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ORIGINAL PAPER

An Innovative Approach to Assess Similarity Between Sex Partners

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Abstract
We present a simple, comprehensive method for assessing similarity between sex partners of a participant and demonstrate its application using data collected in 2015 as part of CDC's National HIV behavioral surveillance (NHBS) among persons who inject drugs (PWID). We found that the pairwise similarity between sex partners of a survey participant was high. The similarity between second-to-last and third-to-last partners in the past 3 months was significantly higher than that between last and second-to-last partner in partner type, frequency of sex acts, and the contextual characteristics of sex behavior at last sexual encounter. The proposed approach provides an innovative measure of the added value of multi-partner series. The empirical analysis suggests that querying additional sex partners contributes limited data to characterize a participant's sexual behaviors among NHBS PWID. Future studies should apply the proposed method to evaluate the added value of data on multiple sex partners among other populations.

Keywords Pairwise similarity · Sex partners · HIV · Behavioral surveillance · Persons who inject drugs

Introduction

In many HIV-related behavioral surveys, researchers assess sexual risk behavior by asking participants specifically about their sexual activities with each partner for a certain number of partners [1, 2]. These detailed partner specific data, such as frequencies of vaginal and anal sex with and without condoms and number of unprotected sex acts with an infected individual can inform estimation of transmission risk and are required for studies that model transmission dynamics [3], evaluate intervention effectiveness [4, 5], and seek to explain disparities [6]. Collecting partner specific data also may facilitate survey participants' recall of previous experiences or events [7, 8]. However, collecting partner specific data can increase questionnaire length, data complexity, and participant burden, resulting in abbreviated answers and less assessment time or withdrawal from the survey [5]. For survey participants with a lower educational attainment, complicated lengthy questionnaires could further affect data accuracy of self-reports [8]. Therefore, it is important to assess whether sexual behavior data from one sex partner (e.g. the last sex partner) are sufficiently representative of those from other sex partners, and to evaluate the potential gains from additional sex partner data beyond data on the last sex partner. Results of these evaluations can inform the future design of behavioral surveys and prevention studies, help researchers prioritize limited research resources, and reduce burden for survey participants.

Although identifying an optimal number of sex partners on which to query participants regarding their sexual activities is important for the design of HIV-, and sexually transmitted infection (STI)-related behavioral studies, there has been very limited research on this topic. Pinkerton et al. [9] assessed the trade-off between the level of sexual behavior detail and the precision of HIV/STI acquisition risk estimates and concluded that aggregate only or aggregate plus detailed information from a partner with whom the respondent most often had unprotected sex, produced estimated HIV risk with very low error and that details on more partners did not appreciably reduce the percentage of error. Pequegnat et al. [5] conducted an empirical analysis to identify the minimum number of sexual partners the participant should be

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asked about to generate an effective predictor of sexual risk behavior (specifically, condomless sex with a non-spousal/non live-in partner), and found that 95% of the sexual risk behavior was captured by asking about two partners.

The goal of this study is to assess the similarity between participants' sex partners in terms of their demographic characteristics and the sexual activities they had with the participant. While the analysis of the Pequegnat study is straightforward and the results are informative, they only focused on one measure. This study approaches the question from the similarity-based perspective, assesses partners' similarity in multiple dimensions and provides rich information for evaluation. We hypothesize that if the survey participant engaged in similar sexual activities with his or her sex partners, querying on sexual behaviors with one partner should provide sufficient information to characterize the participant's sexual risk behavior and querying on additional sex partners may yield diminishing returns.

We describe development of simple and comprehensive similarity measures to calculate a pairwise similarity index, which quantifies the similarity between a pair of sex partners through a series of questions asked for each of them. A high similarity index between a pair of partners in terms of sexual risk behaviors suggests that the participant engaged in similar sexual activities with both partners, thus, sexual risk behavior data collected from querying one partner should provide sufficient information about overall sexual behavior. The proposed similarity measures are original and general and can be applied to other domains or analyses.

Methods

Data Source

Since 2003, the Centers for Disease Control and Prevention's National HIV behavioral surveillance (NHBS) has monitored HIV-associated behaviors and HIV prevalence in cities with high HIV prevalence among 3 populations at high risk for infection: persons who inject drugs (PWID), men who have sex with men, and heterosexual adults at increased risk for HIV infection [10]. Beginning in 2015, survey participants were asked questions about their last sex partner, second-to-last partner, and third-to-last partner in the 3 months prior to interview, when applicable. Cross-sectional data used in this analysis are from PWID recruited for interviews and HIV testing through respondent-driven sampling (RDS) from 20 cities in 2015. NHBS RDS procedures have been previously described and are briefly summarized here [11]. Persons were eligible to participate if they had injected drugs in the previous 12 months, resided in a participating city, were aged ≥ 18 years, and could complete the interview in English or Spanish. Drug injection in the last 12 months was confirmed by observing physical evidence of recent injection (e.g., track marks) and by assessing knowledge of injection practices. Recruitment chains in each city began with initial participants identified during formative assessment, by referral from persons who knew the local population of PWID or through outreach to areas with PWID. Participants who completed the interview were asked to recruit up to 5 other PWID. This recruitment process continued until the sample size had been reached or the sampling period ended. Incentives were given for participating in the survey and HIV testing as well as for recruiting others. Interviews were conducted by trained interviewers using a standardized questionnaire covering demographics, HIV-associated behaviors, and use of HIV prevention and testing services. NHBS activities were approved by local institutional review boards (IRB) in each of the 20 participating cities.

For each study participant, up to 16 questions were asked for each of up to three sex partners: the last sex partner (hereafter referred to as partner 1), the second-to-last sex partner (hereafter referred to as partner 2) and the third-to-last sex partner (hereafter referred to as partner 3) in the 3 months preceding the interview. The 16 questions can be categorized into four domains: sex partner's demographics, partner type, frequency of sex with the partner in the three months prior to the interview, and contextual characteristics of sex activities with the partner at last sexual encounter. The three demographic questions include partner's gender, age in five categories (i.e. 24 years or younger, 25–29 years, 30–39 years, 40–49 years, and 50 years or older) and race/ethnicity in 6 categories (i.e. American Indian or Alaska Native, Asian, black or African American, Hispanic or Latino, Native Hawaiian or other pacific islander, and white). The partner type question asks whether the sex partner was a main partner (someone the participant feels committed to above anyone else) or a casual partner (someone the participant does not feel committed to or doesn't know well). Eight questions assess the frequency of sex with each partner in the three months prior to the interview, including vaginal sex, vaginal sex with condoms, anal sex, anal sex with condoms, insertive anal sex, insertive anal sex with condoms, receptive anal sex, and receptive anal sex with condoms. Because the variables for the frequency of sex acts were highly skewed to large positive numbers, we converted them to categorical variables with 5 levels (0, 1, 2–5, 6–10, >10 sex acts) for analysis. Four binary questions assessed contextual characteristics of the last sexual encounter with each partner, including whether the partner gave the participant money or drugs, whether the participant gave the partner money or drugs, whether the participant knew the partner's HIV status and whether the partner's HIV status was positive or negative.

Partner similarity was assessed for male and female participants separately because different questions were asked of males and females to assess their HIV risk behaviors. Female participants were asked only about their male partners but male participants were asked about both female and male partners. Consequently, the partner-specific questions for female participants excluded partner gender. In addition, male participants with male partners were asked questions to assess the frequency of anal sex by role (insertive and receptive) instead of a single frequency of anal sex question asked about opposite sex partners. Female participants were asked whether they received items in exchange for sex with male partners. Male participants were asked whether they gave items in exchange for sex with female partners and whether they gave or received items in exchange for sex with male partners.

Similarity Measure

Assuming that there are n participants in the survey, and each participant is asked a series of questions for all sex partners (up to, and including the three most recent). We calculate a similarity index between each pair of sex partners. The similarity index between two partners is first calculated for each participant, then averaged across all participants.

Denote by i the study participants, $i = 1, \ldots, n$, by j the question, and by s_{ij} the similarity measure for the question j between participant i's two sex partners. The similarity measure for question j between participant i's two partners is calculated using the following algorithm. If the answer to question j is

1. A binary or a nominal categorical variable, then s_{ij} is set to 1 if the two partners had the same values, and 0 otherwise.
2. An ordinal categorical variable, i.e. having values that can be ordered from minimum to maximum, then s_{ij} is set to 1—[absolute difference in the values between the two partners/(maximum − minimum)].
3. A continuous numerical variable, e.g. a person's age, then s_{ij} is set to 1/exp(absolute difference in the values between the two partners). Note: this particular case is not illustrated in the current analysis, but the measure is included here for other users.

The overall similarity index between a pair of partners (e.g., partner 1 and partner 2) for question j, s_j, is the average of the similarity measure s_{ij} across all study participants, that is $s_j = \frac{\sum_{i=1}^{n} s_{ij}}{n}$, with variance $V(s_j) = \frac{\sum_{i=1}^{n} (s_{ij} - s_j)^2}{\mathrm{n}-1}$.

Questions in the same category can be grouped into domains. Assuming there are k questions in a domain, the similarity measure between participant i's two partners for the domain is $\frac{\sum_{j=1}^{k} s_{ij}}{k}$. The overall similarity index between a pair of partners with respect to a domain, SI, is the average of domain similarity measure across all study participants. That is, $SI = \frac{\sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{k} s_{ij}}{k} \right)}{n}$.

The variance for the overall SI can be approximated by the standard deviation of the SI in the sample. That is,

$$V(SI) = \frac{\sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{k} s_{ij}}{k} - SI \right)^2}{\mathrm{n} - 1}.$$

Values of SI range from 0 to 1, with higher values representing higher similarity. We consider values over 0.75 as high, 0.5 to 0.75 as medium, and below 0.5 as low.

To check whether similarity is significantly higher or lower than a target level or to compare two SIs, a z-test is used. If two SIs share the same partner, the covariance between the two indices is calculated and used in the computation of standard error in the z-test statistic.

Results

In 2015, 10,431 male and female PWID participated in NHBS. Of these PWID, 30 were missing data about the number of sex partners they had in the 3 months prior to the interview. Of the remaining 10,401 PWID, 2785 reported no sex partners, 4327 reported only one partner, 1358 reported two partners, 634 reported three partners, and 1297 reported four or more partners in the 3 months prior to the interview (Table 1). PWID who had two or more partners in the 3 months prior to the interview were slightly younger (median age 42 vs. 45, $p < 0.0001$), and a higher proportion reported being ever homeless in the 12 months prior to the interview (71.2% vs. 60.5%, $p < 0.0001$) and no health insurance at the time of interview (29.7% vs. 24.6%, $p < 0.0001$) than those with zero or one partners.

Of the 3289 PWID who reported having two or more partners in the 3 months prior to the interview, most (71.1%) were male. (Table 1) About a third were white (37.7%), about a third were black (34.4%), and 734 (22.4%) were Hispanic/Latino. The majority reported income at or below the federal poverty level (77.6%), having health insurance at the time of interview (70.3%) and being ever homeless in the 12 months prior to the interview (71.2%).

There were 2338 male participants who reported two or more partners in the 3 months prior to the interview. Between partners 1 and 2, similarity was high for partner's gender (SI = 0.93) and age (SI = 0.79), and medium for race/ethnicity (SI = 0.66) and partner type (SI = 0.65). (Table 2) The similarities for frequency of sex acts and contextual characteristics of sex behaviors at last sexual encounter were generally high, with SI ranging from 0.71

Table 1 Demographic characteristics and risk factors among persons who inject drugs by number of partners in the 3 months prior to interview, National HIV behavioral surveillance, 20 United States Cities, 2015

Characteristics	Total		0 or 1 partner in the past 3 months						2 or more partners in past 3 months							
			0		1		Subtotal		2		3		4 and more		Subtotal	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Gender																
Male	7521	72.1	2116	76.0	3056	70.6	5172	72.7	999	73.6	496	78.2	843	65.0	2338	71.1
Female	2910	27.9	669	24.0	1271	29.4	1940	27.3	359	26.4	138	21.8	454	35.0	951	28.9
Race/ethnicity																
Black	3502	33.6	977	35.2	1385	32.1	2362	33.3	481	35.5	226	35.6	422	32.6	1129	34.4
Hispanic/latino	2349	22.6	645	23.2	968	22.4	1613	22.7	270	19.9	129	20.3	335	25.9	734	22.4
White	4001	38.4	1000	36.0	1749	40.5	2749	38.7	532	39.2	244	38.5	462	35.7	1238	37.7
Other	557	5.4	156	5.6	217	5.0	373	5.3	73	5.4	35	5.5	74	5.7	182	5.5
Age, years																
18–29	1766	17.4	311	11.5	796	18.9	1107	16.0	307	23.2	116	18.9	229	18.3	652	20.4
30–39	2436	24.1	498	18.4	1127	26.8	1625	23.5	334	25.2	145	23.6	327	26.2	806	25.3
40–49	2407	23.8	620	22.9	961	22.9	1581	22.9	304	22.9	163	26.5	351	28.1	818	25.6
≥50	3518	34.7	1273	47.1	1320	31.4	2593	37.6	381	28.7	191	31.1	343	27.4	915	28.7
Median (IQR)	44 (33–54)		49 (37–57)		42 (32–52)		45 (34–54)		41 (30–52)		43 (33–52)		43 (33–51)		42 (32–52)	
Federal poverty level																
Above	2303	22.3	589	21.3	978	22.8	1567	22.2	335	24.9	129	20.4	268	20.8	732	22.4
At or below	8047	77.7	2177	78.7	3311	77.2	5488	77.8	1012	75.1	502	79.6	1019	79.2	2533	77.6
Ever homeless during 12 months prior to the interview																
No	3768	36.1	1088	39.1	1724	39.8	2812	39.5	466	34.3	196	30.9	284	21.9	946	28.8
Yes	6663	63.9	1697	60.9	2603	60.2	4300	60.5	892	65.7	438	69.1	1013	78.1	2343	71.2
Current health insurance at the time of the interview																
No	2715	26.2	680	24.5	1062	24.7	1742	24.6	368	27.2	166	26.2	439	33.9	973	29.7
Yes	7648	73.8	2093	75.5	3246	75.3	5339	75.4	987	72.8	467	73.8	855	66.1	2309	70.3
Total	10,431		2785		4327		7112		1358		634		1297		3289	

IQR interquartile range

Race/ethnicity categories are mutually exclusive and Hispanic/Latino can be of any race

Table 2 Similarity index for each item and each domain between partners 1 and 2, 1 and 3, and 2 and 3 among males, National HIV Behavioral Surveillance among Persons who Inject Drugs, 20 United States Cities, 2015

	Partners 1 and 2			Partners 1 and 3			Partners 2 and 3			p value[a]		
	N	Mean	Std	N	Mean	Std	N	Mean	Std	1, 2 versus 1, 3	1, 2 versus 2, 3	1, 3 versus 2, 3
Demographics												
Gender	2327	0.93	0.26	1317	0.91	0.29	1316	0.91	0.29	0.05	0.06	0.92
Age	2318	0.79	0.20	1313	0.78	0.20	1311	0.77	0.20	0.70	0.04	0.13
Race/ethnicity	2313	0.66	0.48	1312	0.63	0.48	1308	0.62	0.48	0.17	0.09	0.77
Partner type												
Main versus casual	2325	0.65	0.48	1316	0.67	0.47	1315	0.84	0.36	0.28	< 0.001	< 0.001
Frequency of sex acts												
# vaginal sex[b]	1908	0.80	0.20	1007	0.80	0.21	1003	0.86	0.18	0.95	< 0.001	< 0.001
# vaginal with condoms[b]	1509	0.85	0.24	814	0.86	0.22	727	0.88	0.21	0.34	< 0.01	0.10
# anal sex[b]	1033	0.77	0.24	597	0.77	0.25	593	0.81	0.23	0.77	< 0.01	0.01
# anal with condoms[b]	254	0.88	0.21	172	0.90	0.19	124	0.90	0.22	0.44	0.56	0.97
# insertive anal[c]	215	0.78	0.25	164	0.81	0.24	168	0.84	0.22	0.27	0.02	0.31
# insertive anal with condoms[c]	82	0.91	0.19	66	0.94	0.17	52	0.96	0.12	0.43	0.11	0.55
# receptive anal[c]	214	0.81	0.24	164	0.84	0.21	168	0.86	0.19	0.36	0.11	0.50
# receptive anal with condoms[c]	55	0.89	0.19	47	0.95	0.14	33	0.90	0.19	0.12	0.78	0.28
Contextual characteristics of sex behaviors at last sexual encounter												
(Y/N) Receive money/drugs from partner[c]	160	0.71	0.45	122	0.72	0.45	129	0.81	0.40	0.89	0.09	0.16
(Y/N) give partner money/drugs	1167	0.71	0.45	771	0.71	0.45	771	0.76	0.42	0.95	0.01	0.03
(Y/N) know partner HIV status	2323	0.79	0.41	1317	0.77	0.42	1316	0.84	0.36	0.40	< 0.001	< 0.001
Partner's HIV status	690	0.93	0.25	343	0.93	0.26	342	0.94	0.25	0.72	0.96	0.70
Domain[d]												
Demographics	2327	0.79	0.20	1317	0.77	0.21	1316	0.77	0.21	0.04	0.01	0.54
Partner type	2325	0.65	0.48	1316	0.67	0.47	1315	0.84	0.36	0.28	< 0.001	< 0.001
Frequency of sex acts	2125	0.80	0.18	1174	0.81	0.18	1174	0.85	0.16	0.42	< 0.001	< 0.001
Contextual characteristics of sex behaviors at last sexual encounter	2323	0.76	0.37	1317	0.74	0.37	1316	0.81	0.33	0.27	< 0.001	< 0.001

Partner 1 refers to the last sex partner

Partner 2 refers to the second-to-last sex partner

Partner 3 refers to the third-to-last sex partner

[a]p value less than 0.05 indicates that the similarity between two sex partners is significantly different from that between a different pair of sex partners

[b]Only male participants with female sex partners were asked this question

[c]Only male participants with male sex partners were asked this question

[d]A domain includes a group of questions in the same category

to 0.93. When grouped into domains, the SI between partners 1 and 2 was 0.79 for demographics domain, 0.65 for partner type domain, 0.8 for frequency of sex acts domain and 0.76 for contextual characteristics of sex behaviors at last sexual encounter domain. The similarities between partners 1 and 3 were not significantly different from those between partners 1 and 2. There were 1339 male participants who reported three or more partners. Between partners 2 and 3, similarity was also high for gender (SI = 0.91), age (SI = 0.77) and partner type (SI = 0.84), and medium for race/ethnicity (SI = 0.62). The similarities for frequency of sex acts and contextual characteristics of sex behaviors at last sexual encounter were high, with SI ranging from 0.76 to 0.96. When grouped into domains, the SI between partners 2 and 3 was 0.77 for demographics domain, 0.84 for partner type domain, 0.85 for frequency of sex acts domain and 0.81 for contextual characteristics of sex behaviors at last sexual encounter domain. The similarities were higher between partners 2 and 3 than between partners 1 and 2 in partner type domain (0.84 vs. 0.65, $p < 0.001$), frequency of sex acts domain (0.85 vs. 0.80, $p < 0.001$) and contextual characteristics of sex behaviors at last sexual encounter domain (0.81 vs. 0.76, $p < 0.001$).

There were 951 female participants who reported two or more partners in the 3 months prior to the interview. Between partners 1 and 2, similarity was high for age (SI = 0.78), and medium for race/ethnicity (SI = 0.67) and partner type (SI = 0.54) (Table 3). The similarities for frequency of sex acts and contextual characteristics of sex behaviors at last sexual encounter were generally high, with SI ranging from 0.64 to 0.98. When grouped into domains, the SI between partners 1 and 2 was 0.73 for demographics domain, 0.54 for partner type domain, 0.76 for frequency of sex acts domain and 0.72 for contextual characteristics of sex at last sexual encounter domain. There were 592 female participants who reported three or more partners. The similarities between partners 1 and 3 were not significantly different from those between partners 1 and 2. Between partners 2 and 3, similarity was high for age (SI = 0.77) and partner type (SI = 0.82), and medium for race/ethnicity (SI = 0.64). The similarities for frequency of sex acts and contextual characteristics of sex behavior at last sexual encounter was high, with SI ranging from 0.80 to 0.99. When grouped into domains, the SI between partners 2 and 3 was 0.7 for demographics domain, 0.82 for partner type domain, 0.84 for frequency of sex acts domain and 0.81 for contextual characteristics of sex at last time domain. Except for the demographics domain, the similarities were higher between partners 2 and 3 than between partners 1 and 2 in partner type domain (0.82 vs. 0.54, $p < 0.001$), frequency of sex acts domain (0.84 vs. 0.76, $p < 0.001$), and contextual characteristics of sex behaviors at last sexual encounter domain (0.81 vs. 0.72, $p < 0.001$).

Note: The reported pvalues are calculated from available samples of different sizes. If we limited the comparison of similarities to persons with 3 or more sex partners, the p values were not different.

Discussion

In this paper, we developed a simple and comprehensive method based on the concept of similarity analysis to assess similarity between participants' pairs of multiple sex partners in a single item or a domain of combined items. We applied the proposed method to analyze the 2015 NHBS data among PWID. The results show that in this sample of PWID with two or more partners in the 3 months prior to interview from 20 U.S. cities, the pairwise similarity between a participant's sex partners was high. The similarity between second-to-last and third-to-last partners was significantly higher than that between last and second-to-last partner in partner type, frequency of sex acts in the past three months and the contextual characteristics of sex behavior at last sexual encounter.

Consistently for both male and female participants, the pairwise similarity between participant's multiple sex partners was high, particularly in frequency of sex acts and partner's HIV status, suggesting that the participant was likely to engage similar sex activities with all his or her partners. Of all the 16 items evaluated, the lowest similarity in a participant's two sex partners was found in partner type, followed by race/ethnicity. Higher similarity between second-to-last and third-to-last partners in partner type and sexual acts suggest that participants' last sex partners might more likely to be a main partner while second-to-last and third-to-last sex partners were more likely to be casual partners. Though participants engaged similar sex activities with all partners, sex acts engaged with multiple casual partners were more similar than with a main partner and a casual partner. These results support previous findings that detailed information from one main partner provided estimated HIV risk with very little error [5] and querying two sexual partners would capture 95% of sexual risk behavior [9]. These results imply that querying detailed sex acts from one partner may be sufficient to meet research goals of most modeling studies and ongoing routine behavioral surveys. Asking participants about their last two partners would provide a rather complete profile of both their main and casual partners. It is not necessary to query beyond two sex partners.

In addition to the empirical findings that might help with future survey design, this study innovatively applies the concept of similarity analysis to assess the similarity

Table 3 Similarity index for each item and each domain between partners 1 and 2, 1 and 3, and 2 and 3 among females, National HIV Behavioral Surveillance among Persons who Inject Drugs, 20 United States Cities, 2015

	Partners 1 and 2			Partners 1 and 3			Partners 2 and 3			p value[a]		
	N	Mean	Std	N	Mean	Std	N	Mean	Std	1, 2 versus 1, 3	1, 2 versus 2, 3	1, 3 versus 2, 3
Demographics												
Age	923	0.78	0.21	564	0.77	0.22	562	0.77	0.22	0.20	0.24	0.93
Race/ethnicity	923	0.67	0.47	565	0.64	0.48	561	0.64	0.48	0.22	0.25	0.94
Partner type												
Main versus casual	926	0.54	0.50	570	0.57	0.49	567	0.82	0.38	0.38	< 0.001	< 0.001
Frequency of sex acts												
# vaginal sex	921	0.75	0.23	563	0.76	0.21	560	0.84	0.18	0.70	< 0.001	< 0.001
# vaginal with condoms	690	0.81	0.26	421	0.79	0.27	367	0.86	0.23	0.26	0.01	< 0.01
# anal sex	462	0.75	0.26	304	0.79	0.25	302	0.85	0.22	0.17	< 0.001	< 0.01
# anal with condoms	67	0.91	0.18	39	0.90	0.22	28	0.90	0.26	0.82	0.82	0.98
Contextual characteristics of sex behaviors at last sexual encounter												
(Y/N) receive money/drugs from partner	706	0.64	0.48	497	0.66	0.47	494	0.82	0.39	0.56	< 0.001	< 0.001
(Y/N) know partner HIV status	926	0.76	0.43	569	0.71	0.45	566	0.80	0.40	0.10	0.09	< 0.01
Partner's HIV status	259	0.98	0.15	117	0.98	0.13	119	0.99	0.09	0.76	0.37	0.55
Domain[b]												
Demographics	927	0.73	0.27	570	0.70	0.27	567	0.70	0.27	0.11	0.15	0.86
Partner type	926	0.54	0.50	570	0.57	0.49	567	0.82	0.38	0.38	< 0.001	< 0.001
Frequency of sex acts	922	0.76	0.20	564	0.76	0.19	562	0.84	0.16	0.79	< 0.001	< 0.001
Contextual characteristics of sex behaviors at last sexual encounter	926	0.72	0.37	569	0.70	0.38	566	0.81	0.31	0.26	< 0.001	< 0.001

Partner 1 refers to the last sex partner

Partner 2 refers to the second-to-last sex partner

Partner 3 refers to the third-to-last sex partner

[a]p value less than 0.05 indicates that the similarity between two sex partners is significantly different from that between a different pair of sex partners

[b]A domain includes a group of questions in the same category

in sexual activities between participants' multiple sex partners. We propose simple and straightforward similarity measures for both categorical and continuous variables, and calculated SI based on the similarity measures. Values of calculated SI range from 0 to 1, with higher values representing higher similarity, making it easy for understanding and interpretation. The similarity measures are similar but more general than the kappa statistic which is limited to binary or categorical outcomes [12]. While the kappa statistic excludes possible agreement due to random effect in computation, the proposed similarity measures do not because we believe that the random agreement truly exists and is part of overall agreement; excluding it from the computation would result in a measure not reflective of the overall similarities between partners of interest examined in this study.

There are several limitations with this study. First, the calculated SI only assessed similarity between a pair of sex partners. Even so, when there are a large number of sex partners, the number of pairs can increase exponentially, making it unrealistic to evaluate the similarity of all the pairs. Thus, it makes more sense to evaluate the similarity for selected or representative pairs. Second, we calculated SI for each single item and a domain of combined multiple items. The SI of a domain is calculated as the average SI of nonmissing items in the domain, meaning that each item is considered equally important in the domain. Alternatively, if there is a reason to believe that one item is more important than others, one can use weighted average to calculate the SI. However, it is important to determine an appropriate weight for each item. Further, as long as a person has at least one nonmissing item in the domain, he/she contributes to the sample size for the domain SI. Thus, the sample size for a domain SI is bigger than most single item SIs, causing smaller p values when comparing domain SIs. Finally, the empirical analysis was based on PWID data from NHBS, which operates in 20 U.S. cities with high HIV prevalence, and may not be generalizable to other areas or populations.

In summary, our study proposed an innovative measure of the added value of multi-partner series. The proposed similarity measures quantify the similarity of a single item or a set of items between a pair of sex partners through a series of questions on demographics, partner type, frequency of sex acts, and contextual characteristics of sex at last sexual encounter. We demonstrated the usefulness of the proposed similarity measure through its application of evaluating the similarity of sex partners among a sample of persons who inject drugs. The empirical analysis results suggest that in the routine behavioral survey data we used, second-to-last and third-to-last partners contributed limited additional value to characterize a participant's sexual behaviors. Future studies can apply the proposed approach to evaluate the added value of multiple sex partners among other populations, for example, men who have sex with men and heterosexuals who are at increased risk for HIV infection. Further, the proposed method can be used in other studies to evaluate agreement or similarity for a number of mixed-type outcomes.

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Compliance of Ethical Standards

Conflict of interest None of the authors has a conflict of interest as regards this publication or the research on which it was based.

Ethical Approval The study is in compliance with ethical standards of institutional review boards (IRBs) in each participating city.

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