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**Title**

A Recommendation for Estimating Mean Degree in the RADAR Project Sexual Network of Chicago YMSM, Suggestions from the ART-Net Study

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**Running Head**

Mean Degree Estimation Method Comparison of Chicago YMSM Mean Degree Estimation Chicago YMSM Sexual Network

**Conflicts of Interest**

None

**ABSTRACT**

**Background** The American Men’s Internet Survey (AMIS), from which the ART-Net Study sources data, and the RADAR project survey collect information from young men who have sex with men (YMSM) in Chicago that may be used to inform the construction of a sexual partnership network. The mean degree of a sexual partnership network is a measure of connectivity representing the average number of concurrent, active, and ongoing partners of an individual in the network. The ART-Net survey requests participants to identify whether reported partnerships are active and ongoing at the day of survey administration to inform mean degree estimation. The RADAR project survey does not collect information from participants regarding which reported partnerships are active and ongoing at the day of survey. Alternate methods must be considered to estimate mean degree from the RADAR project survey.

**Methods** We propose a method for estimating partnership mean degree in the RADAR project through analysis of results from the ART-Net survey. The ART-Net survey captures partnership start and end dates and collects whether these reported partnerships are active and ongoing at the day of survey administration. The RADAR project survey captures partnership start and end dates but does not request participants to distinguish whether these partnerships are active and ongoing at the day of survey. We suggest that by reviewing partnership concurrency in the ART-Net study at the day of survey administration and in the months prior, we may be able to find may be used to suggest In the absence of information on active and ongoing partnerships, using reported partnership start and end dates and is used as a proxy to estimate active and ongoing partnerships at the day of survey administration in the RADAR project survey, we suggest a relationship between describing the relationship between compare two methods for estimating mean degree in the ART-Net study to inform estimation of mean degree in the RADAR project. The day-of-survey method calculates mean degree in the ART-Net survey by calculating the mean number of partnerships identified as active and ongoing at the day of survey administration. The N-month-offset method calculates mean degree in the ART-Net survey by calculati Both the ART-Net survey and RADAR project survey collect information on partnership start and end dates. We examine the relationship between .observe the relationship between reported partnership start and end date and reported active and ongoing partnerships at the day of survey administration. The day-of-survey method calculates mean degree study of men who have sex with men (MSM). At baseline, men were asked about whether recent sexual partnerships were ongoing.

**Results** Across partnership types, the baseline ongoing status measure was 70% accurate, with higher negative predictive value (91%) than positive predictive value (39%). Partnership factors associated with higher accuracy included partnership exclusivity and racial pairing. Baseline degree generally underestimated confirmed degree. The bias, or the number of ongoing partners different than predicted at baseline, was -0.28 overall. This ranged from -1.91 to -0.41 for MSM with any ongoing partnerships at baseline. Comparing MSM of the same baseline degree, the level of bias was stronger for black MSM compared to white MSM, and for younger MSM compared to older MSM.

**Conclusions** Degree may be overestimated in studies when quantified cross-sectionally. Research studies and HIV/STI prevention interventions using degree measures should account for this bias through adjustment and structured sensitivity analyses.

**KEYWORDS**

Sexual networks, HIV, sexually transmitted infection, men who have sex with men

INTRODUCTION

An estimated 1.1 million persons in the United States were living with HIV, with 40,000 new diagnoses occurring in 2017.1 Despite substantial progress in the development of new tools for HIV prevention, including preexposure prophylaxis (PrEP), incidence has stabilized overall in the past half-decade.2 Men who have sex with men (MSM) accounted for 66% of new HIV diagnoses but less than 5% of the population in 2017,3 and new cases have increased among several marginalized MSM subgroups such as young black and Hispanic MSM.2 Meeting HIV prevention targets, such as the newly established *Ending the HIV Epidemic Plan* calling for a 90% reduction in HIV incidence by 2030,4 will require sustained efforts to understand the drivers of HIV infection among MSM, the causes of disparities, and optimal methods for targeting prevention tools.

Networks of sexual partnerships have long been a focus of HIV research and intervention development.5 A network framework addresses the ongoing challenge that individual-level behavior and biology, by themselves, do not sufficiently explain the size of the HIV epidemic.6 Sexual partner concurrency, defined by having two or more ongoing partnerships, has been identified as a central explanatory cause for the shape of the HIV epidemic in Sub-Saharan Africa and the large sex differentials in HIV prevalence there.7,8 Concurrency amplifies the speed of HIV transmission across the population, compared to serial monogamy with the same number of cumulative partners.9 Concurrency is a binary categorization of momentary network degree (hereafter, degree), which is the number of ongoing partners at any point in time. Sexual networks may be characterized by a range of features, but degree, assortative mixing, and partnership duration are three important measures for HIV transmission.10 Recent network studies among MSM have characterized the interacting effects of these three features on the trajectory of HIV incidence.11,12

Network degree and duration are typically measured through cross-sectional study designs given the difficulty in longitudinal assessment. Although the time period for quantifying degree in these designs has been debated,13 one preferred approach is a measure on the day of study. Use of day-of-study degree is preferred because it allows for joint estimation of degree and duration following common statistical assumptions.14 Duration may be based on partnership start and end dates with the latter censored for ongoing partnerships. A challenge with the day-of-study degree measure, however, is that it requires study participants to predict whether partnerships will continue. Because of uncertainty in that prediction, measured degree may be a biased estimator of true degree. If the ongoing status of partnerships is systematically overpredicted, estimates for network degree and partnership duration would be biased upward.

Assessment of bias in estimates of network degree is uncommon because of the validation data needed. Linked partnership studies have evaluated agreement in degree within sexual dyads, and retrospective studies have evaluated temporal changes in degree over time.15,16 But no studies have assessed the accuracy of a day-of-study degree measure. Such bias assessment would require prospective data in which persons would be asked at follow-up to confirm whether partnerships reported as ongoing at baseline were truly ongoing, and whether those reported as not ongoing were truly not. The overall bias in the cross-sectional only degree measurement would likely have important heterogeneity by demographic characteristics. If black MSM underestimate degree more than white MSM, for example, the explanatory power of degree for research on racial disparities is weakened.17 Bias also likely varies by partnership characteristics, such as partnership type: ongoing status is less often known in casual partnerships.18

Validation of degree measures and heterogeneity in bias across individual and partnership-level factors will have important implications for both mathematical modeling studies that incorporate these measures in their parameters and also HIV/STI prevention efforts that incorporate on network features.19 The CDC’s clinical practice guidelines for PrEP recommend PrEP for MSM having condomless anal intercourse outside of non-monogamous partnerships.20 Non-monogamy is an implicit reference to concurrency, and thus network degree. Clinicians prescribing PrEP based on these guidelines may make systematic errors if cross-sectional degree reports are wrong. Multiple studies have suggested that the CDC guidelines do not have high predictive value for identifying which MSM become HIV-infected.21,22 Changes in risk behavior (whether the past accurately predicts the future) is one clear cause,23 but biased network measures may be another.

In this study, we use prospective cohort data on reported partnerships to quantify how accurately participants predicted the continuing status of their partnerships, as well as the total number of ongoing partnerships (degree). To maximally inform HIV prevention and mathematical modeling activities, we evaluated how accuracy, as well as negative and positive predictive values, varied across definitions of baseline degree, and by key factors. Our broader goal was to estimate the level of potential bias in degree to generate bias adjustment factors for future HIV prevention research and interventions.

METHODS

Study Design.This analysis used data from Involvement, a prospective cohort study in 2010–2014 to investigate multilevel factors for HIV risk among black and white MSM in the Atlanta metropolitan area.24 Study procedures included a standardized survey measuring behavioral, biological, and sexual network attributes hypothesized to influence HIV risk. Study participants were recruited through structured time-location sampling of sites where MSM congregated in Atlanta, supplemented with web-based recruitment. Locations and time periods were purposefully selected to increase enrollment of black MSM to ensure a balanced cohort.

Enrollment eligibility criteria were male sex, age between 18 and 39, non-Hispanic black or white race, residence in the Atlanta Metropolitan Statistical Area, at least one male sex partner within the past three months, and not being in a mutually monogamous relationship. Overall, 560 of the 803 participants screened as HIV-negative at baseline and enrolled into the cohort for follow-up. At each follow-up, participants received HIV and bacterial STI screening and completed additional behavioral surveys. Previous reports have described the sampling, recruitment, and enrollment protocols in further detail.22,24 The Emory University Institutional Review Board approved this study.

Measures. Our analyses included measures at the baseline and Month 6 (M6) follow-up visits. At baseline, participants reported on up to their 5 most recent partners over the prior 6 months, including whether they considered these partnerships as ongoing (those in which participant expected to have sexual contact again). Participants could report yes, no, or don’t know to these questions. At the M6 visit, participants were asked again about the same partners they reported on at baseline, including whether any sexual activity occurred after the baseline visit. The ongoing status of those partnerships reported at baseline could be confirmed with this M6 data in that way.

Degree refers to the sum of all ongoing partnerships at baseline. *Baseline Degree* is the number of ongoing partnerships reported on baseline data only, and *Confirmed Degree* is the baseline degree confirmed with M6 data. Confirmed degree would be lower than baseline degree if partnerships categorized as ongoing at baseline were not truly ongoing upon reevaluation at M6. Confirmed degree would be higher than baseline degree if partnerships categorized as not ongoing at baseline were truly ongoing upon reevaluation at M6. We define the bias in baseline degree as the difference between confirmed degree and baseline degree.

For this analysis, we excluded partnerships with women, those missing ongoing partnership status at baseline or month 6 follow-up, and partners with an unknown confirmed degree measure. We evaluated several individual predictors for degree agreement and bias, including age, race, and number of male sex partners. Partner-level covariates for predictions of accuracy for specific relationships included partnership type, frequency of sexual contact, race combination, age homophily, perceived concordant HIV status, and agreement about having outside sexual partnerships. Partnerships were categorized as main (primary with repeated sexual contacts), casual (non-primary but repeated sexual contacts), and one-time as of baseline. Note that one could misclassify different relationships as ongoing or not, while still correctly estimating their overall momentary degree, if the numbers misclassified in each direction were equal.

Statistical Analyses*.* To evaluate how well baseline ongoing status was predicted after confirmation by M6 data, we calculated positive predictive value (proportion of partnerships predicted at baseline as ongoing that were confirmed ongoing), negative predictive value (proportion of partnerships predicted at baseline as not ongoing that were confirmed not ongoing), accuracy (proportion of partnerships for which the baseline and M6 ongoing status values matched). We defined unknown baseline status as either not ongoing (unknown=no) or missing (unknown=missing; observations were dropped) to evaluate sensitivity of missing data.

We then used logistic regression models (analytic unit: partnerships) to estimate predictors of accuracy of baseline ongoing status within partnerships. Partnership-level predictors of interest were race and age homophily, frequency of sex, perceived partner HIV status, and agreement about outside sexual partnerships. Sandwich variance estimators for robust standard errors were used to calculate 95% confidence intervals to account for nesting of partnerships within participants. Finally, we estimated the association between baseline and confirmed degree with individual-level (analytic unit: participants) Poisson regression models for main and casual partnership types. Baseline degree was the primary predictor, confirmed degree was the outcome, and race and age were included as hypothesized confounders. These models were used to estimate the overall direction and magnitude of the degree bias. All analyses were conducted using R 3.5.3.

RESULTS

Compared to all MSM enrolled in the Involvement cohort, the analytic sample (N = 496) were of a similar race and age composition. With respect to partnership characteristics, partnerships in the analytic sample (N = 1397) were more likely to be main and casual than one-time partnerships compared to those reported by the full cohort (N = 1758). Most partnerships (94%) were within the same race and nearly 40% were perceived to be HIV discordant (meaning the reported partner was HIV-infected, given that the cohort enrolled only HIV-uninfected MSM at baseline) or unknown (meaning the partner’s HIV status was unknown).

Table 2 shows the accuracy of the baseline reported ongoing status with the M6 data as the gold standard. The sum of baseline and confirmed ongoing statuses of each partnership equals the baseline and confirmed degree for each participant, respectively; marginal degree distributions are reported in Supplemental Table 1. Overall, there was more consistency between the two measures than inconsistency, with variation by partnership type and classification of unknown status partnerships. Limited to known baseline ongoing status (yes/no responses only, where baseline unknown responses were set to missing), accuracy was 63.2% overall, highest in main partnerships (68.6%), and lowest in casual partnerships (58.1%). When classifying unknown status partnerships as not ongoing, accuracy overall improved to 69.5% and increased to 72.3% in casual and one-time partnerships. The row percentages may be interpreted as positive and negative predictive values when unknown ongoing partnerships were classified as missing. These show that the overall accuracy is driven by the negative predictive values (86–92%), which was much higher than positive predictive values (19–58%). The negative predictive values are reduced when classifying unknown ongoing partnerships were classified as not ongoing (the positive predictive values would not change with this different classification of these partnerships).

Table 3 presents the results of logistic regression models for partnership-level predictors of accuracy of the baseline ongoing status. The categorization of accuracy was the same as in Table 2. Overall, accuracy of baseline degree measures was higher in partnerships with smaller age gaps, white-white racial composition, main partnership type (compared to casual partnership type), and agreement about partnership exclusivity. When unknown status partnerships were coded as not ongoing, each 5-year increase in absolute age gap was associated with 9% lower odds of accuracy. That association was strengthened (OR = 0.87 versus 0.91) when treating unknown partnerships as missing. White-white partnerships across types were 1.4 times more accurate compared to black-black partnerships, and the effect was larger in main white-white partnerships compared to casual white-white partnerships. Partnership agreements about exclusivity with respect to outside partners were associated with accuracy, but this was driven by main partnerships. Perceived HIV status and coital frequency had minimal and inconsistent relationships to accuracy.

In Table 4, we show the result of the Poisson regression models estimating the association between confirmed degree (outcome) and baseline degree (predictor). Marginal degree distributions for both degree measures are provided in Supplemental Table 1. Models are stratified by participants who had main and casual partnerships (n = 405), only main partnerships (n = 220), or only casual partnerships (n = 299). We also ran models for the different classifications of unknown baseline status partnerships, and with adjustment for participant age and race. Overall, baseline degree was strongly associated with confirmed degree across partnership types, for both unknown status classification methods and after demographic adjustment. Positive values of these regression coefficients indicate an increase in predicted confirmed degree as a function of baseline degree. Confirmed degree increased by a relative factor of 1.6 (*e0.48)* with each increase in baseline degree. The coefficient sizes were greater and confidence intervals wider for estimation with unknown baseline degree coded as missing as a result of greater effect size but smaller sample size.

The bias in baseline degree for all partnerships was -0.28 when unknown ongoing partnerships were coded as not ongoing and -0.49 when coded as missing. This bias also emerged in estimates of concurrency, or the proportion of men exhibiting a degree of 2 or more across main and casual partnerships. The proportion concurrent using baseline degree only was 17.2% when unknown ongoing partnerships were coded as not ongoing and 22.0% when coded as missing. The proportion concurrent based on confirmed degree was 9.6%.

Figure 1 shows the predicted difference between confirmed and baseline degree as a function of baseline degree from the model in which unknown baseline partnerships were classified as not ongoing. If baseline degree perfectly predicted confirmed degree, the estimates (points) would fall on the horizontal dashed line representing no difference between baseline and confirmed degrees. The plots were stratified by partnership type, with x-axis ranges limited to the range of empirical data for each type. Confirmed degree was 0.28, 0.59, and 1.25 for those with baseline degrees of 0, 1, and 2 main partnerships, respectively. The corresponding bias sizes were therefore 0.28, -0.41, and -0.75. Confirmed degree was 0.26, 0.44, 0.74, 1.24, 2.09, and 3.51 for those with baseline degree of 0 to 5 casual partnerships, respectively. The corresponding bias sizes were 0.26, -0.56, -1.26, -1.76, -1.91, and -1.49. Therefore, baseline degree overestimated confirmed degree for MSM engaged in any ongoing partnerships (degree > 0), but underestimated degree for MSM in no ongoing partnerships at baseline.

In Supplemental Figure 1, we present the model-estimated confirmed degree as a function of baseline degree rather than the bias itself, stratified by race and age group instead of partnership type. A perfect prediction of degree from baseline degree would result in the point estimates overlapping with the diagonal dashed identity line. The associations here were similar to Figure 1 with respect to baseline degree as the primary predictor of interest. However, the level of bias was greater for younger MSM (age 18–29) compared to older MSM and for black MSM compared to white MSM. For example, for MSM with a baseline degree of 2, the predicted confirmed degree was 0.65 for Black MSM aged 18–29, 0.94 for White MSM aged 18–29, 0.79 for Black MSM aged 30–39, and 1.15 for White MSM aged 30–39.

DISCUSSION

In this study, we evaluated the potential for bias in estimating sexual network degree using only a cross-sectional (“day-of-study”) measure by reconfirming the ongoing status of partnerships with prospective cohort data. We found high accuracy of the baseline ongoing status using this longitudinal data as the standard, with generally higher accuracy in main compared to casual partnerships but with the results dependent upon categorization of unknown status partnerships. Baseline degree underestimated true network degree when confirmed longitudinally, with the level of bias ranging from -1.91 to -0.41 for men with any ongoing partnerships. Baseline degree overestimated true degree for men with no predicted ongoing partnerships at baseline (0.26–0.28 average bias). The average bias across baseline degree for main and casual partnerships was -0.28. These results held across partnership type and other covariates, but the bias was higher for younger and for black MSM.

These findings have implications for how we measure and interpret network degree and related network measures in cross-sectional studies. Our study provides strong support for the need to validate network measures such as degree. Errors in the classification of the ongoing status of partnerships also impact estimation of partnership duration, since partnerships assumed to be ongoing have a censored end date, leading to a overestimation of duration if partnerships are truly not ongoing.14,25 From an HIV transmission perspective, overestimation of degree and duration may lead to conclusions that MSM networks are riskier than they truly are. After confirmation with longitudinal data, the fraction exhibiting concurrency was roughly half of that estimated based on baseline data alone (9.6% versus 17.2%). Although the biases in degree found here appear small, minor differences in network measures at the individual-level can cascade into large network-level outcomes like the temporal network path reachable by infectious disease pathogens.26

Biases in network measurements have consequences for using networks to explain HIV disparities by race in the U.S. HIV disparities research has been challenged over the past two decades to identify explanatory factors for the large racial disparities in HIV prevalence; individual-level risk factors (e.g., coital frequency and condom use) have consistently been equal or lower in the group with higher prevalence (i.e., black MSM).6,17 Empirical studies across multiple populations of MSM have suggested some racial differences in network degree, although the results are not consistent.24,27,28 We found that the level of bias in degree measurements was higher for black MSM compared to white MSM, and conversely the accuracy of baseline ongoing status was highest in white-white partnerships. We had hypothesized that the groups with higher HIV incidence (black MSM) would overestimate degree less than groups with lower incidence (white MSM), which would strength the role of network factors in understanding disparities.17 We found just the opposite: a greater overestimation of degree for black MSM. This suggests that the explanatory power of network factors in explaining disparities could be diluted.

The estimated biases support reevaluation of network measures used in both epidemiological research and public health practice. Network-based mathematical modeling research in particular depends on unbiased measures of degree and duration to simulate HIV transmission dynamics.29 Our findings that bias was higher in casual compared to main partnerships and for MSM with larger baseline degrees suggests previous models may have overestimated the role of these factors for explaining HIV transmission.17,30 With respect to public health practice, network measures such as degree are implicitly used for targeting HIV PrEP based on the CDC guidelines.20 Previous evaluations have suggested that 25% of MSM meet these indications.31 Our study suggests that proportion may be an overestimate, and that if clinicians were using momentary degree evaluated on the day of clinic visit, they may be prescribing PrEP to some unindicated MSM. This compounds the difficultly in inferring future HIV risk as a function of past or present behavior.23 Although the current challenge for HIV PrEP is finding ways to increase uptake, provision of PrEP to unindicated MSM may detract from costly targeting efforts to deliver and maintain PrEP to those at the highest risk.32 A lower number of MSM indicated for PrEP would suggest greater success in the fraction of indicated MSM who are receiving it.33

Limitations. First, we excluded 16% of individuals and 21% of partnerships enrolled in the cohort, largely due to missing or unknown data for baseline or confirmed (Month 6) degree. This resulted in fewer one-time partnerships and more main/casual partnerships, which could have resulted in a higher level of estimated of bias if they had been included. Second, other factors within the longitudinal study design may have resulted in lower degree at follow-up in a way that could contribute to the observed biases: 1) participant recall issues about partnerships at baseline; and 2) participant knowledge at follow-up that the study survey is completed faster when reporting on fewer partners. Although it is impossible to know how much these alternative explanations could have affected the results, they were our primary motivation to limit the comparisons to baseline and Month 6 data and not data from subsequent follow-up visits.

Conclusions. We have five concrete suggestions about how to apply these findings. First, if longitudinal degree data are available for other target populations, quantifying potential biases using our methods is suggested. Second, if longitudinal data are not available and it is reasonable to transport our estimates, applying our estimated bias factors to other cross-sectional estimates may suffice. Third, if longitudinal data are not available but unknown ongoing status is measured, reclassifying unknown partnerships to not ongoing may reduce bias, as it did here. Fourth, if retrospective data on degree at multiple time points is available, comparison of degree over time would be a useful evaluation of measure stability. Previous studies have directly compared measures of concurrency across retrospective time points;13,34 this would be a useful exercise for network degree and other network measures more generally. Fifth, with any of the above four approaches to degree adjustment and evaluation above, we recommend using structured sensitivity analyses for the impact of biased degree on the primary study outcome or clinical decision, with degree ranging from that observed value to the estimated biased value.35 We hope this will inform future research or public health practice activities that incorporate degree and related network measures.

REFERENCES

1. Centers for Disease Control and Prevention. *HIV Surveillance Report*. Atlanta; 2017. http://www.cdc.gov/hiv/library/reports/hiv-surveillance.html

2. Centers for Disease Control and Prevention. *Estimated HIV Incidence and Prevalence in the United States, 2010–2016: HIV Surveillance Supplemental Report.*; 2019.  http://www.cdc.gov/ hiv/library/reports/hiv-surveillance.html.

3. Grey JA, Bernstein KT, Sullivan PS, et al. Estimating the Population Sizes of Men Who Have Sex With Men in US States and Counties Using Data From the American Community Survey. *JMIR Public Health Surveill*. 2016;2(1):e14.

4. Fauci AS, Redfield RR, Sigounas G, Weahkee MD, Giroir BP. Ending the HIV Epidemic. *JAMA*. 2019;321(9):844. doi:10.1001/jama.2019.1343

5. Morris M. Sexual networks and HIV. *AIDS*. 1997;11 Suppl A:S209-16.

6. Millett GA, Peterson JL, Wolitski RJ, Stall R. Greater risk for HIV infection of black men who have sex with men: a critical literature review. *Am J Public Health*. 2006;96(6):1007-1019.

7. Goodreau SM. A decade of modelling research yields considerable evidence for the importance of concurrency: a response to Sawers and Stillwaggon. *J Int AIDS Soc*. 2011;14:12.

8. Eaton JW, Hallett TB, Garnett GP. Concurrent sexual partnerships and primary HIV infection: a critical interaction. *AIDS Behav*. 2011;15(4):687-692.

9. Morris M, Kurth AE, Hamilton DT, Moody J, Wakefield S. Concurrent partnerships and HIV prevalence disparities by race: linking science and public health practice. *Am J Public Health*. 2009;99(6):1023-1031.

10. Jenness SM, Goodreau SM, Morris M. EpiModel: An R Package for Mathematical Modeling of Infectious Disease over Networks. *J Stat Softw*. 2018;84(1):1-47.

11. Janulis P, Phillips G, Birkett M, Mustanski B. Sexual Networks of Racially Diverse Young MSM Differ in Racial Homophily But Not Concurrency. *J Acquir Immune Defic Syndr*. 2018;77(5):459-466.

12. Rosenberg ES, Millett GA, Sullivan PS, Del Rio C, Curran JW. Understanding the HIV disparities between black and white men who have sex with men in the USA using the HIV care continuum: a modeling study. *Lancet HIV*. 2014;1(3):e112-e118.

13. Glynn JR, Dube A, Kayuni N, et al. Measuring concurrency. *AIDS*. 2012;26(8):977-985.

14. Krivitsky P, Morris M. Inference for Social Network Models from Egocentrically-Sampled Data, with Application to Understanding Persistent Racial Disparities in HIV Prevalence in the US. *Ann Appl Stat*. 2017;11(1):427-455.

15. Drumright LN, Gorbach PM, Holmes KK. Do people really know their sex partners?: Concurrency, knowledge of partner behavior, and sexually transmitted infections within partnerships. *Sex Transm Dis*. 2004;31(7):437-442.

16. Nelson SJ, Manhart LE, Gorbach PM, et al. Measuring sex partner concurrency: it’s what’s missing that counts. *Sex Transm Dis*. 2007;34(10):801-807.

17. Goodreau SM, Rosenberg ES, Jenness SM, et al. Sources of racial disparities in HIV prevalence in men who have sex with men in Atlanta, GA, USA: a modelling study. *Lancet HIV*. 2017;4(7):e311-e320.

18. Goodreau SM, Carnegie NB, Vittinghoff E, et al. What drives the US and Peruvian HIV epidemics in men who have sex with men (MSM)? *PLoS One*. 2012;7(11):e50522.

19. Jenness SM, Goodreau SM, Rosenberg E, et al. Impact of the Centers for Disease Control’s HIV preexposure prophylaxis guidelines for men who have sex with men in the United States. *J Inf Dis*. 2016;214(12):1800-1807.

20. US Public Health Service. *Preexposure Prophylaxis for the Prevention of HIV Infection in the United States*. US Public Health Service; 2014.

21. Lancki N, Almirol E, Alon L, McNulty M, Schneider JA. PrEP guidelines have low sensitivity for identifying seroconverters in a sample of Young Black men who have sex with men in Chicago. *AIDS*. 2018;32(3):383-392.

22. Sullivan PS, Rosenberg ES, Sanchez TH, et al. Explaining racial disparities in HIV incidence in black and white men who have sex with men in Atlanta, GA: a prospective observational cohort study. *Ann Epidemiol*. 2015;25(6):445-454.

23. Jones J, Hoenigl M, Siegler AJ, Sullivan PS, Little S, Rosenberg E. Assessing the Performance of 3 Human Immunodeficiency Virus Incidence Risk Scores in a Cohort of Black and White Men Who Have Sex With Men in the South. *Sex Transm Dis*. 2017;44(5):297-302.

24. Sullivan PS, Peterson J, Rosenberg ES, et al. Understanding racial HIV/STI disparities in black and white men who have sex with men: a multilevel approach. *PLoS One*. 2014;9(3):e90514.

25. Krivitsky PN, Handcock MS. A Separable Model for Dynamic Networks. *J R Stat Soc Series B Stat Methodol*. 2014;76(1):29-46.

26. Carnegie NB, Morris M. Size matters: concurrency and the epidemic potential of HIV in small networks. *PLoS ONE*. 2012;7(8):e43048.

27. Mustanski B, Morgan E, DʼAquila R, Birkett M, Janulis P, Newcomb ME. Individual and Network Factors Associated With Racial Disparities in HIV Among Young Men Who Have Sex With Men. *J Acquir Immune Defic Syndr*. 2019;80(1):24-30.

28. Hernández-Romieu AC, Sullivan PS, Rothenberg R, et al. Heterogeneity of HIV Prevalence Among the Sexual Networks of Black and White Men Who Have Sex With Men in Atlanta: Illuminating a Mechanism for Increased HIV Risk for Young Black Men Who Have Sex With Men. *Sex Transm Dis*. 2015;42(9):505-512.

29. Morgan E, Skaathun B, Nikolopoulos GK, et al. A Network Intervention to Locate Newly HIV Infected Persons Within MSM Networks in Chicago. *AIDS Behav*. 2019;23(1):15-20.

30. Jenness SM, Maloney KM, Smith DK, et al. Addressing Gaps in HIV Preexposure Prophylaxis Care to Reduce Racial Disparities in HIV Incidence in the United States. *Am J Epidemiol*. 2019;188(4):743-752.

31. Smith DK, Van Handel M, Wolitski RJ, et al. Vital Signs: Estimated Percentages and Numbers of Adults with Indications for Preexposure Prophylaxis to Prevent HIV Acquisition--United States, 2015. *MMWR Morb Mortal Wkly Rep*. 2015;64(46):1291-1295.

32. Siegler AJ, Mouhanna F, Giler RM, et al. The prevalence of pre-exposure prophylaxis use and the pre-exposure prophylaxis–to-need ratio in the fourth quarter of 2017, United States. *Annals of Epidemiology*. 2018;28(12):841-849.

33. Smith DK, Van Handel M, Grey J. Estimates of adults with indications for HIV pre-exposure prophylaxis by jurisdiction, transmission risk group, and race/ethnicity, United States, 2015. *Annals of Epidemiology*. 2018;28(12):850-857.e9.

34. Rosenberg ES, Rothenberg RB, Kleinbaum DG, Stephenson RB, Sullivan PS. Assessment of a new web-based sexual concurrency measurement tool for men who have sex with men. *J Med Internet Res*. 2014;16(11):e246.

35. Lash TL, Fox MP, Fink AK. *Applying Quantitative Bias Analysis to Epidemiologic Data*. Springer Science & Business Media; 2011.

TABLES

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| --- | --- | --- | --- | --- | --- | --- |
| **Table 1.** Individual-Level and Partnership-Level Characteristics of Enrolled Cohort and Analytic Sample in a Study of Black and White Men Who Have Sex with Men, Atlanta, 2010–2014 | | | | | | |
| **Characteristic** |  | **Enrolled Cohort** | |  | **Analytic Sample** | |
|  | **n** | **%** |  | **n** | **%** |
| *Individual* |  | *N = 560* |  |  | *N = 469* |  |
| **Age** |  |  |  |  |  |  |
| 18–19 |  | 40 | 7.1 |  | 32 | 6.8 |
| 20–24 |  | 189 | 33.8 |  | 150 | 32.0 |
| 25–29 |  | 165 | 29.4 |  | 140 | 29.9 |
| 30–39 |  | 166 | 29.6 |  | 147 | 31.3 |
| **Race** |  |  |  |  |  |  |
| Black |  | 257 | 45.9 |  | 205 | 43.7 |
| White |  | 303 | 54.1 |  | 264 | 56.3 |
| **Sexual Partners in Past 6 Months** |  |  |  |  |  |  |
| Total Partners (mean, sd, median) |  |  | 5.7, 8.3, 5 |  |  | 5.8, 8.9, 5 |
| Condomless Partners (mean, sd, median) |  |  | 1.9, 3.4, 1 |  |  | 1.8, 3.5, 1 |
| *Partnership* |  | *N = 1758* | |  | *N = 1397* | |
| **Partnership Type** |  |  |  |  |  |  |
| Main |  | 267 | 15.3 |  | 253 | 18.1 |
| Casual |  | 533 | 30.5 |  | 494 | 35.4 |
| One-Time |  | 945 | 54.2 |  | 650 | 46.5 |
| **Racial Composition** |  |  |  |  |  |  |
| Black-Black |  | 557 | 39.6 |  | 449 | 39.0 |
| Black-White |  | 95 | 6.8 |  | 73 | 6.4 |
| White-White |  | 754 | 53.6 |  | 628 | 54.6 |
| **Age Homophily** |  |  |  |  |  |  |
| Absolute Difference in Years (mean, sd) |  |  | 8.1, 1.9 |  |  | 8.1, 1.7 |
| **Perceived Concordant HIV Status** |  |  |  |  |  |  |
| Concordant |  | 965 | 57.9 |  | 814 | 60.6 |
| Discordant/Unknown |  | 702 | 42.1 |  | 530 | 39.4 |
| **Coital Frequency in Past 6 Months** |  |  |  |  |  |  |
| Total Frequency (mean, sd, median) |  |  | 12.6, 18.4, 4 |  |  | 12.7, 18.5, 4 |
| **Partnership Agreement about Outside Sex** |  |  |  |  |  |  |
| No Agreement |  | 565 | 71.6 |  | 527 | 71.6 |
| No Outside Sex |  | 112 | 14.2 |  | 103 | 14.0 |
| Outside Sex with Conditions |  | 43 | 5.45 |  | 40 | 5.4 |
| Outside Sex without Conditions |  | 69 | 8.8 |  | 66 | 9.0 |
| The analytic sample includes only men with same-sex partnerships, no missingness in report of baseline and 6-month degree, and no unknown responses for 6-month degree. | | | | | | |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table 2**.Accuracy of Baseline Reported Ongoing Status as Confirmed at 6-Month Follow-Up in a Study of Black and White Men Who Have Sex with Men, Atlanta, 2010–2014. | | | | | | |
| **Partnership Type** | **Baseline Ongoing** | **Confirmed Ongoing** | | **Baseline Accuracy** | | **Negative Predictive Value** |
| *Yes* | *No* | *Unknown =  No* | *Unknown =  Missing* | *Unknown = No* |
| Main (N = 253) | *Yes* | 73 (57.5%) | 54 (42.5%) | 68.6% | 67.2% | 77.0% |
| *No* | 11 (13.8%) | 69 (86.3%) |  |  |  |
| *Unknown* | 18 (39.1%) | 28 (60.9%) |  |  |  |
| Casual (N = 494) | *Yes* | 92 (42.4%) | 125 (57.6%) | 58.1% | 67.0% | 86.3% |
| *No* | 9 (8.7%) | 94 (91.3%) |  |  |  |
| *Unknown* | 29 (16.7%) | 145 (83.3%) |  |  |  |
| One-Time (N = 650) | *Yes* | 29 (18.6%) | 127 (81.4%) | 64.4% | 72.3% | 89.3% |
| *No* | 21 (8.1%) | 239 (91.9%) |  |  |  |
| *Unknown* | 32 (13.7%) | 202 (86.3%) |  |  |  |
| Overall (N = 1397) | *Yes* | 194 (38.80%) | 306 (61.20%) | 63.2% | 69.5% | 86.6% |
| *No* | 41 (9.26%) | 402 (90.74%) |  |  |  |
| *Unknown* | 79 (17.40%) | 375 (82.60%) |  |  |  |

Table 3.Partner-Level Logistic Regression of Accuracy of Baseline Reported Ongoing Status as Confirmed

at 6-Month Follow-Up, in a Study of Black and White Men Who Have Sex with Men, Atlanta, 2010–2014

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Partnership Type (Odds Ratio, 95% CI)** | | |
|  | *Main, Casual, &*  *One-Time (n = 1397)* | *Main*  *(n = 253)* | *Casual*  *(n = 494)* |
| **Unknown = No1** | | | |
| **Absolute Age Difference** |  |  |  |
| Per 5 Years | 0.91 (0.81, 1.02) | 0.91 (0.72, 1.15) | 0.90 (0.79, 1.04) |
| **Racial Composition** |  |  |  |
| Black-Black | 1.00 | 1.00 | 1.00 |
| Black-White | 1.10 (0.50, 2.41) | 2.23 (0.43, 11.50) | 0.94 (0.37, 2.38) |
| White-White | 1.41 (0.96, 2.07) | 2.42 (1.26, 4.66) | 0.99 (0.61, 1.61) |
| **Perceived Concordant HIV Status** | | | |
| Discordant/Unknown | 1.00 | 1.00 | 1.00 |
| Concordant | 0.82 (0.55, 1.21) | 1.10 (0.54, 2.26) | 0.73 (0.45, 1.19) |
| **Coital Frequency in Past 6 Months** | | | |
| Per 5 Acts | 1.00 (0.95, 1.06) | 1.05 (0.97, 1.13) | 0.92 (0.84, 1.00) |
| **Partnership Agreement about Outside Sex** | | | |
| No Agreement | 1.00 | 1.00 | 1.00 |
| No Outside Sex | 1.85 (1.06, 3.21) | 1.88 (0.90, 3.94) | 0.91 (0.15, 5.59) |
| Outside Sex with Conditions | 0.58 (0.28, 1.20) | 0.37 (0.12, 1.18) | 0.79 (0.28, 2.23) |
| Outside Sex without Conditions | 1.15 (0.59, 2.23) | 0.98 (0.40, 2.40) | 1.03 (0.29, 3.68) |
| **Unknown = Missing2** | | | |
| **Absolute Age Difference** |  |  |  |
| Per 5 Years | 0.87 (0.76, 0.99) | 0.88 (0.69, 1.12) | 0.86 (0.73, 0.97) |
| **Racial Composition** |  |  |  |
| Black-Black | 1.00 | 1.00 | 1.00 |
| Black-White | 1.11 (0.45, 2.77) | 3.82 (0.54, 26.79) | 0.89 (0.31, 2.56) |
| White-White | 1.54 (0.99, 2.40) | 2.31 (1.11, 4.81) | 1.12 (0.63, 1.98) |
| **Perceived Concordant HIV Status** | | | |
| Discordant/Unknown | 1.00 | 1.00 | 1.00 |
| Concordant | 0.83 (0.52, 1.31) | 1.03 (0.46, 2.30) | 0.73 (0.42, 1.28) |
| **Coital Frequency in Past 6 Months** | | | |
| Per 5 Acts | 1.06 (0.99, 1.12) | 1.14 (1.04, 1.25) | 0.95 (0.87, 1.04) |
| **Partnership Agreement about Outside Sex** | | | |
| No Agreement | 1.00 | 1.00 | 1.00 |
| No Outside Sex | 2.59 (1.40, 4.80) | 2.04 (0.86, 4.79) | 1.37 (0.21, 9.10) |
| Outside Sex with Conditions | 0.75 (0.32, 1.73) | 0.39 (0.11, 1.31) | 1.01 (0.26, 3.94) |
| Outside Sex without Conditions | 1.47 (0.73, 2.97) | 0.89 (0.32, 2.46) | 1.46 (0.41, 5.22) |

1 Responses for unknown baseline degree were coded as not ongoing.

2 Responses for unknown baseline degree were coded as missing and observations dropped from the model.

Table 4.Individual-Level Poisson Regression for Confirmed Degree as a Function of Baseline Degree

in a Study of Black and White Men Who Have Sex with Men, Atlanta, 2010–2014.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Confirmed Degree**  Coefficient (95% CI) | | | |
|  | *Main & Casual*  *(n = 405)* | *Main Only*  *(n = 220)* | *Casual Only*  *(n = 299)* |
| **Unknown = No1** | | | | |
| **Unadjusted Model** |  |  |  |
| Intercept | -1.04 (-1.24, -0.85) | -1.28 (-1.65, -0.94) | -1.35 (-1.60, -1.11) |
| Baseline Degree | 0.48 (0.34, 0.56) | 0.75 (0.38, 1.13) | 0.52 (0.38, 0.65) |
| **Adjusted Model** |  |  |  |
| Intercept | -1.33 (-1.90, -0.75) | -1.73 (-2.63, -0.84) | -1.74 (-2.52, 0.97) |
| Baseline Degree | 0.46 (0.34, 0.57) | 0.79 (0.41, 1.19) | 0.53 (0.39, 0.67) |
| Age (Per 5 years) | 0.00 (-0.10, 0.10) | 0.03 (-0.13, 0.18) | 0.03 (-0.11, 0.16) |
| Race |  |  |  |
| *Black* | 0.00 | 0.00 | 0.00 |
| *White* | 0.41 (0.13, 0.70) | 0.42 (0, 0.86) | 0.34 (-0.04, 0.73) |
| **Unknown = Missing2** | | | | |
| **Unadjusted Model** |  |  |  |
| Intercept | -1.20 (-1.49, -0.93) | -1.55 (-2.05, -1.08) | -1.49 (-1.87, -1.13) |
| Baseline Degree | 0.48 (0.34, 0.61) | 0.97 (0.51, 1.44) | 0.56 (0.38, 0.72) |
| **Adjusted Model** |  |  |  |
| Intercept | -1.45 (-2.19, -0.71) | -1.97 (-3.01, -0.94) | -1.74 (-2.77, -0.71) |
| Baseline Degree | 0.48 (0.34, 0.63) | 1.05 (0.57, 1.55) | 0.57 (0.39, 0.74) |
| Age (Per 5 years) | -0.01 (-0.14, 0.12) | 0 (-0.18, 0.17) | 0.01 (-0.18, 0.18) |
| Race |  |  |  |
| *Black* | 0.00 | 0.00 | 0.00 |
| *White* | 0.46 (0.08, 0.85) | 0.56 (0.08, 1.06) | 0.31 (-0.19, 0.84) |

1 Responses for unknown baseline degree were coded as not ongoing.

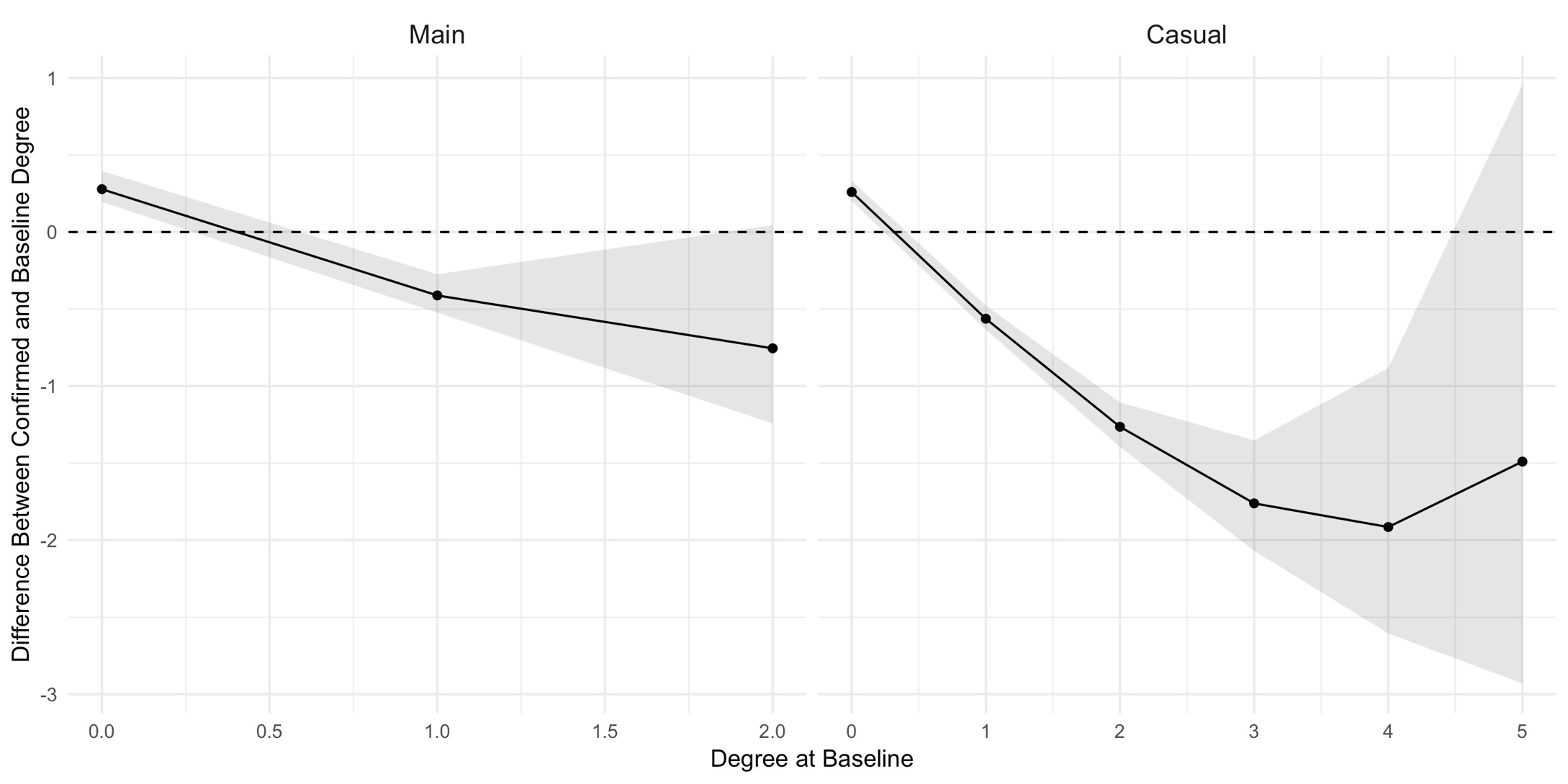
2 Responses for unknown baseline degree were coded as missing and observations dropped from

the model.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Supplemental Table 1.** Distribution of Baseline and Confirmed Degree in a Study of Black and White Men Who Have Sex with Men, Atlanta, 2010–2014. | | | | | | |
|  | **Main Partnerships** | | **Casual Partnerships** | | **Main/Casual Partnerships** | |
|  | n | % | n | % | n | % |
| **Baseline Degree** |  |  |  |  |  |  |
| *Unknown = No* |  |  |  |  |  |  |
| 0 | 97 | 44.1 | 145 | 48.5 | 159 | 39.3 |
| 1 | 119 | 54.1 | 110 | 36.8 | 176 | 43.5 |
| 2 | 4 | 1.8 | 30 | 10.0 | 49 | 12.1 |
| 3 | 0 | 0.0 | 10 | 3.3 | 15 | 3.7 |
| 4 | 0 | 0.0 | 3 | 1.0 | 5 | 1.2 |
| 5 | 0 | 0.0 | 1 | 0.3 | 1 | 0.2 |
| *Unknown = Missing* | |  |  |  |  |  |
| 0 | 56 | 32.2 | 51 | 31.9 | 64 | 27.6 |
| 1 | 114 | 65.6 | 71 | 44.4 | 117 | 50.4 |
| 2 | 4 | 2.3 | 26 | 16.2 | 34 | 14.7 |
| 3 | 0 | 0.0 | 8 | 5.0 | 11 | 4.7 |
| 4 | 0 | 0.0 | 3 | 1.9 | 5 | 2.2 |
| 5 | 0 | 0.0 | 1 | 0.6 | 1 | 0.4 |
| **Confirmed Degree** |  |  |  |  |  |  |
| 0 | 121 | 55.0 | 191 | 63.9 | 219 | 54.1 |
| 1 | 96 | 43.6 | 89 | 29.8 | 147 | 36.3 |
| 2 | 3 | 1.4 | 16 | 5.4 | 32 | 7.9 |
| 3 | 0 | 0.0 | 3 | 1.0 | 7 | 1.7 |
| 4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |

FIGURES

Figure 1**.** Difference between confirmed and baseline degree as a function of baseline degree, stratified by partnership type. Dashed horizontal line at 0 displays value where there is no difference between baseline and confirmed degree. Predictions below the dashed line indicate overestimates of confirmed degree based on baseline degree. Lines/dots display the point estimates and grey polygons display the 95% confidence intervals around the estimates.

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Supplemental Figure 1**.** Confirmed degree as a function of baseline degree, and race and age of the study participant.Dashed line with a slope of 1 displays the value where baseline degree perfectly predicts confirmed degree. Predictions below the dashed line indicate overestimates of confirmed degree based on baseline degree. Lines/dots display the point estimates and grey polygons display the 95% confidence intervals around the estimates.

