PUBLIC HEALTH 160 (2018) 81–86

Available online at www.sciencedirect.com

Public Health

journal homepage: www.elsevier.com/puhe

Original Research

Combining the randomized response technique and the network scale-up method to estimate the female sex worker population size: an exploratory study

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ARTICLE INFO

Article history:
Received 3 October 2017
Received in revised form
28 March 2018
Accepted 4 April 2018
Available online 21 May 2018

Keywords:
Network scale-up method
Female sex worker
Population size

ABSTRACT

Objectives: Recall bias, barrier effects, transmission error, and response bias affecting the network scale-up method (NSUM) led the Joint United Nations Programme on HIV/AIDS and the World Health Organization to designate NSUM as a developing method for estimating the size of high-risk populations in 2010. The method has subsequently been adjusted for three of these biases. The present study, therefore, aimed to explore the combination of the randomized response technique (RRT) and NSUM to adjust the last remaining bias.

Study design: RRT was used in an NSUM survey to estimate the population proportion of female sex workers (FSWs) in Taiyuan, China, in 2012.

Methods: Multiplier method estimates and national-level estimates of the population proportion of FSWs were used as criteria to assess the aforementioned results.

Results: Successful interviews were completed with 96.4% of the respondents selected for the NSUM survey. The NSUM estimate fell within the range of the national-level estimates of the population proportion of FSWs in Asia and was close to the estimate yielded by the multiplier method.

Conclusions: In the present study, the combination of RRT and NSUM obtained a high response rate and produced a reliable estimate of the size of a high-risk population.

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https://doi.org/10.1016/j.puhe.2018.04.002

Introduction

High-coverage interventions are required to reduce HIV transmission effectively among populations at high risk for HIV, such as female sex workers (FSWs), injecting drug users (IDUs), and men who have sex with men (MSM), and reliable estimates of the size of these high-risk populations are essential for comprehensive combination HIV prevention.[1–3] Therefore, the Joint United Nations Programme on HIV/AIDS (UNAIDS) and the World Health Organization (WHO) have explored various size estimation methods.[1,2] Unfortunately, data on the estimated size of high-risk populations in many countries remain unavailable.[4] There is a strong need for developing more cost-effective size estimation methods, especially for use in developing countries. For this reason, in 2010, the network scale-up method (NSUM) became the latest method recommended by UNAIDS and the WHO.[2] This method has the unique advantage of producing size estimates for multiple high-risk populations using a single survey.[2,5] This means that, using NSUM, size estimates for FSWs, IDUs, and MSM could be generated through one survey, in contrast to all of the previous methods which were only able to estimate the size of one of these populations per survey. Therefore, a successful NSUM survey is comparable to a cross-sectional study that is able to produce a data set containing the comprehensive and current information necessary for a successful and rapid HIV/AIDS response.

Unfortunately, NSUM was characterized by four known biases that required adjustment, leading UNAIDS and the WHO to consider it a developing method. These biases are recall bias, barrier effects, transmission error, and response bias.[2] In 2010, McCormick et al.[6,7] adjusted for recall bias, and in 2011, Salganik et al.[8,9] adjusted for barrier effects and transmission error. Thus, adjusting for response bias is the last step in improving NSUM. In an NSUM survey, respondents from the general population are required to report the proportion of high-risk individuals in their personal networks. However, such sensitive questions often cause response bias, which influences respondents to answer in ways that are not genuine.[2,5,10] Thus, protecting the privacy of respondents is the most important factor in obtaining an accurate or truthful response when sensitive questions are asked. The randomized response technique (RRT) is a survey technique designed to eliminate response bias. This technique allows respondents to answer a question that is randomly received from a pool of sensitive and unrelated survey questions.[10,11] The researchers implementing this technique do not know which question the respondent is answering. Before the interview, respondents will be told how the RRT works, so they know no one knows the question they are answering. Therefore, sensitive questions are more likely to be answered truthfully.[10,11] After the interview, the researchers can use a formula to calculate the mean response of the sensitive question. As a result, for the respondents, privacy is protected. In the meantime, for the researcher, the truthful information can be obtained, although it is at the population level instead of the individual level. The present study aimed to explore the combination of RRT and NSUM to adjust for response bias in NSUM.

Study design

RRT was used in an NSUM survey to estimate the population proportion of FSWs in the female population aged 15–49 years in the urban district of Taiyuan, China, in 2012.

Methods

The estimate of the population proportion of FSWs in this same time period and location yielded by the multiplier method and national-level estimates of the population proportion of FSWs in Asia were used as criteria to assess the results. As a method recommended by UNAIDS and the WHO, the multiplier method has been the most commonly used method for estimating the size of high-risk populations.[1,2,12] The national-level estimates of the population proportion of FSWs in Asia were taken from a worldwide systematic literature review on the population proportion of FSWs in the female population aged 15–49 years.[13] MEDLINE and the relevant surveillance reports from national or regional branches of the WHO and UNAIDS from 1995 to 2005 were searched. Published and unpublished studies from 57 cities in Asia were reviewed, and mapping, census, and the multiplier method were applied to estimate the population proportion of FSWs.

The multiplier method

The multiplier method uses overlapping information from two data sources to estimate the size of a high-risk population. The first source should be available data from a random or non-random program, where the high-risk individuals attend institution or service. The second source should be a representative survey, where respondents from the high-risk population provide information on whether they participated in the program. The number of participants is divided by the proportion of the respondents to the survey stating that they participated in the program to estimate the size of the high-risk population. To apply this method, two assumptions should be met: (1) every member of the high-risk population was given the chance to participate in the program and to respond to the survey; and (2) participating in the program is independent of being a respondent to the survey.[1,2,12,14]

The network scale-up method

NSUM was proposed by Bernard, Killworth, Johnsen, and Robinson in 1991,[15] based on the basic principle of the personal network structure of the general population reflecting the social network structure in a given region.[16–22] Initially, NSUM is conducted in two steps. The first step is the estimation of the average size of the personal networks of the general population (c_0) using the known populations method in a region with the formula $c_0 = (m_0 \times t)/e_0$, where t is the latest annual average population in the region; e_0 is the sum of a list of specific populations, such as those whose last names are on a given list of last names (e.g. An, Chang, Lan, Mei, Mo, and Niu), for which the actual size of the population is known by researchers (hereafter in this text, these populations are described as known populations); and m_0 is the sum of reported known populations in the personal network of each respondent from the general population. Membership in a personal network was defined using the following statement: 'They know you and you know them by name or by sight, they live in this region, and you have had some contact with them in the past 12 months.'[6,7,23–26] The second step in conducting NSUM is estimating of the size of the high-risk populations (e_1) in the region using the formula $e_1 = (m_1/c_0) \times t$, where m_1 is the reported average number of high-risk population members in the personal network of each respondent from the general population, c_0 is the average size of the personal networks of the general population in the region, and t is the latest annual average population in the region.[16–22,26]

As was introduced previously, recall bias, barrier effects, transmission error, and response bias affect the results of NSUM.[2,5,8,9,26] First, recall bias can result in the average size of personal networks being difficult to estimate accurately. The known population method asks respondents how many people there are in their personal networks from a list of specific populations. This method is highly dependent on each respondent having an accurate memory. Fortunately, in 2010, McCormick et al.[6] verified that recall bias can be minimized through the approach of using given last names, with each accounting for 0.1–0.2% of the urban population in a region, as a known population to estimate the average size of personal networks. The second bias is barrier effects, which concern the possibility that the opportunity of members of the high-risk population to be members of the personal networks of the general population may be reduced because of the hidden nature of the high-risk population, who have a smaller average personal network size.[5,8,9] In 2010, Salganik et al.[8,9] used the popularity ratio (δ) of the high-risk population to adjust for barrier effects. The third bias is transmission error, which results from the fact that the members of the personal networks of the high-risk population may be unaware that these people engage in high-risk behaviors.[5,8,9,26] The information transmission rate (τ) of the high-risk population was used to adjust for transmission error by Salganik et al. in 2010.[8,9]

Randomized response technique

RRT was first proposed by Warner in 1965 and then developed by Greenberg in 1969.[10,11] Unrelated question RRT model allows respondents to answer with a quantitative response rather than responding 'yes' or 'no.' In a survey, respondents are randomly split into two groups. Respondents of one group randomly receive a sensitive question or an unrelated question, with the proportion of the two questions indicated by *m:n*. The proportion of the two questions for the second group of respondents is *n:m*. The researchers do not know which question a respondent is answering; therefore, the privacy of the respondents is protected, and sensitive questions are more likely to be answered truthfully. The researchers can then use a formula to calculate the mean response to the sensitive question:

$$\mu = \frac{(1 - P_2) \times \mu_1 - (1 - P_1) \times \mu_2}{P_1 - P_2}, \qquad (1)$$

where μ_1 is the mean of responses from group one, μ_2 is the mean of responses from group two, P_1 is $m/(m+n)$ (i.e. the proportion of sensitive questions in group one), P_2 is $n/(m+n)$ (i.e. the proportion of unrelated questions in group two). In recent years, parameter estimation of RRT in complex sampling was explored. In 2009, Zhu et al.[27] developed formulae for the mean and variance in a stratified two-stage cluster survey using the unrelated question RRT model.

Field survey

The multiplier method

To use the multiplier method to estimate the population proportion of FSWs in Taiyuan, the available data were obtained from the outpatient records of 12 sexually transmitted infection (STI) clinics (the first source) from June 2012 to August 2012 and the field survey was from a respondent-driven sampling (RDS) survey (the second source) in which 301 respondents from the FSW population were interviewed from September to October 2012. A bootstrap method (10,000 resamples) was used to calculate the 95% confidence interval (CI) for the RDS survey.[28–30]

The network scale-up method

NSUM was applied to estimate the population proportion of FSWs in the urban district of Taiyuan, China, in 2012. In general, NSUM uses information collected in household surveys of the general population to estimate c_0 and e_1.[1,2,26] We piloted a household survey in this study. Unfortunately, the response rate was very low (11%). Respondents were embarrassed by sensitive questions asked in household settings, such as those asking them to admit that there were FSWs in their personal networks. Therefore, we administered a survey of the general population in respondents' workplaces. A stratified two-stage cluster survey of the general population was conducted in Taiyuan. According to the sample size estimation formulae for stratified multistage sampling, in total, 174 institutions, organizations, and companies (primary units) from all 20 sectors (industry, agriculture, manufacturing, transportation, construction industry, service industry, public administration and social organization, and so forth) were drawn in the first stage. In the second stage, 405 departments (second-stage units) were selected. Finally, 8031 individual respondents from the departments chosen in the second stage (third-stage units) were interviewed in their workplaces. An additional 231 unemployed respondents were interviewed in their former workplaces. In our surveys, respondents were first asked how many people in their personal networks had last names on a list of 48 last names. Each of the 48 last names accounted for 0.1–0.2% of the urban population of Taiyuan (population information from the Public Security Bureau of Taiyuan). Respondents then are randomly split into two groups. Respondents in group one randomly received a sensitive question or an unrelated question, and the proportion of the two questions was 8:2. This proportion for group two was 2:8. The sensitive question was 'How many FSWs are there in your personal network?', and the unrelated question was 'How many hours do you spend reading newspapers per week on average?' All of the surveys were conducted from March to October 2012.

In addition, an RDS survey of the FSW population was conducted to estimate the popularity ratio and the information transmission rate in Taiyuan, and 301 respondents belonging to the FSW population were interviewed from September to October 2012. Respondents were asked how many people there were in their personal networks whose last names were on a list of 48 last names and how many of these people were aware of their high-risk behavior.

Results

Results based on the multiplier method

The data analysis was conducted in 2012. A total of 1607 FSWs attended the 12 STI clinics in Taiyuan from June to August 2012. Of these individuals, 34 were interviewed in the RDS survey from September to October 2012, accounting for 11.3% (34/301) of the respondents to the survey. Therefore, the estimated population size of FSWs in Taiyuan was 14,221 (1607/11.3%; 95% CI: 6753–26,101), accounting for 1.55% (95% CI: 0.74%–2.84%) of the female population aged 15–49 years.

Results obtained with NSUM

The data analysis was conducted in 2012. Ultimately, 96.4% (7964/8262) of the selected respondents from the general population were successfully interviewed. The annual average population (t) in the urban district of Taiyuan in 2012 was 3,454,927. The sum of 48 known populations of given last names (e_0) was 242,368. The average of reported known populations in the personal network of each respondent from the general population (m_0) was 9.61. Therefore, the maximum likelihood estimate of the average size of the personal networks of the general population (c_0) in the urban district of Taiyuan was 137 ([9.61 × 3,454,927]/242,368). Similarly, the estimate of the average size of the personal networks of the FSW population was 56 ([3.93 × 3,454,927]/242,368), and the average size of the personal networks of the FSW population, counting only those members of the personal networks of the FSW population who are aware of their high-risk behaviors, was 45 ([3.14 × 3,454,927]/242,368). Therefore, the popularity ratio (δ) was 0.41 (56/137; 95% CI: 0.35–0.46), and the information transmission rate (τ) was 0.8 (45/56; 95% CI: 0.77–0.84). δ and τ were collected in the RDS survey of the FSW population; therefore, a bootstrap method (10,000 resamples) was used to calculate the 95% CI for δ and τ.

The reported average number of FSW population members in the personal network of each respondent from the general population (m_1) was 0.15. Therefore, the initial NSUM estimate of the size of the FSW population (e_1) in Taiyuan was 3866 ($e_1 =$ [0.15/137] × 3,454,927; 95% CI: 3532–4201), corresponding to 0.42% (95% CI: 0.39%–0.46%) of the female population aged 15–49 years. Finally, δ and τ were used to adjust the initial NSUM estimate. Therefore, the adjusted NSUM allowed us to estimate the number of FSWs in Taiyuan to be 11,787 (3866/[0.41 × 0.80]; 95% CI: 10,767–12,808), corresponding to 1.3% (95% CI: 1.17%–1.4%) of the female population aged 15–49 years.

Discussion

In China, all provinces are divided into seven grades according to the number of people living with HIV/AIDS (PLHIV) as determined by the Ministry of Health of China, UNAIDS, and WHO in 2011.[31] Taiyuan is the capital city of Shanxi province (the third PLHIV grade is 5000–10,001), which is close to the middle grade of all provinces. The adjusted NSUM estimate (1.3%) in Taiyuan fell within the middle of the range of the national-level estimates of the population proportion of FSWs (0.2–2.6%).[13] Additionally, the adjusted NSUM estimate was close to the estimate of the multiplier method in Taiyuan (1.55%; Fig. 1). Therefore, the adjusted NSUM estimate of FSWs in Taiyuan truly reflects the actual situation. So far there has been another adjusted NSUM application in China, which was used to estimate the population proportion of FSWs in Harbin in 2011.[32] The adjusted NSUM estimate in Harbin (0.75%) was

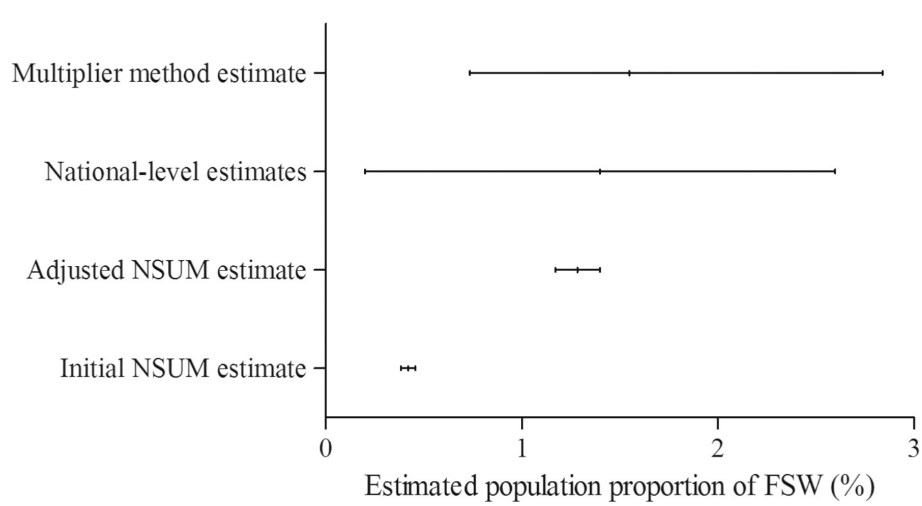

Fig. 1 – Adjusted NSUM estimate compared with the multiplier estimate and national-level estimates. NSUM, network scale-up method; FSW, female sex worker.

lower than that in Taiyuan (1.3%). There may be two reasons: (1) Harbin is the capital city of Heilongjiang province, which is a lower PLHIV grade (the second PLHIV grade is 1001–5000); and (2) only popularity ratio ($\delta = 0.24$) was used to adjust the NSUM estimate, but information transmission rate (τ) was not calculated.

As it is more cost-effective than other available methods, the successful adjustment of NSUM for the four biases described in this article makes NSUM likely to be the most promising approach for estimating the size of high-risk populations. In our study, 48 known populations of given last names, each accounting for 0.1–0.2% of the urban population of Taiyuan, were used to adjust for recall bias in estimating the average size of personal networks. These known populations worked well in that the 48 population sizes reported by the respondents were strongly correlated with the 48 actual population sizes ($r = 0.79$, $P < 0.01$).

In 2011, popularity ratio (δ) and information transmission rate (τ) have been used to adjust the estimate of the IDU population size by Salganik et al.[8,9] The estimates of δ and τ of IDU in Brazil were 0.69 and 0.77, respectively. In our study, the estimate of δ of the FSW population was 0.41, indicating that the average size of the personal networks of the FSW population was only 41% of the average size of the personal networks of the general population. Barrier effects thus reduced the opportunity for FSWs to be members of the personal networks of the general population by 59% because of the hidden nature of the FSW population, with its smaller average personal network size.[17–22] Additionally, the estimate of τ of the FSW population was 0.8, indicating that 80% of the members of the personal networks of the FSW population were aware of their high-risk behaviors. In 2012, we also used δ and τ to adjust the NSUM estimate of the MSM population size in Taiyuan.[33] The estimates of δ and τ were 1.06 and 0.048, respectively. There is a large variation between the different high-risk populations, although in the same place and at the same time. However, in the study of FSWs in Harbin in 2011 mentioned previously, the estimate of δ (0.24) was close to the estimate of δ (0.41) of FSWs in Taiyuan (τ of FSWs in Harbin was not calculated).[32] Additionally, so far there has been another adjusted NSUM application to estimate the population proportion of MSM, which was used in Japan in 2012.[34] The estimate of τ (0.014) was close to the estimate of τ of the MSM population in Taiyuan in 2012 (0.048; δ of MSM in Japan was not calculated). It seems that there is not much difference in the same high-risk population and similar social background.

The fourth bias requiring adjustment is response bias. RRT was experimentally used to interview the general population in an NSUM survey for the first time. Indeed, the main principle of RRT is to protect the privacy of respondents; therefore, the following measures were also experimentally proposed to assist in the implementation of RRT: (1) no personally identifying information was collected; (2) both the sensitive question and the unrelated question for e_1 were printed on the inside of an envelope, resulting in no one but the respondent knowing which question he or she was answering; (3) each respondent wrote their answers on a separate answer sheet where the question being answered did not appear, so the researchers did not know which question was answered by the respondent; (4) the respondents were asked to place their answer sheets in a ballot box when the interview was finished, so the researchers did not know which answer sheet was completed by which respondent; and (5) respondents were encouraged to submit an uncompleted sheet instead of answering untruthfully if they still felt embarrassed, despite the use of RRT. Only 297 respondents (3.6%) submitted uncompleted sheets; therefore, RRT ensured that 96.4% of the respondents were successfully interviewed.

In this study, a combination of RRT and NSUM obtained a high response rate and produced a reliable estimate of the size of a high-risk population. Unfortunately, we were unable to conduct a household survey of the general population in the present study. Additionally, we could not estimate the variance of adjusted NSUM estimate at present because this has not yet been worked out mathematically. Thus, the lower and upper limits of the 95% CI for the initial NSUM estimate were divided by δ and τ to estimate the lower and upper limits of the 95% CI for the adjusted NSUM estimate. Consequently, the 95% CI for the adjusted NSUM estimate presented here is not a true 95% CI, and future work should address this issue to improve the estimates of this parameter.

Author statements

Ethical approval

The study was approved by the Medical Ethics Committee of Shanxi Medical University.

Funding

This project was financially supported by MOE (Ministry of Education in China) Youth Fund Project of Humanities and Social Sciences (Project No. 14YJC840014) and Doctoral Startup Research Fund of Shanxi Medical University (Project No. 03201411).

Competing interests

We have no competing interests to disclose.

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