Examination of multidimensional geographic mobility and sexual behaviour among Black cisgender sexually minoritized men in Chicago

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Abstract

Black sexually minoritized men (BSMM) are the most likely to acquire HIV in Chicago- a racially segregated city where their daily travel may confer different HIV-related risks. From survey and GPS data among participants of the *Neighbourhoods and Networks Cohort Study*, we examined spatial (proportion of total activity space away from home), temporal (proportion of total GPS points away from home), and motivation-specific (discordance between residential and frequented sex or socializing neighbourhoods) dimensions of mobility. To identify potential drivers of BSMM's risk, we then examined associations between mobility and sexual behaviours known to cause HIV transmission: condomless anal sex, condomless anal sex with a casual partner, transactional sex, group sex, and sex-drug use. Multivariable logistic regression models assessed associations. Of 269 cisgender BSMM, most were 20-29 years old, identified as gay, and low-income. On average, 96.9% (Standard Deviation: 3.7%) of participants' activity space and 53.9% (Standard Deviation: 38.1%) of participants' GPS points occurred outside their 800m home network buffer. After covariate adjustment, those who reported sex away from home were twice as likely to report condomless sex (Odds Ratio: 2.02, [95% Confidence Interval (CI): 1.08, 3.78]). Those who reported socializing away from home were four times more likely to have condomless sex with a casual partner (Odds Ratio: 4.16 [CI: 0.99, 29.0]). BSMM are on the move in Chicago, but only motivation-specific mobility may increase HIV transmission risk. Multidimensional investigations of mobility can inform place-based strategies for HIV service delivery.

Introduction

The composition and context of our neighbourhoods – and how we move through them – has been associated with HIV-related outcomes among racially minoritized groups (Duncan *et al.*, 2021). As residents of one of the most racially segregated cities in the United States (Menendian *et al.*, 2021), Black people in Chicago face a myriad of poor HIV outcomes due to their spatial segregation and marginalization (Gant *et al.*, 2023; Oluyomi *et al.*, 2023; Rimmler *et al.*, 2022). Chicagoan Black sexually minoritized men (BSMM), in particular, experience disproportionately higher rates of HIV incidence compared to other sexually minoritized men (SMM) (Mustanski *et al.*, 2019) and comprise over one-quarter of new diagnoses in the city (*Getting to Zero Illinois Dashboard*, 2022). However, few studies explore the links

between spatial (im)mobility and HIV transmission risk behaviours exclusively among BSMM.

Geographic mobility – where, how far, and for how long someone travels over a given period – can impact several health outcomes (Morris *et al.*, 2018), including one's sexual behaviours that can cause HIV transmission (Kim *et al.*, 2020). For example, mobility may be associated with condomless anal sex (Patel *et al.*, 2014), transactional sex (Oldenburg *et al.*, 2015), group sex (Lew *et al.*, 2023), and using alcohol or drugs during sex (Tomkins *et al.*, 2019). This is because individuals may experience less social control from known friends, family, or neighbours when they are away from home (DeLamater, 1981; Zenilman *et al.*, 1999). "Journey-to" theory, which spans multiple disciplines, captures how mobility lessens the social controls that govern individual behaviours. In criminology, the "journey to crime" (committing a crime away from one's residential neighbourhood) is associated with victimization and law enforcement outcomes (Donnelly *et al.*, 2021; Luo *et al*., 2021). This theory has been applied to substance use research in which the "journey to overdose" (overdosing in a neighbourhood that is not one's own neighbourhood) was found to result in more accidental deaths than if individuals overdosed at home (Forati *et al.,* 2023). To extend this theory further, "journey to sexual behaviour" – having sex in neighbourhoods away from home – may be associated with greater rates of sexual behaviours that increase the risk of HIV transmission (Cassels *et al.*, 2020; Dharma *et al.,* 2023). Of course, mobility could also introduce individuals to neighbourhoods and networks with varying social norms that can also influence sexual behaviours (Frye *et al.*, 2017). For this reason, it is important to unpack which aspects of BSMM's geographic mobility (e.g., time spent away from home, having sex away from home) relate to which sexual behaviours that may increase HIV transmission risk.

While recent studies among SMM suggest links between mobility and sexual behaviours, none have exclusively studied these associations among BSMM. Duncan and colleagues found that SMM in New York City engage in "spatial polygamy" (using a survey measure) in which individuals spend time outside of their residential neighbourhood for a multitude of reasons like having sex and socializing – and these types of activity spaces differ by key characteristics that relate to HIV vulnerability (Duncan *et al.*, 2014). In New York City among a racially and ethnically diverse sample of SMM, Kim et al. found that the size of one's activity space, using a Global Positioning System (GPS) measure, was positively associated with having condomless anal sex (Kim *et al.*, 2020). Geographic mobility – whether for sex, socializing, or other reasons – among BSMM in the United States remains poorly understood.

Current mobility and health studies, including those with SMM, use either survey or GPS-based measures, each with its own advantages and disadvantages. Survey measures, like from travel histories, are often favoured for describing the motivations for travel, but may be subjective and prone to recall bias (Rezaei *et al.*, 2023; Zare & Pearce, 2022). GPS methods facilitate more objective measurement of mobility and allow for many different quantifications of the scale of movement – like size of one's activity space or the proportion of one's time spent away from home (Duncan *et al.*, 2020). However, without contextualizing GPS-based measures with survey data, associations between mobility and health outcomes may suffer from "selective daily mobility bias" (Chaix *et al.*, 2012). Furthermore, when used in isolation, either of these methods may produce a unidimensional picture of mobility that provides little information. For example, in Kim and colleagues' GPS-based study (Kim *et al.*, 2020), it is unclear whether the sexual acts associated with mobility occurred away from individuals' home neighbourhood (as mobility and sexual behaviours were measured separately) – making it difficult to test the specific effects of traveling for sex. In a sample of young BSMM and transgender women in Chicago, Kolak and colleagues found through survey data that individuals with sexual partners who lived in different non-neighbouring community areas were more likely to have exchanged sex for money, shelter, and other goods (Kolak *et al.*, 2021). This study aims to combine survey and GPS methods to comprehensively describe different mobility dimensions and explore their associations with sexual behaviours, enhancing the understanding of contextual determinants of HIV risk. Applying "journey to" theory (Forati *et al.*, 2023; Luo *et al.*, 2021), i.e., *journey to sexual behaviour*, this study aims to examine multiple dimensions of geographic mobility using GPS and survey measures and their associations with sexual behaviours that may increase HIV transmission risk in a well-characterized sample of Chicagoan BSMM. We leverage individual-level GPS data uniquely linked with survey data from the Neighbourhood and Networks (N2) Cohort Study in Chicago to measure mobility more granularly – including across sex and socializing areas – to deepen understanding about the associations between mobility and sexual behaviour. As place matters for Chicagoan BSMM's uptake of HIV services (Behler *et al.*, 2018), a deeper characterization of their spatial mobility and associated HIV-related risks can help programs to meet these men where they are.

Materials and Methods

The N2 cohort study

The Neighbourhoods and Networks (N2) Cohort Study, described elsewhere (Driver *et al.*, 2023; Duncan *et al.*, 2019), seeks to examine associations between neighbourhood-level and network-level factors and HIV outcomes among BSMM. The cohort includes four sites (Chicago, IL, Jackson, MI, Jackson, MS, New Orleans, and Baton Rouge, LA) with high HIV burdens among BSMM; however, only Chicago's GPS data was available at the time of analysis. In Chicago, 450 participants were recruited via seeds engaged in a variety of local HIV-related research projects (Fujimoto *et al.*, 2017; Khanna *et al.*, 2016, 2017; Morgan *et al.*, 2016; Young *et al.*, 2018). Respondent-driven sampling invited seeds to recruit up to six contacts into the N2 cohort, and so on. Eligible recruits were aged 16-34, assigned male sex at birth, identified as Black or African American, had no plans to leave Chicago during the study period, and reported at least one sexual encounter with another man or transgender woman in the past year.

Self-reported survey data were collected from 2018-2019 on topics such as racial and sexual identity, neighbourhood preferences, housing, sexual behaviour, substance use, and frequently visited locations for sex and socializing. Data also included GPS data from wearable GPS devices (Qstarz BT-Q1000XT, Qstarz International Co., Ltd.) worn by consenting participants for a target of 14 consecutive days as per the protocol (Zenk *et al.*, 2018). Geographic coordinates were recorded every 10 seconds.

The analytic sample comprised cisgender (a person whose gender identity corresponds with the sex registered for them at birth; *i.e.* the opposite to transgender) men in Chicago with a mailing

address who agreed to wear the GPS device. We restricted the sample to cisgender men because only 43 transgender women had complete data. This means a separate multivariable model would lack sufficient statistical power, even though this sub-population requires separate confounder adjustment. This is because the drivers of both mobility and sexual behaviour among transgender women (*e.g.*, social networks and life events) may differ from those of cisgender men (Bowers *et al.*, 2012; Factor & Rothblum, 2007; Morris *et al.*, 2018). For example, Black transgender women may have greater sexual partner turnover, more sexual partners, and lower income or employment compared to BSMM (Ezell *et al.*, 2018; Russell *et al.*, 2021).

Geocoding of home addresses and neighbourhoods

Participants reported their mailing address, operationalized as the "home location" (Duncan *et al.*, 2020), and we geocoded addresses to create two types of home neighbourhood areas based on similar urban research. First, we established a street-network buffer area around the home location at 400m and 800m distances (Duncan *et al.*, 2020) (Figure 1). While buffer-based neighbourhood definitions may more closely reflect individuals' home environments in a walkable city, it is unclear whether 400m and 800m network buffer areas best reflect home neighbourhoods of Chicagoans in the N2 Cohort (Duncan *et al.*, 2012). Second, home locations were categorized within Chicago community areas or zip codes if located outside Chicago, similar to approaches using New York City boroughs (Duncan *et al.*, 2014).

Mobility measures

We used both GPS and survey data to describe participants' geographic movement relative to their home neighbourhood. We used GPS-based measures to represent the amount of space and time individuals spend outside of their home neighbourhood. Activity spaces were created from individuals' approximately 14-day GPS point records, represented by polygons with a 100m buffer area around their daily travel paths (Figure 1) (Duncan *et al.*, 2020; Hirsch *et al.*, 2014; Kim *et al.*, 2021; Lee *et al.*, 2016). The 100m buffer includes humans' line-of-sight, and has been used in prior urban mobility research (Duncan *et al.*, 2020; Kim *et al.,* 2020). The spatial scale of mobility was determined by the proportion of total activity space away from home, and the temporal scale by the proportion of total GPS points away from home – each applying the 400m and 800m home network buffer definitions of "home" (Duncan *et al.*, 2020; Müller *et al.*, 2022; Searle *et al.*, 2017). To represent motivation for mobility, we describe discordance between one's home neighbourhood (employing the community area definition above) and the neighbourhoods where they report socializing or having sex. Participants were asked to list via a survey the top three locations where they most often i) socialize and ii) have sex (Figure 1). These activity-specific locations were geolocated within a Chicago community area (if inside Chicago) or within a zip code (if outside Chicago) and compared to the participant's home (residential) neighbourhood. If at least one of the social or sex locations was discordant with their home neighbourhood, they were classified as having residential-social or residential-sexual neighbourhood discordance, respectively (Duncan *et al.*, 2014).

HIV-related sexual behaviours

Five outcomes were examined that reflect sexual behaviours known to increase the risk of HIV transmission (Driver *et al.*, 2023; Duncan *et al.*, 2019; Timmins *et al.*, 2021). These included i) condomless anal sex (with any partner), ii) condomless anal sex with a casual (non-regular) partner, iii) transactional sex (exchanging sex for money, food, shelter, or other goods – or vice-versa), iv) group sex (sex with more than one person at the same time), and v) sex-drug use (using alcohol or drugs before or during sex to enhance, improve, or extend sex) (Shrader *et al.*, 2023) in the last six months. All were captured in the N2 survey through self-reported responses.

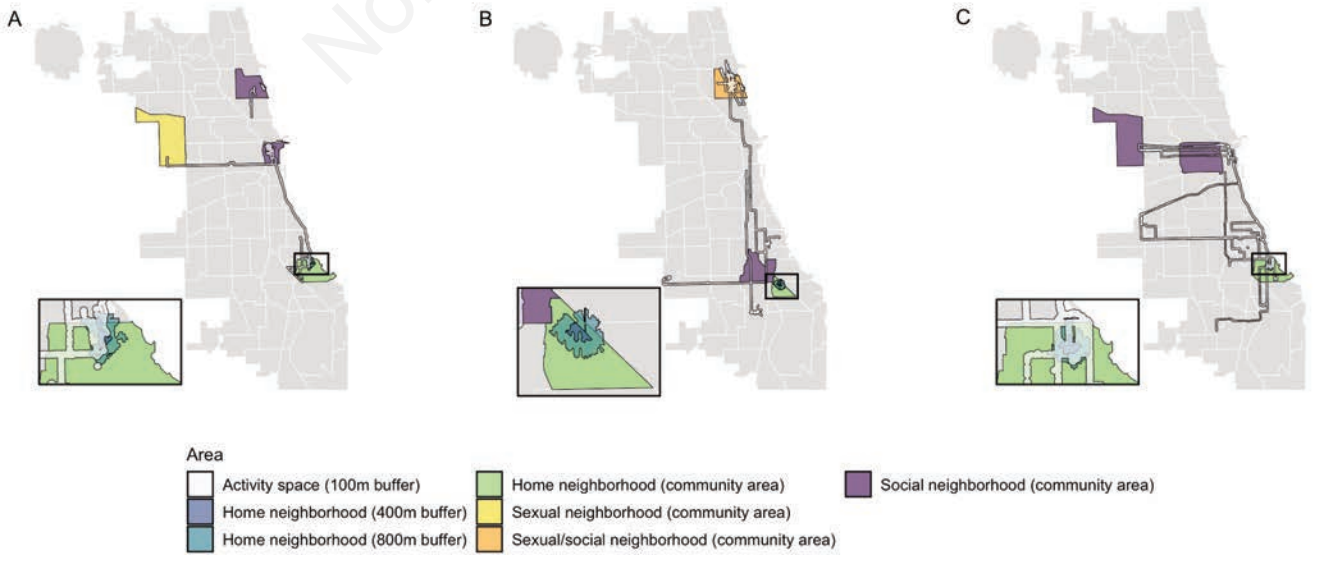

Figure 1. GPS and survey-recorded areas for deriving mobility measures, three randomly selected participants, Chicago, The N2 Cohort Study.

Key covariates

The sample was described in terms of key covariates identified from the scientific literature that influence both mobility and health behaviours. These include individual sociodemographic characteristics (age group, educational attainment, and sexual identity) (Bowers *et al.*, 2012; D'Anna & Chang, 2023), socioeconomic status (income, being currently employed or in school, being unhoused in the last 12 months, and experiencing stable housing in the last 3 months) (Morris *et al.*, 2018; Raymond *et al.*, 2011), and preference for living in a mostly gay neighbourhood (on a scale of not at all important to very important) (Bader & Krysan, 2015; Mauck *et al.*, 2018; Van Dyck *et al.*, 2011).

Statistical analysis

Mobility was described using measures of centrality, including mean, standard deviation (SD), median, and inter-quartile range (IQR) for continuous measures and proportions for dichotomous measures. Univariable and multivariable logistic regressions were conducted for each combination of the six mobility measures and five sexual behaviours. Unadjusted and adjusted odds ratios with 95% confidence intervals were computed. Covariates previously listed were included in the multivariable models if they were identified as a potential confounder via a directed acyclic graph. All analyses were performed using R Studio (Posit team 2023).

Results

Study participants

Of 411 total participants surveyed, 356 (87%) identified as cisgender men. Of those, 87 (24%) were excluded from analysis because they either had no home coordinate (1%) or GPS-recorded activity space (24%). The final analytic sample consisted of 269 Black cisgender SMM with GPS data. Besides their gender identity, there were no statistically significant differences in sociodemographic characteristics between the analytical sample and the overall N2 sample (Table 1). Of the 269 participants, 202 (75.1%) were aged 20-29 years, 165 (61.3%) identified as gay, 224 (83.3%) completed high school or less, and 186 (69.1%) make an annual salary of under $25,000.

Mobility

On average, 96.9% (SD: 3.7%) of individuals' activity spaces were outside their 800m residential buffer area, and 53.9% (SD: 38.1%) of their GPS points were recorded outside their 800 residential buffer area (Table 2). These proportions were higher when considering the 400m buffer area (99.0% (SD: 1.5%) and 60.0% (SD: 37.5%), respectively). Of 262 participants reporting neighbourhoods for socializing, 249 (95.0%) reported a socializing neighbourhood outside of their community area. Of 255 participants reporting neighbourhoods for sex, 183 (71.8%) reported a sexual neighbourhood outside of their community area.

Table 1. Sociodemographic characteristics among Black cisgender sexually minoritized men in Chicago, The N2 Cohort Study (N=269).

Characteristic	n (%)
Age group	
<20 years old	14 (5.2)
20-29 years old	202 (75.1)
30+ years old	53 (19.7)
Born outside the United States	1 (0.4)
Education level attained	
High school or less	224 (83.3)
Above high school	45 (16.7)
Currently employed or in school	152 (56.5)
Unhoused in the past 12 months	78 (29.0)
Living in stable housing in the past 3 months	
Yes	181 (67.3)
No	76 (28.3)
Not known/refused/missing	12 (4.5)
Sexual identity	
Gay	165 (61.3)
Bisexual	77 (28.6)
Straight	7 (2.6)
Other	13 (4.8)
Don't know	7 (2.6)
Annual Income	
<$25,000	186 (69.1)
>$25,000	79 (29.4)
Not reported	4 (1.5)
Prefer to live in a mostly gay neighbourhood	
Not at all important	105 (39.0)
Not too important	79 (29.4)
Somewhat important	58 (21.6)
Mostly important	7 (2.6)
Very important	20 (7.4)

Note: "Other" sexual identities included "bisexually gay," "date biological women and transwomen," "demisexual," "man who has sex with men," "openminded," "pansexual," "same gender loving," and "trisexual."

Table 2. Multidimensional mobility characteristics among Black cisgender sexually minoritized men in Chicago (N=269).

Mobility characteristic	Mean (SD)	Median (IQR)
Proportion of total activity space away from home (%)		
Outside 400m home network buffer area	99.0 (1.5)	99.4 (98.7- 99.8)
Outside 800m home network buffer area	96.9 (3.7)	97.9 (96.3-99.3)
Proportion of total GPS points away from home (%)		
Outside 400m home network buffer area	60.0 (37.5)	65.2 (21.9-99.9)
Outside 800m home network buffer area	53.9 (38.1)	42.5 (18.6-99.5)
Neighbourhood discordance by activity type*	n	%
Residential-Socializing (N = 262 reporting)	249	95.0
Residential-Sex (N = 255 reporting)	183	71.8

**Defined as any named location for sex or socializing outside of the home community area/zip code.*

Associations between mobility and sexual behaviours

Out of 269 SMM, 186 (69.1%) reported condomless anal sex in the last six months, and 110 (40.9%) reported condomless anal sex with a casual partner, and 28 (10.4%) reported transactional sex, 52 (19.3%) reported group sex, 47 (17.4%) reported sex-drug use (Table 3).

In measuring the crude associations between each of the six mobility measures and each of the five sexual behaviours, having sex in a different neighbourhood than your residence (residential-sexual neighbourhood discordance) resulted in 79% greater odds (Odds Ratio: 1.79, 95% [Confidence Interval: 1.00, 3.18]) of having condomless sex (Table 3). Residential-social neighbourhood discordance resulted in four times greater odds (4.01 [1.05, 26.3]) of having condomless sex with a casual partner.

After adjusting for age group, educational attainment, currently employed or in school, being unhoused, stable housing, income, sexual identity, and preference for living in a mostly gay neighbourhood, the association between residential-sexual neighbourhood discordance and condomless sex became stronger; those with this neighbourhood discordance were twice as likely to report condomless sex (2.02, [1.08, 3.78]). After adjusting for the same covariates, residential-social neighbourhood discordance and condomless sex with a casual partner became remained strongly associated (4.16 [0.99, 29.0]). The proportion of activity space or GPS points outside the residential buffer were not associated with any sexual behaviour in the adjusted models.

Discussion

Beyond the nuanced examination of multidimensional geographic mobility, this study uniquely examined journey to sexual behaviour theory and generated evidence for BSMM – for whom there is little data despite their disproportionately high HIV outcomes and the structural racism they experience in American cities and around the world. This study used both survey and GPS-based measures to characterize the temporal, spatial, and social dimensions of BSMM's mobility. These comprehensive measures may improve our understanding of the relationship between mobility and HIV-related sexual behaviours. BSMM in our Chicago sample

Table 3. Crude and adjusted associations between multiple dimensions of geographic mobility and sexual behaviours (N=269).

Exposure-Outcome***	N	n	OR	95% CI	aOR*	95% CI
Condomless anal sex						
Proportion of activity space outside of 400m home network buffer	269	186	1.72	0.31, 8.84	1.56	0.25, 9.22
Proportion of activity space outside of 800m home network buffer	269	186	1.33	0.67, 2.60	1.29	0.62, 2.66
Proportion of GPS points outside of 400m home network buffer	269	186	1.01	0.94, 1.08	1.01	0.93, 1.09
Proportion of GPS points outside of 800m home network buffer	269	186	1.03	0.97, 1.11	1.03	0.96, 1.12
Residential-Social neighbourhood discordance	262	183	1.03	0.27, 3.27	1.04	0.26, 3.65
Residential-Sexual neighbourhood discordance	255	179	1.79	1.00, 3.18	2.02	1.08, 3.78
Condomless anal sex with a casual partner						
Proportion of activity space outside of 400m home network buffer	269	110	1.23	0.25, 6.85	1.20	0.21, 7.71
Proportion of activity space outside of 800m home network buffer	269	110	1.13	0.59, 2.24	1.15	0.57, 2.40
Proportion of GPS points outside of 400m home network buffer	269	110	0.99	0.93, 1.06	0.99	0.92, 1.06
Proportion of GPS points outside of 800m home network buffer	269	110	1.01	0.95, 1.08	1.01	0.94, 1.08
Residential-Social neighbourhood discordance	262	107	4.01	1.05, 26.3	4.16	0.99, 29.0
Residential-Sexual neighbourhood discordance	255	105	1.59	0.90, 2.84	1.75	0.96, 3.24
Transactional sex						
Proportion of activity space outside of 400m home network buffer	269	28	0.27	0.04, 2.64	0.54	0.05, 6.35
Proportion of activity space outside of 800m home network buffer	269	28	0.69	0.29, 1.96	0.88	0.33, 2.65
Proportion of GPS points outside of 400m home network buffer	269	28	1.03	0.93, 1.15	1.02	0.91, 1.15
Proportion of GPS points outside of 800m home network buffer	269	28	1.06	0.96, 1.18	1.05	0.94, 1.18
Residential-Social neighbourhood discordance	262	27	**		**	
Residential-Sexual neighbourhood discordance	255	27	1.43	0.58, 4.03	1.24	0.47, 3.67
Group sex						
Proportion of activity space outside of 400m home network buffer	269	52	0.16	0.03, 0.90	0.16	0.02, 1.09
Proportion of activity space outside of 800m home network buffer	269	52	0.46	0.22, 0.96	0.48	0.22, 1.05
Proportion of GPS points outside of 400m home network buffer	269	52	1.00	0.92, 1.08	0.99	0.91, 1.08
Proportion of GPS points outside of 800m home network buffer	269	52	1.01	0.93, 1.10	1.01	0.93, 1.10
Residential-Social neighbourhood discordance	262	51	1.35	0.35, 8.89	1.27	0.29, 9.11
Residential-Sexual neighbourhood discordance	255	50	1.73	0.84, 3.87	1.56	0.74, 3.56
Sex-drug use						
Proportion of activity space outside of 400m home network buffer	269	47	0.55	0.09, 4.54	0.62	0.08, 6.29
Proportion of activity space outside of 800m home network buffer	269	47	0.78	0.36, 1.84	0.83	0.35, 2.11
Proportion of GPS points outside of 400m home network buffer	269	47	1.02	0.94, 1.11	1.03	0.94, 1.14
Proportion of GPS points outside of 800m home network buffer	269	47	1.03	0.95, 1.12	1.05	0.95, 1.15
Residential-Social neighbourhood discordance	262	47	2.72	0.52, 50.2	7.31	0.89, 193
Residential-Sexual neighbourhood discordance	255	46	1.77	0.84, 4.11	1.55	0.68, 3.84

**Adjusted for age group, educational attainment, currently employed or in school, unhoused, stable housing, income, sexual identity, and preference for living in a mostly gay neighbourhood, **Empty cells, cannot compute; ***All proportion measures have been scaled to reflect changes in 10 percentage points.*

were highly mobile, and having sex or socializing in a neighbourhood other than their residential neighbourhood was associated with elevated risk of having condomless anal sex with a casual partner.

In this study, BSMM largely under age 30, with low-income and limited educational attainment, were highly mobile (e.g., they spent on average half of their time away from their home neighbourhood). By comparison, young SMM in the New York City P18 study spent on average one third of their time away from their home neighbourhood (Duncan *et al.*, 2020) – suggesting that it is not age that explains these differences. Possibly, the experience of structural racism drives mobility. In racially segregated Chicago, young Black men may navigate different neighbourhoods to counteract the negative effects of segregation, seeking opportunities like work, education, and healthcare (Asabor *et al.*, 2022; ReNational Research Council *et al.1*990; Hedman *et al.*, 2021). Moreover, young BSMM may travel to access LGBTQ+ friendly health and social services, potentially better resourced in communities beyond their own . Racial segregation, combined with inadequate social support for SMM living in racialized communities, could drive the high mobility rates we see in this sample, but more research is needed to understand the different mobility experiences between those living in Black vs. non-Black neighbourhoods.

The association between traveling for sex and a potentially higher HIV transmission risk found in the current study reflect similar mechanisms found in the "journey to crime" and "journey to overdose" literature. Associating mobility with sexual behaviours, having sex away from home correlated with condomless anal sex with any partner and casual partners. This was similar to New York City study that found that SMM were more likely to have condomless oral sex if they had sex away from their residential neighbourhood than if they had sex close by (Duncan *et al.*, 2014). Our study may provide evidence for the role of social controls in "journey-to" theory, as people may be more likely to engage in certain behaviours when away from home (Frye *et al.*, 2017).

The proportion of one's activity space and time spent outside the home buffer area was not associated with specific sexual behaviours. This differs from that of another SMM-focused study in New York City, which found that the risk of condomless anal sex increased for each additional square kilometre of activity space (Kim *et al.*, 2020). A qualitative study among Black and Latinx SMM in Los Angeles, CA, is also contradictory: men who felt less belonging were more likely to spend time away from home (Cassels *et al.*, 2020), and likely to experience less social cohesion which would impact sexual risk (Saleh *et al.*, 2016). One explanation for these null findings is that the size of activity spaces among this sample of Chicagoan BSMM may be too similar to detect any differences by an outcome of interest. In this study, the SD equalled the mean of activity space sizes, leaving very little variability.

The study had limitations. First, 87 (24%) of participants were excluded because they did not contribute GPS data. However, a sub-analysis revealed this group did not differ by sociodemographic characteristics or sexual behaviours (Table 1). Second, condomless sex may be an inadequate marker of HIV transmission risk (Jin *et al.*, 2015). Especially in regular partnerships, it is unclear whether both partners adopt other HIV prevention measures, like monogamy, joint testing, or PrEP. Third, due to selective daily mobility bias, we could not disentangle whether mobility caused the sexual behaviour or vice-versa. This is because people may travel away from home with the intention of engaging in certain sexual behaviours away from their normal social controls. Fourth, unmeasured confounding may have created a spurious association between mobility and condomless anal sex. For example, experiencing discrimination against one's sexual orientation or HIV positive status could drive them both to spend time away from their home neighbourhood and to engage in less safe sexual practices (Babel *et al.*, 2021; Newcomb & Mustanski, 2011). However, since associations were relatively weak between mobility and other sexual behaviours, we think the confounding effects of such unmeasured variables are minimal. It is also possible that discrimination is a mediator if BSMM experience stigma or harassment only outside of their home neighbourhood. This may be true if they visit predominantly white neighbourhoods with historical LGBTQ presence, as some non-white transgender and nonbinary people reported in a qualitative study in New York City (Lampe *et al.*, 2020). Importantly, mobility measures might be inaccurate if participants' mailing addresses do not represent their true home locations. This is one explanation for the large number of participants who spent no time in their derived home neighbourhoods. Furthermore, participants' "home" location may frequently change over the study period – so their mailing address may not be the same home location they would have reported while wearing the GPS device. For example, young people may move residences with more frequency, including for reasons like entering cohabitating partnerships. Also, over one-third of the sample reported unstable housing in the past six months – presenting a challenge in ascertaining home locations beyond our specific study in the context of the housing crisis (Chicago Department of Family and Support Services, 2023: Snapshot of Homelessness in Chicago, n.d.).

This study contributes in various ways to the literature on mobility and HIV. First, we built a novel and reproducible analytic framework to examine multiple dimensions of mobility (spatial, temporal, and motivation-specific). Second, we leveraged survey-based mobility measures to supply a deeper understanding of more objective measures obtained from GPS devices. Third, by examining multiple sexual behaviours vis-à-vis multiple mobility indicators, this paper serves to develop hypotheses about specific mechanisms that might link mobility and HIV risk. For example, travel for socializing may only cause condomless sex with casual partners as opposed to regular partners- necessitating a different set of safe sex interventions. Finally, by focusing on a sample of racially and sexually minoritized men, we achieved an adequate sample size – rare in other HIV research (Maulsby *et al.*, 2014) – to describe the varied risks and vulnerabilities within this key population group.

This study highlights various directions for future research. First, beyond the need for more research with BSMM, specific underrepresented populations warrant centring in mobility and HIV research. Studies could over-sample transgender populations, for whom there is a dearth of data (Goedel *et al.*, 2019). Future research could also generate evidence in rural and suburban communities to advance our understanding beyond urban BSMM. Our findings are likely not generalizable to BSMM living in areas without public transportation networks, where their mobility depends on car access and traveling further distances. Second, mixed-methods studies might disentangle the issue of reverse-causation, *i.e.*, whether individuals travel to engage in certain behaviours, or their travel leads them to engage in those behaviours. Such a deep dive into the mechanisms that connect mobility and sexual risk could

better inform behaviour change interventions. Third, mobility measurement everywhere would benefit from more accurate definitions of "home." Here – as in other studies – we equate "home" with a residential address (Duncan *et al.*, 2020), but home can mean many things to different people at different times. Finally, future research could relate multidimensional mobility to HIV service uptake and retention, like PrEP and ART (Chen *et al.*, 2019; Kim *et al.*, 2021).

Due to their reduced condom use, BSMM who have sex away from home – even if just in a different Chicago community area – are at higher risk for HIV acquisition or for transmitting the virus. This means that interventions focused on behaviour change like increasing condom use and other healthy sexual practices should not just be spatially targeted to the areas where high numbers of people vulnerable to HIV reside, but also to where they have sex. This may come in the form of place-based interventions, like promoting safe sex at gay bars and other social venues. With GPS-based mHealth technology, behaviour change interventions could also use geofencing to deliver messages to consenting users when they enter areas where they are more likely to report sexual activity (Tobin *et al.*, 2023). Messages may direct app users to where they might be able to access condoms or PrEP or guide them on how to negotiate safer sex. By considering individuals' activity spaces vis-à-vis their sexual behaviours, more contextually-relevant place-based interventions may be able to interrupt HIV transmission and lessen the HIV burden among BSMM (Duncan *et al.*, 2019).

Conclusions

In a racially and sexually minoritized population, this study among BSMM demonstrated the richness that can be achieved in mobility and HIV research by examining multiple dimensions of human movement. While the scale of BSMM's daily travel away from home was not associated with sexual behaviours that increase HIV risk, having sex or socializing in neighbourhoods away from home may lead to increased risks through decreased condom use during anal sex. Due to the lower social control in places distant from home, some people may either engage in sexual risk behaviour when they are there or purposely travel there to engage in this behaviour. To curb the epidemic among BSMM, more research is needed to understand BSMM's mobility patterns – including where they spend their time and why – so that future interventions can be designed with them in mind, meeting them where they are.

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