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Using social and sexual network structure to model HIV risk disparities in South Africa

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Using social and sexual network structure to model HIV risk disparities in South Africa

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Abstract

Using social and sexual network structure to model HIV risk disparities in South Africa

By Alex de Voux

South Africa is home to the highest number of people living with HIV/AIDS in the world with an adult (15-49 years) population prevalence of 17.8%. The South African HIV epidemic is one of the most disparate health conditions, with young black men and women disproportionately affected. The historical and structural factors underpinning these disparities continue to shape the structure of social and sexual networks which have varying consequences for HIV risk and transmission. Despite its central role in HIV risk disparities, work around understanding social and sexual network attributes that place certain individuals at a heightened risk of infection in South Africa is limited. We addressed these gaps by exploring three key aspects of network structure among men who have sex with men (MSM) and young black women in South Africa.

In the first study we created five social network typologies of MSM based on varying levels of connectivity between friends, family and sex partners. These typologies were characterized in relation to sexual risk-taking and provided insight into how differences in social network structure influence the way in which sexual risk manifests among this key population.

The second study compared race-assortative sexual mixing patterns of MSM using Newman's assortativity coefficient and the E-I statistic. Race assortativity was significantly higher than would have been expected under conditions of random mixing, while comparison of race-specific E-I statistics revealed heterogeneity in race assortativity by ego race.

The final study explored the context of age-disparate sexual partnerships among young women (15-29 years) in rural Kwazulu-Natal by evaluating both individual- and community-level factors within a multilevel modeling framework. The community ratio of unmarried females to unmarried males, female age and marital status were significant predictors of engaging in an age-disparate partnership.

Taken together, these studies demonstrate the utility of evaluating social and sexual network structure in understanding the existence of HIV risk disparities.

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Chapter 1: Background and Significance

Striking disparities in HIV risk exist in the South African HIV epidemic

South Africa has the largest number of people living with HIV (PLHIV) in the world, estimated at 6.4 million people in 2012, translating to an adult (15-49 years) population prevalence of 17.8% [1, 2]. There exist significant HIV incidence and prevalence disparities by gender, race, and locality and these disparities parallel the persisting socioeconomic inequalities largely borne from a political system that up until the early 1990's institutionalized race-based discrimination and segregation [3]. The current HIV epidemic in South Africa is symptomatic of Apartheid-era political and economic policies that structured society according to race, gender, and age-based hierarchies and significantly impact social life including access to primary healthcare and services [3]. Black South Africans have an estimated HIV prevalence of 13.6%, compared to 1.7% among coloured and 0.3% among white South Africans [4]. HIV incidence is estimated to be nine times higher among black South Africans compared to any other race groups [5]. Females are disproportionately affected and constitute 59% of PLHIV [2]. Gender-based disparities are largest among the younger age categories with women aged 15-24 years making up 90% of the recent HIV infections and young, black women living in peri-urban townships are disproportionately affected [5, 6]. There is also significant geographical variation, with the highest HIV prevalence in the KwaZulu-Natal province estimated at 17% in 2008 [4]. Key populations found to have a HIV prevalence higher than the general population and identified as most-at-risk populations (MARPs) in the 2008 *South African National HIV Prevalence, Incidence, Behaviour and Communication Survey*, include black females aged 20-34 years, black males aged 25-49 years, males 50+, and men who have sex with men (MSM) [4]. Among these key populations the social, economic and political context is central to their increased risk of HIV infection.

HIV risk among men who have sex with men in South Africa

MSM in South Africa were shown to be disproportionately affected early on in the HIV epidemic after an outbreak among white gay men in 1982 [7]. This initial HIV outbreak was however quickly overshadowed by a larger emerging outbreak among black heterosexual South Africans five years later [7, 8]. This alarming development and sheer magnitude of the HIV epidemic among heterosexual South Africans in part explains why despite an early outbreak among white MSM, contemporary research on MSM and HIV is still in the early stages [9].

There is currently no accurate estimate of the size of the South African MSM population and reports of the prevalence of male same-sex behavior ranges between 0.06 [10] and 3.6%. [11]. These prevalence estimates have been extrapolated to yield a total of 750,000 South African MSM [4, 6]. MSM were only recently included in the *National HIV survey and National Strategic Plan on HIV, STIs and TB* for the first time in 2008 [4, 6].

Published studies of MSM in sub-Saharan (SSA) Africa have reported elevated risks of HIV infection compared to the general population [12], with HIV prevalence estimates among MSM in South Africa ranging between 10 and 50% [13-16]. It has been estimated that 7.9% of all new HIV infections in South Africa occur among MSM and 9.2% of all new infections are due to MSM and their partners [6]. Multiple factors place MSM at a heightened risk of HIV infection including biological transmission routes, stigma and discrimination as well as psychosocial characteristics such as internalized homonegativity [14, 17, 18].

Ethnographic studies have revealed a diverse MSM population in South Africa with variations by race, locality and sexual identity [8]. Often these variations are associated with structural and economic inequalities, a lasting legacy of Apartheid-era segregation of communities under the Group Areas Act, resulting in disparities in HIV risk and other health outcomes [19]. These structural determinants place black and coloured MSM living in peri-urban

and rural areas of South Africa at an increased exposure of HIV risk factors such as poor healthcare access, increased stigma and discrimination and a higher likelihood of minority stress [20]. This is further compounded by the fact that mainstream public health services largely fall short of addressing the health needs of MSM living in neighborhoods which fall outside of the major metropolitan areas [8]. This increased social vulnerability among MSM has been shown to negatively affect health-seeking behaviors such as HIV testing, with studies showing black race, township residence and a lower income was associated with a lower likelihood of getting tested [21].

Given the heterogeneity across MSM subpopulations, which results in disparities in healthcare access and exposure to HIV risk factors, effective HIV prevention research among MSM needs to take into account contextual factors in addition to individual-level risk factors influencing sexual risk behavior. In 2007 the *HIV & AIDS and STI National Strategic Plan for South Africa 2007 – 2011* recognized MSM as a vulnerable group serving as a call to researchers to start to fill in the information gaps in HIV research among MSM [22]. A first step in gaining a better understanding of the challenges faced by MSM needs to start with characterizing the socioeconomic and cultural diversity of South African MSM communities and HIV research studies have to begin to look at the social and sexual HIV risk environments of these men. A key attribute of these risk environments is how MSM relate to one another socially and sexually which can be understood in the context of their social and sexual network structure. This strategy will go far in understanding HIV transmission and risk disparities in this key population.

There are a few studies that have looked at the sexual network structure of MSM in South Africa by evaluating dyadic factors associated with sexual risk behavior. These studies have reported a significant association with experiences of homonegativity and unprotected anal intercourse (UAI), while certain partnership-types characterized by whether men were concordant on race age and economic status independently predicted whether UAI was reported [23, 24].

These findings have provided empirical evidence to support interventions focusing on the partner-level as well as demonstrated the socio-cultural aspects of sexual risk among MSM in South Africa [23, 24]. However more work still needs to be done to characterize the varying social context of sexual risk among subpopulations of MSM by race and locality, especially outside of the major urban cities of South Africa.

Disparities in HIV risk among women in South Africa

The higher prevalence of HIV among young women compared to young men in sub-Saharan Africa is a well-documented phenomenon [25]. For young women in South Africa HIV prevalence peaks five years earlier among 25-29 year olds compared to males, where HIV prevalence peaks among 30-34 year olds [4]. The disparity becomes more pronounced when comparing HIV incidence which is 5.6% among 20-29 year old women, more than 6 times the incidence among similarly-aged men [5]. Furthermore, among youth (15-24 years old), females constitute 90% of recent HIV infections [5].

These HIV prevalence disparities by age and sex are largely attributed to increased biological, social and structural vulnerability experienced by women and related to socially constructed gender and economic inequalities [26, 27]. The disparate risk of HIV infection is further exacerbated among younger women in female-headed households and among those with an earlier sexual debut [27]. Women have an increased biological susceptibility to HIV infection with a higher per act risk of transmission associated with receptive vaginal sex and young women experience an increased risk of infection due to a still maturing vaginal mucosa [26, 28, 29]. Socially constructed gender and economic inequalities result in relational power imbalances influencing individual risk behaviors such as condom use and the choice of sexual partner [30, 31]. Higher levels of intimate partner violence experienced by women further exacerbate their biological vulnerability by increasing the likelihood of forced sex and making it harder for women to negotiate safer sex practices [32]. Age-disparate and intergenerational relationships

have been found to be associated with gender power imbalances, economic inequality and gender-based violence which in turn increases the likelihood of exposure to these HIV risk factors [32, 33].

The socio-structural context of HIV risk among women in South Africa is further developed when compared to similar HIV research among MSM. However, causal patterns of gender disparities in HIV risk can be modified by locality, resulting in different observations depending on whether women are living in urban or rural contexts. These contexts differ in the prevailing gender norms, such as educational and employment expectations for women, gender-related barriers in access to healthcare services for women, as well as rates of sexual partner change and mixing patterns. Given this complex interplay of factors at the individual-, dyadic- and community-level, a comprehensive assessment of gender-based HIV risk disparities requires a multilevel analytical framework which allows for the simultaneous evaluation of these determinants.

Network-based approaches to better understand HIV risk disparities

Considering the existing HIV risk disparities in South Africa alongside the prevailing theories and evidence underlying why these disparities exist calls for HIV prevention research that integrates the role of social and sexual network structure. This research direction is likely to result in further insights into the social context of HIV risk, enhance the overall reach and efficacy of behavioral and biomedical prevention efforts and is in line with the key objective of "*addressing social and structural barriers that increase vulnerability to HIV, STI and TB infection*" outlined in *The South African National Strategic Plan on HIV, STIs and TB 2012-2016* [34].

Studies of social and sexual networks have made several important contributions to developing a better understanding of the existence of health disparities [35]. These studies assess population-level parameters such as the density and composition of one's social network, the

extent to which individuals have sexual connections with like individuals (assortativity) and the extent to which community environments, such as economic and gender norms, influence sexual risk-taking behaviors in the modeling of HIV transmission and prevention [23, 36-39]. The composition and structure of one's social and sexual network has been shown to be an important contributing factor to one's risk for HIV [40]. Often epidemiologic HIV modeling assumes random contacts between sex partners, but as social and structural factors influence when, how and the types of sex partners we encounter this assumption is not a realistic one. Sex partners are not chosen at random, but rather sexual networks tend to be highly structured according to attributes such as race, religion, political views and physical traits [41]. Furthermore given the historical influence of Apartheid-era policies which dictated where South Africans could live under the Group Areas Act [42] and who they could have sexual relations with under the Immorality Act [43], it would be naïve to evaluate existing HIV disparities outside of the context of these social determinants [3].

Among MSM the composition and density of social networks have been shown to influence sexual risk-taking [44]. Networks with a higher proportion of gay- or bisexual-identified men shape HIV risk by presenting more opportunities for sexual partnering. Men reporting a higher overlap between their social and sexual networks have been shown to be at increased risk of HIV infection [45]. However, increased network density, indicating higher familiarity between members, has been associated with a lower number of reported sex partners [46], suggesting that denser networks may be subject to greater peer scrutiny thereby encouraging conservative sexual behavior. The disclosure of MSM behavior and HIV serostatus are also influenced by social network composition. Men reporting emotionally supportive HIV-positive network members were more likely to have disclosed MSM behavior and HIV serostatus [47]. Failure to disclose HIV serostatus is a barrier to seeking healthcare and associated with depression leading to increased sexual risk-taking [48]. Men reporting a higher proportion of their

social network members being aware of their MSM behavior also report lower levels of sexual risk-taking, suggesting that increased social support may reduce sexual risk-taking [49]. These social network profiles are likely to vary by different types of MSM. Non-disclosing men may have less connected and more straight-identified networks, while gay-identifying men may have larger, more connected networks with a higher proportion of friends who identify as lesbian, gay, bisexual, transgender or queer (LGBTQ).

Assortativity refers to the extent to which partnerships are more likely to occur between persons with similar attributes [50]. Whether sexual mixing is assortative or dissortative has significant implications for the dynamics of an epidemic [50]. Since dissortative sexual mixing results in a partnership between two individuals with different risk profiles it acts as a bridge facilitating HIV transmission between two groups that are otherwise sexually separate from one another. This mixing pattern has previously been associated with sexually transmitted infection (STI) outbreaks [50]. Studies exploring assortativity and sexual network structure in sub-Saharan Africa have found low rates of assortativity by age and high rates of assortativity by race/ethnicity and education [51]. Network-level explanations for differences in HIV prevalence by race have included differences in the levels of concurrency working to create networks of sexual partnerships differing in their density and connectivity which have implications for HIV spread [52]. In the United States assortativity on sexual risk behaviors such as the number of sex partners, concurrent sex partners as well as drug use has been associated with STI outbreaks [50].

When partners are chosen based on relatively ‘stable’ characteristics such as race, gender, and sexual orientation, stable mixing groups are likely to form. However when characteristics change over time, such as age or marital status, we have formation of more fluid mixing groups and the potential for transmission of disease is higher [41]. One way in which marked prevalence disparities can be sustained is through highly assortative sexual partnering by race [53].

Network studies in South Africa

Current work exploring the effect of network and population-level parameters on HIV transmission in South Africa has largely focused on the role of concurrency, labor migration and age differences and this has been limited within the context of the generalized heterosexual epidemic [30, 52, 54]. Although these findings have been key in shaping HIV prevention interventions it is not clear to what extent they apply to key populations. More work remains to be done in characterizing the social contexts of HIV risk among MSM and evaluating the role of network structure as well as relational determinants. Social network connectivity as well as race assortativity are network attributes not as widely studied in relation to sexual risk-taking among MSM and if better characterized could potentially represent a highly effective intervention.

Age-disparate and intergenerational sex in South Africa is a well-established risk factor for HIV and complex theories have been developed around why certain women are more likely to engage in these relationships [30, 55]. However, many of the studies supporting these theories have looked at individual-level determinants or ecological associations. Fewer studies have looked at the role of household- or community-level factors, while controlling for individual-level determinants influencing young women engaging in these relationships. In South Africa a significant proportion of national HIV campaigns have focused on discouraging young women from engaging in age disparate sexual partnerships representing a considerable investment in this intervention [56]. Characterization of the context of these relationships would help better direct these funds to areas most affected as well as help identify points of intervention.

As the profile of the South African HIV epidemic starts to shift with improved research and awareness among key populations, there is a need for South Africa to improve and diversify its current arsenal of HIV prevention tools. Network-based and combination prevention interventions have the potential to better address underlying structural and social determinants

and also promise to be more scalable with the potential to impact a larger proportion of those infected with HIV.

In this dissertation we address the above gaps through the following three aims. In the first, we expand the literature regarding social network structure among MSM by identifying and characterizing social network typologies of MSM in Cape Town and Port Elizabeth in relation to sexual risk behavior. In the second aim we describe sexual mixing patterns of MSM in Cape Town by quantifying race assortativity with Newman's assortativity coefficient and the E-I statistic. In the final aim, we evaluate the context of age-disparate relationships by looking at both individual- and community-level determinants of young women engaging in age-disparate relationships.

The implications of this work are potentially far-reaching. As a collective body of work our findings will help to expand the literature on the social and sexual network structure of key populations in South Africa. This is a timeous contribution as there is a growing recognition in South Africa of the importance of focusing on concentrated epidemics within the context of the larger generalized HIV epidemic. Part of this objective is a need to expand the evidence base for disparate HIV risk among key populations and our work will directly contribute to this. Through this work we will also demonstrate the utility and range of methods that can be used to explore social and sexual network structure as well as the value of these methods in helping to understand the existence of HIV prevalence and sexual risk disparities.

By explicitly evaluating the role of network structure in HIV risk we also introduce points for network interventions aimed at diminishing HIV disparities. By relating social network structure to sexual risk we introduce the possibility of tailored HIV risk reduction counseling using social network map analysis as a screening tool. Quantifying sexual mixing patterns by race provides population and race-specific parameters which serve as parameter inputs when modeling

HIV transmission among MSM in Cape Town. Furthermore by describing the context of age-disparate relationships in a multilevel context we shed light on whether anti-'sugar daddy' campaigns are applicable within the rural South African context and whether they need to be targeted by place.

In the next chapter (Chapter 2) we describe our qualitative characterization of MSM in social networks in relation to sexual risk as part of the Sibanye Health Project. In Chapter 3 we describe our race assortativity analysis of MSM in Cape Town enrolled as part of the Cape Town HIV Clades and Social Networks Study. In Chapter 4 we shift focus to young black women within rural Kwazulu-Natal, where we contextualize age-disparate relationships by evaluating both community- and individual-level determinants, and finally in Chapter 5 we discuss overall conclusions, contributions and future directions of our work.

Chapter 2: Social network typologies and sexual risk-taking among men who have sex with men in Cape Town and Port Elizabeth, South Africa

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Abstract

Despite the high risk of HIV infection faced by men who have sex with men (MSM) in South Africa, currently very little is known about the social and sexual lives of MSM in this region. Given the influence of social network structure on sexual risk behaviors, a better understanding of the varied social contexts of MSM is essential when developing HIV prevention programming for this key population.

This study further explored social network connectivity, an understudied network attribute, which looks at familiarity between friends, family and sex partners. In this six-week qualitative study in Cape Town and Port Elizabeth, South Africa, 79 MSM participated in activity-based in-depth interviews which included a social network mapping component. Five social network typologies emerged from the visual analysis of these social network maps.

Participants described homophobia and non-disclosing sex partners as reasons behind maintaining disconnected networks. Sexual risk-taking was ubiquitous, but manifested differently across the five network typologies. Results reveal diversity in social network profiles among MSM and emphasize the importance of social context when evaluating HIV risk. Furthermore HIV prevention programming and messaging for this population can greatly benefit from incorporating a social network analysis to help frame messaging and interventions for different MSM.

Introduction

After an early HIV outbreak among white gay-identified men in the 1980s in South Africa, white men who have sex with men (MSM) were thought to be disproportionately affected by the epidemic [7, 57]. However, a second pattern of HIV transmission soon emerged revealing a larger, growing epidemic among black heterosexual South Africans [58, 59] which led to a re-characterization of the epidemic as generalized with heterosexual sex as the dominant transmission mode [22]. During this demographic shift in the epidemic the possibility that black MSM might represent a vulnerable risk group was never considered [8]. As a result, national HIV programs have largely focused on heterosexual and mother-to-child transmission, to the exclusion of other high risk groups [60]. As the HIV research landscape in South Africa matures, evidence continues to emerge suggesting a more diverse HIV epidemic, including concentrated epidemics among key populations including MSM. HIV prevalence estimates derived from observational studies enrolling urban MSM range between 10 and 50% [13, 14, 16] and HIV prevalence among MSM has been estimated to be more than twice that of other reproductive age men [6, 61]. These studies have highlighted the extent of the HIV epidemic among MSM as well as the variation in HIV risk among MSM subpopulations, particularly by race, locality and sexual identity [13-16]. They have also helped underscore that black urban MSM, previously undocumented in the characterization of the South African HIV epidemic, are a particularly vulnerable subpopulation [8], requiring urgent attention.

In South Africa, there is a growing recognition that key populations are not only critical in countries with concentrated epidemics only but are also an important focus area in generalized epidemics, as they are at higher risk of HIV infection in these contexts [14, 62]. In this regard, there have been deliberate efforts to focus HIV prevention efforts toward key populations in South Africa. For example, the South African National AIDS Commission (SANAC) has organized ongoing dialogues to determine systematic approaches to scaling up HIV services for

key populations. SANAC also set up an MSM Think Tank to help develop the National HIV/AIDS Prevention, Treatment, Care and Support Strategic Plan for MSM [63]. Furthermore, MSM were recently included as a key population in the National Strategic Plan on HIV, STIs and TB [4, 22]. The government is working closely with various institutions in implementing national programs addressing the health needs of MSM, including the Anova Health Institute Health4Men initiative [64, 65] and Desmond Tutu HIV Foundation (DTHF) [66]. These programs play a vital role in the MSM community as national programs lag behind growing health needs, however they still face challenges in reaching more marginalized MSM.

MSM in South Africa have often been considered a homogenous group confined to gay-identified, effeminate and visibly identifiable stereotypes [67]. However socio-epidemiological research continues to suggest a socio-culturally complex MSM community, comprised of diverse men with variation in sexual identities, race, locality [11, 18, 19] and sexual behaviors that drive HIV transmission [8, 14]. Recognition and understanding of these different sociocultural and sexual identities is important because it both renders differences in health needs and disparities in HIV risk profiles, and necessitates variation in programmatic approaches and health messaging. For instance, MSM residing in communities with higher levels of homophobia and HIV stigma, often more prevalent in peri-urban and rural areas, may be less likely to seek healthcare and would benefit from access to discreet, MSM-friendly messaging and healthcare facilities [18, 65]. Sexual role identities impact HIV risk, such as men who practice receptive anal sex facing a higher risk of HIV infection [68, 69]. Public health messaging that emphasizes these differences in behavioral risks may be valuable and could facilitate tailored interventions. Another programmatically different dimension is that some MSM may identify as gay and only have sex with men, while other MSM may be straight- or non-gay-identified and have sex with both men and women. These two groups have different HIV risk profiles and may respond differently to heteronormative or overtly ‘gay’ public health campaigns. Any effective response to the MSM

HIV epidemic should encompass interdisciplinary research which seeks better understanding of the sociocultural diversity of South African MSM.

The composition and density of MSM social networks has been to shown to influence sexual risk-taking [44]. Networks with a higher proportion of gay- or bisexual-identified men shape HIV risk by presenting more opportunities for sexual partnering. Men reporting a higher overlap between their social and sexual networks have been shown to be at increased risk of HIV infection [45]. However, increased network density, indicating higher familiarity between members, has been associated with a lower number of reported sex partners [46], suggesting that denser networks may be subject to greater peer scrutiny thereby encouraging conservative sexual behavior. The disclosure of MSM behavior and HIV serostatus are also influenced by social network composition. Men reporting emotionally supportive HIV-positive network members were more likely to have disclosed MSM behavior and HIV serostatus [47]. Failure to disclose HIV serostatus is a barrier to seeking healthcare and associated with depression leading to increased sexual risk-taking [48]. Men reporting a higher proportion of their social network members being aware of their MSM behavior also report lower levels of sexual risk-taking, suggesting that increased social support may reduce sexual risk-taking [49]. These social network profiles are likely to vary by different types of MSM. Non-disclosing men may have less connected and more straight-identified networks, while gay-identifying men may have larger, more connected networks with a higher proportion of LGBTQ-identified friends.

Social network connectivity, specifically looking at familiarity between friends, family and sex partners, is a network attribute that is not as widely studied in relation to sexual risk-taking among MSM. This study sought to address this gap in the literature by identifying and characterizing social network typologies of South African MSM, based on network connectivity, in relation to sexual risk-taking.

Methods

Social network data were collected as part of a larger qualitative study which sought to assess health-care access, uptake of and structural barriers to using prevention services, sexual behaviors and social networks among MSM in South Africa [70, 71]. The qualitative study was part of the third phase of the Sibanye Health Project [72] and took place over a 6-week period in early 2012. The objective of Sibanye is to develop and evaluate a combination package of biomedical, behavioral and community-level HIV prevention interventions and services for MSM in South Africa.

Study Population and Recruitment

Ethical clearance for the study was provided by boards at Emory University, University of Cape Town and the Human Sciences Research Council (HSRC). Eligible participants were aged ≥ 18 years, assigned male sex at birth, reported sex with a man in the last 6 months and lived in Cape Town (CT) or Port Elizabeth (PE), South Africa. Participants were recruited using preexisting contact lists of MSM, gathered by collaborating community-based organizations (CBOs) Desmond Tutu HIV Foundation (DTHF) in CT and HSRC in PE, and by further snowball sampling from this initial list of men. Participants were contacted by telephone and screened for eligibility. If men expressed interest they were scheduled for in-person interviews at one of several private locations most convenient to the participant. All participants provided informed consent and were remunerated 80 Rand (10 USD) for their time and travel expenses.

The mean age was 30 years, ranging from 19 to 67. Close to two-thirds (60%) identified as black, 18% as coloured (South African term indicating mixed ancestry) and 19% as white. Almost all participants identified as gay (95%), with 4 identifying as bisexual (5%). Nineteen participants (26%) reported living with HIV; self-reported HIV status was not confirmed by testing.

Study Procedures

Activity-based interviews included a social network map activity, supplemented with a narrative provided by the participant. Seventy-nine interviews, 40 in CT and 39 in PE, were conducted.

The social network map activity focused on the past 6 months of the participant's life. Men were asked to "name the first names or nicknames of people you have felt closest to in the past 6 months" and then to indicate which "categories each of those people fall in" i.e., friend, family or sex partner. Men were also asked for their total number of sex partners in the past 6 months and to name a subset of those partners. Next, men were asked to indicate "which of these people know each other". Connections reported by men were recorded by trained interviewers in a graphical data collection form. From this social network map, participants were asked to select three friends and three sex partners to provide quantitative data on.

Data Analysis

All 79 in-depth interviews (IDIs) were recorded and evaluated. Since we expected data saturation to occur before all 79 interviews were analyzed, 34 interviews were subsampled based on a typical case purposive sampling strategy [73]. To obtain variation in major groups in the MSM population, the subsample was targeted to be representative with respect to race (white, coloured, black), HIV status and age (18-25, >25).

Social network typologies were created by examining the connectivity between members across subgroups of friends, family and sex partners with men categorized into one of these typologies. Specifically we looked at whether there were any connections between friends and family and between sex partners and family. Key themes explored in more detail during the analysis were family and social network dynamics, sexual identity, sexual risk-taking behavior, HIV testing behavior and sex partner typologies.

Data were analyzed using constant comparison methods, drawing from Grounded Theory [74]. Codes and memos were applied to text and social maps, leading to further characterization of the social network typologies in relation to sexual risk-taking. Analysis was conducted using MAXQDA version 10 (Verbi Software, Berlin, Germany).

Results

Social Network Typologies

There were 78 MSM with completed social network maps. Five social network typologies emerged from the visual analysis of these social network maps based on connectivity between network subgroups i.e., family, friends and sex partners.

Disconnected Typology (N=2)

This typology included participants without any connections between friends, family or sex partners; only connections within subgroups existed. Disconnected men had very limited connectivity to LGBT organizations. One participant described belonging to LGBT organizations as difficult because '*most of the organizations feel I must look a certain way to be gay… so I must just refrain from taking part*'.

Even though both participants in this group identified as gay, they described homonegative feelings, suggestive of internal struggles with their sexual identity. One participant regarded public displays of affection between men as outside of the norm.

> *Why must you walk hand in hand? I don't think there's a reason, why must you walk hand in hand and then kiss, like, eh, because imagine if it was me. If I must see other gay guy with another gay guy, and they are holding and kissing I would stare, it's not normal.*

One participant described engaging in sex with other men as an '*indulgence'*.

I think it was an exploration at first. Because then I ended up indulging in it. I ended up wanting more and more of it. I think that's indulgence.

Both men in this group had main partners – gay-identifying men that they felt emotionally connected to – as well as concurrent casual partnerships with straight-identifying men. One participant was intentional about maintaining this partner profile because it enabled him to keep his network subgroups disconnected. As a married man, having straight-identifying casual partners meant they were both invested in keeping his extramarital sexual partnerships hidden from his husband and gay-identified friends.

I don't go with gay guys, because gay guys talk, they gossip. And that's why I'd rather go with the straight guys so tomorrow, you don't know me, I don't know you.

Sex within these casual partnerships happened in public spaces (i.e., on the street downtown, the taxi rank, mall toilets and the graveyard), but sex with main partners took place at the participant or partner's home. These public venues were either a function of convenience (i.e., partners were encountered in these spaces) or indicative of the secrecy of the partnership (i.e., sex partners did not want to be discovered having sex with men). All sexual encounters were unprotected by condoms, unless the partner requested a condom, and in some cases sex was transactional.

I: *Can you tell me a little bit about why you used condoms with men, like when?*

P: *Sometimes it's requested. I could use a condom*

I: *And then when would you not use a condom*

P: *If not requested or under the influence.*

HIV testing behaviors were different between these two participants. One was a maintenance tester and tested annually, while the other reported risk-based HIV testing, having

had his first test at the age of 21 years after discovering that his sex partner had been diagnosed HIV positive.

I: When did you, when did you first test for HIV?

P: That was, 2 years ago. Cause I was cheating [LAUGH]. And my one friend told me that this guy has HIV and we didn't use a condom.

Poorly Connected Typology (N=4)

This typology was defined by men with minimal connections between friends and family and no connections between sex partners and friends or between sex partners and family. Unlike disconnected men, almost all poorly connected men reported connectivity to LGBT organizations. One participant was involved with DTHF through enrollment in the iPrEX study, one participant became involved with the Triangle Project in Cape Town [75] after being diagnosed HIV positive, and one participant was involved with Eastern Cape Gay and Lesbian Association.

Safer sex practices among men in this group was mixed. One participant was a male sex worker who reported inconsistent condom use; while one participant reported only one condom-protected anal sex experience in his lifetime. All poorly connected men reported only casual partners. HIV testing behaviors were mixed with some participants testing regularly either as a result of their participation in a men's health study or at their private healthcare provider.

Connected Typology (N=40)

This typology was defined by men with connections between friends and family and between friends and sex partners, but no connections between sex partners and family. The connected typology had a large proportion of participants from one township in Port Elizabeth, most of who reported connectivity to the same local LGBT group (Masiphume).

Three main themes emerged explaining the lack of connectivity between sex partner and family members. A few participants were engaged in sex work, some participants described homophobic discrimination from their families, and a large number of participants had non-disclosing partners who were in concurrent relationships with women. These participants spoke about keeping their sexual relationships hidden from their families because of non-disclosing straight-identified sex partners in concurrent relationships with women, referred to as "*after nines*" (referring to men who were only available to meet for sex at night unbeknownst to their female sexual partners). These men described the difficulty in finding an openly gay sex partner and the struggle with having to maintain these secret relationships.

> *'It's difficult for us to have a guy who would show himself. Many of the times, we have to hide. If you slept over, we must wake up early at 4 so that people will not see you slept together*.'

Participants spoke about having to accept that their partners have to maintain these concurrent relationships and mitigating the risk of HIV infection by insisting on condoms each time they have sex. Some of these men experienced adverse mental health outcomes including depression and alcoholism as they struggled to deal with maintaining these secret relationships.

> *No we broke up when I was in PE. I was drinking too much because I was so frustrated. I was so depressed and stressed. My mom said, 'Why don't you try to go to your family in Cape Town. You will change whatever, because your behavior, now here in PE, I don't like it. It worries me because you drink a lot.' Everything was just messed up now.*

Two participants in this group were very careful to keep their same-sex partnerships from their disapproving families. These men were financially dependent on and living with their families and felt forced to maintain separate identities. To appease his family, one participant felt forced to have a female partner concurrent to his male relationship. Both participants spoke about their frustration with maintaining these double identities.

> *Yeah, um, to be honest with you, um, it's like I live in a crazy world. Sometimes I just pray to God to end up with this world, because I will get sick of it. I get concerned that my brother will find out that I'm gay. But, sometimes, it goes up in my head to tell my brothers 'Man this is me', you know? But at the same time, I'm like OK, if I tell them, they're obviously going to tell mom. And then mom she's going to be like, what a disappointment.*

These men described emotionally inhibited relationships with their male sexual partners and relied on their friends for emotional support.

> *Look, with my dad every day I feel like I'm moving forward with him. I would slip up and do something and just leave it. You know what, you've got to be yourself. I mean, I'm almost 40 and I still haven't had a serious relationship because I'm still dealing with so much. I still can't give anything. In a relationship you give 50/50. I feel like I can't give if I don't know what I'm giving, if I'm so inhibited in so many ways.*

Sexual risk behaviors among these two participants were low, with only one or two recent condom-protected sexual encounters. This may be due to limited sexual opportunities given their secretive lifestyles. The participant in a concurrent relationship with a woman reported consistent condom use and only non-penetrative thigh sex with his male partner.

A large number of participants in the connected typology preferred short-term casual partnerships. Some ascribed this to a matter of convenience, while one participant cited bad past experiences with abusive long-term relationships as the main reason. These men preferred not to introduce these casual '*hookups*' to their families. Two of these participants were sex workers and one of them did not list any family members that he felt close to. A number of friends listed in his social network were also sex workers and encouraged him to engage in sex work to earn extra cash. Unlike participants in the previous two connected subgroups, men did not express any desire to have meaningful or intimate relationships and described these casual hookups as '*stress free*', not having to be concerned with whether the partner was in a concurrent relationship.

'*Having a booty call is stress free. You don't have to explain yourself.*'

Reporting of safer sex practices was mixed. Two participants in this group were HIV positive and reported inconsistent condom use. One of these participants spoke disapprovingly about the disregard that people in his community have for HIV, despite not practicing safer sex himself and admitting to being '*reckless'*. He had not disclosed his HIV status to any of his sex partners.

> *In this community, the issue of one's status isn't an issue. When you go to bed with a person, very seldom that you talk about condom use or that you talk about HIV status. It's as if it doesn't exist. There's a lot of carelessness so much that I think that the rate of HIV infection must be very high here. If the people that you're going to interview after me are honest, you will see what I'm talking about. I think over the past 13 years, there may be only 3 or 4 people who ask for a condom.*

Both sex workers preferred to exclusively engage in oral sex to minimize the risk of HIV infection and reported consistent condom use when forced to have anal sex. The remaining participants also reported consistent condom use with their sex partners.

Well-connected Typology (N=27)

This typology was comprised of men with connections between family and sex partners, and between friends and sex partners. Unlike the connected group, a large number of men reported a main partner, although this was not always the only sex partner reported in the past 6 months. Connections between sex partners and family were more likely to occur with main partners.

Higher levels of connectivity did not always resonate with safer risk profiles. Condom use varied depending on the *type* of sex partner. A number of men reported ceasing condom use with main partners, despite not having had a recent HIV test or being unaware of their partner's serostatus. One sex worker didn't use a condom with one of his regular clients because the client was married and as a result the participant trusted him more.

I: *OK. What about condoms? Do you use condoms with [NAME]?*

P: *No, [NAME] he don't like condoms. Especially I know I'm not positive, and that I trust him just because he is married.*

Two participants who were married to one another used condoms consistently because one partner was HIV positive.

Transactional sex was reported by a number of participants who either identified as a sex worker or by '*tagging*' their sex partners which involved buying them clothing or giving them money.

Densely Connected Typology (N=5)

This typology was defined by men who had connections between every person in their social network, including connections between family and sex partners and between friends and sex partners. LGBT connectivity among these men was in stark contrast to disconnected men. One participant was the founder of a local LGBT group which supported men coming out to their families. His house was a favorite meeting spot for local gay men in support groups, but also served as a place to for him to meet new sex partners.

P: *Or we can all sometimes have orgies, like say it's 3 of us here in the room, we call boys and then it's BAH!*

I: *OK, and this is at your place?*

P: Yeah

A number of densely connected men reported connectivity to the same support group and described the house as a favorite meeting spot for gay men in the community.

These men reported a higher prevalence of HIV risk behaviors. Condom use in this group was inconsistent and men reported a significant number of casual partners also in concurrent relationships. Similar to well-connected men, condom use varied by the type of sex partner and type of sex, with condom use less likely with casual partners and exclusively oral sex encounters. Men reported being more likely to use a condom if they were unfamiliar with the partner or if the partner requested it. Participants were able to rationalize why partners would request condom use and seemed eager to concede when asked.

I: Do you ever ask [NAME], why do you want to use condoms? Is it because you think you're HIV positive? Do ever have a conversation about that?

P: No, it doesn't bother me because really they're younger than me and obviously maybe because I've been around a lot longer than them, so they just want to protect themselves against something that they don't know. That's how I take it so I don't really want to ask them any questions.

I: And you said that when you were younger you had the same idea.

P: Yes. So, I just don't want to jeopardize what I have with them by asking like, why do you want to use a condom. Maybe that'll give them, give them another mindset about me.

All but one participant reported straight-identified or bisexual casual partners, while the main partners tended to publicly identify as gay. Similar to connected men, participants expressed frustration with partners in concurrent relationships with women.

I: Did that develop into a relationship with the guy?

P: Not really a relationship because he had his girlfriend. And we would fight about him having his girlfriend and he would tell me that when we started this whole thing, you knew I had a girl. So I think you should just accept things the way they are. So, I had to settle for being a second.

Most of the participants in this group only had one lifetime HIV test, with one participant living with HIV. Participants were either tested as part of their screening intake prior to medical male circumcision, because of suspected STI symptoms, or because of encouragement to get tested as part of a larger group of friends.

Discussion

Participants in our study were classified into five social network typologies based on connectivity between their friend, family and partner subgroups. These typologies ranged between disconnected men with no connections between subgroups to densely connected men with connections between every network member.

At the one end of the spectrum disconnected men showed signs of struggling with their sexual identity and feelings of homonegativity. Both men reported a main partner as well as concurrent casual partnerships. These casual partnerships were secretive and with straight-identifying men in concurrent relationships with women. Sex occurred in public spaces, was unprotected and sometimes transactional. This public nature and anonymity of sexual encounters has been reported to be more prevalent among straight-identifying MSM, where the urgency of the encounter and risk of being caught is not amenable to condom use [76]. Feelings of internalized homophobia have been shown to be negatively associated with condom access increasing the likelihood of unprotected sexual encounters [44, 77, 78].

At the other end of the spectrum, densely connected men reported being more comfortable with their sexual identity. Not surprisingly, these men also reported greater involvement with LGBT organizations. However, increased connectivity and LGBT involvement

did not necessarily translate into safer risk profiles. A number of men reported multiple casual sexual encounters not protected by condoms. Larger and more connected networks have been shown to be associated with riskier sexual profiles by presenting more sexual partnering opportunities and exposing men to more varied sexual practices including unprotected anal intercourse (UAI) and transactional sex [45, 49, 61]. Comparisons of risk behaviors across typologies suggest that risk is ubiquitous, but manifests itself differently across the typologies.

Concurrent relationships were more prevalent among densely connected men. This is in contrast to findings that familiarity between sexual partners and friends was associated with a 52% reduction in concurrency among young South Africans (14-25 years) [79]. Interestingly, the same study reported higher concurrency among black males whose partner knew the family of the respondent [79]. Other predictors of engaging in concurrent relationships include knowing that one's partner is in a concurrent relationship and reporting emotional and sexual dissatisfaction – all salient themes among densely connected men [79-81]. The high prevalence of concurrency is concerning since it has been shown to be associated with higher levels of UAI among MSM and may be significant for HIV transmission within the setting of dense, overlapping networks [81-83]. Although densely connected men reported greater comfort with their sexual identity and greater visibility in their community, their health-seeking behaviors were still limited. Most men reported only one lifetime HIV test. The majority of densely connected men were township residents suggesting that social vulnerability, limited healthcare infrastructure and stigma, all more prevalent in this setting, may still represent significant barriers to HIV preventative behaviors even within the context of robust social support and networks [18, 21]. Our findings are consistent with studies evaluating social integration as a buffer in the association of risky sexual behaviors and homophobia among black MSM in the United States [84]. Social integration included measures of social support, closeness to family members and friends, attachment to the

black gay community as well as social network size and similarly none of these measures were found to mitigate the effects of homophobia on risky sexual behavior [84].

Well-connected men, with connections between all subgroups including family and sex partners, were more likely to be in a monogamous committed relationship. These men had the lowest median number of sex partners, but were more likely to cease condom use with their main partner, despite not having had a recent HIV test or not knowing their partners' status. Despite greater transparency and connectivity leading to a more committed, long-term relationship, these men were not immune to the pressures of ceasing condom use with their main partners, suggesting that benefit can still be derived from dyadic-level interventions such as Couples Voluntary Counseling and Testing [85, 86].

The connected typology exhibited the most intragroup variability in HIV risk behaviors and social context, with men having a range of different reasons for keeping their sex partners disconnected from their families. The connected typology included sex workers, men experiencing familial homophobia and men in relationships with non-disclosing partners. Participants experiencing familial homophobia felt forced to maintain dual identities and reported a lower number of, mostly protected, sexual encounters. This finding is in contrast to studies reporting that familial discrimination and a need to maintain a heterosexual identity are associated with high risk behaviors [87, 88]. Since both men lived with their families the lower number of sexual encounters may be as a result of limited sexual opportunities and may also be a strategy employed by these men to limit being in stigmatizing situations [89].

The qualitative characterization of these social network typologies highlights the role of social context in shaping the pool of potential sex partners and the influence of prevailing sexual norms on risk behaviors. The two disconnected men exploited homonegative norms by only engaging in casual partnerships with non-disclosing straight-identifying partners, thereby hiding

their same-sex behaviors. Connected men were forced to keep the relationships hidden because of non-disclosing partners who were in concurrent relationships with women. These men minimized their risk by insisting on condom use. Connected men reported feeling constrained in their ability to have open and emotionally satisfying relationships with these types of partners and many reported adverse mental health outcomes such as depression and suicidal ideation.

This study's limitations include the limited diversity in recruitment methods and heavy reliance on local CBOs for recruitment. Although snowball sampling from the initial group of men enabled access to more marginalized MSM, it is still limited because men connected to CBOs may be fundamentally different than other South African MSM. For example, the majority of our sample was gay-identified. In addition, the network data collection focused on the last 6 months and may not be completely representative of the participant's social network. To our knowledge this is the first study to create and characterize social network typologies among South African MSM. Strengths include a strong representation of MSM in a peri-urban context in PE, a region of South Africa that has been understudied.

In conclusion, these typologies emphasize the diversity in the social networks of South African MSM and offer an alternative lens through which to view the different ways in which sexual risk is manifested. Furthermore, it reiterates the limitations of treating South African MSM as a homogenous risk group and underscores the importance of reframing public health messaging to different types of men which may be better guided by the characterization of social networks. Future HIV prevention programs may benefit from including a social network analysis to determine the type of messaging men may be more receptive to. Disconnected and poorly connected men may benefit from more generic public health campaigns or discreet MSM-tailored healthcare facilities, while densely connected men may prefer more explicit and overtly MSM-focused campaigns.

Table 1: Description of the Social Network Typologies of men who have sex with men (MSM) in Cape Town and Port Elizabeth, as determined by the level of connectivity between social network subgroups i.e., friends, family members and sex partners

Social Network Typology	**Description**
Disconnected	No connections between any friends, family or sex partners. Only connections within network subgroups
Poorly connected	Minimal connections between friends and family members and no connections between sex partners and friends or between sex partners and family
Connected	Most connections between friends and sex partners, or between friends and family, but none between sex partners and family
Well-connected	Connections between family and sex partners as well as friends and sex partners
Densely connected	Connection exists between every person in network

Table 2: Demographic and behavioral characteristics of 78 men who have sex with men (MSM) participants in Cape Town and Port Elizabeth, South Africa

	All MSM	Disconnected (N = 2)	Poorly connected (N = 4)	Connected (N = 40)	Well-connected (N = 27)	Densely connected (N = 5)
Age, median (range)	30 (19-67)	32 (22-42)	44 (29-55)	30 (19-67)	27 (19-59)	24 (22-31)
HIV positive, %	26	0	25	34	20	0
Gay-identified, %	95	100	100	92	96	100
No. sex partners, median (IQR)	3 (1-7)	11 (10-11)	7 (2-15)	3 (1-5)	1 (1-3)	3 (3-7)
Unemployed, %	38	50	25	54	19	40
Education beyond high school, %	25	50	50	21	33	0

Chapter 3: Race assortativity among men who have sex with men in Cape Town, South Africa

Abstract

Men who have sex with men in South Africa are at a disproportionately high risk of HIV infection compared to the general population, with estimates of HIV prevalence ranging from 10 to 50%. Disparities in HIV prevalence by race also exist, with recent prevalence estimates of 31% among black MSM in Cape Town, compared to 19% among coloured and 8% among white and Indian MSM. Despite this heightened risk of HIV infection, currently very little is known about the structure and composition of MSM sexual networks. Sexual network structure influences the dynamics of disease transmission and is a necessary factor in sustaining prevalence disparities. A better understanding of the sexual network structure of MSM is essential to developing effective public health interventions for this key population.

This study characterized racial homophily among 315 MSM from urban and peri-urban areas in Cape Town, South Africa. Chance-corrected race assortativity was quantified by Newman's assortativity coefficient (r) among dyads stratified on demographic and behavioral characteristics. Race-specific patterns of race assortativity were quantified using the E-I statistic.

Overall same-race partnering was high, above and beyond random mixing, with a Newman's assortativity coefficient of 0.51 (95% CI: 0.45 - 0.56) and an overall E-I statistic of -0.45 (p = 0.002). There were variations in race-specific racial assortativity, with black egos having higher assortativity (E-I = -0.58), compared to white MSM (E-I = -0.47) and coloured (E-I = -0.17) MSM. When stratified on HIV serostatus, race assortativity was higher among HIV positive egos (r = 0.52, 95% CI: 0.45 - 0.59) compared to HIV negative egos (r = 0.48, 95% CI: 0.40 - 0.57).

Our findings reveal significantly high levels of racial assortativity among MSM in Cape Town with implications for HIV transmission modeling within this key population. These patterns of race assortativity provide context for the existence of HIV prevalence disparities by race among MSM in South Africa and suggest that future interventions should take into account specific sexual network mixing patterns by race.

Introduction

Although the first AIDS cases in South Africa were identified among white gay men in the 1980s [57, 59] it is only fairly recently that there has been a rise in published scientific literature on the HIV epidemic among men who have sex with men (MSM) in South Africa. These observational studies have revealed the presence of a concentrated HIV epidemic among MSM amidst one of the largest generalized HIV epidemics [4]. South African MSM are at a disproportionately high risk of HIV infection compared to the general population, with overall HIV prevalence estimates ranging between 10 and 50% [13-15, 90, 91]. A recent bio-behavioral study recruiting MSM from three South African cities reported an overall HIV prevalence of 22% in Cape Town [92] as well as striking disparities in HIV prevalence by race with 31% of black MSM, 19% of coloured MSM and 8% of white and Indian MSM testing HIV positive [92].

The structure of sexual networks, particularly mixing patterns within sexual networks, have been shown to have an effect on HIV transmission, both within and across groups [93, 94]. Assortativity is a sexual mixing pattern that describes the propensity for individuals with similar attributes to associate with each other [95]. An example of assortativity is the increased likelihood of individuals with the same race or ethnicity to partner with one another, while dissortative mixing, which implies the association of individuals with dissimilar characteristics, is illustrated by the propensity of young MSM to partner with older MSM [93]. Whether sexual mixing is assortative or dissortative has significant implications for the dynamics of an epidemic [50]. Since dissortative sexual mixing results in a partnership between individuals with different risk profiles it acts as a bridge facilitating HIV transmission between two groups that are otherwise sexually separate from one other. This mixing pattern has previously been associated with sexually transmitted infection (STI) outbreaks [50]. When partners are chosen based on relatively ‘stable’ characteristics such as race, gender, and sexual orientation, stable mixing groups are likely to

form. However when these characteristics change over time such as age or marital status we have formation of more fluid mixing groups and the potential for transmission of disease is higher [41]. Assortativity therefore has the effect of containing disease within specific groups i.e., limited sexual partnering between partners of different races or racial homophily, can help to sustain disparities in HIV prevalence by race. Given the social nature of sexual partnering and the fact that sexual partners tend not to be chosen at random, sexual networks are usually highly structured according to certain social attributes e.g., physical traits, religion, political views, which vary systematically from one social group to the next [41]. Therefore, it is not surprising that the majority of sexual partnerships occur between individuals of the same race/ethnicity.

Given the disparities in HIV prevalence by race among MSM in South Africa a critical question is what role sexual network structure, specifically assortativity by race, plays in sustaining these disparities. Although limited in explaining the development of these disparities, high levels of racial homophily among sex partners is a necessary, albeit not sufficient, factor for maintaining these disparities [52]. Research studies exploring network-level determinants of HIV prevalence disparities in South Africa have tended to focus on concurrency and intergenerational sex, with fewer studies exploring sexual mixing by race [30, 54, 81, 96]. One study exploring racial homophily among youth in Carletonville, a mining township outside of Johannesburg, reported relatively low interracial mixing compared to the National Health and Social Life Survey (NHSLS) conducted in the United States [51]. Findings from this work suggest that network-level determinants are important to consider when trying to understand HIV prevalence disparities and that levels of racial assortativity may be higher in South Africa compared to those seen in the United States. It is however not clear to what extent these findings are generalizable to MSM in South Africa. De facto geographic segregation by race, with black and coloured men largely residing in peri-urban neighborhoods, further limits the geographic range of MSM and increases the likelihood that men will encounter partners of the same race. This segregation by

neighborhood will likely result in dense, interconnected, and homogenous network structures which has implications for the transmission of HIV [97].

Better characterization of sexual mixing patterns in this key population is crucial to understanding the dynamics of HIV transmission and implications for future disease dynamics. This study sought to describe and quantify sexual mixing patterns by race among a group of MSM in Cape Town, South Africa.

Methods

Recruitment and study sample

Data used in this analysis were collected as part of the MSM Social Networks and HIV Clade Study, conducted by The Desmond Tutu HIV Foundation (DTHF) [98]. The aim of the MSM Social Networks and HIV Clade Study was to describe circulating clades of HIV-1 subtypes among MSM in Cape Town and to further explore possible links and differences between both the generalized epidemic and historically geographically and racially defined communities [98]. Data for this study were collected over an 8-month period between 2009 and 2010 from MSM living in urban and peri-urban areas of Cape Town. Men were recruited from organizations and venues frequented by MSM, through internet advertising as well as subsequent referrals from enrolled participants. Eligible men were those who self-identified as MSM, were 16 years or older, reported sex with a man in the last 12 months, and were willing to undergo HIV testing. Participant race was recorded using official South African census terms i.e., black/African, coloured and white, where ‘coloured’ refers to individuals of mixed ancestry from Europe, Asia and native Khoisan and/or black tribes [99]. Urban areas were defined as those in the central business district of Cape Town, formerly designated as ‘white only’ areas, while peri-urban areas were defined as townships or low-income communities, formerly designated as black/African or coloured communities. Although neighborhood segregation by race is no longer

enforced legally in post-Apartheid South Africa, *de facto* segregation by race still largely persists resulting in peri-urban areas with an almost exclusively black or coloured population and the overwhelming majority of white South Africans living in urban areas [100].

Socio-demographic and behavioral information on participants (egos) were collected via interviewer-administered questionnaires as well as information on three sex partners in the past 6 months. Data collected on sex partners (alters) included race, neighborhood, the most recent HIV test result, whether the partner was main or casual as well as dyadic behavioral information including condom and lubricant use as well as whether the ego or alter were engaged in any concurrent relationships. HIV testing was performed using finger prick rapid antibody screening tests, following the South Africa National HIV Counseling and Testing Guidelines [101]. The analytic sample for this study was derived from 315 egos who reported data on 714 alters with no missing race information.

The purpose of our secondary analysis was to further characterize sexual mixing patterns of these sexual networks by evaluating racial assortativity using Newman's assortativity coefficient and the E-I statistic.

The mixing matrix

The mixing matrix was used to summarize and aggregate dyadic data by cross tabulating the ego race by the alter race (Figure 1). Mixing matrices are natural summaries of assortativity for discrete characteristics such as race and can also be assembled for subgroups in the dataset by stratifying the matrix by categories of the covariate of interest [102].

Figure 1: Mixing matrix cross-tabulating ego race with alter race

		Alter race		
Ego race	Black	Coloured	White	Total
Black	n_{11}	n_{12}	n_{13}	$n_{1.}$
Coloured	n_{21}	n_{22}	n_{23}	$n_{2.}$
White	n_{31}	n_{32}	n_{33}	$n_{3.}$
	$n_{.1}$	$n_{.2}$	$n_{.3}$	

Newman's assortativity coefficient

Newman's assortativity coefficient (r) is commonly used in the analysis of sexual networks to quantify sexual mixing patterns and is a measure used to describe the mixing matrix [103, 104]. Newman's assortativity coefficient r is defined as

$$r = \frac{\sum_{i=1}^{k} e_{ii} - \sum_{i=1}^{k} a_i b_i}{1 - \sum_{i=1}^{k} a_i b_i}$$

where e_{ii} is the frequency of dyads where the respondent and partner are concordant for characteristic i, a_i represents the frequency of respondents with characteristic i and b_i represents the frequency of partners with characteristic i. Newman's assortativity coefficient is mathematically identical to Cohen's kappa statistic [103, 105]. The maximum value of r is equal to +1, which indicates perfect assortativity, and occurs when the observed proportion of agreement, $\sum_{i=1}^{k} e_{ii}$ is equal to 1, which occurs when all off-diagonal elements of the mixing matrix are equal to 0 (i.e., when there are only same-race partnerships in the matrix). When

mixing is entirely random, $\sum_{i=1}^{k} e_{ii}$ is close in value to the expected proportion of agreement $\sum_{i=1}^{k} a_i b_i$ and r approaches 0 [106], while negative values of r suggest dissortativity.

Newman's assortativity coefficient provides a global summary for the mixing matrix [102]. This measure facilitates comparisons across mixing matrices stratified on variables of interest, but does not facilitate comparison of patterns of assortativity by attributes included in the mixing matrix. More specifically when looking at mixing matrices of ego and alter race, Newman's assortativity coefficient will not allow us to look at race-specific differences of same-race partnering. Since assortativity will be higher for racial groups that are more numerous simply by virtue of its larger size it is important to point out that Newman's coefficient takes into account this bias by calculating a chance-corrected measure of assortativity.

Newman's assortativity coefficient was computed using a pair of three races for ego and alters (black, coloured and white) for marginal and stratified tables. Mixing matrices were constructed by cross tabulating ego and alter race for all dyads as well as dyads stratified on demographic characteristics (neighborhood, main or casual partnership, HIV serostatus) and behavioral characteristics (unprotected anal intercourse [UAI] and concurrency).

The E-I statistic

To compare the propensity for same-race partnering by race the E-I statistic was calculated [107]. The E-I statistic summarizes the propensity for an ego to have connections with alters in the same group of the attribute of interest, which in our case is race. The E-I statistic was calculated by summing the number of ties to 'external' alters (different race than the ego) and subtracting the total number of 'internal' alters (same race as the ego) and dividing by the total number of ties. This results in egos with ties to only internal alters with an E-I statistic of -1, while egos with ties to only external alters will have an E-I statistic of +1 [107]. Unlike Newman's assortativity coefficient which calculates the above-chance agreement, the E-I statistic measures the actual level of agreement by race and is therefore not chance corrected.

Race-specific (i.e., black, coloured and white) as well an overall E-I statistic was calculated for dyads stratified on demographic characteristics (neighborhood, main or casual partnership, HIV serostatus) and behavioral characteristics (UAI and concurrency).

Permutation test

In evaluating levels of race assortativity our null hypothesis (H_0) was that the observed levels of racial assortativity were above what would have been observed if sexual partnering were truly random. In order to test this null hypothesis we needed to generate a null sampling distribution for the E-I statistic which we computed using a permutation test. A null sampling distribution was generated for the E-I statistic under H_0 (random sexual partnering) and compared our observed E-I statistic (H_A) in order to test our hypothesis.

In order to compute the sampling distribution under H_0, multiple samples were generated under simulated conditions of random partnering. Variables containing ego ID and race were separated from variables containing alter ID and race. Alters were randomly assigned a number from a uniform distribution and ranked in ascending order by that randomly assigned number. Egos and alters were re-matched by row number resulting in randomly matched dyads. Finally the overall E-I statistic was calculated. This process was repeated 10,000 times resulting in a null sampling distribution for the population E-I statistic. The observed E-I statistic (H_A) was then compared to the sampling distribution in order to determine the corresponding percentile.

Results

Demographics and Behaviors

The sample included 315 egos who provided partner-level data on 914 dyads. The median age of egos was 31 years (IQR: 25, 37). Overall 66% (n =209) of egos were black, 28% (n =87) were coloured and 6% (n =19) were white (Table 3). The majority of black MSM (69%) were from peri-urban neighborhoods, with 33% of coloured MSM and 0% of white MSM from

peri-urban neighborhoods. In total 63% of men identified as homosexual or gay, 31% identified as bisexual and 6% as heterosexual. White MSM were older with a median age of 40 years (IQR: 31, 47) and were less likely to report being heterosexual/straight or report a current female partner (Table 3). Sixty-one percent (n =194) of the sample tested HIV positive.

Examining individual-level sexual behaviors, black MSM were significantly less likely to have disclosed their same-sex behavior to anyone and reported significantly fewer lifetime male sex partners compared to white and coloured MSM. There was no significant difference by race in the number of MSM reporting UAI with at least one partner in the last 6 months.

Dyadic Measures

There were a total of 714 dyads with no missing partner race (Table 4). Approximately half of the dyads were black egos and black alters (52%), followed by coloured-coloured (17%), and coloured-white (8%). White MSM were significantly more likely to report having a HIV positive partner (67%) compared to black (18%) or coloured (17%) MSM (Table 4). Black MSM were significantly more likely to have a racially concordant partnership compared to both coloured and white MSM and significantly more likely to report using a condom with their partner compared to coloured MSM. The majority of partnerships, across all races, were with casual partners. Comparison of behavioral and demographic characteristics of racially concordant dyads compared to racially discordant dyads yielded no significant differences (Table 5). Some notable results include a similar proportion of dyads with a HIV positive ego among racially concordant and racially discordant dyads as well as a similar proportion of dyads with a peri-urban resident ego.

Sexual network patterns

Newman's assortativity coefficient

Newman's assortativity coefficient (r) summarizing overall race assortativity was 0.51 (95% CI: 0.45 - 0.56) (Table 6). Assortativity was higher for dyads with a HIV positive ego, r = 0.52 (95 % CI: 0.45 - 0.59), compared to those with a HIV negative ego, 0.48 (95% CI: 0.40 - 0.57). Newman's assortativity coefficient for dyads with an urban resident ego was lower compared to all dyads, r = 0.47 (95% CI: 0.40 - 0.54) (Table 6). For main partnerships r = 0.51 (95% CI: 0.41 – 0.62), while for casual partnerships r = 0.50 (95% CI: 0.44 - 0.57). Among dyads where the ego reported a concurrent relationship, r = 0.49 (95% CI: 0.41 - 0.56) and among dyads engaging in UAI, r = 0.56 (0.47 - 0.65). We were unable to calculate r for peri-urban egos since there were no white peri-urban residents.

The E-I statistic

The overall E-I statistic was -0.45, while race-specific E-I statistics for black, coloured and white egos were -0.58, -0.17 and -0.47 respectively (Table 6). Among dyads where the ego was HIV positive, the overall E-I statistic was -0.51, while the overall E-I statistic for dyads with a HIV negative ego remained unchanged at -0.45. The race-specific E-I statistic for white HIV negative egos (n = 2) was +0.33 suggesting dissortativity, compared to HIV positive white egos with a race-specific E-I statistic of -0.69.

Peri-urban egos demonstrated a higher level of race assortativity, with an overall E-I statistic of -0.60 compared to an overall E-I statistic of -0.29 among urban egos.

Discussion

Our results suggest high levels of racial homophily among MSM in Cape Town. The overall Newman's assortativity coefficient was high compared to homophily bias statistics reported in Carletonville, South Africa, which ranged from 0.17 - 0.59 [51]. Similar work among MSM in the United States reported a Newman's assortativity coefficient of 0.21 (95% CI: 0.19-0.24) [108]. In our study Newman's assortativity coefficient compared across dyads stratified on demographic and behavioral characteristics, revealed higher levels of assortativity among dyads with HIV-positive egos compared to HIV-negative egos. Across sexual risk behaviors, racial assortativity was highest among dyads where the ego reported UAI, while racial assortativity was highest among HIV serodiscordant dyads compared to HIV negative or positive concordant dyads. Comparison of race-specific racial assortativity using the E-I statistic revealed the highest levels of racial homophily were among black MSM followed by white and coloured MSM. Comparison of our summary E-I statistic to a simulated null distribution shows that our observed E-I statistic was significantly higher than what would have been observed under conditions of random mixing. Findings from the HIV Social Networks and HIV Clade Study molecular analysis, which looked at the circulating HIV-1 clades, suggested links between urban and peri-urban (largely synonymous with black and coloured race) communities in Cape Town, but our results suggest that dissortative partnering by race is still very limited [98].

The overwhelming majority of black MSM were from peri-urban neighborhoods, while all white MSM were urban residents, suggesting that residential segregation by race is still very pervasive in Cape Town. Geographical studies have shown that although segregation has decreased between 1991 and 2011, Cape Town still remains highly segregated [109]. De facto neighborhood segregation by race limits the proximity of MSM of different races, increasing the likelihood of race assortativity and 'geographical compactness' of sexual networks. This pattern of sexual partnering is likely to sustain existing disparities of HIV prevalence by race and result

in peri-urban hyperendemicity [97]. The E-I statistic for urban coloured egos indicated a much lower degree of assortativity compared to coloured egos from peri-urban areas, underscoring the important role played by the peri-urban/urban context in the likelihood of same-race partnering.

Our study has several considerations which may limit the generalizability of our findings to the larger MSM population in South Africa. A number of different recruitment methods were used employing a purposive sampling strategy. HIV positive men were oversampled in order to meet the objectives of the original HIV Social Networks and HIV Clade Study. Data collected were egocentric and therefore reliant on the accurate reporting of alter characteristics by the egos; the validity of ego responses were not verified. The egocentric nature of the data did not allow us to observe the partnering process directly, rather we were limited to observing only those partnerships the ego chose to report. Moreover we observed only successful outcomes, or those partnerships that actually occurred. Thus, we know nothing about the partnerships that were available but never pursued or about intimate relationships that did not reach the point of sexual involvement. This 'missing data' skews the representation of the expected patterns of sexual mixing since we have a limited and biased view of what the potential pool of partners looks like. Furthermore individuals with many partners will be overrepresented in the mixing matrix, although egos were limited to three partners. Since egos were able to report on multiple partners this is analogous to a repeated measures design, which violates the independence assumption underlying many statistical techniques. Statistical methods to correct for this dependence in the context of network analysis have only begun to be developed and so there is no clear way to correct for this bias

Despite these limitations, this study is among the first to present data on sexual mixing patterns by race among MSM in Cape Town. We were able to quantify chance-corrected measures for dyads overall using Newman's assortativity coefficient, as well as race-specific measures for race assortativity using the E-I statistic. Results from these two measures paint a

coherent picture when describing racial mixing patterns among MSM in Cape Town, suggesting high levels of same-race partnering. The computation of a null sampling distribution for the E-I statistic allowed significance testing of observed levels of racial assortativity compared to racial assortativity under conditions of random mixing. The small p-values associated with our E-I statistics suggest that racial homophily between MSM in Cape Town is significantly different to what would be expected under conditions of random mixing. Our findings have significant implications for the modeling of HIV disease transmission in this key population and provide context for the existence of striking disparities in HIV prevalence by race among MSM in South Africa.

Table 3: Individual-level demographic and behavioral characteristics of 314 MSM participants in Cape Town, South Africa

	Black (n=209)		Coloured (n=87)		White (n=19)		p-value
Age (years)	30	(25, 37)	31	(24, 37)	40	(31, 47)	0.004[a]
HIV positive	129	(62)	47	(54)	17	(89)	0.02
Urban location	65	(31)	58	(67)	19	(100)	<0.001[b]
Sexual orientation							
Heterosexual/Straight	12	(6)	5	(7)	0		<0.001[b]
Homosexual/Gay	112	(57)	52	(70)	17	(94)	
Bisexual	73	(37)	17	(23)	1	(6)	
In a relationship with a woman	51	(25)	11	(13)	0		<0.001[b]
Sexual history:							
Age at first sex with a man	19	(16, 26)	16	(13, 19)	17	(14, 22)	<0.001[a]
Disclosed same-sex behavior	135	(65)	68	(80)	19	(100)	< 0.001[b]
Lifetime male sex partners	8	(3, 20)	30	(7, 88)	69	(20, 100)	< 0.001[a]
Lifetime UAI[c] male sex partners	2	(1, 5)	5	(2, 25)	6	(5, 20)	< 0.001[a]
Male sex partners in past 6 months	3	(2, 6)	5	(2, 20)	2.5	(1, 4)	0.001[a]
UAI male partners in past 6 months	1	(0, 2)	1	(0, 5)	0.5	(0, 1)	0.01[a]
Reported UAI[c] with at least one partner in last 6 months	85	(45)	45	(56)	8	(53)	0.23
Reported concurrent partner, no. dyads[d] (%)	260	(36)	103	(14)	14	(2)	0.2
Ever had vaginal sex	136	(66)	35	(40)	11	(58)	< 0.001
Had sex with a woman in the past 6 months	30	(43)	7	(47)	0		0.4[b]

Data for categorical data are frequency and (percentage), data for continuous data are medians and (interquartile ranges)

[a]Wilcoxon-Mann-Whitney non-parametric test for differences in medians

[b]Fisher's exact test

[c] UAI = unprotected anal intercourse

[d]Total number of dyads reported by respondent race: Black (n = 625), Coloured (n = 259), White (n = 57)

Table 4: Characteristics of 714 partnerships reported by 201 black, 82 coloured and 15 white MSM in Cape Town, South Africa

	Black		Coloured		White		p-value
Racially concordant	375	(52)	123	(17)	25	(4)	< 0.001
Where partner was met:							
Participant's township or suburb	12	(50)	21	(68)	-		
Another township/ suburb	8	(33)	3	(10)	-		
Internet	4	(17)	7	(23)	-		0.1[a]
Main	144	(30)	54	(26)	12	(35)	0.33
Unprotected anal intercourse	140	(32)	85	(46)	13	(41)	< 0.01
HIV positive seroconcordant	15	(36)	9	(32)	9	(69)	0.06
Had pre-sexual HIV serodiscussion	116	(24)	56	(27)	15	(44)	0.18
Partner engaging in extradyadic concurrent sex	147	(65)	72	(61)	10	(63)	0.79

[a]Comparing only black egos to coloured egos

Table 5: Ego and dyad-level demographic and behavioral characteristics by race assortativity

	Racially concordant		**Racially discordant**		**p-value**[a]
Ego characteristics:					
Age, median (IQR)	31	(24, 37)	31	(25, 37)	0.19
HIV positive, N (%)	311	(54)	264	(46)	0.25
Peri-urban location, N (%)	300	(58)	219	(42)	0.13
Dyad-level characteristics:					
Where partner was met[b]					
Ego's neighborhood	28	(67)	5	(38)	
Different neighborhood	8	(19)	3	(23)	
Internet	6	(14)	5	(38)	0.13
HIV positive seroconcordant[b]	7	(21)	26	(79)	0.8
Had pre-sexual HIV serodiscussion	141	(75)	46	(25)	0.28
Engaged in UAI	305	(74)	106	(26)	0.51
Main partner	157	(75)	53	(25)	0.41

[a]Two-sided p-values from chi-square or Fisher's exact test (categorical variables) or median two-sample tests (continuous variables)

[b]more than 50% of data missing

Table 6: Contingency tables by ego and alter race stratified by demographic and behavioral characteristics

	Alter's race			Newman's assortativity coefficient (95% CI)	E-I statistic[a]
	Black	Coloured	White		
	N (row %)				
Ego's race					
Overall				0.51 (0.45 - 0.56)	-0.45
Black	375 (79)	51 (11)	47 (10)		-0.58
Coloured	28 (13)	123 (59)	57 (27)		-0.17
White	1 (3)	7 (21)	25 (76)		-0.47
HIV$^+$ ego				0.52 (0.45 - 0.59)	-0.51
Black	217 (78)	28 (10)	33 (12)		-0.62
Coloured	17 (15)	71 (61)	29 (25)		-0.17
White	0	6 (21)	23 (79)		-0.69
HIV$^-$ ego				0.48 (0.40 - 0.57)	-0.45
Black	158 (80)	23 (12)	17 (8)		-0.60
Coloured	11 (12)	52 (57)	28 (31)		-0.20
White	1 (25)	1 (25)	2 (50)		0.33
Peri-urban ego					-0.60
Black	254 (83)	33 (11)	20 (6)		-0.66
Coloured	24 (18)	92 (70)	16 (12)		-0.35
White	0	0	0		n/a
Urban ego				0.47 (0.40 - 0.54)	-0.29
Black	121 (73)	18 (11)	27 (16)		-0.44

Coloured	16 (11)	77 (54)	49 (35)		-0.08
White	1 (3)	7 (21)	25 (76)		-0.47
HIV^+ - HIV^+(N=33)				0.53 (0.40 - 0.66)	
Black	14 (100)	0	0		
Coloured	0	3 (100)	0		
White	1 (6)	6 (37)	9 (56)		
HIV^+- HIV^- / HIV^-- HIV^+ (N=54)				0.55 (0.36 - 0.74)	
Black	26 (87)	4 (13)	0		
Coloured	3 (19)	11 (69)	2 (12)		
White	1 (12)	4 (50)	3 (38)		
HIV^- - HIV^- (N=75)				0.50 (0.34 - 0.68)	
Black	43 (91)	3 (6)	1 (2)		
Coloured	5 (26)	14 (74)	0		
White	4 (44)	5 (56)	0		
UAI (N=230)				0.56 (0.47 - 0.65)	
Black	103 (92)	9 (8)	0		
Coloured	19 (24)	57 (73)	2 (3)		
White	15 (37)	14 (35)	11 (27)		
Ego in concurrent partnership (N=373)				0.49 (0.41 - 0.56)	
Black	211 (92)	17 (7)	0		
Coloured	22 (27)	55 (68)	4 (5)		
White	25 (39)	30 (47)	9 (14)		
Main partnerships (N=210)				0.51 (0.41 - 0.62)	
Black	117 (92)	9 (7)	11 (9)		
Coloured	14 (31)	30 (67)	1 (2)		

White	13 (34)	15 (39)	10 (26)	
Casual partnerships (N=490)				0.50 (0.44 - 0.57)
Black	258 (78)	37 (11)	34 (10)	
Coloured	19 (12)	93 (60)	42 (27)	
White	0	6 (29)	15 (71)	

[a]p-value < 0.01 for all E-I statistics

Chapter 4: Understanding the context of age-disparate relationships among young women in rural South Africa

Abstract

In South Africa HIV prevalence peaks at 33% for women between the ages of 25 and 29 years, which is 5 years younger than males, whose HIV prevalence peaks among 30 to 34 year olds. Age-disparate relationships are considered a key risk factor for HIV for young women in South Africa and thought to be a major contributing factor to this age-specific prevalence profile. As a result numerous public health campaigns discouraging young women from engaging in relationships with older "sugar daddies" have been implemented across South Africa. Increased risk for engaging in age-disparate relationships is widely recognized to be associated with economic differentials by gender, yet there have been few studies looking at contextual determinants of these relationships. We conducted a multilevel analysis of age-disparate relationships among a cohort of young women in rural South Africa.

This analysis was based on data collected by the Africa Centre Demographic Information System (ACDIS), located in a predominantly rural district of Kwazulu-Natal. We ran a multilevel logistic regression model to determine individual and community-level factors associated with 15- to 29-year-old women engaging in a relationship with a sex partner at least 5 years older. Community-level variables representing three domains (i.e., demographic composition, economic conditions and gender norms and inequalities) as well as individual-level demographic and behavioral variables were explored.

Significant determinants of engaging in an age-disparate relationship included the ratio of unmarried women to unmarried men, the age and marital status of the woman as well as whether the sex partner was a member of the same household. Age-disparate relationships were more prevalent among older and married women.

Our results suggest that the ‘sugar daddy’ narrative and messaging may not be applicable in this context. HIV prevention programs aimed at reducing the prevalence of age-disparate relationships could benefit from tailoring their message, by considering the cultural and demographic factors that influence women to engage in age-disparate relationships.

Introduction

Young females in South Africa bear a disproportionate burden of the HIV epidemic, representing 59% of HIV infected adults in South Africa [4]. HIV prevalence peaks at 33% among females aged 25-29 years; among males, HIV prevalence peaks between 30-34 years, at 26% [4]. HIV incidence among 20-29 year old females is reported to be 5.6%, more than 6 times the incidence among similarly-aged males, with females between the ages of 15 and 24 years representing 90% of recent HIV infections [5].

Intergenerational sex or age-disparate sexual partnerships have been proposed to play a key role in these gendered HIV disparities. Age-disparate relationships are defined as a relationship between partners with at least a 5-year age difference, while intergenerational sex occurs between partners with at least a 10-year age difference [30]. In the majority of these relationships the younger partner is the woman. Engaging in age-disparate relationships increases a young woman's vulnerability to HIV infection through three main causal pathways: behavioral, biologic, and epidemiologic. Behavioral HIV risk factors, such as intimate partner violence (IPV) and forced sex, are more prevalent in age-disparate relationships [26, 28, 33, 110, 111]. Biologically, young women have a still-maturing vaginal mucosa rendering an increased susceptibility to a sexually transmitted infection (STIs) such as HIV upon exposure [112-114]. Epidemiologically, given the age-specific HIV prevalence by sex, older males are more likely to be HIV infected than younger males, increasing the likelihood of the young female partner in an age-disparate relationship being exposed to the virus. Furthermore, unequal power dynamics often prevalent in these types of relationships compromise the female's ability to negotiate safer sex practices [31, 115, 116]. National behavioral surveillance data show a statistically significantly lower proportion of females between the ages of 15 and 24 years reporting condom use at last sex compared to similarly-aged males [4]. Power imbalances in age-disparate relationships also increase the likelihood of IPV, and women who experience IPV are up to 3

times more likely to be infected with HIV than those who have not [32]. Forced sex often happens in the context of IPV and further increases the susceptibility of a still-maturing vaginal mucosa to infection upon exposure, due to tears and lacerations [117, 118]. Despite their disproportionately high HIV prevalence and incidence younger women are often viewed as "safer" partners representing overall good health and fertility. The greatest risks young women associate with these sexual partnerships include pregnancy and the potential loss of social standing if the relationship were to be uncovered, rather than the more pertinent risk of HIV and STI infection [30]. In 2008, 28% of South African females compared to 0.7% of males reported having a partner at least 5 years older than themselves [4] and overall there was an increase in the percentage of teenagers reporting an older sex partner, from 9.6% in 2005 to 14.5% in 2008 [4].

Early studies in West Africa have highlighted how dire economic conditions motivated women to seek older male partners in exchange for money or gifts, referred to as "survival sex". Further work revealed that sometimes these motivations were not simply to meet basic needs, but also to acquire luxury items and attain a modern consumer lifestyle [30]. From this characterization the term "sugar daddy" was borne depicting a wealthy and powerful man luring young vulnerable women with the promise of increased social status and consumer goods [30, 119]. As research in this field has matured, it has highlighted the complex interplay of causal factors, including individual, community, cultural, social and psychological factors, driving this relationship typology and suggests that perhaps the "sugar daddy" narrative, although important, is perhaps overly simplistic and overstated [30]. Relationships with age and economic asymmetries are pervasive in sub-Saharan Africa (SSA) and are not limited to a certain socioeconomic sector of the population [25]. While socioeconomic reasons are certainly key drivers of this relationship, studies have shown that even when African women are relatively well off, many continue to engage in age-disparate relationships [120, 121]. The role of the "sugar daddy" has also been shown to be played by relatively poor men, suggesting that gender

economic inequalities rather than absolute wealth may be more important [115]. Although widely associated with casual transactional partnerships, in certain populations the largest age-gaps have been shown to occur within marital relationships [25, 122]. The social acceptance of age-disparate relationships also vary, while the majority happen out of sight and secretly some have the approval and even encouragement of families [123]. There are a limited number of studies exploring the different contexts of these age-disparate relationships outside of transactional sex and "sugar daddy" hypotheses. Growing gendered economic inequalities, shifting cultural norms and changing demographics, in the context of highly active antiretroviral therapy (HAART), all influence age-gaps between sexual partners. Work uncovering the risk determinants of engaging in age-disparate relationships, particularly in the context of the maturing SSA HIV epidemic, emphasizes the need for a better understanding of the sexual dynamics between younger women and older men.

Community-level determinants of age-disparate sexual relationships

From the observational work done characterizing age-disparate sexual relationships it is clear that these relationships are inextricably tied to contextual constructs such as social hierarchies and unequal gender power dynamics [25]. An analysis of the determinants of these relationships would be incomplete without taking into account community-level factors shaping these interactions. Community economics and gender inequities in education, employment and access to social capital are significant factors influencing a number of sexual and relational behaviors [37]. The demographic composition of populations shape the pool of eligible sex partners [124]. Social and cultural norms may also influence the prevalence of age-disparate relationships by shaping what is considered normal and acceptable relationship typologies [30]. In the case of intergenerational sexual relationships, community gender norms would also be important to capture, since these are influential in perpetuating gender inequities. Communities where women have less access to social capital, educational opportunities and employment due to

conservative gender norms could be expected to have a higher prevalence of intergenerational sexual partnerships [37]. Often a number of these aspects are intertwined and occur at the same time. A complex interplay of factors is likely to be driving the occurrence of these relationships and analyses which seek to determine to what extent this could be explained by demographic composition, prevailing social and cultural norms and community economics would offer additional insight.

Variables representing population composition in a way that meaningfully characterizes the pool of available sex partners include age-specific male to female sex ratios and age-specific proportions of unmarried women [38]. Cultural and social norms can be explored by looking at the sex-specific mean age at first marriage and mean age at sexual debut [37]. Meaningful community-level representations of socioeconomic determinants include the ratio of female-headed households to male-headed households, the average rate of migration, male to female ratio at relevant education levels and the ratio of employed females to males [37, 38]. Besides community-level determinants, individual, dyad and household-level factors also play a role in the development of these relationships.

Previous studies have predominantly looked at this relationship in the context of individual-level determinants. Much less work has been done exploring determinants of these relationships in a multilevel analytical framework, which would allow the analysis of individual- and community-level determinants simultaneously. This study set out to identify predictors of engaging in age-disparate relationships in a multilevel framework by evaluating both individual- and community-level covariates.

Methods

Data

This analysis was based on data collected by the Africa Centre Demographic Information System (ACDIS) which is coordinated by the Africa Centre for Health and Population Studies (hereafter referred to as the Africa Centre) [125]. The ACDIS surveillance area is located in the market town of Mtubatuba, a predominantly rural community in the Kwazulu-Natal province of South Africa. ACDIS covers an area of 435 km^2 and collects data at the individual, household and community level. Data for the outcome and multilevel exposure variables were compiled from two annual surveys conducted by the Africa Centre between 2005 and 2012 i.e., The Women's General Health Survey (WGH) and the Household Socioeconomic Survey (HSE).

The Women's General Health Survey is completed via a face-to-face interview and collects data on demographics, general health as well as recent sexual relationships among all women currently resident in the ACDIS surveillance area and at least 15 years old. The outcome of interest i.e., age gap between respondent and most recent sex partner was obtained from this survey, as well individual-level characteristics such as marital status, age, condom use, whether the sex partner was a member of the same household as well as the number of sex partners in the last 12 months. Women between the ages of 15 and 29 years who had participated at least once in the WGH surveillance between January 2005 and December 2012 comprised our study sample.

The Household Socioeconomic Survey (HSE) is conducted annually and collects socio-demographic information on each household member including employment status and the highest level of education obtained. Individual-level information on household members collected via the HSE was aggregated at both the local-area and *isigodi* level in order to construct our community-level variables. Community-level variables were treated as time invariant and baseline values from 2005 were used. Trend tests were conducted to determine whether there

were any significant changes in community-level variables between 2005 and 2012. Community-level variables as well as their corresponding domain are described below (Table 7).

Measures

The study outcome was whether or not a woman engaged in age-disparate relationship which we defined as a woman reporting a most recent sex partner at least five years older than herself on her baseline WGH survey. Women were asked whether their most recent sex partner was "older, younger or about the same age". For sex partners reported to be "older/younger" the age difference, in years, compared to the female respondent was recorded. Responses to these two questions were combined to create a dichotomous outcome i.e., woman engaged in an age disparate relationship vs. woman did not engage in an age disparate relationship.

Three levels of determinants of engaging in an age-disparate relationship were explored: individual, local area and *isigodi*. Local areas are defined as groups of neighboring homesteads that identify with a recognized and accepted local area name, while *izigodi* (singular: *isigodi)* are traditional Zulu communities for which a single *Induna* (chief) is responsible for [126, 127]. *Isigodi* are demarcated tribal areas analogous to administrative primary sampling units (PSUs), while local areas are local neighborhoods identified by residents and thought to better represent neighborhoods qualitatively.

Individual-level determinants included age group (15-19, 20-24 and 25-29 years old), highest level of education attained, employment status, marital status, age at sexual debut, condom use, whether the woman was ever pregnant and whether the sex partner was a member of the same household.

Community-level data were derived from aggregating individual responses to the primary sampling unit to form proxy community measures. The selection of community-level variables was informed by theoretical frameworks and previous studies of women engaging in age-disparate relationships in SSA [25, 30, 122]. The community-level variables were selected to represent three domains (Table 7).

Community demographic composition. The types of relationships people engage in is in part shaped by the pool of eligible partners [124, 128]. To represent this in the analysis we included the ratio of unmarried women to unmarried men as well as the ratio of women to men between the ages of 15 to 19 years, 20 to 29 years and 30 years and older.

Community economic conditions. Women engaging in age-disparate relationships may be doing so to access material wealth and social capital, particularly in limited resource environments [30]. We hypothesize that this is more likely to occur in communities with inequities in education and employment by gender. To test this hypothesis, our analysis included the ratio of employed women to employed men, and the ratio of women to men who have at least primary education at the local area.

Community gender norms and inequalities. Differential expectations for women communicated via gender norms may influence the types of relationships women engage in. For example early ages at marriage may reflect conservative views with regards to the roles of women. To represent community gender norms we included the difference in the mean age of first sex for women and men as well as the difference in the mean age of first marriage for women and men.

Analytical Approach and Covariates

Bivariate analyses were performed to examine the reporting of engaging in an age-disparate relationship according to individual determinants. Crude odds ratios (ORs) and corresponding 95% confidence intervals (CIs) evaluated associations between individual-level covariates and engaging in an age-disparate relationship.

Data are structured hierarchically with individuals nested within local areas and local areas nested within larger tribal areas known as isigodi. This hierarchical multilevel structure of the data violates the assumption of independence of ordinary logistic regression, requiring generalized linear mixed modeling (GLMM). GLMM accounts for this lack of independence and allows us to accurately represent the hierarchical structure of observations, by introducing random coefficients to represent each level which are constant within a certain level but varying across levels. Since this was an open cohort and women could have an observation recorded any time between 2005 and 2012, year was included as a control variable for each model run.

Collinearity between community-level variables was assessed and condition indices greater than 30 with a variance inflation factor greater than 0.5 was considered indicative of a collinearity problem. Data analysis was conducted with SAS v. 9.3 (North Carolina, USA).

Ethical approval for the Africa Centre surveillance was granted by the Biomedical Research Ethics Committee, University of Kwazulu-Natal. This data analysis was exempted from additional ethical review by the Emory University Review Board because it made use of secondary de-identified data.

Results

Between January 2005 and December 2012, there were 8290 women with a baseline WGH survey and a non-missing response to our outcome of interest. Baseline characteristics for these women are provided in Table 8. The median age of women included in this analysis was 21 years (interquartile range [IQR]: 19-24) with the overwhelmingly majority (86%) reporting never having been married (Table 8). Most women (65%) lived in rural neighborhoods. The median age at first sex was 18 years (range: 16 - 19) and 43% of women reported using a condom sometimes, while 31% of women reported never using a condom with their most recent sex partner (Table 8).

The median partner age difference was 3 years (IQR: 2-5) (Figure 2). Eighty-seven percent of women reported a sex partner older than herself and 34% of these women reported a sex partner at least five years older.

In bivariate analyses with 15 to 19 year old women as the referent group, women 20 to 24 years old were 1.3 times more likely to report an age-disparate relationship while women 25 to 29 years were 1.7 times more likely to report an age-disparate relationship (Table 8). The proportion of women reporting an age-disparate relationship differed by marital status with married women 5.4 times more likely to report a partner at least 5 years older. Women who reported sometimes using a condom were 1.5 times more likely to report an age disparate relationship compared to those who reported always using a condom, while women who reported never using a condom were 1.2 times more likely to report an age disparate relationship (Table 8).

Community-level variables had minimal variation across local areas grouped by neighborhood type (urban, peri-urban and rural), with rural local areas showing the widest range. Mean ratios of employed women to men were greater than 1 across all neighborhood types, with a ratio of 1.4 (range: 1.0 - 1.4) for urban local areas. Ratios of women to men with at least primary education were also greater than 1 across all neighborhood types (Table 9).

In unconditional regression models including random intercepts for both the community-level sampling units clustering of the outcome was minimal at the isigodi (intracluster correlation coefficient [ICC] = 0.0001) and the local area level (ICC = 0.001) (Table 10). Although the local-area-level ICC was minimal, the random intercept was significant (p-value < 0.05). In a multilevel logistic regression model evaluating only local-area-level variables and excluding individual-level variables, the ratio of unmarried women to men had a significant positive association with engaging in an age-disparate relationship with every one unit increase in the ratio of unmarried women to men, women were 1.6 times as likely to report being in age-disparate

relationship (Table 11). The ratio of employed women to men had a negative, albeit non-significant, association with the outcome. As the ratio of employed women to men increased women were 0.9 times less likely to report being in an age-disparate relationship compared to women living in local areas with every one unit decrease in the ratio. None of the remaining community-level variables (i.e. ratio of women to men with ≥ primary education, difference in average age at first marriage for women and men and the ratio of 20 - 29 year old women to men) showed a significant relationship with the outcome.

In a multilevel logistic regression model evaluating both local-area-level and individual-level variables, the ratio of unmarried women to men remained significant and positively associated with the outcome. A number of individual-level covariates showed a significant association with the outcome. Interestingly older women were more likely to report being in an age-disparate relationship with women between the ages of 20 – 24 years 1.3 times as likely to report being in an age-disparate relationship compared to younger women aged 15 – 19 years old and women aged 25 - 29 years old were 1.5 times more likely to report being in an age disparate relationship. Married or engaged women were 3.0 and 1.5 times as likely to report an age-disparate relationship respectively compared to those who were never married. Condom use with the most recent sex partner was also positively associated with being in an age-disparate relationship, with women reporting *never* using a condom with their partner 1.4 times as likely to report being in an age-disparate relationship compared to women who reported *always* using a condom with their partner.

Discussion

The small intraclass correlation coefficients from our multilevel analysis show negligible variation in the outcome at both community PSUs i.e., the local-area- and isigodi-level. The PSUs included in this multilevel analysis may be limited in operationalizing neighborhoods and as such may be poor proxies for the theoretically relevant area in relation to our outcome of interest.

Studies of neighborhood and area effects on health outcomes are hampered by a number of conceptual and methodological difficulties, not least of which include properly defining the relevant neighborhood [129, 130]. The ACDIS study area was relatively homogenous with regards to language and tribal and ethnic composition, which is almost exclusively Zulu, and this homogeneity may explain why we see negligible variation in our outcome [131]. Nevertheless, despite limited variation in our outcome by neighborhood, we argue that a multilevel analysis is still appropriate and necessary, given the nested and hierarchical structure of the data. Our study demonstrates the utility and feasibility of conducting a multilevel analysis in the ACDIS and suggests that clustering at both the local-area- and isigodi-level does not need to be taken into account.

The positive significant association of the outcome with the local-area ratio of unmarried women to unmarried men is an interesting finding. Studies looking at marital patterns in South Africa have found that both the quantity and quality of unmarried men relative to unmarried women are significant predictors of marriage and economic-based indicators of 'marriageability' have a greater effect on marriage outcomes compared to sex ratios [132]. This is particularly relevant in the context of Zulu traditions, where marriage customs include a dowry (*lobola*) paid by men to the female's family which places an additional economic constraint on marriage and biases the economic burden of marriage toward men. The higher ratio of unmarried women to unmarried men in certain local areas may be indicative of declining rates of marriage among women due to limited economic eligibility of males in the local marriage market. Given that women in these local areas are also more likely to report being in relationships with older men may be reflecting the improved economic status of older men relative to younger men. The fact that we also see an independent significantly higher likelihood that married women in these local areas are in age-disparate relationships provides further support for this hypothesis.

The fact that we do not see a significant association with our community-level variables indicating community economics (i.e., ratio of employed women to men and ratio of women to men with ≥ primary education) is somewhat counterintuitive, but the observed null association may be as a result of high levels of outmigration across this area suggesting that men who remain behind and contribute education and employment data may be more likely to be unemployed or have limited educational attainment and resulting in smaller differentials between women and men. In addition the older partners that women are reporting may not be residents in the local areas from which these community-level variables are derived [125].

Our findings that older (20-24 and 25-29 year old) and married women are more likely to report being in an age-disparate relationship are in contrast to the stereotypical 'sugar daddy' narrative where school-aged women are thought to engage in casual, transactional partnerships with older male partners and suggest that the target group for the anti-'sugar daddy' HIV prevention campaigns in South Africa within this context is not accurate [34, 133]. Furthermore given that age-disparate relationships are more prevalent among older and married women, biological factors such as a still maturing vaginal mucosa among are less significant to establishing HIV infection risk disparities in this context, suggesting that the other two pathways, behavioral and epidemiologic, may be more relevant.

The positive association of women reporting *never* or *sometimes* using a condom with engaging in an age-disparate relationship, suggests an increase in certain risky sexual behaviors in these relationships. Studies have shown that women in age-disparate relationships often have little control over sexual practices due to power imbalances [30, 115]. This may be the case in our study population which is also exacerbated by the decreased likelihood of women using a condom with their main partner or spouse [134]. Despite economic and educational differentials showing a null association with age-disparate relationships relational power imbalances in this context

may be mediated through cultural prescriptions or traditional norms and not economic differentials, both constructs not included in our model [30].

Our study has a number of limitations. Our response is self-reported and given the negative connotations associated with age-disparate relationships women may be less willing to report an older sex partner. Our data are cross-sectional and are therefore limited in evaluating causal inference. The high levels of outmigration for employment introduces selection bias by increasing the likelihood that unemployed individuals are more likely to be included in the demographic surveillance.

Taken together our results indicate that within this study population interventions looking to decrease the prevalence of age-disparate relationships will be more efficient by targeting older and married women. Furthermore when considering the HIV risk continuum, distal factors along the pathway between engaging in an age-disparate relationship and HIV infection are more likely to be along the behavioral and epidemiologic, rather than biological, causal pathway. Furthermore negligible variation in the outcome at the local-area- and isigodi-level suggest that interventions need not be targeted by place within this context.

Figure 2: Age disparity between female respondent (15-29 years old) and her most recent male sex partner

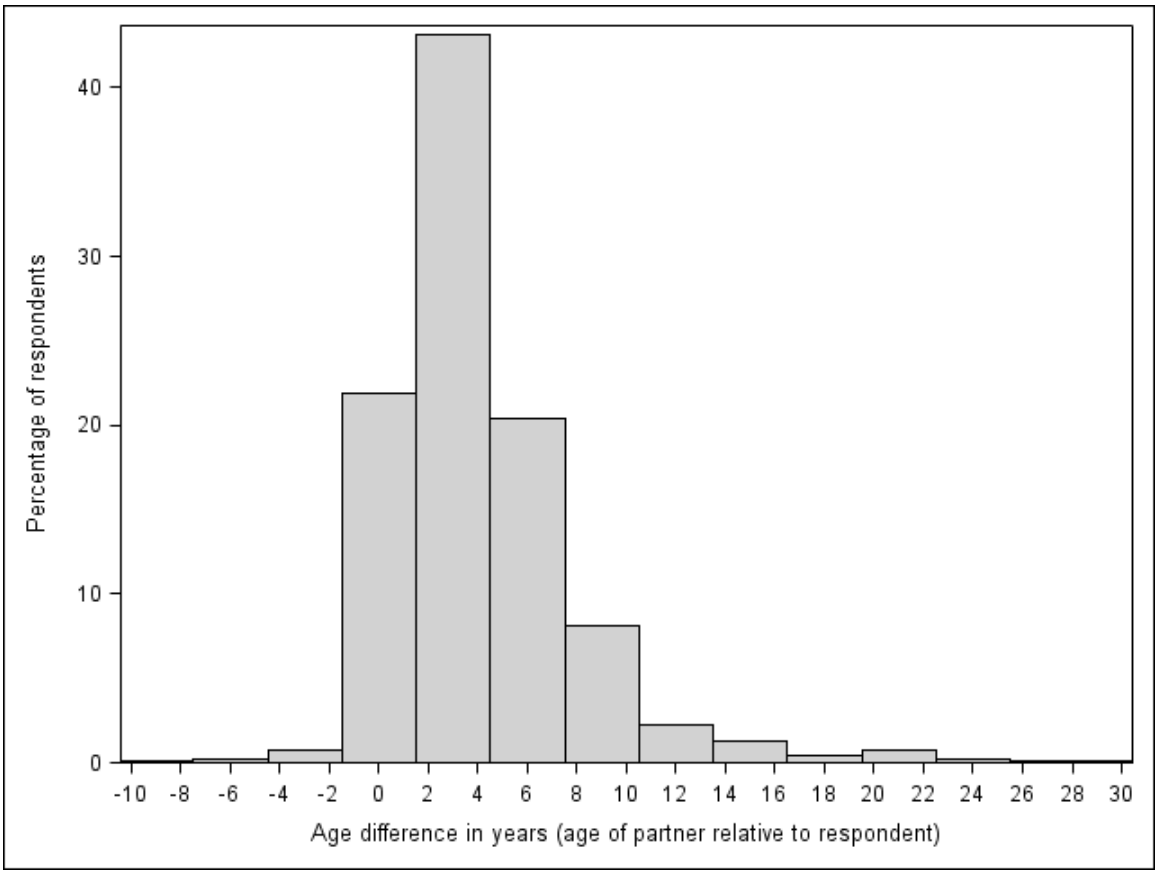

Table 7: Community-level variables and corresponding domains included in a multilevel logistic regression model evaluating the context of women (15-29 years) engaging in an age-disparate relationship

Domain	Variable
Demographic composition	Ratio of unmarried females to unmarried males
	Ratio of females to males by age categories (15-19, 20-29 and 30+)
Economic conditions	Ratio of females to males with ≥ primary education
	Ratio of employed females to employed males
Gender norms and inequalities	Difference in average age at first marriage for females compared to males
	Difference in age at sexual debut for females compared to males

Table 8: Baseline characteristics of study sample of 15- to 29-year old women (n=8290)

	Overall (n=8290)	Partner < 5 years older (n = 5488)		Partner ≥ 5 years older (n = 2802)		
Age group						
15 - 19 yrs	2873 (35)	2078	(72)	795	(28)	1.00
20 - 24 yrs	3410 (41)	2246	(66)	1164	(34)	1.3 (1.2-1.4)
25 - 29 yrs	2007 (24)	1164	(58)	843	(42)	1.7 (1.6-1.9)
Marital status						
Never married	7098 (86)	4899	(69)	2199	(31)	1.00
Engaged	979 (12)	525	(54)	454	(46)	1.8 (1.6-1.9)
Married	200 (2)	57	(29)	143	(72)	5.4 (4.3-6.8)
Divorced/widowed	7 (0.1)	3	(43)	4	(57)	3.5 (1.1-10.6)
Highest educational attainment						
None or < 1 yr	48 (1)	33	(69)	15	(31)	0.9 (0.5-1.7)
Primary (0-7 yrs)	614 (9)	391	(64)	223	(36)	1.2 (1.0-1.4)
Secondary (8-12 yrs)	5617 (85)	3774	(68)	1843	(33)	1.00
Tertiary	306 (5)	183	(60)	123	(40)	1.4 (1.1 1.7)
Employed	709 (13)	448	(63)	261	(37)	1.1 (0.9-1.3)
Age at first sex	18 (16-19)	18	(16-19)	18	(16 - 19)	p-value = 0.4
Condom use						
Always	2109 (25)	1530	(73)	579	(27)	1.00
Sometimes	3579 (43)	1735	(67)	861	(33)	1.5 (1.4-1.6)
Never	2596 (31)	2220	(62)	1359	(38)	1.2 (1.1-1.4)
Neighborhood						
Rural	5355 (65)	3588	(67)	1767	(33)	1.00

Peri-urban	2671 (32)	1742	(65)	929	(35)	1.0 (1.0-1.1)
Urban	264 (3)	158	(60)	106	(40)	1.2 (1.0-1.5)

Data for categorical data are frequency and (percentage), data for continuous data are medians and (interquartile ranges)

Table 9: Selected community-level characteristics by neighborhood type

	Overall	**Urban**	**Peri-urban**	**Rural**
Ratio of women to men 15 -19 yrs	1.0 (0.4 - 7)	1.2 (1.0 - 1.2)	1.0 (0.5 - 2.3)	1.0 (0.4 - 7)
Ratio of women to men 20 - 29 yrs	1.3 (0.3 - 3.9)	1.5 (1.1 - 1.5)	1.1 (0.5 - 2.9)	1.4 (0.3 - 3.9)
Ratio of women to men ≥ 30 yrs	1.7 (1.0 - 3.6)	1.7 (1.5 - 1.6)	1.6 (1.0 - 3.6)	1.8 (1.0 - 3.6)
Ratio of unmarried women to men	1.4 (0.6 - 4.3)	1.6 (1.3 - 1.6)	1.3 (0.7 - 2.2)	1.4 (0.6 - 4.3)
Average age of unmarried women	27 (22 - 32)	27 (27 - 28)	27 (23 - 30)	26 (22 - 32)
Average age of unmarried men	25 (21 - 34)	24 (24 - 26)	26 (23 - 28)	25 (21 - 34)
Ratio of employed women to employed men	1.1 (0 - 5.0)	1.4 (1.0 - 1.4)	1.0 (0.4 - 1.7)	1.1 (0 - 5)
Ratio of women to men with ≥ primary education	1.5 (0.5 - 6.5)	1.6 (1.2 - 1.6)	1.3 (0.6 - 2.2)	1.6 (0.5 - 6.5)
Women's average number of partners in last year	0.9 (0.5 - 2.7)	0.9 (0.9 - 0.9)	0.9 (0.8 - 2.7)	0.9 (0.5 - 2.7)
Men's average number of partners in last year	1.2 (0.7 - 2.8)	1.3 (1.2 - 1.3)	1.2 (0.9 - 2.3)	1.2 (0.7 - 2.8)

All values are mean and (ranges)

Table 10: Unconditional multilevel logistic regression model for assessing associations among women engaging in age-disparate relationships

	Model 1 (a)	**Model 1 (b)**
Local area	0.01 (0.01)	0.01[a] (0.007)
Isigodi	0.001 (0.007)	-

Model 1 (a): Includes both local area and isigodi random intercept

Model 1 (b): Includes only local area intercept

[a]p-value < 0.05

Table 11: Odds ratios (and 95% confidence intervals) from multilevel logistic regression model assessing associations among women engaging in age-disparate relationships

	Model 1	Model 2	Model 3
Characteristic			
Local area			
Ratio of women to men (20 - 29 yrs)		1.10 (0.87 – 1.89)	0.95 (0.72 - 1.24)
Ratio of unmarried women to men		1.56 (1.07 – 2.27)	1.69 (1.09 - 2.61)
Ratio of employed women to men		0.91 (0.81 – 2.23)	0.92 (0.80 - 1.06)
Ratio of women to men with ≥ primary education		0.99 (0.86 – 1.14)	0.98 (0.83 - 1.16)
Difference in average age at marriage for women compared to men		1.00 (0.98 – 1.01)	0.99 (0.98 - 1.01)
Individual			
Age group			
15 – 19 yrs			1.00
20 – 24 yrs			1.27 (1.10 – 1.48) [a]
25 – 29 yrs			1.50 (1.24 – 1.81) [a]
Education			
High school			1.00
Primary school			1.04 (0.85 – 1.26)
None/ less than one yr			1.00 (0.50 – 2.02)
Tertiary			1.20 (0.91 – 1.57)
Age at first sex			0.95 (0.92 – 0.98)[a]

Ever pregnant			
No			1.00
Yes			1.28 (1.11 – 1.47)[a]
Marital status			
Never married			1.00
Married			3.01 (1.96 – 4.63)[a]
Engaged			1.54 (1.29 – 1.84)[a]
Divorced			1.23 (0.07 – 20.55)
Condom use			
Always			1.00
Sometimes			1.16 (0.99 – 1.36)
Never			1.36 (1.17 – 1.58)[a]
Sex partner a member of household			
No			1.00
Yes			1.67 (1.35 – 2.07)[a]
Local area random intercept	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)

[a]p-value < 0.01

Model 1: Unconditional model (local area random intercept only)

Model 2: Model 1 + local area fixed effects

Model 3: Model 2 + individual-level fixed effects

Chapter 5: Conclusions and Future Directions

In this final chapter, we summarize the findings of our three analytical studies and evaluate their broader position within the field of HIV prevention research in South Africa. These conclusions will also inform directions for future research and implications for HIV prevention interventions.

Review of major findings and study-specific implications

In our first study we constructed and qualitatively characterized five social network typologies based on connectivity between friends, family and sex partners in relation to sexual risk-taking among MSM in Port Elizabeth and Cape Town. These typologies ranged from men without any connections between social network members to men with dense overlapping connections between network subgroups. Characterization of these social network typologies provided insight into how differences in social network structure influence the way in which sexual risk manifests among this key population. Men with completely disconnected networks were hesitant to disclose their same-sex behavior and described feelings of internalized homonegativity and minimal connectivity to LGBT organizations. Sex was described in the context of secretive, casual and anonymous sexual encounters making safer sex practices less likely. Men with more connections across subgroups particularly between family and sex partners were more likely to be in a committed relationship with a main partner and to report cessation of condom use in these long-term relationships. Findings from this study demonstrate the utility of social network mapping as an exposure assessment tool when evaluating sexual risk among MSM in Cape Town and Port Elizabeth. Specifically by relating social network connectivity to sexual risk behaviors and health outcomes we have demonstrated how this social network attribute can help identify MSM that are more prone to depressive behaviors or feelings of internalized homonegativity which are associated with increased sexual risk-taking. There are a number of ways in which this type of social network assessment may shape HIV interventions. During HIV

counseling and testing, counselors would be able to assess the degree of social support offered to MSM based on their social network connectivity, which may in turn shape the counseling and referral process. Similar network assessment tools have been used successfully in the context of identifying undiagnosed HIV and HIV risk-reduction counseling [135-138]. Connected men who are in long-term relationships with main partners may be more amenable to couples HIV counseling and testing (CHCT), while disconnected men may prefer more discreet prevention interventions such at-home HIV testing and pre-exposure prophylaxis (PrEP). Social network analysis assessing social connectivity may also be helpful when trying to determine the number of seeds required for successful respondent driven sampling as well as help target more marginalized and socially disconnected MSM in the recruitment process, which is a current limitation in South African research among MSM [8]. Future work would need to be done to assess the validity of this social network map assessment in different MSM populations in South Africa. Finally this study explores the social contexts of MSM, in Cape Town and Port Elizabeth, and makes an important contribution to the limited evidence base to inform programming for this key population in South Africa. This article is currently under review by the journal *Culture, Health and Sexuality*.

In the second paper, we characterized sexual mixing patterns by race among MSM from urban and peri-urban areas of Cape Town. Patterns of sexual mixing by race were quantified using Newman's assortativity coefficient to describe overall racial assortativity and the E-I statistic to describe and compare race-specific racial assortativity. A high level of racial assortativity was found among this population, which was significantly different to what would have been expected under conditions of random sexual mixing. This is the first study to report and compare race-specific patterns of assortativity among MSM in South Africa, which is facilitated by the E-I statistic. Black MSM had the highest levels of same-race partnering, followed by white MSM and coloured MSM. Across demographic strata HIV positive MSM had

higher levels of same-race partnering compared to HIV negative MSM. These results underscore the segregated patterns of sexual partnering by race and provide a potential explanation for the striking HIV prevalence disparities by race among MSM in South Africa. Furthermore race-specific E-I statistics provide input for parameters in the modeling of HIV transmission among MSM in Cape Town and given the significantly high level of same-race partnering it would be naïve to disregard this pattern of sexual mixing in the modeling of HIV transmission among MSM in Cape Town. Development of a permutation test allowed us to append a significance level to our E-I statistic and we outline methodology that can be applied to assortativity measures in similar studies. Furthermore these results have implications for the planning, allocation of resources and programming for HIV prevention in this key population, suggesting that if these patterns of sexual mixing are to continue we are likely to see sustained HIV prevalence disparities by race, which coupled with geographic segregation is likely to result in peri-urban hyperendemicity of HIV [97]. Future work would include comparing patterns of racial assortativity across subgroups of MSM and assessing how this relational determinant influences sexual risk-taking among South African MSM. This article is being prepared for submission to *PLOS ONE*.

The third paper sought to better understand the context of age-disparate relationships by evaluating determinants within a multilevel analytical framework. Our study extended the current work around age-disparate relationships in South Africa by including community-level factors, representing three domains i.e. economics, demographic composition and gender norms, in our analysis. Use of generalized linear mixed models allowed us to simultaneously evaluate the effect of individual and community-level factors on our outcome with the hopes of constructing a more realistic model of age-disparate relationships [139]. Existing epidemiological insights regarding age-disparate relationships have almost exclusively come from individual-level or ecological studies, which are unable to distinguish between contextual and compositional determinants of

age-disparate relationships [140]. To our knowledge this is the first study evaluating age-disparate relationships in rural South Africa within a multilevel framework. Our results suggest that within this rural market town in Kwazulu-Natal there is minimal variation in the outcome by place. The effects of community-level determinants suggest that demographic composition, rather than economic differentials is influential in women engaging in age-disparate relationships. Given the negative association with condom use and women reporting an older partner, engaging in an age-disparate relationship can be used as a screening tool for targeted counseling on condom use or serve as cue to suggest alternatives to woman reporting difficulty in negotiating condom use with their partner, such as the use of PrEP, vaginal microbicides or CHCT. Findings from this study imply that interventions targeting age-disparate relationships in this area need not be tailored by local area. The fact that older and married women were more likely to report being in an age-disparate relationship suggests that the stereotypical 'sugar daddy' narrative is not as relevant within this context and that the pervasive anti-'sugar daddy' campaigns in rural Kwazulu-Natal may as a result have limited efficacy. This article is being prepared for submission to the journal *Health and Place*.

Contributions of this dissertation to HIV research and prevention in South Africa

There has been a gradual shift in the HIV research paradigm in South Africa which has led to an increased recognition of the importance of focusing on key populations even within the context of a widespread HIV epidemic [141]. The effective recognition and inclusion of key populations within the national HIV research, prevention and treatment agenda requires building the evidence base from which to draw on in order to develop strategic, efficacious and tailored HIV prevention interventions. In addition to expanding research among key populations, there has also been a greater emphasis placed on the inclusion of social determinants of health in HIV research in South Africa which would require assessing the role of relational-, network- and community-level factors in HIV risk [34]. This dissertation directly contributes to both of these

objectives through our findings regarding social and sexual network structure of MSM and young women. Existing work on MSM in South Africa is limited to individual-level observational studies and predominantly based in major urban cities such as Cape Town, Durban or Johannesburg. Fewer studies have looked at the social context as well as social and sexual network structure of MSM in relation to HIV risk. Our work highlights the heterogeneity among subgroups and social contexts of MSM as well as heterogeneity in the context of age-disparate relationships, both of which suggest that tailoring of HIV prevention messaging is crucial. Our work also underscores the important role of social and structural determinants in establishing HIV risk disparities cautioning against a pejorative and homogenous narrative when it comes to HIV prevention programming. Not only is it important to recognize the role of social and structural determinants in health outcomes, but there is a need for explicit inclusion of these determinants in the public health research conducted. To this point, our studies have expanded the toolkit for evaluating the role of social and sexual structure in HIV risk disparities and suggests ways in which social determinants of health can be incorporated into South Africa's current public health practices.

The use of social network map analysis in HIV research and prevention in South Africa has not been fully recognized. It is a potential efficient tool of exposure assessment, which may be easily incorporated into standard HIV research practices. Given the relatively early stage of MSM research in South Africa, social network analysis is likely best utilized as a recruitment strategy for marginalized and high risk MSM. These types of social network-based recruiting strategies have shown promise even in areas where same-sex behavior is stigmatized [135, 142].

As routine HIV surveillance and epidemiologic modeling on MSM begins to expand in South Africa, our results from study 2 provide metrics of racial assortativity and suggest race-specific differences in sexual mixing patterns among MSM in Cape Town. Our findings also indicate that inclusion of parameters for racial assortativity is important in accurately modeling

the transmission dynamics and potential impact of the HIV epidemic among MSM in Cape Town. These metrics can also be considered in the modeling of HIV transmission in the generalized HIV epidemic.

Our characterization of age-disparate relationships in rural Kwazulu-Natal show the importance of evaluating health outcomes within a multilevel context. Our finding that the community-level ratio of unmarried women to men is related to women engaging in age-disparate relationships offers a place-based characteristic to better target public health messaging. As the South African Department of Health continues to focus on messaging and interventions around age-disparate and intergenerational sex it is important to think about making these campaigns more effective and tailoring focus groups [133]. The demographic composition of a region may be difficult to intervene on, but further work could explore the determinants leading to patterns of high ratios of unmarried women to unmarried men, e.g., forced migration for labor or higher mortality among certain population strata. In addition we offer a place-based characteristic in order to better target or tailor public health messaging and suggest that anti-'sugar daddy' messaging may not always be appropriate in certain contexts.

In conclusion, this dissertation has furthered the understanding of the role played by social and sexual network structure in HIV risk disparities among key populations in South Africa. The findings of this work underscore the importance of including network metrics and analysis when planning HIV interventions and provide tangible tools in assessing network attributes.

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Appendix

A1. Code for running a permutation test by constructing a study population under the null hypothesis of random mixing of partners (SAS)

```
LIBNAME CLADE  'H:\Fwd__SAS_code';
*ASSIGN A PARTNER ID TO EACH PARTNER LINKING THEM TO THE
PARTICIPANT. USE THE FOLLOWING FORMAT:
IF PARTICIPANT ID IS 1 THEN FOR FIRST PARTNER THE PARTNER ID WILL
BE 101, FOR SECOND PARTNER THE PARTNER ID WOULD BE 102 ETC;
PROC SORT DATA = CLADE.DYADS; BY PID; RUN;
DATA CLADE.EI_MACRO;
      SET CLADE.DYADS;
      PARTNER_ID + 1;
      IF FIRST.PID THEN PARTNER_ID = PID*100+1;
      BY PID;
      KEEP PID PARTNER_ID Q2_RACE Q38_RACEPART;
      WHERE Q38_RACEPART NE .;
RUN;

* CREATE FINAL OUTPUT DATASET TO STACK MEAN EI_STATISTIC FROM
EACH ITERATION (10,000);
DATA CLADE.MEAN_EI_TABLE;
      label MEAN = "MEAN";
      length MEAN 8;
      stop;
RUN;
/*SUPPRESS THE SAS LOG */
```

```
OPTIONS NONOTES NOSOURCE NOSOURCE2;


/*CALL MACRO*/
%EITESTSTATISTIC(10000, 553856) RUN; QUIT;


/*START MACRO HERE*/
%MACRO EITESTSTATISTIC (NUM, SEED);
data _NULL_;
      CALL STREAMINIT (&seed); *SET SEED;
run;
%DO I = 1 %TO &NUM;
      /*STEP 0: CLEANUP WORK LIBRARY*/
            PROC DATASETS LIBRARY = WORK KILL;
            RUN;
            QUIT;
      /*STEP 1: ASSIGN A RANDOM NUMBER TO EACH PARTNER - CANNOT
SET A SEED OTHERWISE THE SAME SEQUENCE OF RANDOM NUMBERS GET
ASSIGNED EACH TIME WHICH WILL FAIL TO RE-ORDER PARTNERS*/
            DATA RND_PARTNERS;
            SET CLADE.EI_MACRO (DROP = PID Q2_RACE);
            RND = RAND ('UNIFORM');
            RUN;
            /*STEP 2: SORT THE RESULTANT DATASET BY THAT RANDOM
NUMBER*/
            PROC SORT DATA = RND_PARTNERS;
            BY RND;
```

```
            RUN;
      /*STEP 3: USE ROWNUM AS ORDERING VARIABLE*/
            DATA RND_PARTNERS;
            SET RND_PARTNERS;
            ROWNUM = _N_;
            RUN;
      /*STEP 4: USE ROWNUM TO ORDER PARTICIPANTS*/
            DATA PARTICIPANTS;
            SET CLADE.EI_MACRO (KEEP = PID Q2_RACE);
            ROWNUM = _N_;
            RUN;
      /*STEP 5: MERGE PARTNERS AND PARTICIPANTS DATASET USING
ROWNUM*/
            DATA SHUFFLED;
            MERGE PARTICIPANTS RND_PARTNERS;
            BY ROWNUM;
            /*COMPUTE 0/1 VARIABLES FOR SAME OR NOT SAME FOR THE
VARIABLE OF INTEREST I.E. RACE*/
            IF Q38_RACEPART = . THEN RACE_CONCORDANT = .;
            IF Q2_RACE = Q38_RACEPART THEN RACE_CONCORDANT = 1;
            IF Q2_RACE NE Q38_RACEPART AND Q38_RACEPART NE . THEN
            RACE_CONCORDANT = 0;
            RUN;
            /*NEED TO COMPUTE INDIVIDUAL-LEVEL E-I STATISTIC =
SUM_RACE_CONCORDANT/ TOTAL PARTNERS
```

```
            STEP 6: FIRST OUTPUT THE TOTAL NUMBER OF
RACE_CONCORDANT DYADS PER PID*/
            PROC SORT DATA = SHUFFLED ;
            BY PID;
            RUN;
            *ODS OUTPUT SUMMARY = RACE_CONCORDANT_SUM ;
            PROC MEANS DATA = SHUFFLED NOPRINT;
            VAR RACE_CONCORDANT;
            class PID; /** change BY to CLASS **/
            output out = RACE_CONCORDANT_SUM sum(RACE_CONCORDANT)
            = RACE_CONCORDANT_SUM; /* change ODS OUTPUT to
            OUTPUT*/
            RUN;
            DATA WORK.RACE_CONCORDANT_SUM;
            SET WORK.RACE_CONCORDANT_SUM (KEEP = PID _FREQ_
            RACE_CONCORDANT_SUM);
            WHERE PID NE .;
            RUN;
      *ODS OUTPUT CLOSE;
      /*STEP 7: ASSIGN A VARIABLE INDICATING PARTNER_NUM WHERE
PARTNER RACE IS NOT MISSING*/
            DATA SHUFFLED;
            SET SHUFFLED;
            PARTNER_NUM + 1;
            IF FIRST.PID THEN PARTNER_NUM = 1;
            BY PID;
```

```
            WHERE Q38_RACEPART NE .;
            RUN;
      /*STEP 8: OUTPUT THE MAXIMUM VALUE OF PARTNER_NUM FOR EACH
PID, WHICH WILL INDICATE TOTAL NUMBER OF PARTNERS PER PID*/
            *ODS OUTPUT SUMMARY = TOTAL_PARTNERS;
            PROC MEANS DATA = SHUFFLED noprint;
            VAR PARTNER_NUM;
            class PID;
            output out = total_partners max(partner_num) =
            total_partners; /*change ODS OUTPUT to OUTPUT*/
            RUN;
            DATA WORK.TOTAL_PARTNERS;
            SET WORK.TOTAL_PARTNERS (KEEP = PID _FREQ_
            TOTAL_PARTNERS);
            WHERE PID NE .;
            RUN;
            *ODS OUTPUT CLOSE;
      /*STEP 9: MERGE THE TOTAL_PARTNERS DATASET WITH THE
RACE_CONCORDANT_SUM DATASET*/
            PROC SORT DATA = TOTAL_PARTNERS; BY PID;RUN;
            PROC SORT DATA = RACE_CONCORDANT_SUM; BY PID;RUN;

            DATA EI_STATISTIC;
            MERGE TOTAL_PARTNERS RACE_CONCORDANT_SUM;
            BY PID;
            RUN;
```

```
     /*CREATE A VARIABLE INDICATING EXTERNAL (I.E. MISMATCHED
ALTERS)*/
          DATA EI_STATISTIC;
               SET EI_STATISTIC;
               EXTERNAL_ALTERS = TOTAL_PARTNERS -
               RACE_CONCORDANT_SUM;
          RUN;
     /*STEP 10: CALCULATE INDIVIDUAL LEVEL EI- STATISTIC =
(EXTERNAL ALTERS - INTERNAL ALTERS) / TOTAL ALTERS*/
          DATA EI_STATISTIC;
               SET EI_STATISTIC;
          EI_STATISTIC = (EXTERNAL_ALTERS - RACE_CONCORDANT_SUM)
          / TOTAL_PARTNERS;
          RUN;
     /*STEP 11: OUTPUT THE OVERALL TOTAL INTERNAL ALTERS,
EXTERNAL ALTERS AND TOTAL PARTNERS*/
          PROC MEANS DATA = EI_STATISTIC;
               VAR EXTERNAL_ALTERS RACE_CONCORDANT_SUM
          TOTAL_PARTNERS;
               output out = TOTAL_EI_STATS SUM(EXTERNAL_ALTERS)
               = TOTAL_EXTERNAL SUM(TOTAL_PARTNERS) =
               TOTAL_PARTNERS
               SUM(RACE_CONCORDANT_SUM)= TOTAL_INTERNAL;
               where pid ne .;
          RUN;
```

```
      DATA TOTAL_EI_STATS;
      SET TOTAL_EI_STATS (drop = _type_);
      OVERALL_EI = (TOTAL_EXTERNAL - TOTAL_INTERNAL) /
      TOTAL_PARTNERS;
      RUN;
      *ODS OUTPUT CLOSE;

*STEP 12: UPDATE FINAL TABLE;
      PROC SQL;
      INSERT INTO CLADE.MEAN_EI_TABLE_TEST
      SELECT OVERALL_EI
      FROM TOTAL_EI_STATS;
      QUIT;
%END;
%MEND;
```