Working title:

The Strength of Long Ties for Aging Healthy with HIV: The Case of Rural South Africa

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Abstract

Objectives

In lower-income settings with few alternatives to family-based care, personal social networks have been suggested as primary channels for accessing resources and support for older adults. We tested the health returns of long ties – ties that span greater geographical and network distances – on HIV treatment dynamics in a rural South African community with one of the largest aging populations with HIV.

Methods

We used data from the "Health and Aging in Africa: a Longitudinal Study of an INDEPTH community in South Africa" (HAALSI), a population-based panel study of adults aged ≥ 40 years in a poorer rural setting. Using random- and fixed-effects regressions, we examined how the proximity of important social contacts, defined by geographical and network spaces, correlated with viral suppression dynamics among HIV-positive respondents.

Results

Respondents who maintained social ties in greater South African regions had better-managed HIV viral suppression status than those without such ties. Long ties that are strong, defined by kinship and high communication intensity, appeared most beneficial. These distant connections were positively associated with better-managed viral suppression among respondents who lived alone, had less education, and were unemployed. Long ties were characterized predominantly by similar-age non-household members.

Discussion

The observed patterns highlight an important but less-discussed social network channel in older adults' personal relationships. Findings emphasize that personal ties spanning greater geographical distances can be as important as close proximity ties for healthy aging with HIV, particularly among the socially isolated and those with fewer personal resources.

Introduction

The concomitant rise in the levels of disability and chronic disease among older adults living with HIV (OPLHV) has received considerable attention in recent public health discussions. South Africa, in particular, bears one of the largest aging populations with HIV, with an estimated of 36% by 2040 (United Nations, 2019). While recent studies suggest that those who achieve viral suppression through antiretroviral treatment (ART) are better at managing comorbidities (Rohr et al., 2020) – likely due to consistent engagement with formal healthcare systems and increased health awareness – an important question remains: how to improve the health of OPLHV in settings with few alternatives to family-based care? In such contexts, informal support channels, or social networks, have emerged as important modifiable factors for the health and well-being of aging populations.

Under network theory, there are two main arguments for how social networks can shape health for older adults: theories of network embeddedness and diversity. The embeddedness hypothesis suggests that a tightly-connected, cohesive, and socially integrated network, often composed of stronger ties, reinforces higher levels of support, exchange, and trust (Aral & Van Alstyne, 2011; Aral & Walker, 2014; Heider, 1958; Newcomb, 1961); hence, these networks may provide greater health benefits for individuals. Conversely, the network diversity hypothesis – rooted in the concept that weaker ties act as local bridges to diverse social communities – posits that unique, structurally, and economically diverse connections facilitate the spread of valuable resources and knowledge that are not readily available within one's primary social circle (Burt, 1992; Granovetter, 1973; Lin, 2001), thereby providing greater health returns for individuals.

To this end, the embeddedness argument has received notable attention in social gerontology, or research on social network and health more generally. Over the past few decades,

substantial evidence has accumulated showing that social ties and support are positively associated with mental health, physical health, and longevity (Berkman, 1995; Cohen & Janicki-Deverts, 2009; House et al., 1988; Perkins et al., 2015; Smith & Christakis, 2008; Thoits, 2011; Uchino, 2004). Being in a cohesive network, in particular, has been consistently linked to improved health outcomes among older adults. Studies in high-income countries, for example, have demonstrated that such robust networks can mitigate depression and loneliness, enhance cognitive and functional abilities, and reduce the risk of long-term institutional care and mortality (Cohen & Janicki-Deverts, 2009; Cornwell & Qu, 2024; Kuiper et al., 2015; Litwin & Stoeckel, 2016). In sub-Saharan Africa, where formal support systems are less prevalent, having a supportive personal network is also positively correlated with improved access to medical care, mental health, and support adherence to ART (Comfort et al., 2024; Harling et al., 2020; Jennings et al., 2020; Musheke et al., 2013). The focus on strong ties and cohesive networks underscores the significant body of evidence highlighting the benefits of these relationships for healthy aging. However, emerging evidence has demonstrated how the induction of health information and behaviors, in contrast, may be spread more efficiently through distant and weaker ties (Airoldi & Christakis, 2024; Eckles et al., 2024).

In this study, we highlight the importance of long ties – ties that span greater geographical or network distances (Park et al., 2018) – in facilitating the flow of influential resources for the health and well-being of older adults, particularly among low-resource populations. We examine the correlations between a diverse set of network parameters and HIV viral suppression status among middle- and older-aged adults residing in a rural South African community with one of the largest aging populations with HIV. Our findings highlight the utility of these long ties as an important contributing factor to health care engagement, with differential

effects based on adults' socio-demographics, household dynamics, and the characteristics of long ties.

The Strength and Formation of Long Ties

The central argument underlying the theories of network diversity stems from the idea that social networks provide valuable resources that can be directly or indirect accessed, and these resources are often redundant and overlap in a closely-knit social environment (Granovetter, 1973). Long ties are defined as connections that span distant social groups (Park et al., 2018). Unlike weak ties, which are characterized by their infrequent or emotionally distant interactions, long ties can also be strong ties that maintain a high level of communication despite spanning greater network distances. These ties, or network "wormholes", thus provide high-bandwidth shortcuts across vast reaches of network space (Eckles et al., 2024; Park et al., 2018).

Long ties are predominantly measured through network spaces, which involve analyzing the structural distance (or steps) between individuals within a network (Eckles et al., 2024; Park et al., 2018). These structural-based measures reflect the nonheritable component of long ties, which are formed in part due to variations in personality traits (Burt et al., 1998) and exogenous social and environmental factors such as institutional segregation, advances in communication technology, and migration for economic opportunities and healthcare (Fowler et al., 2009; Jahani et al., 2023). Therefore, the formation of long ties may be attributed to the spuriousness of tie formation, where connections are largely structured by geography and social spaces (Small & Adler, 2019). Given this spatial foundation, there are three plausible explanations for how long ties might generate differential health returns.

The Health Returns of Long Ties

First, long ties may impact health through their instrumental pathways. Social contacts in greater geographical spaces will likely obtain different values, beliefs, and behaviors that may modify how one perceives health information and, subsequently, alter their behavior for better or worse health. Adults who maintain long ties with others living in distant areas, for instance, may receive more diverse health advice and support, such as alternative health practices or medical treatments, potentially leading to improved health outcomes (Airoldi & Christakis, 2024). Conversely, they might also be influenced by misinformation or unhealthy behaviors prevalent in those distant sources (Christakis & Fowler, 2008).

Moreover, long ties can provide key financial resources for adults seeking health treatment. For example, migration – both internal and international – has spurred research on the health impacts for migrants and those who left behind, especially in the Global South (Ginsburg, Bocquier, Béguy, et al., 2016). Beyond discussions on migrant selectivity in health, recent studies show that these "disruptive" events may concomitantly foster geographically distant ties, which offer higher transmission of novel information, resources, and greater economic returns (Aral & Van Alstyne, 2011; Chetty et al., 2022; Eckles et al., 2024; Jahani et al., 2023; Rajkumar et al., 2022). In low-income settings, long ties are likely structured around kinships, involving financial support from family working in distant towns, cities, and countries (Bank et al., 2020). As such, these ties may help alleviate financial burdens for people at older ages.

Second, long ties may impact health through their psychological pathways. On the one end, greater access to interpersonal resources may improve one's sense of security, agency, and self-esteem without the perception of incapability due to structural constraints. Sociological research identifies this as network-based social capital, where connections to individuals in

higher socioeconomic strata broaden one's resource base and help navigate various challenges (Lin, 2001). Prior research has shown that greater access to social capital is associated with improved mental health (Song, 2011), even in rural South African communities (Yu et al., 2022).

By contrast, distant ties may also lead to feelings of disconnection and distress, especially when immediate support is needed but not available (Hank, 2007) or when there is no kin-based support system in close proximity (Patterson & Margolis, 2023). Meanwhile, the social and psychological costs of maintaining these connections may increase synchronously with their levels of connectivity, echoing with a double-edged function of social network on health (Song et al., 2021). Consequently, the physical separation of contact networks may in turn warrant negative health returns.

Third, there may be a selection effect, whereas healthier adults are more capable of generating and maintaining long ties. At older ages, healthier individuals are more mobile and socially active, which may enable them to form and sustain more geographically diverse and non-kin social connections (Harling et al., 2020). This health selection effect may thus amplify the observed health implications associated with long ties.

Long Ties in Rural South African Contexts

In this study, we explore the health returns of long ties by analyzing whether ties that span greater geographical and network distances may be correlated with the dynamics of HIV treatment in a rural South African community that bears one of the highest HIV prevalence to date (Gómez-Olivé et al., 2018; Kahn et al., 2012). In South Africa, the long-entrenched labor migration system, due mostly to apartheid policy, has led many rural communities to be exposed to social settings and contacts in distant areas. The HIV epidemic, however, has drastically altered population dynamics, with many working-age adults experiencing AIDS-related deaths or

having to return home for care (Clark et al., 2007). This has consequently placed a heavy caregiving burden on rural populations, especially older adults and particularly women (Schatz & Seeley, 2015). The livelihood of rural households thus continue to rely heavily on the monthly non-contributory older-age grant received by adults aged 60 and above (i.e., pension).

In such contexts, long ties may be generated through two streams: (1) through one's close personal social contacts – either family or friends – permanently or temporarily moving to different areas for economic, educational, or healthcare opportunities, and (2) through their present or past migration experiences. In South Africa, with its ongoing urban transition and highly centralized economic system, existing studies indicate a continuum of circular labor migration among rural communities, historically higher among men but increasingly involving women (Ginsburg, Bocquier, Collinson, et al., 2016). Long ties are thus likely structured around families working in distant locations who continue to contribute to the welfare of those who remain in rural areas (Bank et al., 2020).

However, many older adults become less socially integrated with age, reporting fewer important social contacts, kinship ties, and lower communication intensity (Harling, Morris, et al., 2018). With a large share of these adults retuned to rural areas predominantly due to their HIV-related illness, an important question is how best to ensure a smooth transition of urban-to-rural healthcare adherence (Rohr et al., 2020). In these settings, while greater social capital has been linked to improved health in older ages (Comfort et al., 2024; Yu et al., 2022), little is known about how distant channels – in the form of both network and geographical spaces – correlate to healthcare engagement among OPLHV.

Here we provide a baseline investigation into the dynamics of HIV treatment through the lens of long ties. If long ties yield positive health implications for older adults, we might expect

differential effects based on adults' living arrangements and socio-demographic characteristics. Specifically, given limited formal support resources, the benefits of distant ties may be most pronounced among those who are less socially integrated and possess fewer personal resources. Our research therefore aim to address two main questions: (1) Is maintaining distant social connections linked to HIV-positive older adults' heath care engagement, beyond other personal, network, and institutional factors? (2) Who benefits or suffers most from the presence or absence of these ties?

Methods

Sample

We utilized data from the first and second waves of the Health and Aging in Africa: A Longitudinal Studies in South Africa (HAALSI, 2015 and 2019), a population-based cohort study of that follows 5,059 South African aged 40-plus (Gómez-Olivé et al., 2018). This cohort study is sampled from the Agincourt Health and Socio-Demographic Surveillance System (AHDSS) in rural Mpumalanga province (Kahn et al., 2012). HAALSI collects extensive household and individual data, including socio-demographics, employment, social networks, health behaviors, and biomarker information.

HAALSI contains a social network module that gathers information on up to six important social contacts. This module begins with a name generator question: "Please tell me the names of six adults with whom you have communicated, whether in person, by phone, or by internet, in the past six months, starting with the person most important to you for any reason". If the respondent is married and does not name their spouse, the spouse is automatically added as a seventh contact. Following the name generator question, a name interpreter approach is employed. Respondents (egos) are then asked a series of questions about each named contact

(alter), including their age, sex, any conflicts with the ego, the types and frequency of support received by the ego, and the perceived relationships among alters, as well as the geographical location of named alters. In wave 2, HAALSI required all respondents to name at least six contacts.

Long Ties and Personal Network Measures

Given the spatial foundation of social tie formation (Small & Adler, 2019), long ties were measured based on a series of binary indicators that captured any named contact within the (1) same household, (2) village, (3) AHDSS study site, and (4) broader South African (SA) regions. We binary-coded these network measures to address discrepancies in reporting named contacts between wave 1 and 2. However, we also tested for different classifications and model specifications, addressed in the result section. Moreover, we differentiated these ties by kinship (kin/non-kin), communication intensity (weekly/monthly), and literacy ability (literate/illiterate) to examine the health implications of stronger versus weaker long ties, and those requiring varying maintenance efforts and levels of social capital.

While egocentric network measures do not allow for the measurement of long ties in broader network spaces (egocentric versus sociocentric), we indirectly operationalized ego network effective size (E_{it}), where $E_{it} = S_{it} - R_{it}$. This measure captures the number of nonredundant social ties (R_{it}) given ego i's total network size in wave t. Effective size thus reflects the potential to obtain distinct resources accessible to egos, with a higher score suggesting a greater number of unique social connections (Burt, 1992).

In addition, we included other personal network measures that may be correlated with our main predictors and outcome. These measures included the total number of named contacts

(network size), the proportion of women in the network, and whether the ego had received any emotional, informational, or financial support on a monthly basis from any alter.

Outcome Variable: Controlled Viral Load Counts

The outcome variable examined viral suppression at each wave of HAALSI (2015 and 2019). We created a binary outcome variable as follows: (1) virally suppressed (<400 copies/mL) and (2) virally unsuppressed (≥400 copies/mL). This measure directly captured one's engagement with rural formal health care systems.

Covariates

We introduced a range of controls to account for potential confounding factors stemming from other socio-demographic and household-level parameters. At the individual level, we included respondents' sex (men/women), age groups (younger/older than 60 years old, an indication of pension eligibility), country of origin (Mozambique or others/South African), education level (no education/1-7 years/8-11 years/and 12+ years), employment status (unemployed/employed/homemaker), marital status (never-married/in union/separated or divorced/widowed), and spouses' literacy (illiterate/literate). At the household level, we adjusted for household wealth quintiles (poorest (1) to wealthiest (5)), and household size (alone/with one other person/with 3-6 persons/with 7-plus persons). Lastly, we adjusted for survey waves.

Analytic Approach

We began by examining bivariate associations between respondents' socio-demographic characteristics, network topologies, compositions, and viral suppression status. Next, we

employed random-effects logistic models, with survey observations t nested per respondent i. The binary outcome variable, viral suppression status ($ViralLoad_{it}$), was regressed on the presence of long ties, defined geographically (D_{it}) and by the number of nonredundant ties (E_{it}). The predictor (D_{it}) included a vector of four binary variables, where $D_{it} = \{H_{it}, V_{it}, AHDSS_{it}, RSA_{it}\}$, that respectively captured ties within household, village, study site, and greater SA regions. We controlled for interview month ($Month_{it}$) and interviewer ID (α_i) to adjust for potential interviewer bias in the reported network size in the baseline survey (Harling, Perkins, et al., 2018). Additional controls included vectors of individual-level (θX_{it}) and network-level (γX_{it}) variables. The model accounted for unobserved, time-constant respondent characteristics (u_i) and survey fixed effects (λ_t), which can be formally expressed as:

$$ViralLoad_{it} = \beta_0 + \beta_1 D_{it} + \beta_2 E_{it} + \beta_3 Month_{it} + \theta X_{it} + \gamma X_{it} + u_i + \alpha_i + \lambda_t + \varepsilon_{it} \quad (1)$$

To investigate the effect heterogeneities of long ties on viral suppression, we classified these ties by kinship status, literacy, and communication patterns using separate random-effects models. We further examined the moderating effects of long ties among socially isolated adults and those with fewer personal resources by adding interaction terms between long ties and respondents' education, employment, and household characteristics. When significant, we reported predicted probabilities from average marginal estimates, varied by demographic variables. All analyses were based on complete-case data. In addition, we conducted a series of supplementary analyses to ensure robustness, which can be found throughout and at the end of the results section.

Results

A total of 5,059 adults aged 40 years or older were included in the baseline survey and followed longitudinally. Of these, 4,582 provided a dried blood spot for HIV testing in the baseline wave, and 4,555 returned a conclusive result. About 3,818 (~85%) remained in the second wave, while the remaining ~15% had either passed away, refused to be re-interviewed, or were unidentifiable. We excluded proxy responses (n = 116). Our analysis included those who tested HIV-positive and provided a conclusive result (n = 1,804 person-waves). Table 1 presents the descriptive statistics of these observations by respondents' socio-demographic characteristics.

[Table 1 about here]

Baseline statistics indicated that men and adults who were not pension-eligible were more likely to be virally unsuppressed compared to having managed viral loads. HIV-positive adults in wealthier households appeared to have better-managed viral loads. Regarding within-household relationships, never-married, separated or divorced respondents were more likely to be virally unsuppressed. Similarly, those living alone or in larger households were more likely to have unmanaged viral suppression status.

[Table 2 about here]

Table 2 shows the bivariate associations between viral suppression status and personal social network measures. Adults with unmanaged viral status had less social capital and integration. Specifically, viral unsuppression was less likely among those with close social

contacts in the same household ("short ties"), in greater SA regions ("long ties"), and those who had received various supports ("strong ties"). In addition, adults with smaller personal networks and less diverse network structures were more likely to be virally unsuppressed.

Long Ties and Viral Suppression Status

To investigate whether maintaining varying distant social connections was correlated with viral suppression status, we first ran a random-effects logistic regression. After controlling for personal and household-level covariates, we found that those with close social contacts in the greater SA regions had approximately 56% lower odds of being virally unsuppressed compared to those without such distant ties (95% CI: 0.27 – 0.72). This result remained consistent when we adjusted the predictor to a categorical indicator (number of distant SA ties), communication intensity (distant SA ties that communicated monthly), or a multilevel model specification (Supplementary Table 1).

[Table 3 about here]

However, unobserved within-person factors such as family background, cultural customs, and other community and geographical confounders may influence the observed association. To address this, we ran a fixed-effects logistic regression to control for time-constant characteristics (Table 3). The long tie effect remained consistent under this specification, though the removal of between-person variations introduced greater uncertainty (OR = 0.23; 95% CI: 0.09 – 0.58).

We further examined the effect heterogeneities by the strength of distant SA ties using three additional random-effects models (Figure 1). These models assessed the relative

probabilities of having ties in greater SA regions by kinship status (model 2), literacy (model 3), and communication frequency (model 4). The estimates indicated that the positive effects of long ties on viral suppression were more tightly concentrated among kinship and illiterate ties, as well as those with higher communication intensity.

[Figure 1 about here]

Moderating Effects of Long Ties on Viral Suppression

When we considered effect modifications by respondents' household characteristics, we observed a significant interaction effect between household size and long ties on viral suppression status (Figure 2). Specifically, among adults living alone, those with a tie in greater SA regions had a lower probability of being virally unsuppressed ($\hat{P}$ = 0.18; 95% CI: 0.09 – 0.27) compared to those without such ties ($\hat{P}$ = 0.41; 95% CI: 0.32 – 0.49).

[Figure 2 about here]

We also found that the effects of long ties varied significantly by respondents' education and employment statuses. For example, the probability of being virally unsuppressed was lower among adults with primary education who maintained a tie in the greater SA regions. Similarly, the probabilities were lower for both employed and unemployed respondents.

Supplementary Analyses

A key question arising from the above analysis concerned the characteristics of these distant social contacts. Given the high intensity of circular labor migrations, these contacts might have been labor migrants within the same household. To explore this, we constructed an additional measure to capture the total number of household members away for at least six months in a given year – typically classified as circular labor migrants in this context (Kahn et al., 2012) – and included this parameter in the model (Supplementary Table 2). This parameter was not statistically significant, regardless of whether it was treated as a continuous, categorical, or binary indicator. This finding highlighted the importance of social ties extending beyond immediate household members in low-resource settings.

Another concern was related to selection bias, where healthier adults might be better able to maintain social connectivity as they age. While we could not claim causality, we included three additional controls for respondents' mental and physical health to more precisely estimate the correlation between long ties and viral suppression status (Supplementary Table 2). This inclusion did not alter our main result.

Lastly, to better characterize the population to whom our results most directly generalize, we compared the descriptive characteristics of the entire HAALSI sample who did and did not maintain distant SA social ties (Supplementary Table 3). Overall, these findings suggested that long ties were embedded among adults who already had more personal, economic, and household-level capital. Respondents were also likely to name close contacts who, on average, shared a similar age range (Supplementary Figure 1).

Discussion and Conclusion

With formal market constraints, a network-centered intervention has been proposed as an efficient and ground up alterative for improving population health and well-being. Building upon extensive research on the health returns of social networks, this study emphasizes on the importance of long ties – ties that span greater geographical and network spaces (Park et al., 2018) – in facilitating the flow of influential resources linked to improved health outcomes among rural populations. Our analysis shows that geographically distant connections are correlated with better-managed HIV treatment status among older adults living in a rapidly aging rural South African setting. To this end, our work raises several avenues for future research.

First, our findings provide a baseline understanding of how distant social ties can be as important as those in close proximity. While existing research emphasizes on the role of social integration, cohesiveness, and support in older adults' health – aligned with the theories of network embeddedness – this perspective can be limited by the redundancy of resources within a tightly-knit social environment. Recent public health intervention and network experiment studies have highlighted that socially and emotionally distant, "weaker" ties may create more efficient social spreading (Airoldi & Christakis, 2024; Eckles et al., 2024). Prior evidence in social gerontology has also indicated that older adults with a diverse network structure report better health (Cornwell, 2009). Our study further demonstrates that the geographical reach of social ties plays an important role for healthcare engagement and utilization; particularly, long ties that are strong – such as those with kin or high communication intensity – may be most effective. A key question arising from this work is how long ties might correlate with other health-related outcomes across various social contexts.

Second, this study highlights the diverse functions of social connections extending beyond individual households in poorer environments. Our findings demonstrate that the health benefits of long ties may not be driven by having circular labor migrants within the household, which is a key financial channel for rural populations. Nonetheless, the nature of relationships with these distant social contacts remains unclear. It may be that adults who maintain close contact with similar-age adults have better-managed HIV status, given that the health implications of long ties are more concentrated among kin and illiterate ties. This finding aligns with prior research showing that family support channels in low-resource settings are not entirely bound by physical spaces, with many continuing to financially and emotionally support one another in different households (Fafchamps et al., 2004; Stack, 1974). We therefore emphasize the need to unpack the qualitative facts about long ties to better characterize the mechanisms through which distant support channels link to improved health outcomes.

Third, the heterogeneous effects of long ties across individuals with varying employment, education, and household characteristics point to the need to move beyond average network effects. Existing research highlights that HIV prevalence, treatment, and ART adherence vary significantly by the socio-demographics of sub-populations (Gómez-Olivé et al., 2020; Rohr et al., 2020). In rural South African contexts, prior research has indicated that those in smaller households face greater health risks (Schatz et al., 2017), and that kin-based social connections, in particular, associated positively with ART adherence (Comfort et al., 2024). Our study reveals that individual, household, and social network factors can interact to produce diverse health outcomes for older adults living with HIV, with long ties being most beneficial for the socially isolated and those with limited personal resources. To leverage social networks for improved

population health outcomes, our findings highlight the importance of accounting for the varied network effects across population subgroups.

It is important, nonetheless, to interpret these results with their limitations. First, there may be other confounding factors that could affect our findings, and we are unable to establish causality in the observed relationships. While we employed multiple model specifications to mitigate potential confounders, it remains possible that those with better-managed HIV status are more capable of forming diverse social connections. Follow-up studies are needed to more precisely estimate causal network effects. Second, we were unable to measure long ties based on broader network spaces, as this requires complete sociocentric network data. We therefore encourage further research using a complete network approach to better understand the health implications of long ties.

Implementing health policies in rural or poorer settings remains exceptionally challenging due to the unique local social dynamics that may influence the quality of rural domestic life. The importance of long ties, as demonstrated in this study, highlights a less-discussed social network channel that is also associated with improved formal healthcare engagement among older adults living with HIV. These findings call for future research to better conceptualize and contextualize the importance of broader network environments for the health and well-being of rural populations.

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Tables and Figures

Table 1. Descriptive statistics of viral suppression status by respondents socio-demographic characteristics in wave 1 and 2 of the HAALSA survey (n = 1,804 person-wave)

	Suppressed		Unsuppressed		
	n	%	*n*	%	χ^2
Sex					
Women	722	57.35	283	51.93	<0.05
Men	537	42.65	262	48.07	
Age groups					
<60	733	58.78	360	66.3	<0.01
60-plus	514	41.22	183	33.7	
Origin					
Mozambique/other	411	32.72	202	37.13	0.07
South African	845	67.28	342	62.87	
Education					
No formal education	503	40.05	218	40.3	0.98
Some primary (1-7)	446	35.51	187	34.57	
Some secondary (8-12)	198	15.76	89	16.45	
Secondary/higher (12+)	109	8.68	47	8.69	
Employment					
None	924	73.74	371	68.2	0.05
Homemaker	81	6.46	42	7.72	
Employed	248	19.79	131	24.08	
Union status					
Never-married	88	6.99	53	9.74	<0.05
In union	485	38.52	201	36.95	
Separated/divorced	241	19.14	125	22.98	
Widowed	445	35.35	165	30.33	
Spouse's literacy					
No/no spouse	897	71.25	395	72	0.59
Yes	362	28.75	150	27.52	
Household wealth					
Lowest quintile	254	20.17	158	28.99	0.01
Quintile 2	261	20.73	107	19.63	
Quintile 3	282	22.4	112	21	
Quintile 4	244	19.38	89	16.33	
Highest quintile	218	17.32	79	14.5	
Household size					
Living alone	157	12.47	104	19.08	<0.001
With 3-6 people	615	48.85	214	39.27	
With 7+ people	358	28.44	169	31.01	
With one other	129	10.25	58	10.64	

Table 2. Descriptive statistics of viral suppression status by personal social network measures.

	Suppressed		Unsuppressed		
	n	%	*n*	%	χ^2 / $Logit(p)$
Long ties (any named contact)					
Within household					
No	420	33.36	225	41.28	<0.01
Yes	839	66.64	320	58.72	
Within village					
No	291	23.11	149	27.34	0.06
Yes	968	76.89	396	72.66	
Within AHDSS					
No	897	71.25	403	73.94	0.24
Yes	362	28.75	142	26.06	
In greater SA regions					
No	882	70.06	412	75.6	<0.01
Yes	377	29.94	133	24.4	
Support (monthly)					
Emotional					
No	102	8.1	68	12.48	<0.01
Yes	1,157	91.9	477	87.52	
Informational					
No	108	8.58	63	11.56	<0.05
Yes	1,151	91.42	482	88.44	
Financial					
No	131	10.41	84	15.41	<0.05
Yes	1,128	89.59	461	84.59	
	Mean	*[IQR]*	*Mean*	*[IQR]*	
Network size	4.49	[3-6]	3.86	[2-6]	<0.001
Effective size	1.91	[1-2.6)	1.72	[1-2.2]	<0.05
% of women in ego's network	0.17	[0-0.33]	0.15	[0-0.25]	0.086

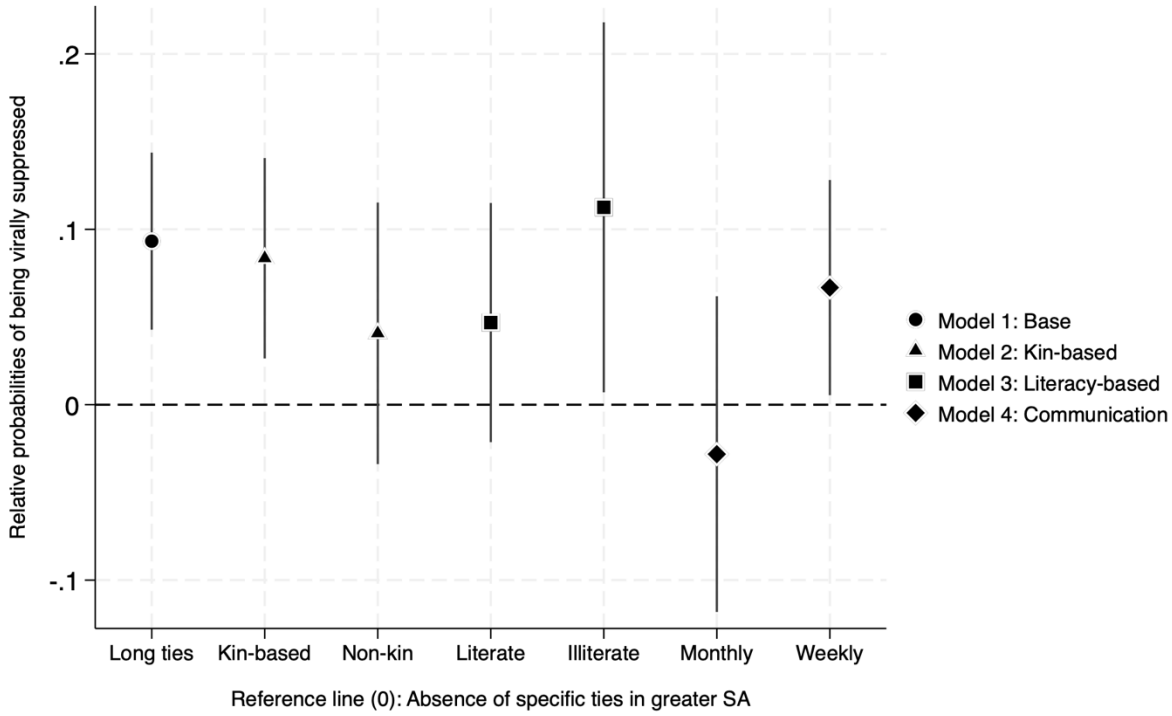
Notes. We ran three unadjusted logistic regressions to examine the bivariate correlations of network size, effective size, and proportion of women in the ego's network on viral suppression status. IQR: Interquartile range.

Table 3. Random- and fixed-effects logistic regressions predicting managed viral suppression status by individual, household, and personal network measures.

	Random-effects		Fixed-effects	
	OR	95% CI	OR	95% CI
Sex (ref: women)				
Men	0.63*	[0.40, 0.99]		
Age groups (ref: <60)				
60-plus	1.34	[0.85, 2.10]	0.45	[0.12, 1.66]
Origin (Mozambique/other)				
South African	1.4	[0.85, 2.28]		
Education (ref: none)				
Some primary (1-7)	0.95	[0.57, 1.59]		
Some secondary (8-12)	0.8	[0.40, 1.59]		
Secondary/higher (12+)	0.63	[0.27, 1.49]		
Employment (ref: none)				
Homemaker	1.31	[0.57, 3.01]	0.54	[0.10, 2.80]
Employed	0.87	[0.54, 1.41]	4.06*	[1.35, 12.18]
Union status (ref: never-married)				
In union	1.75	[0.74, 4.17]	7.97	[0.87, 73.15]
Separated/divorced	0.83	[0.39, 1.80]	0.39	[0.07, 2.13]
Widowed	1.36	[0.64, 2.88]	7.1*	[1.02, 49.38]
Spouse's literacy (ref: unemployed)				
Literate	0.71	[0.38, 1.31]	0.2	[0.01, 6.27]
Household wealth (ref: lowest)				
Quintile 2	1.95*	[1.15, 3.33]	1.08	[0.36, 3.23]
Quintile 3	2*	[1.15, 3.47]	1.11	[0.33, 3.79]
Quintile 4	1.77*	[0.99, 3.19]	1.01	[0.26, 3.92]
Highest quintile	2.09*	[1.08, 4.04]	3.03	[0.57, 16.29]
Household size (ref: alone)				
With 3-6 people	1.73	[0.93, 3.23]	0.38	[0.06, 2.42]
With 7+ people	0.91	[0.46, 1.80]	0.42	[0.05, 3.55]
With one other	1.55	[0.73, 3.31]	1.56	[0.25, 9.74]
Network size	0.95	[0.78, 1.16]	0.65*	[0.42, 0.99]
Effective size	0.95	[0.82, 1.11]	1.13	[0.86, 1.49]
% of women in ego's network	2.86	[0.97, 8.46]	1.45	[0.18, 11.44]
Long ties (any named contact)				
Within household	0.89	[0.52, 1.52]	1.22	[0.43, 3.48]
Within village	1.98**	[1.19, 3.28]	2.38	[0.85, 6.66]
Within AHDSS	1.17	[0.76, 1.80]	0.5	[0.20, 1.27]
In greater SA regions	2.25**	[1.39, 3.64]	4.4**	[1.73, 11.21]
Support (monthly)				
Emotional	1.24	[0.61, 2.53]	0.38	[0.06, 2.32]
Informational	0.72	[0.35, 1.48]	0.36	[0.07, 1.82]
Financial	1.2	[0.64, 2.26]	16.49*	[1.77, 153.5]
Number of observations	1,717		364	

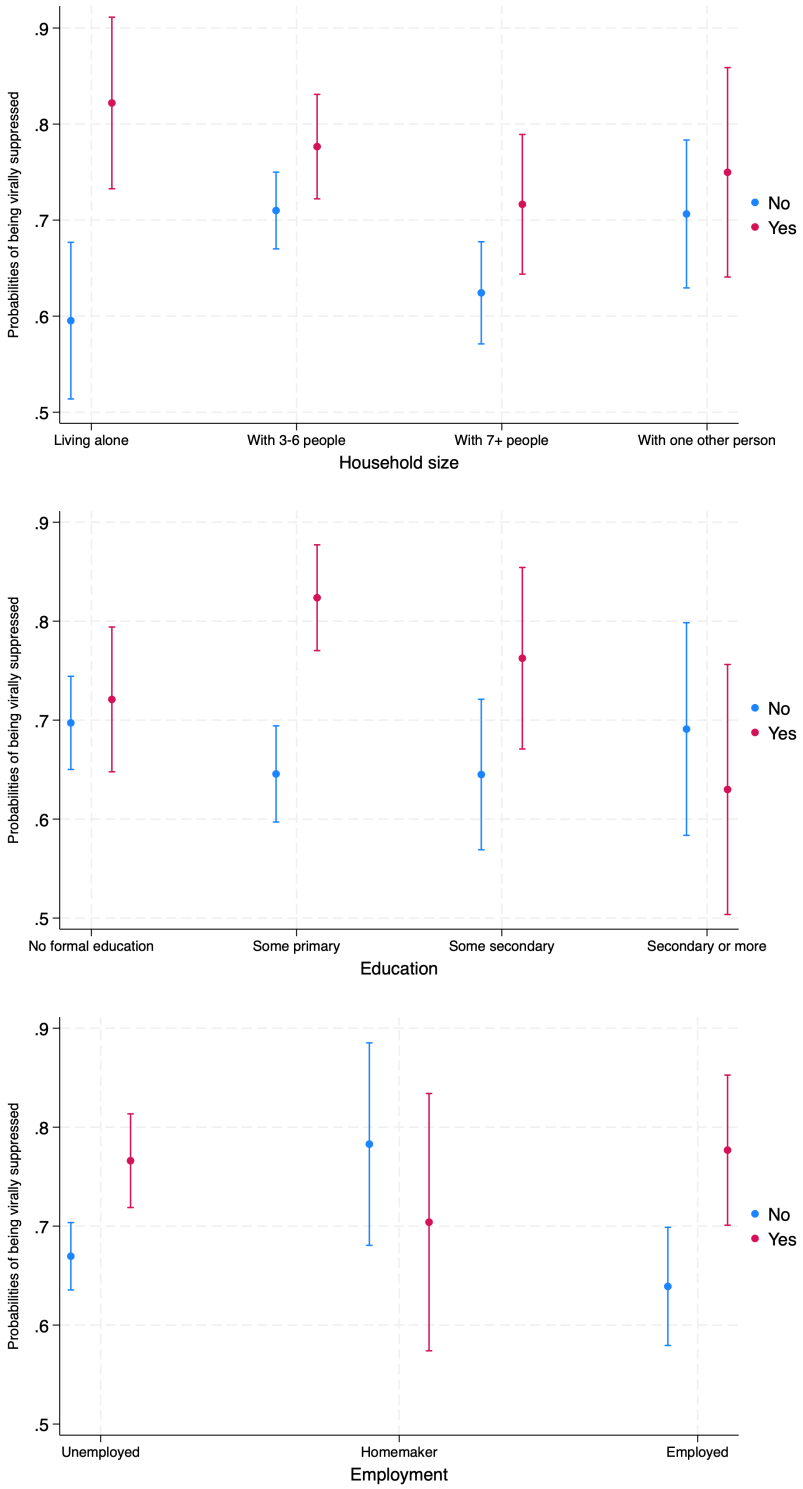
Notes. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. OR: Odds Ratio. These models also adjusted for survey wave, interview months, and interviewer's ID.

Figure 1. Relative probabilities of various long tie characteristics on viral suppression status**.**



Notes. Estimates derived from four separate random-effects regressions. Long ties indicate to any named social contact in the greater South African regions. These models controlled for all covariates.

Figure 2. Average marginal probabilities of being virally suppressed by the interactions of long ties with household structure, education, and employment status.



Notes. Estimates came from three separate random-effects logistic regressions. These models controlled for all covariates.

Supplementary Files

Supplementary Table 1. Alternative model specifications for testing the effect of long ties on viral suppression status (n = 1,708).

	Model I (n = 1,717)			Model II (n = 1,717)			Model III (n = 364)			Model IV (n = 1,720)		
	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
Ref (0)												
1	2.48***	1.42	4.34	2.02*	1.17	3.49	4.13*	1.29	13.19	1.61**	1.14	2.27
2	1.60	0.78	3.29	1.68	0.80	3.50	2.14	0.57	8.07	1.21	0.77	1.92
3	3.95*	1.35	11.55	3.12*	1.08	9.01	15.76*	1.76	140.83	1.75	0.92	3.33
4	2.14	0.40	11.39	1.26	0.25	6.21	0.86	0.03	25.34	1.46	0.48	4.44
5	0.60	0.07	4.98	0.98	0.10	9.77	0.00	0.00	.	0.58	0.16	2.10
6	0.08	0.00	3.45	0.24	0.00	16.60	4.63	0.00	9361.4	0.12	0.01	1.44

Notes. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. OR: Odds Ratio. Here we included the reported numbers of named contacts in the greater South African regions in a series of random-effects, fixed-effects, and multilevel logistic regressions. Model I aligned with the primary model specification but treated the predictor as a categorical variable. Model II altered this categorical predictor to represent any named contact in the greater South African regions who communicated with the respondents on a monthly basis. Model III extended model II but applied a fixed-effects specification. Model IV adopted a three-level multilevel modeling framework, with repeated observations nested within respondents, and respondents nested within interviewers. These models controlled for all covariates.

Supplementary Table 2. Health- and migrant-adjusted random-effects logistic regression predicting viral suppression status (n = 1,708).

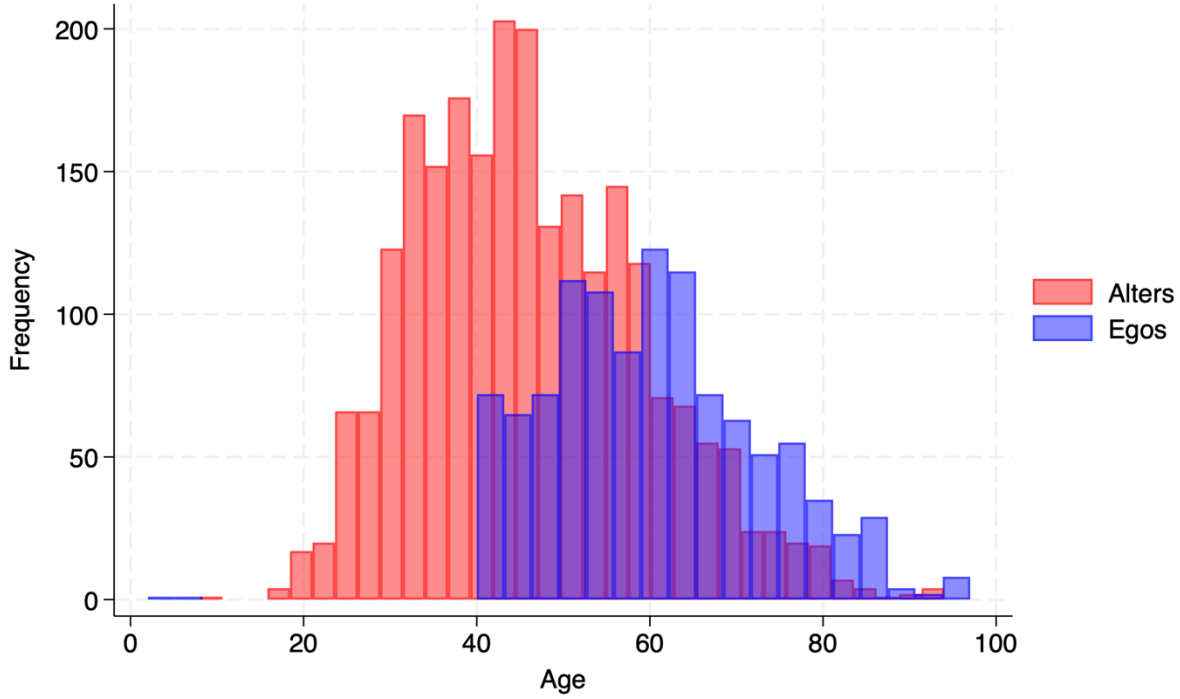
	OR	95% CI
Sex (ref: women)		
Men	0.65	[0.41, 1.02]
Age groups (ref: <60)		
60-plus	1.31	[0.84, 2.05]
Origin (Mozambique/other)		
South African	1.41	[0.86, 2.30]
Education (ref: none)		
Some primary (1-7)	0.97	[0.58, 1.61]
Some secondary (8-12)	0.81	[0.41, 1.59]
Secondary/higher (12+)	0.63	[0.27, 1.49]
Employment (ref: unemployed)		
Homemaker	1.3	[0.57, 2.98]
Employed	0.87	[0.54, 1.39]
Union status (ref: never-married)		
In union	1.58	[0.67, 3.75]
Separated/divorced	0.78	[0.36, 1.68]
Widowed	1.26	[0.60, 2.67]
Spouse's literacy (ref: no)		
Literate	0.72	[0.39, 1.32]
Household wealth (ref: lowest)		
Quintile 2	2.02**	[1.19, 3.44]
Quintile 3	2.06*	[1.19, 3.57]
Quintile 4	1.8*	[1.00, 3.23]
Highest quintile	2.08*	[1.07, 4.03]
Household size (ref: alone)		
With 3-6 people	1.79	[0.96, 3.32]
With 7+ people	0.95	[0.48, 1.87]
With one other	1.59	[0.75, 3.36]
Network size	0.95	[0.77, 1.16]
Effective size	0.95	[0.82, 1.11]
% of women in ego's network	2.78	[0.95, 8.16]
Long ties (any named contact)		
Within household	0.91	[0.53, 1.56]
Within village	1.95*	[1.18, 3.22]
Within AHDSS	1.16	[0.76, 1.79]
In greater SA regions	2.24***	[1.38, 3.61]
Support (monthly)		
Emotional	1.26	[0.62, 2.56]
Informational	0.74	[0.36, 1.52]
Financial	1.19	[0.63, 2.23]
Any migrant	1.06	[0.72, 1.55]
Life satisfaction (0-10)	0.98	[0.89, 1.08]
Depressed	0.96	[0.60, 1.53]
Self-rated health (1-5)	1.05	[0.84, 1.32]

Notes. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. These models included survey wave, interview month, and interviewer ID. Life satisfaction was measured using the Cantril ladder (0-10), where respondents rated their current life and compared it to others in their village, with higher scores indicating greater well-being. Depression was measured using the 8-item (wave 1) and 20-item (wave 2) Center for Epidemiologic Studies Depression (CES-D) scale. For consistency, we binary-coded these items according to thresholds of 8 and 16 in waves 1 and 2 for clinically probable depression, respectively. Self-rated health was measured on a five-point scale by asking, "In general, how would you rate your health today?". Responses ranged from very bad (1) to very good (5).

Supplementary Table 3. Socio-demographic characteristics of HAALSA adults maintaining social ties to those in greater South African regions (n = 10,098 person-wave)

	Any named contact in greater SA regions				
	No		Yes		
	n	%	*n*	%	χ^2
Sex					
Women	3,849	52.13	1,565	57.66	<0.001
Men	3,535	47.87	1,149	42.34	
Age groups					
<60	2,878	39.12	1,082	39.97	0.441
60-plus	4,478	60.88	1,625	60.03	
Origin					
Mozambique/other	2,330	31.59	714	26.33	<0.001
South African	5,046	68.41	1,998	73.67	
Education					
No formal education	3,521	47.85	1,075	39.73	<0.001
Some primary (1-7)	2,463	33.47	967	35.74	
Some secondary (8-12)	788	10.71	358	13.23	
Secondary or higher (12+)	586	7.96	306	11.31	
Employment					
None	5,145	80	1,974	72.92	<0.001
Homemaker	306	4.73	278	10.27	
Employed	1,017	15.72	455	16.81	
Union status					
Never-married	481	7.4	135	4.98	<0.001
In union	3,063	47.09	1,381	50.9	
Separated/divorced	854	13	314	11.57	
Widowed	2,106	32.38	883	32.55	
Spouse's literacy					
No/no spouse	4,989	67.26	1,674	61.61	<0.001
Yes	2,428	32.74	1,043	38.39	
Household wealth					
Lowest quintile	1,438	22	451	17	<0.001
Quintile 2	1,316	20	505	19	
Quintile 3	1,284	19.73	527	19.4	
Quintile 4	1,260	19.36	574	21	
Highest quintile	1,210	18.59	660	24.29	
Household size					
Living alone	732	11	288	11	<0.001
With 3-6 people	2,958	45.45	1,291	48	
With 7+ people	2,177	33	802	29.52	
With one other	641	9.85	336	12.37	

Supplementary Figure 1. Comparing the distribution of egos' ages with the mean ages of alters in their personal social networks.



Notes. The *y*-axis indicates the number of respondents who provided complete observations of the ages of their social contacts in the greater South African regions.