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Byoungjun Kim, Seann D. Regan, Denton Callander, William C. Goedel,  
Basile Chaix, Dustin T. Duncan

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**Associations of Spatial Mobility with Sexual Risk Behaviors among Young Men Who Have Sex with Men in New York City: A Global Positioning System (GPS) Study**

Byoungjun KIM, MUP<sup>1</sup>

Seann D. REGAN, MA<sup>1</sup>

Denton CALLANDER, PhD<sup>1</sup>

William C. GOEDEL, BA<sup>2</sup>

Basile CHAIX, PhD<sup>3</sup>

Dustin T. DUNCAN, ScD<sup>1</sup>

<sup>1</sup>. Department of Epidemiology, Columbia University Mailman School of Public Health, New York, New York, United States

<sup>2</sup>. Department of Epidemiology, School of Public Health, Brown University, Providence, Rhode Island, USA

<sup>3</sup>. Sorbonne Université, INSERM, Institut Pierre Louis d'Epidémiologie et de Santé Publique IPLESP, Nemesis team, F75012 Paris, France

**Address Correspondence to:** Byoungjun Kim, MUP, Columbia University Mailman School of Public Health, Department of Epidemiology, Social and Spatial Epidemiology Unit, 722 West 168th Street, New York, NY 10032. Email: bk2767@cumc.columbia.edu

## 2 **Abstract**

3 Spatial contexts and spatial mobility are important factors on the HIV epidemic and sexually  
4 transmitted infections. Using global positioning system (GPS) devices, we examined the  
5 associations of objectively measured spatial mobility with sexual risk behaviors among gay,  
6 bisexual and other men who have sex with men (MSM) in New York City. This observational  
7 study included a subgroup of 253 HIV-negative MSM from the Project 18 Cohort Study, who  
8 participated in the GPS monitoring sub-study. Spatial mobility was measured as (1) distance  
9 traveled and (2) activity space size defined as daily path area during 2-week of GPS tracking. We  
10 examined the associations of these measures with numbers of male sexual partners and condomless  
11 anal intercourse (CAI) acts during last six months using quasi-Poisson models, adjusting for socio-  
12 demographics. Results demonstrated that spatial mobility was positively associated with sexual  
13 risk behaviors, for example, with CAI (incidence rate ratio [IRR] = 1.01 for a 10 km increase in  
14 distance traveled and IRR=1.04 for a 1 km<sup>2</sup> increase in 50m-buffer activity space size). Our  
15 findings may enhance the understanding of spatial contexts of HIV risk. Future studies should be  
16 conducted to examine the mechanisms for the associations between spatial mobility behaviors with  
17 sexual risk behaviors as well as the influence of neighborhood characteristics in various  
18 neighborhood contexts, which may guide the place-based HIV prevention services.

19 **Keywords:** spatial analysis; mobility; Global Positioning System (GPS); sexual behavior; Men  
20 who have Sex with Men (MSM); HIV prevention;

21

## 22 **Introduction**

23 The incidence rate of human immunodeficiency virus (HIV) is disproportionately high among gay,  
24 bisexual and other men who have sex with men (MSM), especially young MSM. In 2018, MSM  
25 accounted for 69.6% of new HIV cases among adult and adolescent (age over 13 years) in the  
26 United States (U.S.), and young MSM (aged 13 to 29 years old) made up 48.6% of new HIV  
27 infections among MSM (Centers for Disease Control and Prevention, 2019). Furthermore, even  
28 though HIV incidence in the general population in the U.S. has decreased since 2008, the rate  
29 among MSM during 2008-2015 remained high and even increased by 5.7% per year among MSM  
30 between age 25 and 34 (Singh et al., 2018).

31

32 In addition to standard individual-level sociodemographic factors affecting vulnerability to HIV  
33 infection, geographic factors such as the spatial mobility behavior and characteristics of spatial  
34 contexts have been studied to explain variations in HIV incidence in heterosexual population as  
35 well as among MSM. Theoretical and empirical studies have identified that spatial mobility,  
36 including migration, commuting, and local mobility, is one of important factors influencing HIV  
37 transmission (Vaughan et al., 2017, Cassels and Camlin, 2016, Cassels et al., 2017, Deane et al.,  
38 2010, Coffee et al., 2007, Camlin et al., 2013). The theoretical frameworks suggested multiple  
39 pathways that may explain the associations between mobility and HIV risks. Mobile individuals  
40 may have potentials to be connected to riskier sexual network with larger number of partners in  
41 different places (Cassels et al., 2017). In addition, non-residential places may be separated from  
42 conventional HIV prevention supports and have higher risk of environmental exposures (Frye et  
43 al., 2014, Vaughan et al., 2017). Lastly, exposure to diverse non-residential contexts may increase  
44 HIV risk, since lack of social-monitoring and non-kin ties in the neighborhoods may facilitate

45 more frequent engagement in sexual risk behaviors (Seeley and Allison, 2005, Camlin et al., 2013).  
46 To illustrate, previous studies have demonstrated that highly mobile men are more likely to be  
47 engaged in risky sexual behaviors, such as more frequent engagement in condomless sex and  
48 having increased number of sexual partners (Saggurti et al., 2008, Saggurti et al., 2009, Lydie et  
49 al., 2004, Kishamawe et al., 2006, Khan et al., 2008, Gupta et al., 2010, Schuyler et al., 2017).  
50 However, most of the studies on local daily mobility and HIV infection have investigated  
51 heterosexual populations in African or low-income countries, and only a handful of studies have  
52 assessed the role of spatial mobility in the context of the HIV epidemic among MSM in the U.S.  
53 (Mustanski et al., 2015, Tobin et al., 2013)

54  
55 The spatial context of risk behaviors may also be salient to MSM population in the U.S., since  
56 studies have shown that MSM experience different types of neighborhoods (Koblin et al., 2017,  
57 Tobin et al., 2014, Koblin et al., 2013, Duncan et al., 2014), and thus may have differential  
58 influences from diverse neighborhood environments. Two recent studies have shown that few  
59 MSM reside, socialize, and meet sexual partners in the same neighborhoods (Koblin et al., 2013,  
60 Duncan et al., 2014). Young MSM are especially likely to have higher degree of spatial mobility  
61 compared to general MSM, due to the developmental characteristics of this age group during their  
62 transition to adulthood (Schachter, 2001). In addition, MSM with higher mobility may experience  
63 different venues to meet their sexual partners, and such diverse venues play important role in  
64 shaping sexual risk behaviors (Al-Ajlouni et al., 2018a, Young et al., 2017).

65  
66 The scant research on spatial mobility behavior and HIV among MSM has examined a limited  
67 measure of mobility, mostly relying on self-reported mobility, raising concerns of recall bias and

68 misclassification. Objective measures of mobility and spatial context are increasingly used in the  
69 field of physical activity and obesity research (Jia et al., 2019, James et al., 2016, Chaix et al.,  
70 2013), but not widely applied in HIV epidemiology. Use of global positioning system (GPS)  
71 technologies is an objective approach to investigate the aspects of spatial mobility by allowing  
72 researchers to identify participants' continuous spatial location over time. Such spatio-temporal  
73 data can be used to measure local daily mobility and construct activity spaces, and these data, in  
74 conjunction with survey data, can measure time and duration of different types of neighborhood  
75 exposures (Duncan et al., 2016). GPS technologies present an opportunity to enhance  
76 understandings of the relationship between personal spatial mobility behavior and HIV risk among  
77 MSM population.

78  
79 As such, the purpose of this study was to investigate the association of spatial mobility behavior  
80 measured using GPS, with sexual risk behaviors among young MSM. In the present study, we  
81 hypothesize that more mobile young MSM may have higher numbers of sexual partners and more  
82 frequently engage in condomless anal intercourse.

83

## 84 **Method**

### 85 **P18 Neighborhood Study**

86 The present study recruited participants of the *Project 18 Cohort Study*, a prospective cohort study  
87 of 665 HIV-negative MSM in New York City designed to study longitudinal trajectories of sexual  
88 behavior, substance use, and mental health among young MSM (Halkitis et al., 2013). Venue-  
89 based (e.g., community events, afterschool events, service agencies, public spaces, and nightlife  
90 venues) and internet-based (e.g., social networking and dating websites) recruitments was

91 employed for the original cohort. Both active (e.g., approaching individuals to solicit study  
92 participation) and passive (e.g., flyers, advertising on internet) methods were used for the  
93 participant recruitment. Inclusion criteria for the original cohort were: (a) age 18 to 19 years old;  
94 (b) male sex assignment at birth; (c) currently identify as male; (d) residence in the New York City  
95 metropolitan area; (e) report sexual contact with another man in the preceding six months; and (f)  
96 reported negative or unknown HIV status. The study started from May 2009. We randomly sorted  
97 the 665 P18 Cohort participants and invited them to the sub-study, known as the P18  
98 Neighborhood Study. We contacted to the randomly sorted participants via email or text messaging  
99 until the number of enrollments was reached to 250. Total 450 participants were contacted, and  
100 the 250 participants enrolled in the sub-study between January 2017 and January 2018. The  
101 response rate was 56%. Additional eligibility criteria were applied for the subgroup study,  
102 including (1) having no mobility restrictions through a screening question, “Do you have serious  
103 difficulty walking or climbing stairs?”, (2) being comfortable carrying a GPS device for two weeks,  
104 and (3) being able to come in for the first and follow-up visits. The selected sub-group of 250  
105 participants showed similar socio-demographics with the original cohort. For example, the  
106 percentages of Black/African-American in the sub-cohort and the original cohort were 30% and  
107 27% respectively (White: 32% vs. 25%; Asian: 10% vs. 8%, school enrollment: 25% vs 33%, less  
108 than high school:34% vs. 39%; Associate: 11% vs 13%; College: 55% vs. 48%) (Jaiswal et al.,  
109 2018).

110 At the first visit, participants were consented to the subgroup study, completed the first survey,  
111 and received instructions on GPS device. At the follow-up visit, they returned the GPS device,  
112 completed an exit survey, and were compensated \$110. Three participants did not complete the  
113 two visits, therefore, three additional participants were randomly selected and enrolled in the sub-

114 study. The University Committee on Activities Involving Human Subjects at New York University  
115 and the institutional review board of the New York University School of Medicine approved the  
116 research protocol prior to subject enrollment.

117

### 118 **GPS Protocol**

119 Participants were asked to carry a small GPS device (BT-Q1000XT, QStarz International Co., Ltd.,  
120 Taipei, Taiwan) at all times over a two-week period, except when sleeping, swimming, and  
121 showering. The device collected location data in 10-second intervals, and additional GPS-use diary  
122 was used to evaluate the GPS data quality. Feasibility and acceptability of proposed GPS protocol  
123 was tested from a prior pilot study (Duncan et al., 2016), and a similar protocol was applied for  
124 this study. Of total 250 participants with GPS data, 39 participants were excluded as they (1) lived  
125 outside of New York City, (2) had invalid addresses, and/or (3) had less than 1 hour of GPS data  
126 for one day, which did not meet the data quality protocol. A total of 211 participants were used in  
127 the analysis. GPS data cleaning used a set of processing scripts to eliminate erroneous data, such  
128 as duplicated time stamps and isolated GPS points. Spatially isolated points were identified using  
129 400-meter distance between two consecutive points (10 second apart), and those points were  
130 removed from the dataset.

131

### 132 **Geographic Mobility Calculation**

133 To quantify the local daily mobility of participants, we employed two measures; distance traveled  
134 and activity space size (Figure 1). The distance traveled was measured using inter-point distance  
135 calculation, and for the activity spaces, daily path area calculation was employed (Boruff et al.,  
136 2012, Sherman et al., 2005, Hirsch et al., 2014, Duncan et al., 2018b). The daily path area was



137 defined by creating 50, 100, 200, and 400-meter buffering radiuses around the GPS points in New  
138 York City. We selected 50-meter buffer activity space as the main metric of exposure, based on  
139 the line-of sight theory and existing studies on GPS-based activity space. It is suggested that micro  
140 street-level features may impact on how individuals perceive and interact with the urban context  
141 (Llobera, 2003, Ewing et al., 2006), thus we assumed that the 50-meter buffer can effectively  
142 capture the street-level environments, especially in the settings of New York City. In addition,  
143 previous studies on GPS-based mobility described that the 50-buffer can avoid potential  
144 dependence of the urban environmental characteristics between consecutive points when assessing  
145 neighborhood exposures from walking activity (Rodriguez et al., 2012, Troped et al., 2010). As  
146 the estimates may be sensitive to the sizes of buffer due to the modifiable areal unit problem (Wong,  
147 2009), we also ran sensitivity analyses for different buffer sizes, and reported in the supplement  
148 table. The activity space sizes (i.e., the sizes of the daily path area) were expressed in square  
149 kilometers (km<sup>2</sup>), based on Universal Transverse Mercator (UTM) zone 18N projection, one of  
150 two-dimensional Cartesian coordinate systems corresponding to New York City metropolitan area.  
151 All GPS data processing and cleaning were conducted using ESRI ArcGIS 10.4 and Quantum  
152 QGIS 2.6.

153

#### 154 **Sexual behavior outcomes**

155 In this study, we focused on sexual behaviors associated with risk of HIV infection among MSM.  
156 The Project 18 Cohort Study collected data on sexual behaviors including number of male sexual  
157 partners and number of condomless sexual encounters in past six months. The number of male  
158 sexual partners was assessed from two questions: (1) “In the past 6 months, how many male steady  
159 partners have you have anal or oral sex with?,” (2) “In the past 6 months, how many casual male

160 partners have you had anal or oral sex with?”. The total number from those two questions was used  
161 as one outcome and was considered a count type variable in the analyses (Koblin et al., 2006,  
162 Vittinghoff et al., 1999, Page-Shafer et al., 1997, Kuiken et al., 1990, Darrow et al., 1987). In  
163 addition, numbers and types of sexual encounters were assessed to create three variables: total  
164 numbers of condomless anal intercourse (CAI) acts, (2) total numbers of condomless insertive anal  
165 intercourse (CIAI) acts, and (3) total number of condomless receptive anal intercourse (CRAI) acts  
166 in past six months (Patel et al., 2014, Koblin et al., 2006, Vittinghoff et al., 1999, Page-Shafer et  
167 al., 1997, Kuiken et al., 1990, Darrow et al., 1987).

168

### 169 **Covariates**

170 Participants reported their socio-demographic characteristics, such as age (years), ethnicity  
171 (Hispanic or non-Hispanic), and race (Black, Asian, White, and others), education attainment (high  
172 school or less, some college/ technical school, college degree or more), current school enrollment  
173 status (yes/no), and foreign-born status (yes/no). Homelessness was also included in the analyses,  
174 as it is an important factor of mobility and risk behaviors (Aidala et al., 2005). Self-reported total  
175 individual annual income was categorized as less than \$15,000, between \$15,000 and \$35,000,  
176 more than \$35,000 per year, which approximates national poverty level (<\$15,000) (U.S.  
177 Department of Health and Human Services, 2017). The national poverty level is criterion of  
178 various social support programs, such as Supplemental Nutrition Assistance Program (SNAP) and  
179 Home Energy Assistance Program (HEAP), thus the categorical value may reflect people who  
180 were eligible for such programs (Falk and Aussenberg, 2013).

181

182 Other potential confounders were included: drug use (any type of substance in any form except  
183 marijuana) in the past 6-month (yes/no), numbers of alcoholic drinks in the past 30 days, and  
184 number of days of experiencing mental health problems (stress, depression, and emotional  
185 problems in the past 30 days). In addition, participants' sexual identification (gay or bisexual) and  
186 relationship status (currently having a main romantic partner), were included in the analyses  
187 (Harawa et al., 2008, Everett, 2013, Mustanski et al., 2011, Hoff et al., 2012).  
188 Lastly, residential self-selection of individual, which describes that people choose where to live  
189 based on their travel needs and preferences, may influence the mobility patterns and health  
190 behaviors (Boone-Heinonen et al., 2011, Mokhtarian and Cao, 2008), thus two ordinal variables  
191 were included: (1) "How important was housing price to you when choosing to live in your current  
192 neighborhood?" and (2) "How important was living in the city center to you when choosing to live  
193 in your current neighborhood?". Response options for the two questions were (1) not at all  
194 important, (2) not too important, (3) somewhat important, (4) mostly important, and (5) very  
195 important. All abovementioned variables were included in the multivariate models.

196

## 197 **Statistical Analyses**

198 Descriptive statistics were generated to summarize data of the study. In order to identify  
199 associations between spatial mobility and sexual risk behaviors, quasi-Poisson regression models  
200 were fitted with a logarithmic link function, and for CAI, CIAI, and CRAI models, total number  
201 of anal intercourse acts was included as an offset variable. We examined bivariate and  
202 multivariable models of different mobility measures with covariates. Adjusted multivariate models  
203 were fitted with abovementioned covariates. Lastly, we tested effect modification between the  
204 exposure and two potential modifiers (sexual identification and relationship status) using

205 multiplicative interaction terms. All estimates are presented with 95% confidence intervals (CIs).  
206 All statistical analyses were conducted using R.3.3.2 with built-in functions including “glm” for  
207 quasi-Poisson modeling.

208

## 209 **Results**

210 Socio-demographic characteristics of participants are shown on Table 1. The average distance  
211 traveled during the two-week monitoring period was 400.9 kilometers and the size of activity  
212 spaces for 50, 100, 200, and 400 m buffers were 6.0 km<sup>2</sup>, 9.4 km<sup>2</sup>, 16.3 km<sup>2</sup>, 29.2 km<sup>2</sup>, respectively.  
213 Participants reported an average of 5.6 male sexual partners in the past six months (standard  
214 deviation [SD]: 7.1). Over the same period, participants engaged in CAI an average of 15.1 times  
215 (SD: 25.9), including 8.3 CIAI acts (SD: 18.1) and 7.0 CRAI acts (SD: 13.8). The sample was  
216 relatively young (mean age of 24.9, SD=0.9) and mostly gay (84%). The participants were diverse  
217 in terms of race/ethnicity; 32% White, 30% Black, 17% others, 10% Asian; and 30%  
218 Hispanic/Latino.

219 Table 2 describes the results of quasi-Poisson models for the associations between distance  
220 traveled and sexual risk behaviors. From the multivariate models, distance traveled during the two-  
221 week period was not associated with the number of male sexual partners. The total distance  
222 traveled was associated with CAI acts and CIAI acts. The number of CAI acts increased by 1%  
223 per additional 10 kilometers traveled (IRR: 1.01, 95% CI: 1.00–1.02) and the number of CIAI acts  
224 increased by 2% from the full models.

225 Table 3 shows model results with activity space size, measured as 50m buffer daily path area.

226 Activity space size was associated with the number of male sexual partners from the full model  
227 (IRR:1.04, CI: 1.00-1.08). Activity space size was associated with the number of CAI acts (IRR:

228 1.04, CI: 1.01-1.06). In particular, the number of CIAI acts increased by 5% (IRR: 1.05; 95% CI:  
229 1.01–1.09) for each additional square kilometer increase in activity space size as defined with a  
230 50-meter buffer from the full model. The number of CRAI acts was not associated with the  
231 activity space size from the full model. The association of interest between activity space size  
232 and sexual risk behaviors tended to decrease, as the radius considered defining the daily path  
233 area was larger (Supplemental Table 1), yet the direction of coefficients and confidence intervals  
234 remain consistent with main findings.

235 The coefficients of covariates showed similar directions and trends from both the distance  
236 travelled and the activity space size models (Table 2 and 3). Drug use was positively associated  
237 with the number of sexual partners, presence of romantic partner was positively associated with  
238 CAI. Increased age was associated with higher numbers of CIAI. Alcohol use was negatively  
239 associated with CIAI, while it is positively associated with CRAI. School enrollment status and  
240 presence of romantic partner were strong and positive predictors of CRAI.

241 Lastly, the multivariate models with multiplicative interaction terms showed no interactions  
242 between geographic mobility and the two potential effect modifiers; sexual identification and  
243 presence of romantic partner (data not shown).

244

## 245 **Discussion**

246 This study examined mobility-related correlates of sexual risk behaviors among a sample of HIV-  
247 negative young MSM in New York City. From our models, we found that higher local daily  
248 mobility, defined as longer distance traveled and larger activity space sizes, was correlated with  
249 increased total numbers of CAI acts. Despite the relatively small effect sizes, these finding suggest  
250 that local daily mobility is predictor of sexual behaviors of young MSM in New York City.

251

252 Spatial mobility may be related to sexual risk networks, as greater mobility may be associated with  
253 expanded sexual networks (Cassels et al., 2017, Vaughan et al., 2017). Formation of sexual  
254 networks is linked to spatial mobility, and people with greater spatial mobility are likely to develop  
255 more social ties in different places (Gesink et al., 2019, Belot and Ermisch, 2009, Carrasco et al.,  
256 2008, Larsen et al., 2006). The total number of CAI may also be related to potential engagement  
257 in risky sexual networks in different places. Our findings are consistent with existing findings on  
258 mobility and risk of HIV infection. Previous studies found that MSM with high mobility were at  
259 higher risk for HIV infection (Ramesh et al., 2014, Mustanski et al., 2015) and MSM who travel  
260 for leisure engage in more frequent sexual risk behaviors than those who do not (Benotsch et al.,  
261 2006b, Benotsch et al., 2006a, Benotsch et al., 2011, Harry-Hernandez et al., 2019).

262

263 In addition, personality may play an important role in determining both mobility and sexual risk  
264 behaviors. Under this hypothesis, the mobility measures would reflect aspects of the personality  
265 that are also related to sexual risk behaviors (e.g., a preference for new and exciting experiences  
266 may lead an individual to meet sexual partners in different neighborhoods and a proclivity for  
267 CAI). However, it should be mentioned that visiting several places with sexual purposes during  
268 the GPS observation period might have contributed to increased local daily mobility. To illustrate,  
269 large proportions of young MSM in the U.S. uses diverse range of social networking smartphone  
270 applications to meet male partners, and such internet or app-users may be more likely to have  
271 higher mobility compared to non-users (Duncan et al., 2018a, Benotsch et al., 2011, Card et al.,  
272 2018). The latter particular case does not correspond to a causal effect of spatial mobility behavior  
273 on sexual risk behavior.

274

275 This study is not without limitations. First, study was conducted in New York City, and the  
276 participants were sampled from HIV-negative and mobile young MSM. Thus, our findings may  
277 not be generalizable to other environments, such as small cities and rural areas, and other MSM  
278 populations including HIV-positive, older, or disabled. Second, the measured mobility does not  
279 capture the content of experiences of participants within neighborhoods. In other words, we did  
280 not investigate the characteristics of neighborhood exposures, such as social and physical features  
281 of neighborhoods that participants visited or the types of places that participants visited and related  
282 activities. Studies suggest that the venue of partner meeting plays role in shaping sexual risk  
283 behaviors (Al-Ajlouni et al., 2018b, Grov et al., 2007, Colfax et al., 2001), however, the increased  
284 spatial mobility did not reflect actual exposures to risky environments, rather it may indicate longer  
285 commutes or travel routes Previous studies suggested that higher mobility may be associated with  
286 lack of conventional social supports for HIV prevention (Frye et al., 2014, Vaughan et al., 2017),  
287 however, we was not able to ascertain the differential social environments of diverse neighborhood  
288 exposures. Also, although the two-week monitoring period is relatively long compared to most  
289 health studies using GPS (Duncan et al., 2018b), the measured mobility assessed over the period  
290 may not represent participants' typical travel behaviors. However, a recent study by Zenk et al  
291 reported that a two-week period is adequate to measure individual travel behavior (Zenk et al.,  
292 2018). Third, the GPS protocol was designed for 2-week data collection, but not all of participants  
293 engaged in the full-period tracking. We did not standardize the distance traveled and activity space  
294 size by number of days of tracking. Fourth, GPS signal errors and data losses may be introduced  
295 due to special settings in large metropolitan locations such as subway, underground, and large  
296 buildings (Georgiadou and Kleusberg, 1988). Despite the GPS error, we processed the data to

297 maximize reliability by eliminating isolated points and duplicated timestamps. Lastly, there are  
298 several limitations inherent in any cross-sectional survey including difficulties to infer causality.  
299 We were not able to examine temporal association between the mobility behaviors and sexual risk  
300 behaviors, and so it remains possible as discussed above that sexual risk behaviors, especially the  
301 willingness to have a large number of partners, may have influenced the size of the activity space  
302 captured over the monitoring period due to participants travelling to meet their sexual partners.

303

304 Our study also has numerous strengths, including assessing the objective measure of local daily  
305 mobility, a large sample size for a sensor-based study, and a relatively long period of GPS tracking  
306 period (Zenk et al., 2018, Duncan et al., 2018b). To our knowledge, this study is the largest GPS  
307 study to examine the association between objectively measured mobility and sexual risk behaviors  
308 in any MSM population. The GPS protocol allowed 10-second epochs, which high monitoring  
309 frequency enhanced the overall quality of the GPS data. Moreover, the two-week monitoring  
310 period was longer than most existing GPS studies that typically monitor participants over one week,  
311 capturing more variations of travel behavior of participants, and is a significant step forward  
312 beyond place-based analysis based on residential administrative boundaries such as census tracts  
313 or ZIP codes.

314

315 As noted above, further studies should be conducted to examine the effects of different  
316 neighborhoods and meeting venues including residential, work, social, and sexual contexts to  
317 understand actual influences of neighborhoods. In addition, temporal dimensions (e.g. duration)  
318 of exposure can be tested with the GPS data to test dose-response associations. Social and physical  
319 characteristics of the various neighborhoods will have to be considered, on the basis of the GPS



320 data that we collected, for instance population density, HIV prevalence, crime rates, neighborhood  
321 disorder, racial segregation, and proximity to clinical and social services (Duncan et al.,  
322 Forthcoming). One could test psychosocial factors and social network characteristics that may  
323 shape sexual health behaviors, in order to increase our level of understanding of the impact of  
324 socio-spatial contexts on the sexual risk behaviors. Additionally, GPS-based ecological  
325 momentary assessment (EMA) method will be helpful to better understand the actual exposures to  
326 neighborhood characteristics (Duncan et al., 2019). Lastly, longitudinal studies should be  
327 conducted to investigate causal influences over time of spatial mobility behavior and socio-spatial  
328 contexts on sexual risk behaviors.

329

## 330 **Conclusions**

331 Our innovative study found that local daily mobility was associated with sexual risk behaviors,  
332 confirming the role of geographic mobility in the context of the HIV epidemic among MSM in the  
333 U.S. Future research should seek to understand the impacts of different types of neighborhoods  
334 and places visited on HIV risk behaviors using this mobility-based approaches in order to enhance  
335 place-based HIV prevention by allowing specific target places for interventions.

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595 Table 1. Socio-demographic characteristics, activity space size, and sexual risk behaviors, The P18  
 596 Neighborhood Study (n=211)

Variables	Levels	Mean (SD) or N (%)
<b>Age</b>	In years, min=23, max=26	24.9 (0.9) <b>597</b>
<b>Race</b>	White	67 (32%)
	Black/African American	64 (30%) <b>598</b>
	Others	35 (17%)
	Asian	21 (10%) <b>599</b>
	Two or more	21 (10%) <b>600</b>
<b>Ethnicity</b>	Non-Hispanic/Latino	148 (70%) <b>601</b>
	Hispanic/Latino	63 (30%) <b>602</b>
<b>Annual income (total, individual)</b>	<\$15,000	51 (24%) <b>603</b>
	\$15,000 - \$35,000	70 (33%) <b>604</b>
	>\$35,000	76 (36%) <b>605</b>
<b>Current student</b>	Yes	52 (25%) <b>606</b>
<b>Education</b>	≤ High School	71 (34%) <b>607</b>
	Associate	23 (11%) <b>608</b>
	College/Graduate	116 (55%) <b>609</b>
<b>Homeless</b>	Yes	7 (3%) <b>610</b>
<b>Foreign-born</b>	Yes	30 (14%) <b>611</b>
<b>Drug use in the past 6 months</b>	Yes	101 (48%) <b>612</b>
<b>Alcohol use in the past 30 days</b>	Number of drinks	8.3 (7.5) <b>613</b>
<b>Experience of mental health issues</b>	Number of days	5.0 (7.5) <b>614</b>
<b>Sexual identity</b>	Gay	177 (84%) <b>615</b>
	Bisexual	30 (14%) <b>616</b>
<b>Relationship type</b>	Has a romantic partner	77 (36%) <b>617</b>
<b>Distance traveled</b>	(in km <sup>2</sup> )	400.9 (224.9) <b>618</b>
<b>Importance of price in current housing choice</b>	Not at all important	13 (6%) <b>619</b>
	Not too important	4 (2%) <b>620</b>
	Somewhat important	39 (18%) <b>621</b>
	Mostly important	45 (21%) <b>622</b>
	Very important	92 (44%) <b>623</b>
<b>Importance of being city center in current housing choice</b>	Not at all important	25 (12%) <b>624</b>
	Not too important	55 (26%) <b>625</b>
	Somewhat important	59 (28%) <b>626</b>
	Mostly important	33 (16%) <b>627</b>
	Very important	27 (13%) <b>628</b>
<b>50m activity space size</b>	(in km <sup>2</sup> )	6.0 (5.1) <b>629</b>
<b>100m activity space size</b>	(in km <sup>2</sup> )	9.4 (8.2) <b>630</b>
<b>200m activity space size</b>	(in km <sup>2</sup> )	16.3 (14.1) <b>631</b>
<b>400m activity space size</b>	(in km <sup>2</sup> )	29.2 (24.3) <b>632</b>
<b>Number of male sexual partners</b>	In the past 6 months	5.6 (7.1) <b>633</b>
<b>Number of CAI</b>	In the past 6 months	15.1 (25.9) <b>634</b>
<b>Number of CIAI</b>	In the past 6 months	8.3 (18.1) <b>635</b>
<b>Number of CRAI</b>	In the past 6 months	7.0 (13.8) <b>636</b>
		<b>637</b>
		<b>638</b>

639 SD: standard deviation,  
 640 CAI: condomless anal intercourse,  
 641 CIAI: condomless insertive anal intercourse,  
 642 CRAI: condomless receptive anal intercourse

