Time-Space Sampling and Respondent-Driven Sampling with Hard-To-Reach Populations

Salaam Semaan
Centers for Disease Control and Prevention

Abstract

Time-space sampling (TSS; also referred to as time-location sampling, TLS) and respondent-driven sampling (RDS) are strategies that can be used for sampling hard-to-reach populations, for whom it is difficult to construct a sampling frame of the individual members of the population. With proper planning, execution, weighting, and analysis of relevant sampling-related data, both strategies have the potential to produce samples that are representative of the target populations. TSS is a probability-based strategy for recruiting members of a target population congregating at specific locations and times. RDS is predicated on the recognition that project participants are better able than project staff to locate and refer to the study site other potential participants; peers from the target population with whom they have an established relationship. Capture-recapture analysis can incorporate TSS and RDS data to estimate the size of a hard-to-reach population. TSS and RDS have been used extensively around the world in public health projects with populations at high risk for HIV infection. The collective experience gained from using TSS and RDS in HIV-related projects can be valuable in using these sampling strategies with other hard-to-reach populations in projects related to economics, political science, or sociology. Although TSS and RDS have specific strengths and limitations in terms of their abilities to produce valid results that enhance generalizability of findings, the choice of a particular sampling strategy depends on characteristics of the target population and the goal and resources of the project. Proper planning, monitoring, and evaluation of the sampling strategy and attention to logistical, regulatory, and ethical considerations are important to the successful implementation and effectiveness of the sampling strategy.

Key words: HIV/AIDS, hard-to-reach populations, respondent-driven sampling, sampling hidden populations, time-space-sampling, time-location sampling

Introduction

Since our previous review of the procedures and applications of time-space sampling (TSS) (also known as venue-based sampling or as time-location sampling), and of respondent-driven sampling (RDS) (Semaan et al. 2002), public health researchers have gained extensive experience in using these strategies for sampling persons at risk for HIV infection who constitute a hard-to-reach population (Malekinejad et al. 2008; Mackellar et al. 2007). We define hard-to-reach populations statistically and sociologically (Kish, 1991). Statistically, there is not usually a traditional sampling frame that lists the individual members of a hard-to-reach population because the sampling frames of these populations are poorly defined or difficult to construct (Sudman et al. 1988). From a sociological perspective, hard-to-reach populations are groups of people who
can be linked by cultural bonds, race or ethnicity, nationality, certain behaviors, socioeconomic conditions, or societal structures. Hard-to-reach populations may refrain from moderate or heavy involvement in majority social institutions for social (e.g., stigma, discrimination, culture), or legal (e.g., illegal behaviors) reasons (Lepkowski, 1991). Traditional full-fledged probability sampling, used when a sampling frame of the target population lists its members, such as in door-to-door household surveys, telephone surveys, or facility-based surveys, is costly to use with hard-to-reach populations and may not even be effective in reaching these populations (Levy & Lemshow, 1991).

The purpose of this article is to review and compare the use of TSS and RDS to recruit hard-to-reach populations in terms of purpose, applications, procedures, theoretical basis or analytical aspects, limitations, and advantages, building on many of the experiences reported during the past two decades. We highlight factors that are important to the successful application of TSS and RDS during the different phases of the sampling process (pre-sampling, during sampling, and post-sampling). We draw on public health experiences involving sampling persons at risk for HIV infection, with whom TSS and RDS have been used extensively. This experience can inform use of TSS and RDS in sampling hard-to-reach populations in projects related to economics, political science, or sociology. TSS and RDS can be used successfully with relevant planning, execution, and evaluation. To ensure successful implementation and evaluation of sampling strategies, it is important to include critical resources such as expertise in the content and topical areas of the project, characteristics of the target population, theoretical and practical aspects of sampling, and factors that influence logistical, regulatory, and ethical aspects of the sampling process.

Time-Space Sampling

**Purpose**

TSS, a probability-based strategy, is used to produce probability estimates of hard-to-reach populations when sampling frames of the individual members of those populations do not exist or are difficult to construct. Venue-day-time units (VDTs) (e.g., a given location, Tuesday, 9 am -12 pm), which represent the universe of locations, days, and times of congregation form the sampling frame. It is important to distinguish TSS from facility-based full-fledged probability sampling (when a sampling frame of the individual members exists) and from non-probability sampling (e.g., convenience sampling in a facility) (Levy & Lemshow, 1991).

**Applications**

TSS has been used extensively since the early 1990s in HIV-related projects to recruit men who have sex with men (MSM) congregating at specific locations (venues) and times (Mackellar et al. 1996). For example, TSS was used in an HIV behavioral intervention research study of young MSM in five cities in the United States (Mackellar et al. 1996). Shortly thereafter, TSS was used for sampling young MSM for survey research (Muhib et al. 2001). TSS was subsequently used to sample MSM for a U.S. national behavioral surveillance project (17-23 metropolitan areas) during 2003–2005 (Mackellar et al. 2007). TSS was also used to sample other hard-to-reach populations, including young (13-24) lesbian, gay, bisexual, transgender, and heterosexual youth in a study of tobacco use (Remafedi et al. 2008) and Latino MSM (Stueve et al. 2001). Additionally, TSS was used to recruit sex workers in different countries, including Congo (Kayembe et al. 2008) and Kenya (Geibel et al. 2008), and to recruit truck drivers in Northeast Brazil (Ferreira et al. 2008).

**Procedures**

TSS proceeds in three main phases: the formative phase, the preparatory phase, and the sampling phase (Muhib et al. 2001; Mackellar et al. 2007). The formative phase includes collection of ethnographic data, interviews with key informants, and analysis of indicator data (variables that serve as proxy variables that describe the characteristics of the target population).

Following formative research, staff members engage in important preparatory steps. First, staff members identify the range of VDTs for members of the target population, and then canvass these VDTs to prepare a list of eligible VDTs based on headcounts (a clicker is often used for this count) of persons congregating in
the VDTs. This step is referred to as primary enumeration because project staff assess whether the VDTs identified through the formative phase are attended by individuals from the target population. Following primary enumeration, project staff members conduct brief interviews to determine eligibility and to estimate for each VDT the number and proportion of persons who belong to the target population and who are eligible for sampling. This step is referred to as secondary enumeration which is useful to estimate the effective yield, defined as the potential number of interviews a VDT can generate during a sampling event.

There are certain factors that can enhance the success of TSS during the preparatory phase. These factors include the need for investigators to include all VDTs in the sampling frame, estimate the number of the target population in each VDT, and determine the proportional allocation of the sample between the different strata (e.g., business strata, recreational strata, clinical strata) of VDTs. For example, a multi-site, HIV prevention study showed the importance of understanding the key differences in the types of venues preferred by young males and females and of recognizing that female-preferred venues were more likely to be closer to where the females lived (Chutuape et al. 2008).

During the sampling phase, staff members use a two-stage sampling process to recruit the sample and to attain the sample size desired for the project. In the first stage, staff members select a simple random sample or a stratified sample of the VDTs listed in the sampling frame, preferably with a probability proportional to the number of the eligible persons at each VDT. It is also relevant to sample entrances of VDTs in proportion to frequency of use. Following that, staff members screen prospective participants, invite eligible participants, using random or systematic sampling to select potential respondents, conduct the surveys, and collect relevant data on those who refuse to participate in the survey or on those who withdraw from the survey.

As part of the data collection process, investigators need to collect data on mobility of respondents (because mobility affects the probability of selection), and relevant data to calculate weights to control for unequal probability of selection (Mackellar et al. 2007). Investigators need also to collect data to assess selection biases in the screening and core interviews. Equally important is the need to train interviewers to use the sampling strategy, consider and implement strategies to boost participation rates in the screening and core interviews (e.g., incentives, appointments for interviews, privacy of data collection). As part of the logistical process, investigators need to supervise the sampling process and to be prepared to implement corrective measures.

When considering whether to use TSS, it is important to assess the attendance habits of the target population at VDTs. Equally important is to consider whether exclusion of VDTs with low attendance or inaccessible VDTs would create selection bias, and to assess whether a higher budget is needed to oversample smaller VDTs. Given potentially changing circumstances that may affect the sampling process (e.g., changes in attendance patterns caused by seasonal weather changes or by social, economic, or legal forces), there is often a need to identify new VDTs and to evaluate the potential effective yield of VDTs already listed in the sampling frame. This dynamic sampling approach is referred to as adaptive sampling (Thompson & Collins, 2002). Sampling projects conducted over a period of several months often require monthly re-construction of the sampling frame of VDTs and development of sampling-event calendars to organize deployment of staff members (Mackellar et al. 2007). A well-trained and experienced sampling manager can be instrumental in carrying out the sampling process efficiently and effectively and in supervising the project staff involved in the sampling process.

**Analytical Aspects**

Because TSS produces a probability sample of visits to VDTs, the visit, rather than the visitor, is the appropriate unit of analysis. To treat the visitor as the unit of analysis, data on unequal selection probabilities must be collected and analyzed (Mackellar et al. 2007). This is relevant because during the sampling process, many members of the target population may revisit the VDTs and, thus, may have multiple chances of selection. Others may rarely visit the VDTs. Accordingly, a weighted analysis can be used where the weight is calculated as the inverse of the participant’s selection probability based on data about attendance of VDTs (Mackellar et al. 2007). Other procedures exist as well for calculating the weights (Kalton, 2009).
Investigators can also compute attendance rates and participation rates at the different strata of VDTs by comparing characteristics associated with the outcomes of interest. They can assess rates of participation in the screening and core interviews and reasons for refusal to participate in the interviews. Determining whether refusals produce selection biases, and assessing representativeness of the selected sample by comparing the data collected on the sample with other data sets (e.g., a similar sampling strategy in a different setting or a different sampling strategy in a similar setting) are important to assess selection biases and the extent of generalizability of the findings. Investigators can assess also the need to use statistical programs that incorporate the intraclass correlation (also known as the clustering or design effect), which arises when persons at a location have homogeneous characteristics. Thus, in evaluating the success of TSS, relevant factors include coverage of the target population, recruitment during the sampling phase, range of VDTs covered, yield of participants by type of VDTs, and representativeness of the sample (Pollack et al. 2005).

**Limitations**

One of the limitations of TSS is that the findings can be limited to accessible VDTs, venue attendees, and more visible or active members of the target population. For this reason, obtaining permission from proprietors to access as many VDTs as possible is important. Lack of access to a substantial percentage of VDTs can provide biased results. Including only accessible VDTs is a concern especially when VDTs that were not easily identifiable or approachable were excluded from the sampling frame and when the target populations in the included VDTs differ from those that could have been selected at the excluded VDTs on important variables associated with the outcomes of interest. In such cases, findings can be limited to the target population who attended the VDTs listed in the sampling frame, unless data are collected and weights are developed to estimate probability of attendance across the universe of VDTs and the target population. Another limitation of TSS is the exclusion of people who do not attend any venue, for example, homeless people who do not attend any kind of outreach services or shelter accommodations. Accounting for their characteristics and how they may influence study results are important.

**Advantages**

TSS can allow investigators to obtain a large, diverse sample of the target population and to generalize the findings to the target population. TSS also allows for identifying venues where the target population can receive services, if this is a goal of the project. TSS is reproducible in many areas, an important consideration in multi-city or multi-year projects (Semaan et al. 2002). TSS can produce findings that can be generalizable to the target population.

**Respondent-Driven Sampling**

**Purpose**

RDS is predicated on the recognition that peers are better able than project staff members to locate and recruit peers whom they know as members of a hard-to-reach population. Through the use of operational and statistical procedures, RDS can overcome biases of other non-probability chain referral methods, such as snowball sampling, which tends to oversample participants with larger personal networks (Goodman, 1961). RDS also differs from other probability chain referral methods, such as the random walk approach (Klovdahl, 1989), and the targeted personal network sampling approach (Spreen & Swaagstra, 1994). By relying on peer-driven chain referral strategies, theoretical and statistical underpinnings, use of a structured system of recruitment procedures, and remuneration to encourage recruitment and participation, RDS tends to reduce biases typically associated with non-random recruitment by using post-stratification weighting procedures (Heckathorn, 1997).

**Applications**

Researchers and practitioners have been using RDS since the mid-1990s to reach populations at risk for HIV, initially in intervention and research projects with injection drug users (Heckathorn, 1997; Heckathorn et al.
Recent reviews have summarized experiences of using RDS in HIV-related projects in more than 80 countries (Johnston et al. 2008; Malekinejad et al. 2008; Des Jarlais et al. 2009).

**Procedures**

RDS begins with a small number of peers from the target population termed “seeds.” The “seeds” are the first recruiters who are usually chosen by project staff in a non-random fashion. The seeds recruit the first “wave” of participants, who in turn, as recruiters, recruit the second wave, who then recruits the third wave, and so forth, until the sample size is achieved. The most common approach for establishing the sample size for any sampling project is to do a power analysis to determine the size of the sample that can detect the variable of interest. The usual approach for a power analysis assumes a simple random sample which, by definition, has a design effect of one. Because RDS has usually a larger design effect, assumed to be 2 (Salganik, 2006), it is recommended to do a standard power analysis, and then to double the sample size in calculating the desired sample size. Alternatively, if similar RDS studies have already been conducted, it is possible to use those studies to get a more precise estimate of the design effect.

Seeds are usually high-energy, well-connected members of the target population who can jump-start the recruitment process and reduce bias by speeding up the attainment of equilibrium (the stage when bias introduced by non-random choice of seeds by staff members disappears when the number of waves is large). Studies generally begin with 6 to 8 seeds, though larger numbers (e.g., 20) can be used when it is a priority to complete the sampling process quickly. During recruitment, the RDS sample grows wave by wave, similar to the way a snowball increases in size as it rolls down a hill (Heckathorn, 2002).

Studies that use RDS rely on the social network structure of participants to achieve the desired sample size by inviting participants to refer (i.e., recruit) their peers (usually a maximum of three peers are allowed) to the study site to be subsequent participants and recruiters. RDS uses recruitment quotas to reduce selection bias and to lengthen referral chains (at least 4-6 recruitment waves) in order to reach deeper into the target population and to produce generalizable estimates (Heckathorn, 2002).

The highly structured referral process used in RDS is referred to as participant-driven recruitment. Participants nominate and refer peers from the target population whom they have a reciprocal relationship (i.e., they both know each other as members of the target population), per the project eligibility criteria for study participation. Recruiters receive a predetermined number of non-transferable, hard-to-duplicate coupons, each with a unique serial number, to refer peers. Project staff members use a coupon management system database to track coupons given to and received by recruiters and recruits. Only recruiters can redeem their non-transferable coupons. Following referral by recruiters and arrival to the study site, staff members explain the study to recruits, screen them, and if they are found to be eligible, invite them to participate in the study.

Adequate formative research is needed to characterize the target population and to develop procedures to use RDS with the target population. Collecting data on the network size and connections of the target population is important because network variables affect the ability to reach the desired sample size (Uuskula et al. 2010). Indicator data should also be analyzed to characterize the network connections of the target population because recruitment is dependent on peers who have a reciprocal relationship with peers in the target population. Another important step in preparing to use RDS include developing and implementing protocols for training seeds and participants to serve as recruiters of their peers, pilot-testing remuneration levels for participant-driven recruitment, pilot-testing questions on screening and eligibility criteria, training staff members in using the coupon management system, and establishing stable, safe, and accessible interview sites (Heckathorn et al. 2002; Semaan et al. 2002).

Investigators may share information with the participants about the conditions under which the coupons will not be accepted (e.g., when target sample size has been reached, when the coupon has been tampered with, when the coupon holder has already been interviewed). Quality control measures, such as the extent to which the data in the coupon management system are completed and evaluated, are important in implementing RDS successfully. Training project staff in relevant regulations and ethical considerations to protect the rights and welfare of participants and the integrity of the project is also valuable.
**Theoretical Basis**

Two concepts are important in RDS. The first, referred to as homophily, measures the tendency to recruit peers with characteristics similar to those of the recruiters, and can best be described in lay person language by the adage, birds of a feather flock together. The concept of homophily is important because there is a need to weight the sample to compensate quantitatively for differences between groups because of the tendency to recruit similar peers within groups. The limited number of recruits (usually three) that recruiters can recruit allows for an increase in the social distance between seeds, initial recruits, and later recruits who enrolled in later waves.

Equilibrium is another important concept, which refers to the stage where bias from the seeds chosen by project staff disappears when the number of waves is large (Heckathorn, 2002; Heckathorn, 2007). Equilibrium refers to the point at which sample characteristics cease to fluctuate and theoretically approximate characteristics of participants’ networks. The concept of equilibrium is important because it helps in determining the number of waves needed to reach the desired sample size that is representative of the target population.

RDS is good for sampling people linked by certain factors. While RDS does not call for a priori characterizing the network structure of the target population, such a structure can affect the success of using RDS with a certain population. Network characteristics are usually described in the network literature and are measured by several variables. Network related variables include density (i.e., total number of connections divided by the possible connections) which represents the extent of communication within the network. Centralization measures the extent to which the majority of the connections relate to a small set of nodes and indicates the degree to which communication is centralized around a single participant or a small number of participants. Clique count (i.e., average number of maximally connected subgroups) measures social integration and network cohesion that drives the connection and knowledge process. Effective network size (i.e., average number of personal links reduced by redundant links) measures connections to the same person through more than one link. It is often the network structure that affects the success of a RDS, as reflected by the density of the network that characterizes the target population. Network size is usually based on reported data, for example, the number of the eligible target group that a participant knew and whom they had seen at least once in the previous 6 months.

**Analytical Aspects**

Statistically, RDS relies on several theories (Heckathorn, 2007). These theories include Markov chain and biased network theories. RDS provides valid, probability-based population estimates and standard errors. The theoretical assumptions of RDS can be tested to examine the extent to which RDS was used properly and appropriately. The first assumption relates to respondents’ tendency to recruit those with whom they have a pre-existing relationship (i.e., reciprocal relationships). This assumption can be tested by asking respondents about their relationships to their recruiters and by computing a reciprocity index, indicating the extent to which both recruiters and recruits know each other. Recruits are usually identified as acquaintances, friends, or persons with whom they have closer relationships. The second assumption relates to respondents’ tendency to recruit peers as though recruiters are sampling randomly from their personal networks. This assumption can be tested by asking respondents about the composition of their personal networks and by comparing these data to recruitment patterns, and by asking about the characteristics of those who refused to be recruited and by comparing their characteristics to those who were recruited.

Important analytical activities include using statistical software to control for differential network size and recruitment patterns, conducting validity comparisons to assess the success of the sampling process, and evaluating the sampling process and its outcomes (Heckathorn, 2007, Semaan et al. 2009). An RDS sample is only self-weighting if two conditions are met: (1) groups of analytic interest (e.g., gender, race/ethnicity) have equivalent network sizes, and (2) groups recruit with equal efficacy (Heckathorn, 2007). Because these two conditions are typically not met, post-stratification weights are required to yield population estimates that control for these sources of bias.
Post-stratification weights can be conducted using the RDS analysis tool (RDSAT). This tool can be used to calculate RDS-adjusted population proportion estimates, their 95% confidence intervals, RDS-adjusted standard errors, and sample, population, and equilibrium proportions (RDSAT, 2008). The RDS-adjusted estimates incorporate adjustments based on network-size, cross-group recruitment probabilities, and group-specific recruitment efficiency. RDSAT generates standard errors for population proportion estimates by a bootstrap method (Salganik, 2006). The design effect quantifies the proportionate difference between the variance of RDSAT bootstrap method and the variance that would have been expected if the RDS estimates were normally distributed (Salganik, 2006). Recruitment chains can be diagrammed by means of NETDRAW (NETDRAW, 2008).

**Limitations**

Most studies conclude that RDS is an efficient and effective method to recruit hard-to-reach populations (Abdul-Quader et al. 2006; Abramovitz et al. 2009; Chopra et al. 2009; Heckathorn et al. 2002; Iguchi et al. 2009; McKnight et al. 2006). RDS is based on a body of theory-based assessments of its capacity to produce unbiased estimates of population characteristics (Heckathorn, 2007). There are, however, instances where the sample size desired was not achieved, where recruitment took longer than anticipated, and where the sample characteristics differed from what was expected in terms of racial or ethnic distribution or other demographic characteristics (Burt et al. 2010; Robinson et al. 2006; Abdul-Quader et al. 2006; Platt et al. 2006; Stormer et al. 2006; Ma et al. 2007; Kendall et al. 2008). Several reasons can explain these outcomes. The RDS coupon distribution system might not have effectively penetrated the full universe of the networks of the target population, as could have been reflected by lower recruitment probabilities and network barriers across differing variables such as area of residence, race, ethnicity, or other specific characteristics of the eligible population (e.g., sex work). Logistical factors affect the extent to which RDS can efficiently access the isolated networks of the target population and adequate formative research can enhance the success of using RDS. Efficient penetration of the networks of the target population through a certain community might require several interview sites and a higher number of seeds (Heckathorn et al. 2002; Burt et al. 2010). Successful criteria in RDS implementation usually include longer recruitment waves, the extent to which the sample population approaches the estimated equilibrium values for the characteristics analyzed, recruitment across interview sites, and a low percentage of participants who report that they were recruited by strangers.

**Advantages**

RDS can be effective for sampling people linked by certain factors. RDS allows investigators to select a representative and diverse sample of a connected population, calculate population-based estimates of relevant variables, limit selection bias in a time-efficient and cost-effective manner, and develop a weighting mechanism to control for homophily and network size. RDS can be useful in sampling populations who do not trust sponsoring agencies and for reaching persons who shun public venues. RDS can provide valid, probability-based population estimates and standard errors.

**Logistical, Regulatory, and Ethical Considerations**

**Overall Considerations**

TSS and RDS have important logistical, regulatory, and ethical considerations that may co-exist and influence each other in a given project (Semaan et al. 2010). Each of these three sets of considerations needs relevant safeguards that are specific to five dimensions (1) the target population, especially when it is a marginalized population, (2) the particular topic of the study, especially when dealing with sensitive, private, or potentially stigmatizing topics (e.g., illegal drug use or intimate and private behaviors), (3) the study procedures, some of which can carry social stigma (e.g., HIV testing), (4) the nature of the data collection efforts (e.g., research or surveillance), which is often bound by strict regulatory requirements and policies or scientific standards, and (5) the specific sampling strategy, which may have unique procedures that necessitate specific logistical and ethical safeguards.

It is often the case that reports on each of these five dimensions as they relate to a particular topic and a target population (e.g., HIV testing of sex workers) have appeared in the scientific literature. However, these five
dimensions often interact together in a complex manner, especially in projects with marginalized populations that address socially sensitive topics and use field procedures and sampling strategies for populations for whom a sampling frame is not readily available or easily constructed.

Clarity on the separate, combined, and synergistic role of logistical, regulatory, and ethical requirements and safeguards is important and can be useful in training project staff to protect the rights and welfare of participants and the integrity of projects. To provide appropriate safeguards, investigators need to train staff members in relevant logistical, regulatory, and ethical procedures and policies to maximize success and to reduce concerns. Describing risks or failures should be based on project data to avoid creating the impression that study-level planning and protective measures were inadequate or that harms were actualized (Semaan et al. 2010).

There are general procedures and safeguards that can be used in projects irrespective of the sampling strategy chosen. Relevant procedures include, for example, the use of audio computer-assisted interviewing (ACASI) to enhance the reliability and validity of self-reported data, particularly when the data are sensitive and private in nature. Relevant safeguards include field experience in working with the target population, knowledge of and experience with guidelines and regulations for protecting participants, and knowledge of and attention to local factors that can influence the field work. Equally important is the need to share information about the process and results with representatives of the target population and with the scientific community for consideration and implementation of relevant individual and community-level interventions.

**Logistical Considerations**

Investigators in recent reviews of the RDS literature have identified several important steps in the successful implementation of RDS, based on the experiences of HIV-related projects that have used RDS in more than 80 countries (Johnston et al. 2008; Malekinejad et al. 2008). Guidelines for using RDS include several procedures (Des Jarlais et al. 2009). These procedures include (1) operational procedures (e.g., defining eligibility criteria, assessing social network sizes, designating appropriate incentives), (2) design procedures (e.g., characterizing extent and nature of social networks), and (3) analytic procedures (e.g., using appropriate design effect, assessing equilibrium, and adjusting data for differential network sizes and differential recruitment patterns).

**Regulatory Considerations**

Remuneration for time and effort for project participation and for participant-driven recruitment is a core element in projects that use RDS. In a recent review, we summarized relevant scientific, ethical, and regulatory considerations for remuneration for participant-driven recruitment in HIV-related projects with persons who inject illicit drugs (Semaan et al. 2009). Remuneration is an important element in projects that depend on voluntary participation because although altruism is a necessary force, it may not be sufficient. Because referral quotas limit the number of recruits a recruiter can refer to the study, quotas also limit the remuneration for recruitment. There are several arguments against monetary remuneration for participant-driven recruitment in projects with persons who use illicit drugs (Semaan et al. 2009). These concerns include the potential use of remuneration payments to buy drugs, subversion of altruistic motivations for participation, bartering of referral coupons, and coercion to barter coupons or to surrender remuneration payments. However, these arguments were not supported by scientific data. In contrast, remuneration payments show respect for participants’ judgment to use the money to meet personal needs (Semaan et al. 2009).

As required for protection of participants in research studies, project staff can discuss with recruits the consent process and form to ensure that recruits do not feel pressured by recruiters to participate in the study. Equally important is to inform potential recruits through the informed consent process and form about the conditions under which remuneration payments will be made. In many projects, recruiters are reimbursed for time and effort in participant-driven recruitment after recruits choose to visit the study site and are enrolled by project staff members who have checked that the recruits meet the project eligibility criteria. In other projects, and to reduce the risk for inducement or coercion, recruiters are reimbursed for the recruits’ visit to the study site after recruits bring their coupons to the study site, whether or not the recruits were enrolled in the study or
provided data. In many projects, both recruiters and enrolled recruits receive remuneration for study participation.

There are many public research institutions in several countries that have laws or other prohibitions against some or all project- or research-related monetary remuneration. In these situations, the RDS approach should be pilot-tested to see how it will perform in the absence of monetary remuneration. Non-monetary remuneration was used successfully in an RDS project in Russia (Broadhead et al. 2006). In a previous review, we suggested a checklist of participation-related variables for systematic data collection and reporting, as feasible, in studies that use RDS (Semaan et al. 2009). These variables can also be used, as relevant, in studies that use TSS. The variables include (1) motivation for recruitment, (2) motivation for project participation, (3) the extent of any coercion or undue influence, (4) amount of remuneration for each recruit, (5) amount of remuneration for study participation, (6) methods used to determine remuneration amounts, (7) return rates to collect the allotted remuneration, and (9) differential effects of monetary versus non-monetary remuneration.

Regulatory considerations should be built into the review and approval process of projects before project initiation. Regulatory safeguards can include a consent process and form with its required elements, oversight of institutional and review committees, community advisory boards, and, as necessary, pilot-testing of relevant procedures (e.g., remuneration amount) to avoid or minimize mid-project corrections. All involved parties, including project staff members, have a responsibility to discuss and address warning signs of factors that affect the rights and welfare of study participants and the integrity of projects as soon as project staff members recognize such signs (e.g., risk to privacy).

**Ethical Considerations**

In terms of ethical considerations, procedures for protecting participants have become highly refined. These procedures specify how sensitive information must be guarded and how remuneration for time and effort in survey participation or in participant-driven recruitment must be balanced to preclude undue inducement or coercion. For example, as part of the RDS consent form and process, investigators need to inform participants about the peer-recruitment procedure and remuneration options for participant-driven recruitment and give them an opportunity to choose or to refuse to participate in the participant-driven recruitment process. In working with any target population, it is important that recruiters and recruits do not feel coerced or pressured to participate in participant-driven recruitment and that investigators protect against such occurrences. Respondents need to know that participant-driven recruitment is voluntary and that there is no penalty should participants decide not to recruit their peers.

In a previous review, we highlighted ethical considerations in using RDS, including considerations related to disclosure of information relevant to the health and well-being of others, especially as investigators become aware of health-related information through the coupon management system (Semaan et al. 2009). Our review focused on specific factors related to using RDS in HIV-related projects with persons who use illicit drugs in the United States. These factors, in their general format, are applicable to other populations. For example, the ethical principle of respect for study participants highlights investigators’ obligation for the public health of networks and communities and calls for informing participants during informed consent whether the investigators are going to share with authorities or population databases information that has a bearing on the health of others (e.g., domestic violence, child abuse, an infectious health condition, a genetic marker). The principle of respect also requires that investigators strive to protect the privacy of participants and the confidentiality of the data, and to honor the choices of participants. In a previous review, we suggested a checklist for the collection of data regarding collection and disclosure of sensitive information (Semaan et al. 2009). The checklist includes (1) procedures used to protect privacy of participants and confidentiality of personal information, (2) disclosure options offered to participants, (3) procedures used to protect relationships in projects involving collection or disclosure of sensitive information, and (4) beliefs and behaviors of participants regarding their responsibility to disclose sensitive information and adopt safer behaviors.

Overall, addressing logistical, regulatory, and ethical dimensions of sampling is important to ensure that projects are feasible, provide statistically and scientifically valid data, and are ethically sound.
Choice of a Sampling Strategy

In cases where it is not possible to construct a sampling frame that allows for the use of full-fledged probability sampling (e.g., cluster sampling), TSS or RDS can serve as viable strategies for sampling hard-to-reach populations. In determining whether TSS or RDS is the better sampling strategy, investigators need to assess relevant factors, including congregation habits and network characteristics of the target population (Mills et al. 2004). For example, if the target population does not congregate in VDTs that are identifiable and accessible, RDS can be the sampling strategy of choice if network characteristics of the target population can support the use of RDS. If the target population conglomerates in accessible and identifiable VDTs, and if it is possible to create a list of these VDTs and to access the target population at these VDTs, TSS can be the likely method of choice.

RDS is best used after formative research provides relevant data, including data on the density of networks and on other network-related variables, to characterize the target population and to assess the extent to which RDS can be successful. Formative research with the target population, including economically-disadvantaged and rich populations, can help in understanding the level of incentives that may or may not motivate the target population to participate in a study, and to assess the network characteristics that can influence the success of using RDS or any other chain referral sampling strategy. Adequate formative research or ethnographic evaluation can provide information on whether the target population is sufficiently connected or too fragmented to support the use of RDS. In certain cases (e.g., rural populations, certain racial or ethnic minority populations), members of the target population may associate only with immediate family or community members, and may avoid other members from the target population. In such cases, neither RDS nor any other network-based sampling strategy can work because social networks can be too small and can form many separate components. Alternatively, the presence of institutions that support the target population (e.g., ethnic- or nationality-based institutions, such as community groups, ethnic grocery stores, places of worship, or other places where the target population meets and forms social ties) can provide information about whether TSS is the better sampling strategy, especially when network ties are not robust to support the use of RDS.

There are several key factors for the successful application of both TSS and RDS, including factors such as adequate formative research, pilot studies, articulation of the eligibility criteria, collection of data on design effect and weights, validity assessments to compare the process and outcomes of the sampling strategy, and identification of outcome indicators for evaluating the success of the sampling strategy. Several websites constructed during the past decade can provide useful information on TSS and RDS (listed in the reference list). Recent studies have compared empirically the process and outcomes of several strategies including TSS and RDS (Kendall et al. 2008; McKenzie and Mistiaen, 2009). For example, in a study of MSM conducted in Fortaleza, Brazil, RDS produced a sample with a high proportion of participants with lower socioeconomic status than snowball sampling or TSS (Kendall et al. 2008). This was an important finding because the majority of HIV and AIDS cases were reported among MSM with lower socioeconomic status (Kendall et al. 2008). In addition, the study investigators reported that RDS achieved the sample size faster and at lower cost (Kendall et al. 2008).

Capture-recapture analysis is often used to estimate the total number of individuals in a hard-to-reach population using two or more independent samples or data sources of the target population, with one sample being a representative of the hidden population (International Working Group for Disease Monitoring and Forecasting, 1995). The independent data sources are especially useful when estimates from one source fail to include all individuals of the target population. TSS or RDS can be used to estimate the size of a hard-to-reach population. For example, RDS has been used recently to estimate the size of the target population, persons who used drugs, in combination with data from other sources (Heimer & White, 2010; Hickman et al. 2009). In the basic capture-recapture analysis, all individuals must have the same probability to be captured. As is well known, RDS weighs the sample to compensate for factors such as over-sampling those with large networks. Thus, when using RDS as part of a capture-recapture estimate, it is important to use the RDS estimates that are weighted rather than the raw sample composition estimates, which are not weighted.
Conclusion

TSS and RDS require adequate formative research to acquire relevant information about the target population, provide the basis and rationale for the choice of a particular sampling strategy, and ensure the successful implementation and outcomes of the chosen sampling strategy. The collective public health experience gained during the past two decades in using TSS and RDS with populations at risk for HIV infection can be useful in advancing TSS and RDS in public health projects as well as in projects related to economics, political science, or sociology. Pilot-testing relevant procedures, training staff members, implementing quality control procedures, monitoring the sampling process, establishing criteria to define the successful implementation of the sampling strategy, and use of an interdisciplinary team (across all disciplines, ranging from anthropology to statistics), are important steps to ensure the success of TSS and RDS. Although TSS and RDS have each its own strengths and limitations, they can both be used in sampling hard-to-reach populations with appropriate planning and monitoring, even in contexts where stigma is high. Deciding which method to use and ensuring its success requires application of relevant theoretical and practical knowledge as distilled from the collective experience gained in implementing TSS and RDS during the past two decades.

Acknowledgments

An earlier version of this paper was presented at the Meeting on Sampling Methods for Hard-To-Reach Populations, Institut National D'Etudes Demographiques, Paris, France, May 2009. The author wishes to acknowledge the comments of Dr. Heckathorn, Cornell University, Ithaca, New York, United States on an earlier version of this paper.

The findings and conclusions in this paper are those of the author and do not necessarily represent the views of the Centers for Disease Control and Prevention, Atlanta, United States.

References

Abdul-Quader, A.S., Heckathorn, D.D., McKnight, C., Bramson, H., Nemeth, C., Sabin, K., Gallagher, K. and Des Jarlais, D.C. (2006) ‘Effectiveness of respondent-driven sampling for recruiting drug users in New York City: Findings from a pilot study’, Journal of Urban Health, Vol. 83, pp. 459-476.

Abramovitz, D., Volz, E.M., Strathdee, S.A., Patterson, T.L., Vera, A., Frost, S.D. and Proyecto, E. (2009) ‘Using-respondent-driven sampling in a hidden population at risk of HIV infection: Who do HIV-positive recruiters recruit’, Sexually Transmitted Diseases, Vol. 26, No. 12, pp. 750-756.

Broadhead, R. S., Volkanevsky, V. L., Rydanova, T., Ryabkova, M., Borch, C., Hulst, Y. V., Fullerton, A., Sergeyev, B. and Heckathorn, D. (2006) ‘Peer-driven HIV interventions for drug injectors in Russia: First-year impact results of a field experiment’, International Journal of Drug Policy, Vol. 17, pp. 379-392.

Burt, R.D., Hagan, H., Sabin, K. and Thiede, H. (2010) ‘Evaluating respondent-driven sampling in a major metropolitan area: Comparing injection drug users in the 2005 Seattle area national HIV surveillance system survey with participants in the RAVEN and KIWI studies’, Annals of Epidemiology, Vol. 20, pp. 159-167.

Chopra, M., Townsend, L., Johnston, L., Mathews, C., Tomlinson, M., O’Bra, H. and Kendall, C. (2009) ‘Estimating HIV prevalence and risk behaviors among high-risk heterosexual men with multiple sex partners: Use of respondent-driven sampling’, Journal of Acquired Immune Deficiency Syndrome, Vol. 51, No. 1, pp. 72-77.

Chutuape, K. S., Ziff, M., Auerswald, C., Castillo, M., McFadden, A. and Ellen, J. (2008) Adolescent Medicine Trials Network for HIV/AIDS Intervention (2008) ‘Examining differences in types and location of recruitment venues for young males and females from urban neighborhoods: Findings from a multi-site HIV prevention study’, Journal of Urban Health, Vol. 86, No. 1, pp. 31-42.
Des Jarlais, D. C., Arasteh, K., Semaan, S. and Wood, E. (2009) ‘HIV among injecting drug users: Current epidemiology, biologic markers, respondent-driven sampling, and supervised injection facilities’, *Current Opinion in HIV and AIDS*, Vol. 4, pp. 308-313.

Ferreira, L. O. C., de Oliveira, E. S., Raymond, H. F., Chen, S. Y. and McFarland, W. (2008) ‘Use of time-location sampling for systematic behavioral surveillance of truck drivers in Brazil’, *AIDS and Behavior*, Vol. 12, pp. S32-S38.

Geibel, S., Luchters, S., King’Ola, N., Esu-Williams, E., Rinyiru, A. and Tun, W. (2008) ‘Factors associated with self-reported unprotected anal sex among male sex workers in Mombasa, Kenya’, *Sexually Transmitted Diseases*, Vol. 35, pp. 746-752.

Goodman, L.A. (1961) ‘Snowball sampling’, *Annals of Mathematical Statistics*, Vol. 32, pp. 148-170.

Heckathorn, D. (1997) ‘Respondent-driven sampling: A new approach to the study of hidden populations’, *Social Problems*, Vol. 44, pp. 174-199.

Heckathorn, D. (2002) ‘Respondent-driven sampling II: Deriving valid population estimates from chain-referral samples of hidden populations’, *Social Problems*, Vol. 49, pp. 11-34.

Heckathorn, D. D., Semaan, S., Broadhead, R. S. and Hughes, J. J. (2002) ‘Extensions of respondent-driven sampling: A new approach to the study of injection drug users aged 18-25’, *AIDS and Behavior*, Vol. 6, pp. 55-67.

Heckathorn, D. D. (2007) ‘Extensions of respondent-driven sampling: Analyzing continuous variables and controlling for differential recruitment’, *Sociological Methodology*, Vol. 37, pp. 151-208.

Heimer, R. and White, E. (2010) ‘Estimation of the number of injection drug users in St. Petersburg, Russia’, *Drug and Alcohol Dependence*, 109(1), pp. 79-83.

Hickman, M., Hope, V., Coleman, B., Parry, J., Telfer, M., Twigger, J., Irish, C., Macleod J. and Annett H. (2009) ‘Assessing IDU prevalence and health consequences (HCV, overdose, and drug-related mortality) in a primary care trust: Implications for public health action’, *Journal of Public Health*, Vol. 31, pp. 374-382.

Iguchi, M.Y., Ober, A.J., Berry, S.H., Fain, T., Heckathorn, D.D., Gorbach, P.M., Heimer, R., Kozlov, A., Ouellet, L.J., Shopstow, S. and Zule, W.S. (2009) ‘Simultaneous recruitment of drug users and men who have sex with men in the United States and Russia using respondent-driven sampling: Sampling methods and implications’, *Journal of Urban Health*, Vol. 86, Supplement 1, pp. 5-13.

International Working Group for Disease Monitoring and Forecasting (1995) ‘Capture-recapture and multiple-record systems estimation I: History and theoretical development’, *American Journal of Epidemiology*, Vol. 142, pp. 1047-1058.

Johnston, L. G., Malekinejad, M., Kendall, C., Iuppa, I. M. and Rutherford, G. W. (2008) ‘Implementation challenges to using respondent-driven sampling methodology for HIV biological and behavioral surveillance: Field experiences in international settings’, *AIDS and Behavior*, Vol. 12 (Supplement), pp. S131-S141.

Kalton, G. (2009) ‘Methods for oversampling rare subpopulations in social surveys’, *Survey Methodology*, Vol. 35, No. 2, pp. 125-141.

Kayembe, P. K., Mapatano, M. A., Busangu, A. F., Nyandwe, J. K., Musema, G. M., Kibungu, J. P., Mashinda D.K., Matamba L. T. and Mayala G. M. (2008) ‘Determinants of consistent condom use among female sex workers in the Democratic Republic of Congo: Implications for interventions’, *Sexually Transmitted Infections*, Vol. 84, pp. 202-206.
Kendall, C., Kerr, L. R., Gondim, R. C., Werneck, G. L., Macena, R. H., Pontes, M. K., Johnston L., Sabin K. and McFarland W. (2008) ‘An empirical comparison of respondent-driven sampling, time-location sampling, and snowball sampling for behavioral surveillance in men who have sex with men, Fortaleza, Brazil’, *AIDS and Behavior*, Vol.12, pp. S97-S104.

Kish, L. (1991) ‘Taxonomy of elusive populations’, *Journal of Official Statistics*, Vol. 7, pp. 340-347.

Klovdahl, A.S. (1989) ‘Urban social networks: Some methodological problems and possibilities’ in M. Kochen, (editor) *The Small World* (pp. 176-210). New Jersey: Norwood Press.

Lepkowski, J. (1991) ‘Sampling the difficult to sample’, *Journal of Nutrition*, Vol. 121, pp. 416-423.

Levy, P. & Lemshow, S. (1991) *Sampling of populations: Methods and applications*. New York, N.Y.: John Wiley and Sons.

Ma, X., Zhang, Q., He, X., Sun, W., Yue, H., Chen, S., Raymond, F., Li, Y., Xu, M., Du, H. and McFarland, W. (2007) ‘Trends in prevalence of HIV, syphilis, hepatitis C, hepatitis B, and sexual risk behavior among men who have sex with men’, *Journal of Acquired Immune Deficiency Syndrome*, Vol. 45, No. 5, pp. 581-587.

Mackellar, D., Valleroy, L., Karon, G., Lemp, G. and Janssen, R. (1996) ‘The Young Men's Survey: Methods for estimating HIV seroprevalence and risk factors among young men who have sex with men’, *Public Health Reports*, Vol. 111, pp. 138-144.

Mackellar, D. A., Gallagher, K. M., Finlayson, T., Sanchez, T., Lansky, A. and Sullivan, P. S. (2007) ‘Surveillance of HIV risk and prevention behaviors of men who have sex with men—A national application of venue-based, time-space sampling’, *Public Health Reports*, Vol. 122, pp. 39-47.

McKnight, C., Des Jarlais, D., Bramson, H., Tower, L., Abdul-Quader, A.S., Nemeth, C. and Heckathorn, D. (2006) ‘Respondent-driven sampling in a study of drug users in New York City: Notes from the field’, *Journal of Urban Health*, Vol. 83, pp. 54-59.

Malekinejad, M., Johnston, L. G., Kendall, C., Kerr, L. R., Rifkin, M. R. and Rutherford, G. W. (2008) ‘Using respondent-driven sampling methodology for HIV biological and behavioral surveillance in international settings: A systematic review’, *AIDS and Behavior*, Vol. 12, pp. S105-S130.

McKenzie, D.J. and Mistiaen, J. (2009) ‘Surveying migrant households: A comparison of census-based, snowball, and intercept point surveys’, *Journal of the Royal Statistical Society*, Series A, Vol. 172, No. 2, pp. 339-360.

Mills, S., Saidel, T., Magnani, R. and Brown, T. (2004) ‘Surveillance and modeling of HIV, STI, and risk behaviours in concentrated HIV epidemics’, *Sexually Transmitted Infections*, Vol. 80, pp. ii57-ii62.

Muhib, F. B., Lin, L. S., Stueve, A., Miller, R. L., Ford, W. L., Johnson, W. D. and Smith, P.J. (2001) ‘A venue-based method for sampling hard-to-reach populations’, *Public Health Reports*, Vol. 116, pp. 216-222.

NETDRAW (2008) NETDRAW. http://www.analytictech.com/downloadnd.htm/

Platt, L., Wall, M., Rhodes, T., Judd, A., Hickman, M., Johnston, L., Renton, A., Bobrova, N. and Sarang, A. (2006) ‘Methods to recruit hard-to-reach groups: Comparing two chain referral sampling methods of recruiting injecting drug users across nine studies in Russia and Estonia’, *Journal of Urban Health*, Vol. 83, pp. 39-53.
Pollack, L. M., Osmond, D. H., Paul, J. P. and Catania, J. (2005) ‘Evaluation of the Centers for Disease Control and Prevention's HIV behavioral surveillance of men who have sex with men: Sampling issues’, *Sexually Transmitted Diseases*, Vol. 32, pp. 581-589.

RDSAT, V. 5. 6. 0. (2008) RDSAT. http://www.respondentdrivensampling.org/

Remafedi, G., Jurek, A. M., and Oakes, J. M. (2005) ‘Sexual identity and tobacco use in a venue-based sample of adolescents and young adults’, *American Journal of Preventive Medicine*, Vol. 35, pp. S463-S470.

Respondent-driven Sampling (2009) Respondent-driven sampling [overview]. Available at www.respondentdrivensampling.org

Robinson, W., Risher, J., McGoy, S., Becker, A. Rehman, H., Jefferson, M., Griffin, V., Wolverton, M. and Tortu, S. (2006) ‘Recruiting injection drug users: A three-site comparison of results and experiences with respondent-driven and targeted sampling procedures’, *Journal of Urban Health*, Vol. 83, pp. 29-38.

Salganik, M. J. (2006) ‘Variance estimation, design effects, and sample size calculations for respondent-driven sampling’, *Journal of Urban Health*, Vol. 83, pp. 98-112.

Semaan, S., Heckathorn, D. D., Des Jarlais, D. C. and Garfein, R. S. (2010) ‘Ethical considerations in surveys employing respondent-driven sampling’, *American Journal of Public Health*, Vol. 100, No. 4, pp. 582-583.

Semaan, S., Lauby, J., and Liebman, J. (2002) ‘Street and network sampling in evaluation studies of HIV risk-reduction interventions’, *AIDS Review*, Vol. 4, pp. 213-223.

Semaan, S., Santibanez, S., Garfein, R. S., Heckathorn, D. and Des Jarlais D.C. (2009) ‘Ethical and regulatory considerations in HIV prevention studies employing respondent-driven sampling’, *International Journal of Drug Policy*, Vol. 20, No. 14-27.

Spreeen, M. and Swaagstra, R. (1994) ‘Personal network sampling, outdegree analysis, and multilevel analysis: Introducing the network concept in studies of hidden populations’, *International Sociology*, Vol. 9, pp. 475-491.

Stueve, A., O'Donnell, L. N., Duran, R., San Doval, A. and Blome, J. (2001) ‘Time-space sampling in minority communities: Results with young Latino men who have sex with men’, *American Journal of Public Health*, Vol. 91, pp. 922-926.

Stormer, A., Tun, W., Guli, L., Harxhi, A., Bodanovskaia, Z., Yakovleva, A., Rusakova, M., Levina, O., Bani, R., Rjepaj, K. and Bino, S. (2006) ‘An analysis of respondent driven sampling with injection drug users (IDUs) in Albania and the Russian Federation’, *Journal of Urban Health*, Vol. 83, pp. 73-82.

Sudman, S., Sirken, M. and Cowan, C. (1988) ‘Sampling rare and elusive populations’, *Science*, Vol. 240, pp. 991-996.

Thompson, S. K. and Collins, L. M. (2002) ‘Adaptive sampling in research on risk related behaviors’, *Drug and Alcohol Dependence*, Vol. 68, pp. S57-S67.

Uuskula, A., Johnston, L. G., Raag, M., Trummal, A., Talu, A. and Des Jarlais, D. C. (2010) ‘Evaluating recruitment among female sex workers and injecting drug users at risk for HIV using respondent-driven sampling in Estonia’, *Journal of Urban Health*, Vol. 87, No. 2, pp. 304-317.
