more forthcoming than RDS participants in helping to recruit members of their social networks. Findings indicate that, dependent upon study goals, researchers' choice of design may influence participant recruitment, participant commitment, and impact on staff, factors that may in turn affect overall study success.

Key words: network sampling, hidden populations, random walk, respondent-driven sampling, social networks

1. INTRODUCTION

Sampling designs such as outreach recruitment and targeted sampling have been used to recruit samples from hard-to-reach and hidden populations (Spreen, 1992). However, while these methods accomplish the goal of generating data, the external validity of the samples they generate may be limited by various biases. Newer, network-based sampling methods also allow the researcher to sample from a hidden population (Heckathorn, 1997, Klovdahl, 1985, Klovdahl, 1989, Klovdahl, et al., 1994, Spreen, 1992). Two designs, the random walk (Klovdahl, 1989, Klovdahl, 1990, Liebow, et al., 1995) and respondent-driven sampling (Broadhead, et al., 1995, Heckathorn, 1997), take advantage of social networks within a population and aim to avoid some biases of earlier sampling methods. Appropriate analysis may allow the researcher to minimize biases associated with a given design in order to improve the estimate of population parameters (Gile and Handcock, 2011, Heckathorn, 2007, Thompson, 2011).

Random walk (RW) sampling has been implemented in a relatively small number of studies. In contrast, the use of respondent-driven sampling (RDS) by social scientists has increased substantially in recent years (Gile and Handcock, 2010, Johnston and Sabin, 2010). The disparity in use of these sampling methods warrants comparative assessment of the two designs in practice. At present, little is known about the actual methods employed by members of a hidden population in the RDS recruiting process (Gile and Handcock, 2010). Short of having researchers accompany a sample of such recruiters in the field, the main means of studying differences between RW and RDS is

to compare the responses and participation of those new members of the population who are recruited.

This paper compares experiences of using random walk and respondent-driven sampling to recruit participants from a high poverty, high drug use population. Prior studies have compared RDS to targeted sampling (Robinson, et al., 2006, Rudolph, et al., 2011) and to snowball sampling (Kendall, et al., 2008); the current study is so far as we can determine the first to compare RW and RDS in side-by-side implementation. We identify tradeoffs in participant recruitment, participant commitment and staff impact between RW and RDS designs, factors that may in turn affect the representativeness of the sample, the quality of the data collected, and the overall success of the study.

1.1 Network-based sampling designs

1.1.1 Random walk sampling

The concept of interconnected personal and social networks is inherent to the random walk design (Klovdahl, 1989, Klovdahl, 1990, Liebow, et al., 1995). The random walk method was initiated as a link-tracing design in order to study structure in urban networks (Spreen 1992), and was originally applied in neighborhood studies where persons were well and publicly known to one another (Sudman and Kalton, 1986, Sudman, et al., 1988, van Meter, 1990). Nevertheless, some hidden populations, too, can be seen as collections of linked persons. A random walk can be conceptualized as a series of consecutive linkages from one person to another, and then to another (Sudman and Kalton, 1986, Sudman, et al., 1988, van Meter, 1990). Each "step" in a random walk

involves choosing a random member of the current participant's social network. Early motivations for using random walk with hidden populations included the ability to penetrate more deeply into the population from the initial sample, thereby achieving a more representative sample (Thompson, 2011).

One advantage of a random walk is that its procedures minimize *frame biases (*over- or under-representation of units or subgroups in creating the "list" of all elements in the target population). Random walks generate localized lists by soliciting the names of the peers and acquaintances of people from the target community (Klovdahl, 1985, McGrady, et al., 1995). Staff recruiters generally use targeted sampling to select persons knowledgeable about the population as "seeds," each of whom is seen as connected directly and indirectly to other members of the population. Recruiters then randomly select names from lists of persons known by the "seed" individuals as targets for recruitment. As the random walk moves into the population, each person in the target population who is known by someone else in the population has a statistically non-zero chance of eventually being selected. Frame bias will increase if the population contains multiple networks that are not connected to one another. If all members of the population are connected (in what network researchers call a "connected component"), then all members are potentially reachable through one seed. Loners with no connections and members who belong to small components are liable to be excluded from the sampling frame. If a population contains multiple connected components, this bias can be reduced if the investigator selects multiple starting points ("seeds") in the different networks (Klovdahl, 1989, Klovdahl, 1990, McGrady, et al., 1995). Selecting

multiple seeds aims to minimize sampling bias by finding various pathways into the social network. Random walks, if properly implemented, can thus yield a sample that is highly representative of the target population.

Another advantage of the random walk method is that *participation biases* (those resulting from individuals' unwillingness to participate, inability to participate, or incomplete participation) can be minimized. Recruitment success depends in part on the trust of the potential study participant in the recruiter. Such trust can be increased when the recruiter is introduced to the potential participant by a known member of the network, namely the informant whose list was used to select the potential participant (Sterk-Elifson, 1993, Sudman and Bradburn, 1982). Random walks thus have a built-in tendency to engender trust in participants.

However, a random walk can be expensive in terms of staff time and investment. *Implementation bias* (bias that may occur when researchers either avoid recruiting in certain areas or accept ineligible participants into a study) and/or *response bias* (the result of unusually high or low levels of openness, optimism, cooperation, attention or mood among participants) can be severe unless staff are able to cultivate participant trust and commitment (Sudman & Bradburn, 1982). Members of hidden populations, especially those whose members are engaged in illegal activities, are rarely eager to divulge personal information about themselves and their social networks to strangers (Liebow, et al., 1995). Random walks may induce recruiters to be closely involved in the lives of their subjects because they must personally recruit each one, requiring extensive investment of time and resources (Klovdahl, 1990, McGrady, et al., 1995).

1.1.2 Respondent-driven sampling

In respondent-driven sampling, the members of a hidden population themselves draw upon their own personal networks to recruit other members of the population (Heckathorn, 1997). Staff recruiters select seeds; seeds then become peer recruiters. Research staff tutor peer recruiters on study recruitment goals, give them a limited number of recruitment coupons, and usually offer them incentives for recruiting additional members of the target population. The peer recruiters then distribute recruitment coupons to individuals in their personal networks who fit the study criteria. Eligible study participants are interviewed and then in turn are given their own coupons to recruit the next wave of participants.

Respondent-driven sampling shares certain susceptibilities to frame bias with targeted sampling, because recruitment begins with easily accessible members of the hidden population. However, RDS has two advantages over targeted sampling. First, RDS may improve recruitment efficiency. Since each staff recruiter can give coupons to many peer recruiters, the sample can be generated quickly and relatively cheaply (Broadhead, et al., 1995, Heckathorn, 1997). Second, peer recruiters generally will have greater access to the hidden population and its subpopulations than will a staff recruiter. If those recruited by coupon are given coupons of their own, the sample will eventually move multiple steps into the hidden population (Heckathorn, 1997, Salganik and Heckathorn, 2004). The initial contacts do not have to be chosen at random, because it is assumed that the sample will expand toward representativeness when each new

participant distributes recruitment coupons among his or her peers (Gile and Handcock, 2010).

One disadvantage of RDS is that recruitment is largely outside the control of the researcher (Gile and Handcock, 2011). As a result, implementation biases may be introduced that are not known by the researcher. Participation biases which result from failure to give a coupon to an eligible person or by failure of an eligible person to redeem a coupon cannot be known. Peer recruiters may have varying levels of commitment to research goals. Respondents may disproportionately recruit individuals with whom they have closer ties and/or with whom they are likely to discuss important matters (Wejnert, 2009). Conversely, participation bias may be lowered because peers may be able to recruit participants with greater facility than can field staff (Heckathorn, 1997).

2. METHOD

Two network-based sampling designs, random walk and respondent-driven sampling, were used in the Risk Networks Study (RNS), an investigation of the risk behaviors of a community (non-treatment) sample of drug users and nonusers and their sexual and drug injection partners in 1997-98 (Bell, et al., 2005). The sample for the RNS was drawn from a cluster of census tracts in Houston identified as having high levels of HIV transmission risk behaviors. From this cluster, census tracts with high levels of drug crime as well as large numbers of drug treatment clients were selected. A storefront field research center was opened in an easily accessible location within the

recruitment area. Ethnographic mapping was done to identify active drug user "hot spots" (Broadhead and Fox, 1990, Carlson, et al., 1994, Elwood, et al., 1995, Richard, et al., 1996). During this time, field recruiters established a community presence and built rapport with area residents prior to attempting to recruit informants or participants.

The research team had previously employed targeted sampling as one of 23 participating sites in the NIDA Cooperative Agreement project (Rhodes, et al., 1998, Stark, et al., 1996) and were aware of the bias in this method toward "street" drug users. The RNS project therefore aimed to recruit a more representative sample of participants and members of their risk networks from the hidden population of Houston drug users. Within this recruitment area, targeted sampling methods were used to choose African American, Anglo, and Hispanic contact informants who were both straight and gay/lesbian/bisexual, providing access to many different parts of the social space of Houston central city drug users.

The targets for recruitment were "index participants." The focus of the research was on each index participant's HIV "risk network," those others whom the index participant might infect, or be infected by, with HIV. Thus, after an eligible index participant was recruited and interviewed, we attempted to identify and recruit his/her personal network of "risk partners"—sex partners and drug injection partners. Matched nonusing index participants were also recruited for purposes of comparison, but these participants were recruited by a different method not further discussed here.

"Gatekeepers," some of whom had been participants in previous research, were a great help in the initial recruitment process. Gatekeepers were persons who knew the

field staff and were members of, and knowledgeable about, the local community of drug users. Because of their personal connections, they served as references for the field staff, easing potential participants' fears and concerns. In cases where an informant was unable to help locate a nominated participant, a gatekeeper would sometimes know the person by name and help to locate them.

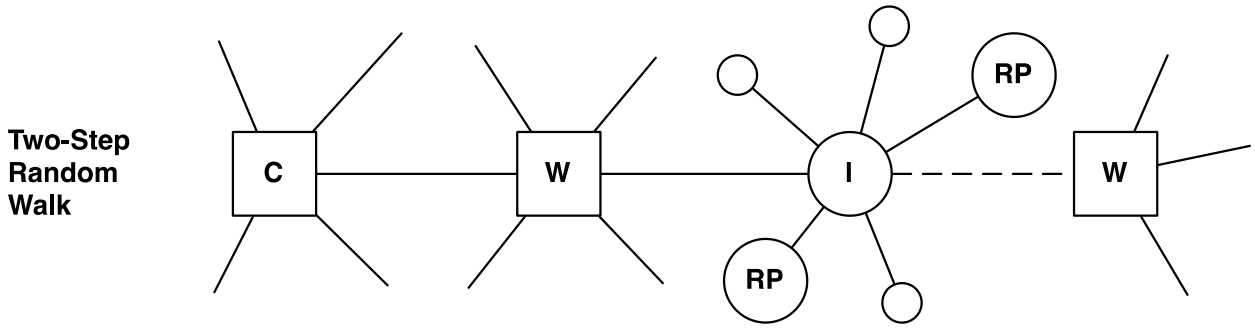
To be eligible to participate, respondents were required to be at least 18 years of age and able to converse in English or Spanish. Drug-using index participants were required: (1) to self-report using cocaine, heroin, or methamphetamine at least three times a week, and (2) to test positive for cocaine or heroin on a urine drug screen or have current injection track marks. It is important to note that the primary purpose of the RNS was not to collect a representative sample of drug users, but rather to collect a representative sample of drug user risk networks. Therefore we did not collect a strictly traditional RW or RDS sample of individuals. Our modifications and their implications are addressed below. Our comparison of the two sampling methods will focus on the recruitment of a total of 126 drug-using index participants across both RW and RDS methods. At the time the RNS project was designed, random walk seemed to be the best published design for use in representative sampling of a hidden population. A two-step RW method was used to recruit participants for the first nine months of the study.

2.1 Two-step random walk

A standard random walk (Klovdahl, 1989) involves asking an informant to provide a list of potentially eligible study participants, one or more of whom is

recruited and interviewed. Then one of these participants is asked to provide a list of additional eligible persons, and so on. In our study, we implemented a two-step random walk between index participants in the networks we studied so as to avoid creating artificial network overlap. The process began with a set of contact informants ("seeds"). Based on their experience in the field, staff recruiters had judged each contact informant to have reliable knowledge of the local drug scene and recruited them from the targeted area. After giving informed consent, each contact informant was asked to name six individuals whom she or he believed to be chronic users as defined above (in practice, contact informants named a range of three to eleven alleged drug users each). One of the persons on the list was randomly selected, located and recruited as a "random walk informant." If this randomly selected individual was found not to be eligible or could not be recruited, we randomly selected a second, or, if needed, a third individual from the list. Only one informant was selected from any list, and no more than three recruitment attempts were made per list.

Figure 1. Two-step Random Walk Design



Note. A "contact person" (C) named known or suspected drug users; one was randomly selected as a "random walk informant" (W). The random walk informant named known or suspected drug users; one was randomly selected as an "index participant" (I). The index participant named network members (attached circles); risk partners (drug

injection and sex partners) within the index participant's social network were recruited and interviewed (large circles: RP).

The RW informant participated in this same procedure, naming persons he or she believed to be chronic drug users, of whom one was randomly selected to become an *index participant* whose network would be studied. Contact informants and RW informants were paid for their brief interviews and were each paid to help recruit an eligible participant they had named. Figure 1 depicts the two-step RW recruitment method used during the first nine months of data collection. For reasons described below, the recruitment approach was changed to the newly published RDS method at the end of the ninth month of data collection.

2.2 Two-step respondent-driven sampling

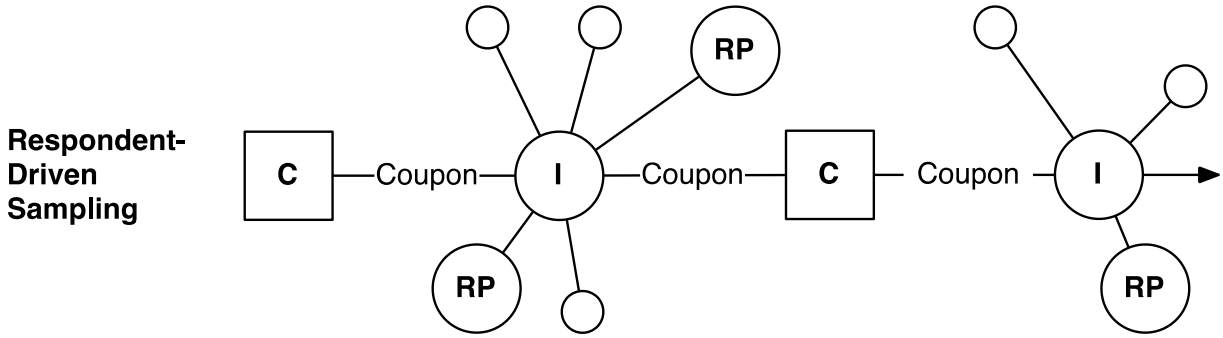
In the respondent-driven sampling method, the field staff recruited the initial contact informants as described above. After giving informed consent, contact informants completed a brief interview, were trained on the recruitment goals of the study, and were given three uniquely coded coupons with which to recruit index participants. Each potential index participant referred with a coupon was screened for eligibility. If eligible, she or he became an index participant and was given a full-length interview. If the referral was eligible and participated in the study, the referring informant was compensated.

Because of the project's focus on recruiting independent personal networks, the study used a modified form of RDS. In particular, if an index participant had helped to

recruit at least 60% of his or her named risk network, he or she was contacted again and given three coupons with which to recruit additional persons into the study who were *not* in his or her risk network (that is, the index participant was asked to recruit up to three contact informants for a subsequent RDS wave). When our index participants did not help to recruit their own sex and drug user partners, we did not subsequently approach them to recruit contact informants. A lack of initial cooperation in the network study was taken to indicate a low probability of success in additional recruitment, so study resources were instead directed to more high-yield activities. Of course, we cannot ensure that the results we report below are better rather than worse due to this modification. We do recognize that RDS methods have advanced substantially since the RNS was implemented and that this aspect of our sampling approach does not represent standard RDS practice today.

Persons recruited by index participants became contact informants. These new contact informants were trained and given coupons to recruit additional index participants. The cycle was repeated until all leads were exhausted. Figure 2 depicts the two-step RDS method. This method was used during the second nine months of recruitment. Field center and field staff were the same as for the previous RW phase.

Figure 2. Two-Step Respondent-Driven Sampling Design



Note. A "contact person" (C) was given three coupons with which to recruit an "index participant" (I). The index participant named network members (attached circles); risk partners (drug injection and sex partners) were recruited and interviewed (large circles: RP). If the index participant recruited at least 60% of his/her risk partners, he/she was given three coupons with which to recruit contact persons. Recruitment procedures continued from there.

3. RESULTS

Here we evaluate and compare the outcomes of random walk and respondent-driven sampling in our study with respect to frame bias, implementation bias, participation bias, and response quality.

3.1 Frame bias

Assessing relative levels of frame bias poses a particular challenge because there is by definition no "gold standard" measure of a hidden population. However, in this case we can make some qualitative judgments by using the previously collected targeted sample as a reference against which to assess the representativeness of the two network samples. Essentially, the RNS sample was designed to reduce biases present in the street-recruited targeted sample from the Houston site of the NIDA Cooperative Agreement ("Coop") study, so we were seeking *less* bias in the network samples. Frame

bias is thus estimated by comparing the random walk and RDS index participants with each other and with the street-recruited sample of drug users drawn from the same geographic area for the Coop study about five years earlier (Bell, et al., 1997, Montoya, et al., 1999, Williams, et al., 1996, Williams, et al., 1995). Note that gender, race/ethnicity, and sexual orientation could not be used meaningfully for comparison because they were used in both studies to create recruitment quotas for seeds.

Table 1 provides a description of the RW and RDS samples in RNS as well as the street-recruited sample collected via targeted sampling in the Coop study. Overall, the combined drug-using RW and RDS sample was about two-thirds male, half African American, a quarter Hispanic and a quarter Anglo, with a quarter being gay, lesbian or bisexual. The median age was 39. Most of the sample had less than a high school education and about half were unemployed. All of the index participants were drug users, and over a third were injection drug users; cocaine was the predominant illegal drug.

Table 1. Sample Characteristics and Frame Bias

	Random walk [1997] N (%)	Respondent-driven sampling [1997-98] N (%)	RW vs. RDS p	Cooperative Agreement [1992-94] N (%)	RW vs. Coop p	RDS vs. Coop p
N	31 (100)	95 (100)		1086 (100)		
Gender						
Male	19 (61)	68 (72)	.282	743 (68)	.401	.524
Female	12 (39)	27 (28)		343 (32)		
Race						
African American	16 (52)	53 (56)	.482	742 (68)	**.009**	**.022**
Anglo	10 (32)	21 (22)		143 (13)		
Hispanic	5 (16)	21 (22)		201 (19)		
Age						
30 and under	10 (32)	12 (13)	**.014**	230 (21)	**.012**	**.021**
31-40	6 (19)	40 (42)		503 (46)		
Over 40	15 (48)	43 (45)		353 (33)		
Sexual Orientation						
Straight	22 (71)	73 (77)	.510	975 (90)	**.001**	**.000**
Gay, lesbian or bisexual	9 (29)	22 (23)		111 (10)		
Marital Status						
Never married	17 (55)	34 (36)	.171	554 (51)	.627	**.004**
Married or living as married	3 (10)	14 (15)		175 (16)		
Formerly married	11 (35)	47 (49)		357 (33)		
Education Level						
Less than high school	21 (68)	48 (51)	.223	465 (43)	**.022**	.212
High school graduate	6 (19)	24 (25)		366 (34)		
More than high school	4 (13)	23 (24)		254 (23)		
Employment (last Six Months)						
Unemployed	18 (58)	41 (43)	**.020**	741 (68)	.482	**.000**
Part time	11 (35)	24 (25)		297 (27)		
Full time	2 (7)	30 (32)		48 (4)		
Drug Use						
Drug injection	13 (42)	33 (35)	.470	265 (24)	**.026**	**.026**
Alcohol	28 (90)	85 (90)	.893	918 (85)	.377	.197
Marijuana	21 (68)	57 (60)	.441	523 (48)	**.031**	**.027**
Crack cocaine	27 (87)	84 (88)	.843	742 (68)	**.026**	**.000**
Powder cocaine	10 (32)	38 (41)	.394	569 (52)	**.027**	**.033**

Heroin	7 (23)	21 (22)	.956	263 (24)	.834	.644
Heroin + cocaine (speedball)	3 (10)	7 (7)	.680	122 (11)	.786	.247
Methamphetamine	2 (7)	13 (14)	.266	13 (1)	**.012**	**.000**

As shown in Table 1, the random walk and respondent-driven samples did not differ significantly from one another on most sample characteristics (p-values are from chi-square tests). Compared to the street-recruited Coop sample, RDS recruited more older persons, while RW recruited both more older (over 40) and more younger (30 and younger) drug users. The RDS sample contained more formerly married persons and more persons employed full time. The RW sample included more participants with less than a high school education. Both RW and RDS samples included more injectors and more marijuana, crack cocaine, and methamphetamine users, and fewer powder cocaine users. Some of the observed differences in drug use probably represent secular change rather than frame bias, as the drug economy appears to have shifted from powder cocaine to crack cocaine and methamphetamine over the time period between the two studies. The RW and RDS samples did not differ from each other on drug use. Thus, if we assume that the Coop sample represents a relatively young, unemployed population, both RW and RDS tap into older persons who spend less of their time on the street. RDS may oversample employed persons, while RW may gain better access to young, less-educated persons.

3.2 Implementation bias

We use index participant recruitment rates as a measure of implementation success and address staff morale qualitatively as a major component in the ability and willingness of research staff to faithfully implement the intended study design. The initial identification of potential contact informants for both RW and RDS was not difficult because of the field staff's previous experiences in targeted sampling and their familiarity with the local neighborhoods through the Coop study and other neighborhood studies of drug users. Many potential recruits either had participated in previous studies or were friends or acquaintances of those who had.

3.2.1 Random Walk

Our previous experience with targeted sampling suggested that the random walk method would be a simple extension of previous field recruitment procedures. However, creating a protocol for the RW design on paper was more straightforward than implementing it in the field. At the start of the RNS, the field staff had been interviewing drug users in the area for over ten years. We had successfully overcome participants' suspicions that we might be associated with law enforcement and persuaded them to come in for interviews about their illegal (drug use) and socially disapproved (sexual) activities. However, we had never before asked for the names of members of their social networks.

Making a list of alleged drug users with a contact or RW informant was technically a simple task, but asking someone to offer up the names of other drug users

could generate concern that those named might become known to authorities. Contact and RW informants sometimes protected the identities of friends, and instead named people who they knew to be drug users, but did not know well personally. In these cases, the informants were less able to help locate and recruit those they named. Properly implementing the RW sampling procedures thus required that staff build rapport with potential informants and participants prior to recruitment attempts. In spite of the prior experience of our field staff, the earliest random walks repeatedly failed to produce the needed eligible participants.

The difficulties in meeting RNS recruitment goals within the allotted timeframe negatively affected field staff morale. It was frustrating for field recruiters to recruit a contact informant, create the list, randomly select a name, solicit additional identifying information, make multiple attempts to locate the person in the neighborhood, and then fail to recruit them to the study. It was doubly frustrating to repeat this process with a second name from the list, only to fail once again. Staff attempts with three of the first four contact informants failed to generate a single random walk informant. In response, the staff developed a strategy of first making appointments with potential contact informants to assess their reliability and commitment. Subsequent to this change, almost every contact informant successfully generated a RW informant on the first attempt. Nevertheless, locating and recruiting informants continued to be a time-consuming and often frustrating process.

The pressures on field recruiters threatened to compromise randomization. Informants were given a financial incentive ($10) for each successfully recruited and

interviewed person. But when the contact informant agreed to participate, there was no guarantee that they would bring in the person randomly selected from their list. Drug using participants often proved resourceful in creating schemes to earn money. Informants thus occasionally tried to pass off a person to the field staff as the one selected from their list. So recruiters adopted procedures for collecting identifying information prior to locating named persons and thoroughly checking the identification of anyone presented as a prospective interviewee from the list. Even in light of previous research successes, staff morale required ongoing effort to maintain. It was this issue of staff morale and associated threats to implementation that led senior study staff to seek additional recruitment techniques, and ultimately to opt for the respondent-driven sampling method (Heckathorn, 1997).

As shown in Table 2, during the first nine months of recruitment for the RNS using random walk, 38 contact informants provided lists of names of suspected drug users as specified by the recruitment criteria. Six of the 38 lists generated by the contact informants yielded no RW informants after three attempts each (18 failures). The remaining 32 contact informants helped to recruit 32 RW informants out of the 36 names selected off of their lists (4 failures). This yielded a 59% (32/[18 + 4 + 32]) recruitment rate for the first leg of the random walk.

Table 2. Implementation and Participation Bias[a]

	Random walk	Respondent-driven sampling	
Implementation success: Recruitment of index participants			
Wave 1 Contact informants (seeds)	38	50	
Random walk informants (RW only)	32		
Index participants	31		53
Wave 2 Contact informants		18	
Index participants			23
Wave 3 Contact informants		15	
Index participants			11
Wave 4 Contact informants		6	
Index participants			8
Total contact informants	38	89	
Total index participants	31		95
Total coupons distributed (RDS only)			345
Participant commitment: Risk network named and recruited			
For one-way ANOVA, cell entries are Mean (Standard Deviation).			
Avg Risk Partners Named	4.19 (2.71)	4.66 (3.00)	F(1,124)=0.60 (ns)
Avg Risk Partners Recruited	1.16 (1.37)	0.61 (1.08)	F(1,124)=5.27 (p<.05)
Risk Recruitment Rate Index	28%	13%	F(1,121)=8.98 (p<.01)
Proportion of sample who recruited a risk partner	55%	38%	$Chi^2(1)=2.75$ (p<.10)
Proportion of sample who recruited a "complete"[b] network	29%	12%	$Chi^2(1)=5.33$ (p<.05)

a. Each recruitment method was implemented for nine months, with the same two staff recruiter/interviewers and a half-time field supervisor.

b. "Complete" refers to the number of index participants who recruited at least 60% of their risk networks.

The RW informants also provided the recruiters with lists of suspected drug users. The lists provided by two of the RW informants yielded no index participants, despite three attempts each. The remaining 30 RW informants' lists generated 33 candidates, of whom 31 were successfully recruited and interviewed. This yielded a 79% (31/[6 + 2 + 31]) recruitment success rate for the second leg of the random walk.

3.2.2 Respondent-driven sampling

Implementing the respondent-driven sampling method improved staff morale substantially. Under this method, the field staff were not required to take such an active role in the recruitment of participants beyond the initial recruitment of contact informants. Distributing coupons to contact informants and study participants and asking them to recruit others was more efficient and less stressful to the field staff than recruiting randomly selected persons from a list of names. Recruiters subjectively reported being both less strained and more productive under the RDS method. Furthermore, informants were relieved of the pressure to divulge personal information about potential recruits without their permission. Peer recruiters could recruit whomever they wanted at their own pace. They were not limited, as in the RW method, to recruiting a specific person chosen by the field staff.

Considering each step in the process as a recruitment "wave," the results of the RDS method are summarized in Table 2. In the first wave of respondent-driven sampling, 50 contact informants were recruited as seeds and given 150 coupons. From these initial seeds, 53 index participants were recruited. Thirteen of the initial index

participants (those who had each recruited at least 60% of their risk networks) were given 39 coupons to recruit contact informants, and 18 contact informants were recruited for the second wave of RDS recruitment, leading to 23 additional index participants. This process continued through two more waves, with 28% of coupons producing eligible index participants over four waves of recruitment. As shown in Table 2, 50 initial wave RDS contact informants plus 39 informants in subsequent waves produced 95 index participants via 345 coupons distributed over the nine months of RDS—over three times as many as the 31 index participants recruited during the previous nine months under random walk.

3.3 Participation bias

Minimizing participation bias requires, in part, maximizing participants' willingness to participate fully in the study, especially when the sampling design depends on participants' active efforts to aid recruitment. Willing participation can be indexed both by respondents' willingness to be interviewed and by their willingness to provide more active support to the study by referring network members. Each RNS participant was asked to name their 30-day sex partners, drug use partners, and "close" partners. Of these personal network members, sex partners and drug injection partners were considered "risk" partners because of the potential for HIV transmission. Since these were persons known to the participant and not to the staff recruiters, participant cooperation was needed for successful recruitment. A measure of participant

commitment may be found in the number and proportion of risk partners named and successfully recruited for interviews.

As discussed above, under random walk, the success of the design depended upon establishing familiarity and trust among field staff, informants and potential study participants. As a result the staff became quite conscious of the group dynamics of each informant's social network. The random walks that did prove successful were those selected from the lists of informants with whom the field staff had solid relationships. With familiarity, a potential participant was much more likely to respond favorably to the prospect of participating in the study.

When names were randomly selected for recruitment from a contact informant's names list, cooperation of the informant was generally needed to locate and recruit the person randomly chosen from the names list, because informants often named drug users who were not known to the field recruiter. Selecting a name of a potential recruit randomly from a list demanded that the contact informant provide an introduction to a specific individual on a schedule compatible with recruiter goals. Attempts to recruit study participants from these introductions were often difficult because these introductions were often short interactions that did not allow the recruiter to establish trust and rapport. The RW method thus introduced an arbitrariness into the process, in that informants were often asked to help recruit persons they knew mainly by reputation. This procedure sometimes placed informants in unfamiliar and uncomfortable roles with respect to the nominated persons. In contrast, under RDS, participants who came to the field center with a coupon were known to the informant,

but had had no previous contact with the interviewer who would conduct the interview, and therefore rapport with staff had to be developed from scratch.

Table 2 displays some of the recruitment outcomes that have implications for participation bias in the two samples. As a sign of the level of participant commitment (and thus a negative indicator of participation bias), we examined willingness to name and to recruit risk partners. RW and RDS index participants *named* approximately the same number of risk partners, but RW index participants were significantly more successful in *recruiting* these risk partners into the study. RW index participants were successful in recruiting an average of 1.16 out of their 4.19 named risk partners, a success rate of 28%. RDS index participants, in contrast, were successful in recruiting an average of 0.61 of their 4.66 risk partners, a significantly lower success rate of 13%. As shown in the table, 55% of RW index participants recruited a risk partner compared to 38% of RDS index participants (a marginally significant difference), and 29% recruited at least 60% of their risk partners compared to only 12% of RDS index participants (a significant difference).

3.4 Response quality

In general, once participants are successfully recruited into a study, response bias may be introduced "because of the mentality or predispositions of respondents" (Alreck, 2003, p. 101) and thus may reduce data quality. The quality of the data in our study depended on participants' truthfulness about their experiences, particularly with risk partners, where truthfulness may well have depended on the participant's level of

trust toward the interviewer. Our interviews substantively focused on drug use and sexual behaviors as primary routes of HIV transmission; there was a significant risk that participants' social desirability concerns might reduce their willingness to report fully on these matters. Building rapport with the respondent and employing procedures that sanction less desirable responses may reduce this form of bias (Singleton and Straits, 2010). Our first measure of response quality assessed the willingness of study participants to acknowledge activities with negative social desirability. This willingness was estimated by reported number of same-gender sex partners, number of sex partners overall, number of sex partners whose names were unknown, and frequency of drug use and drug injection, along with the self-reported level of sexual self disclosure using a 10-item version of Catania's Sexual Self-Disclosure Scale (Catania, 1995).

Second, we compare participant reports with partner reports of joint risk behaviors (Bell, et al., 2000). In network studies in which participants are interviewed along with partners, responses to questions about joint behaviors can be examined for concordance. Participants were asked how often they had had sex with each sex partner or injected drugs with each drug use partner in the previous 30 days and in the previous six months. They were also asked how often they had seen or talked to each other in the previous 30 days. There are limitations to the concordance estimate because dyads were not usually interviewed on the same day, so the time periods did not fully overlap (Bell, et al., 2000). For each measure we computed the absolute difference in response for participant and partner for 89 dyads in which both members were interviewed and tested with one-way ANOVA.

As shown in Table 3, we found few differences in response bias between the RW and RDS sampling designs. Of the seven measures related to social desirability, two were significantly different: RDS index participants were more likely to acknowledge having had a same-gender sex partner during their lifetimes, and RDS participants reported higher frequency of drug use in the past 30 days. There were no significant differences in either number of sex partners named or in number of sex partners acknowledged but not named because their names were not known, and no difference on the sexual self disclosure scale. In terms of drug use, there was no significant difference in acknowledging drug injection either over one's lifetime or in the previous 30 days.

Table 3. Response Quality[a]

	Random walk	Respondent-driven sampling	
Reported Behaviors with Negative Social Desirability			
Same-gender partner, lifetime	**58%**	**77%**	$Chi^2(1)=4.11$ **(p<.05)**
Number of sex partners, 30 days	2.42 (3.37)	4.84 (12.04)	F(1,124)=1.22 (ns)
Number of sex partners whose names are unknown, 30 days	1.10 (2.84)	1.63 (6.57)	F(1,124)=0.19 (ns)
Sexual self disclosure	1.93 (0.66)	1.94 (0.63)	F(1,108)=0.01 (ns)
Drug injection, lifetime	65%	60%	$Chi^2(1)=0.20$ (ns)
Drug injection, last 30 days	42%	35%	$Chi^2(1)=0.52$ (ns)
Drug use frequency, last 30 days	**4.42 (2.05)**	**5.32 (1.70)**	F(1,124)=5.88 **(p<.05)**
Partner concordance			
Sex frequency, last 30 days	2.44 (6.87)	4.48 (8.45)	F(1,85)=1.15 (ns)
Sex frequency, last 6 months	0.84 (1.25)	1.08 (1.94)	F(1,85)=0.33 (ns)
Injection frequency, last 30 days	0.76 (0.93)	0.92 (1.48)	F(1,83)=0.24 (ns)
Injection frequency, last 6 months	0.88 (0.97)	0.97 (1.27)	F(1,85)=0.10 (ns)
Contact frequency, last 30 days	7.06 (9.86)	6.21 (8.28)	F(1,76)=0.12 (ns)

a. For one-way ANOVA, cell entries are Mean (Standard deviation).

When we examined concordance in reports of joint risk behaviors between index participants and their partners, RW and RDS index participants did not differ on any of our five measures (Table 3). Concordance of reports between index participants and their partners did not differ between RW and RDS on frequency of sex or drug injection,

either in the previous 30 days or the previous six months, or in terms of contact ("How many days did you see or talk to [your partner] in the past 30 days?").

4. DISCUSSION

This paper compares link-tracing sampling methods for a study designed with the goal of recruiting a representative sample of personal networks around index participants from within a hidden population of drug users in Houston. Although the study did not set out prospectively to compare two sampling designs, it first used random walk and later shifted to respondent driven sampling in an attempt to improve recruitment outcomes. We have evaluated each of the two sampling methods in terms of frame, implementation and participation biases as well as response quality. Comparing the two designs in terms of these outcomes highlights key tradeoffs for researchers designing studies that incorporate network-based recruitment. Ethical considerations in network studies are also addressed below.

In terms of frame bias, the main goal of the RNS was to measure within-network and between-variable relationships, and not to estimate univariate population parameters. Implementation of a given method must align with the specific goals and target population of each research project. Our primary focus was not on making univariate inferences of population values such as behavior rates, but rather on discovering patterns of relationships within networks. Further, because our study was designed to test theory, we were more concerned with internal than external validity (Campbell and Stanley, 1963). A purely representative sample was thus of less concern

than a sample that adequately reflected variations within the population. In this respect our approach somewhat resembled much of the field of psychology, whose rats, mice, and college sophomores are not representative of the U.S. or world population, but still provide important information.

Given that the study dealt with a hidden population, we cannot definitively estimate representativeness. However, in comparison to a targeted sample collected previously in the same area, both the RW and the RDS samples appeared to avoid or reduce some of the recognized frame biases of the earlier sample. In general, the RW and respondent-driven samples tended to differ from the street-recruited sample in predictable ways by including more participants who did not live a street-oriented lifestyle. Both of the network sampling methods reached more participants over forty years of age than did the street-based method. Random walk recruited a less educated sample, while RDS recruited a sample that was better employed and more likely to be formerly married. Better-employed persons may be more trusting and thus more reachable by RDS. These differences reflect the tendency of targeted sampling to reach persons likely to spend more time on the street: the young and the unemployed. They also provide circumstantial evidence that both network-based sampling methods reached more deeply into the drug-using community than did street-based recruitment.

In comparing the two network based methods to each other, the RDS approach recruited a better employed sample and more participants between thirty and forty years of age than did the random walk approach. Although RDS does not include the randomization procedures associated with random walk, its peer recruitment

procedures may contribute to generation of a representative sample (Heckathorn, 2007, Salganik and Heckathorn, 2004). In the current study, peer recruiters were able to reach drug users at locations and times that were not easily accessible to the field staff.

With respect to implementation bias, although both RW and RDS methods may enable recruitment of more representative samples than non-network methods, their costs and levels of efficiency may differ significantly from one another. In our study, RW proved to be a relatively inefficient and costly means of recruiting the target sample, generating less than a third of the index participants than the RDS method did over a comparable timeframe and at the same staffing level. In addition to the low level of productivity in recruitment, and partly as a result of it, the RW method generated a high level of staff frustration and lowered staff morale, threatening the success of design implementation.

This is not to suggest that the random walk is not feasible for recruiting participants from populations that are more visible, more receptive, or located in more accessible and delimited locales such as office buildings or schools (Liebow, et al., 1995, McGrady, et al., 1995). Furthermore, the RW method may be quite practical for tracing the movement of an infectious disease (Klovdahl, 1985), particularly with a population that is hidden but not generally secretive. Ultimately, we did not find RW to be a feasible method for locating drug users, partly because many potential contacts did not have fixed addresses where regular interaction could occur. The schedules on which informants interacted with target participants without fixed addresses could be

haphazard, making it difficult to match recruiter and informant time with targets' availability.

In our comparison, RDS proved more efficient than RW sampling in recruiting members of the target population of out-of-treatment drug users, and more conducive to maintaining the staff morale necessary for successful study implementation. Shifting responsibility for locating and directly recruiting index participants from research staff to contact informants through the use of coupons considerably reduced staff recruitment time and effort, freeing more time to conduct interviews. The coupon dispersal method attracted more participants, likely because of peer motivator effects and the further incentive of quick cash payment for recruitment (Heckathorn, 1997, Salganik and Heckathorn, 2004). The sample was generated more rapidly using RDS than was the case with random walk, although RDS does not always succeed in rapid recruitment (Bryant, 2014).

Regarding participation bias, although the RW method was frustrating to field staff, it generated greater commitment to the research project in terms of risk partners recruited per index participant. In most cases, the staff member who recruited an index participant was also the one to conduct the network interview with that participant. At the end of the interview, when the interviewer sought to motivate the participant to recruit risk partners into the study, the interviewer had thus already had at least two prior contacts with the participant. A payoff of the intense time spent recruiting index participants under RW was that a majority successfully recruited at least 60% of their respective risk partners. In contrast, under RDS, participants recruited by peers via

coupons had no prior contact with the interviewer through which to develop rapport. While RDS index participants *named* about the same number of risk partners as did RW participants, a greater proportion of risk partners were *recruited* from RW participants than from RDS participants. Thus, although we saw similar openness about risk partners with the two methods, ultimately we saw greater cooperation with recruitment under random walk. Although RW was more expensive than RDS in terms of staff time, at least some of the extra time spent interacting with participants seems to have increased their commitment in aiding recruitment.

If study goals involve collecting information that participants are reluctant to divulge, lack of prior contact and trust may limit recruitment commitment and possibly data quality. Because RDS methods are a comparatively efficient way to recruit a sample, recruitment can proceed quickly with these methods. However, if the design needs participant recruiters to make efforts to recruit from a special targeted population, limited commitment among RDS participants may frustrate research goals. An innovation in some recent implementations of RDS is to use the payment of reward to peer recruiters as an opportunity to collect more information on the peer recruitment process (Heckathorn, 2002, Volz and Heckathorn, 2008) and to provide an opportunity for greater interaction between staff and informants to reduce participation bias.

The level of participant commitment may affect the representativeness of the final sample. Although low levels of commitment may be sufficient when interviewing participants about their individual behaviors, they may be inadequate to collect more intrusive information such as social network data. If the sampling design includes

recruiting social network members, especially reticent partners who use illegal drugs, the additional commitment achieved through greater staff-participant interaction, as in RW, may be critical for study success. Of course, one may not need to implement the entire RW method to obtain some of its advantages. Mainly, repeated contact and interaction with participants is an important element that enhances participant cooperation.

Participation bias results suggest a conundrum of recruitment. All research projects face a reluctance of potential recruits to participate. Researchers report gross demographic comparisons between recruited and not recruited persons to argue against bias. And yet there are certain inescapable and unmeasured differences between those who agree to participate and those who do not. No one in a target population starts out with an intention to participate, if only because they are initially unaware of the research study. Our results suggest that participation bias from reluctance to commit was minimized in RW by the close interaction between the field staff and the persons nominated for recruitment. One may think that the greater recruitment success observed in the RW sample is a kind of "bias." Those informants and participants who were amenable to developing a relationship with field staff may not have been representative of the entire community, creating a participant bias in the other direction, but that is the kind of "bias" on which much successful research recruitment depends.

A RDS design is meant to compensate for increased participation bias in the "short run" through the use of multiple waves of recruitment. Gile and Handcock

(2010) found that using multiple waves can indeed reduce bias introduced by seed selection, provided the sampling design provides access to all subgroups within the population. In our study, the success rate of only 28% for coupons distributed using the RDS method suggests a high level of participation bias through self-selection and partner selection. Heckathorn (1997) has reported, nevertheless, based on simulated and empirical results, that a peer-driven sample will tend to approach a representative sample after three to five waves. In this study only 20% of index participants were recruited in the third wave or later. This failure to recruit extended chain referrals suggests that, despite the difference from the street-recruited sample, the representativeness of the RDS sample may still be problematic.

In both RW and RDS designs, if data are collected about the size of each participant's network, recruitment probabilities for each participant can be estimated. Procedures for these adjustments have been developed for RDS samples, and sample values can be scaled up to relatively unbiased estimates of population parameters (Gile and Handcock, 2011, Heckathorn, 2002, Thompson, 2011, Volz and Heckathorn, 2008). Some concern has been expressed that RDS analytics are based on network assumptions that are sometimes not met (Yamanis, et al., 2013). Furthermore, in one study, corrected values did not differ from uncorrected values (Yamanis, et al., 2013), which suggests that the analytics are not always needed.

With respect to response quality, the RNS was designed to gather information about index participants' risk networks—sex and drug use partners with whom they risked HIV transmission—and about risk behaviors, particularly those in which they

engaged with such partners. Participants' ability to trust interviewers may have affected their willingness to share complete information about risk behaviors constructed as socially undesirable. In a related study, Pilon et al (2011) found that viral transmission in injection drug use networks appeared to occur between more distally related members of a recruited network rather than among close members. In an apparently similar dynamic, participants in the current study may have been more inclined to recruit marginal members rather than close members of their networks.

In evaluating relative response quality under random walk and RDS, we found significant differences on only two of twelve measures. RDS participants were more likely to report having had a same-gender sex partner, and reported a somewhat higher average frequency of 30-day drug use**.** There were no significant differences in reports of five additional socially undesirable behaviors, and no significant differences between the two sampling designs in concordance of partners' reports of joint risk behaviors. Thus, while greater contact with participants in our implementation of RW appears to improve network recruitment success, there appears to be little consistent difference in the quality of responses about their own behavior between the two samples based on the measures we constructed.

Beyond matters of sampling bias, the ethical issues involved in network-based studies deserve special consideration. All network studies have the problem of gaining prior identifying information on named alters. RW extends this problem to recruitment, a problem avoided in RDS by using coupons. RDS researchers learn the identities of

coupon participants only after the coupon has been presented, and recruited participants must then give informed consent to participate.

Some Institutional Review Boards (IRBs) may question network studies because, by the Common Rule regulations (45 CFR 46 Subpart A), named alters are human subjects who should give consent to participation prior to being named. Many researchers who would like to use network recruitment methods are themselves unfamiliar with the NIH regulations and thus are unequipped to educate their IRBs. In fact, the regulations give IRBs some authority to waive this requirement if adequate human subjects protections are in place. However, especially when dealing with members of stigmatized groups who risk harm if their identities or behaviors were revealed, persuading an IRB to waive privacy rules may be difficult to justify. Further, state statutes regarding revealing another's HIV status may constrain an IRB's purview, posing a potentially grave limitation on RW implementation.

In the several network studies that we have conducted, the PI undertook to educate the IRB on the relevant rules, and we were able to convince multiple IRBs that we would provide the same protections to named alters as to active study participants. [insert refs to recommended Semaan et al articles.]

4.1 Conclusions

Our comparison of the random walk and respondent-driven sampling methods in practice illustrates key tradeoffs for consideration in deciding which type of recruitment method to utilize in a social network study. Like all technological

innovations, recruitment approaches such as RW and RDS oblige investigators to make more choices, not fewer, in the process of designing a study. In weighing the relative advantages and disadvantages of the elements of RW and RDS designs, investigators must balance costs relative to results. Depending upon the research question, the local research context, and the levels and sources of reticence within a specific hidden population, investigators may find one method or the other more effective.

Both RW and RDS use social networks to recruit a representative sample of participants starting at the public periphery of a hidden population and moving into the interior. However, our results indicate potential differences in participant commitment and in the level of impact on field staff. If potential participants within the hidden population are resistant to recruitment, the prior contact with RW may generate greater commitment among participants and thus a lower level of participation bias. Thus, RW may generally produce better data than RDS when the burden on participants is high, as it is in many social network studies with hidden populations. At the same time, the psychological cost to staff can be high under RW, leading to costly staff turnover and threats to successful design implementation. In general, the economic and resource costs of frequent contacts can also be high, as intensive fieldwork is necessary to meet recruitment goals.

Respondent-driven sampling makes recruitment less time consuming for staff and removes many of the frustrations experienced by recruiters under RW. However, if participant commitment is lessened, there is a greater burden on staff interviewers to develop rapport with study participants without the earlier positive interactions with

staff recruiters. One potential solution is to incorporate some elements of the RW method into an RDS-based design, such as increased contact prior to interview. For rapid recruitment, especially with minimally intrusive instruments, RDS may be recommended. However, researchers should consider potential threats to participant commitment as factors influencing representativeness, data quality and study quality overall.

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