BMJ Open

Effect of screening young men for *Chlamydia trachomatis* on the rates among women: a network modelling study for high-prevalence communities

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To cite: Qu Z, Azizi A, Schmidt N, *et al*. Effect of screening young men for *Chlamydia trachomatis* on the rates among women: a network modelling study for high-prevalence communities. *BMJ Open* 2021;**11**:e040789. doi:10.1136/bmjopen-2020-040789

► Prepublication history and additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2020-040789).

Received 22 May 2020
Revised 23 December 2020
Accepted 05 January 2021

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ABSTRACT

Objective *Chlamydia trachomatis* (Ct) is the most commonly reported sexually transmitted infection in the USA and causes important reproductive morbidity in women. The Centers for Disease Control and Prevention recommend routine screening of sexually active women under age 25 but not among men. Despite three decades of screening women, chlamydia prevalence in women remains high. Untested and untreated men can serve as a reservoir of infection in women, and male-screening based intervention can be an effective strategy to reduce infection in women. We assessed the impact of screening men on the Ct prevalence in women.

Design We created an individual-based network model to simulate a realistic chlamydia epidemic on sexual contact networks for a synthetic population (n=5000). The model is calibrated to the ongoing routine screening among African American (AA) women in the USA and detailed a male-screening programme, Check It, that bundles best practices for Ct control. We used sensitivity analysis to quantify the relative importance of each intervention component.

Setting Community-based venues in New Orleans, Louisiana, USA.

Participants Heterosexual AA men, aged 15 to 24, who had sex with women in the past 2 months.

Intervention Venue-based screening, expedited index treatment, expedited partner treatment and rescreening.

Results We estimate that by annually screening 7.5% of the AA male population in the age-range, the chlamydia prevalence would be reduced relatively by 8.1% (95% CI 5.9% to 10.4%) in AA women and 8.8% (95% CI 6.9% to 10.8%) in AA men. Each man screened could prevent 0.062 (95% CI 0.030 to 0.094) cases in men and 0.204 (95% CI 0.143 to 0.267) cases in women. The model suggested the importance of intervention components ranked from high to low as venue-based screening, expedited index treatment, expedited partner treatment and rescreening.

Conclusion The findings indicated that male-screening has the potential to substantially reduce the prevalence among women in high-prevalence communities.

Strengths and limitations of this study

- The network-based model captures the complex assortative mixing in sexual partnerships among an African American (AA) population in New Orleans using the survey data on sexual behaviours.
- We present a novel modelling study to assess the impact of a new male-screening programme that bundles the best practices for chlamydia control on the current chlamydia prevalence in AA women, given the ongoing routine screening among AA women in the USA.
- The proposed stochastic, heterosexual and individual-based model provided a flexible framework for a public health team to answer 'what if' questions that are hard to address in the field.
- The model is parametrised using data from two surveys on sexual behaviours, which reflects our best understanding of the AA population in the New Orleans area.
- The model assumed a closed and stable population in an area, and the quantitative results are only valid for a short-term prediction that does not consider impacts by the external factors, such as behaviour changes, natural disasters and changes in mixing patterns.

INTRODUCTION

Chlamydia trachomatis (Ct) is the most commonly reported infectious disease in the USA, with over 1.7 million cases each year.[1] It is a major cause of infertility, pelvic inflammatory disease and ectopic pregnancy among women[2] and has been associated with increased HIV acquisition.[3] Because women experience the most severe sequelae, the focus of Ct prevention in the USA has been on screening sexually active women <25 years old, providing her and her partner(s) with treatment and rescreening. Despite three decades of screening women, chlamydia prevalence remains high in the sexually active young women in the USA.[1]

There is no recommendation for Ct screening among men in the USA. In 2007, an expert panel at the Centers for Disease Control and Prevention (CDC) concluded that the evidence is not sufficient to recommend routine screening for Ct in sexually active young men.[4] The conclusion

was based on the Ct prevalence in 2007 and the feasibility, efficacy and cost-effectiveness of screening men. However, since then, evidence of the benefit of screening young men for Ct in high prevalence areas has been mounting. More recent modelling studies indicate that screening men in high prevalence populations can be cost-effective due to averted cases among women.[5 6]

The community-based programme, Check It,[7] Ct screens African American (AA) men aged 15 to 24 in New Orleans. The core of this intervention is Ct screening for men. We hypothesise that men are an important reservoir of infection for women and therefore need to be targeted for intervention.[7] The Check It programme bundles several key Ct control strategies (table 1):

- Venue-based screening (VBS) of participants at non-clinical community venues, such as barbershops, colleges and universities, in high-prevalence neighbourhoods characterised by similar demographic and geographical factors. This venue-based enrolment is enhanced with marketing strategies, such as the distribution of flyers, web education, social media and informational cards.
- Expedited treatment by providing medication for the Ct-positive men (or index) (expedited index treatment or EIT) and his sexual partner(s) (expedited partner treatment or EPT) via partnering community pharmacies without a medical examination to speed up the treatment of his sexual partners and reduce reinfection rates in the index.
- Rescreening of Ct-positive men; retesting for infection 3 months after treatment.
- Social network peer referral (SNPR) that encourages men to refer young AA men in their social network to Check It via flyers, social media or text messages to promote the programme and increase the total enrolment.

Mathematical models create frameworks for understanding the underlying epidemiology of disease and help test the potential effectiveness of different approaches to bring the epidemic under control. Our modelling effort created a detailed simulation to model the specific practices implemented by the Check It programme. Most chlamydia simulations studies use differential equation-based compartmental models. These models are parametrised at the population level and assume homogeneous mixing of the individuals in the same compartment. We formulated an agent-based model at a more granular level that captures the complex assortative mixing pattern in sexual partnership networks. The structure of the sexual network affects the spread of the infection and the effectiveness of the mitigation efforts. We calibrated the agent-based model based on the sexual behaviour surveys[7 8] and assessed the impact of these male-screening-based strategies on mitigating the Ct epidemic among AA women aged 15 to 24 years old in New Orleans.

METHODS

We modelled the Ct transmission among a synthetic population connected through heterosexual partnership networks. These sexual networks were generated based on the data from two survey studies[7 8] that investigated the sexual behaviour of young AA men and women in New Orleans. The model parameterised the transmission pathways on the individual level, and it simulated the sexual behaviour and kept track of the infection status for each individual in the synthetic population over time. We then modelled the intervention strategies, including both the standard preventive healthcare for women (routine Ct screening) and the Check It intervention, for each individual to study the impact of male-screening on the Ct prevalence in women.

Generation of a synthetic population over dynamic sexual networks

We constructed a closed 5000-member population, where the heterosexual partnerships were represented by bipartite sexual networks. The heterosexual networks captured the assortative mixing pattern among our targeted AA population by matching the population-level quantities (the degree distribution and joint-degree distribution, online supplemental appendix A.1) from two surveys: the ongoing Check It study[7] and the 'You Geaux Girl!' (YGG) study,[8] which enrolled 1318 AA men (May 2017 to April 2019, ongoing, age range 15 to 24) and 473 AA women (September 2012 to December 2015, completed, age range 18 to 19), respectively, in New Orleans. All

Table 1 Summary of interventions involved in the Check It programme

Intervention	Description
VBS	Venue-based screening by recruiting male participants at non-clinical community venues
EIT	Expedited index treatment by providing medication to the Ct-positive men
EPT	Expedited partner treatment by providing medication to partners of the index men without a medical examination
SNPR	Social network peer referral encourages men to refer young AA men in their social network to Check It to increase the total enrolment
Rescreening	Ct-positive men are retested for infection 3 months after treatment

AA, African American; Ct, *Chlamydia trachomatis*.

participants gave written informed consent before taking part in the studies.

We assumed that the population is closed and men and women in our model only have sexual partnerships within this population cohort. This assumption closely agrees with our data sets, where about 92% of the male participants (Check It study) and 94% of the female participants (YGG study) have partners in the same age cohort (15 to 24 years old). The surveys also found that about 90% of the partners for male participants (Check It study) and 95% of the partners for female participants (YGG study) were also AA. We included the technical details of network descriptions in online supplemental appendix A.1.

To further characterise sexual behaviours, we categorised one's partner as either primary or casual partner, depending on the survey responses to questions such as level of commitment and the duration of the relationship (detailed criteria in online supplemental appendix A.1.2 and the distributions in online supplemental appendix A.2). These categorisations can be asymmetric: A is B's primary partner, but B may be A's casual partner, and there are three types of partnerships in the networks: primary-primary, primary-casual and casual-casual partnership.

When modelling the epidemics over a long time (several months or years), we updated the sexual partner(s) every 2 months (the time-frame covered by the Check It survey) and created a series of dynamic sexual networks that are evolving in time. To simulate the partner updating behaviour, we employed a detailed realistic social contact network that modelled the daily activities for 150 000 people in New Orleans.[9] Then the heterosexual networks were updated through people's contacts in the social network. Specifically, we assumed that the primary-primary partnerships were preserved throughout the simulation period and half of the primary-casual and all of the casual-casual partnerships are replaced by one's social contacts every 2 months (details in online supplemental appendix A.1.3). There were, on average, 80% of the sexual partnerships coming from one's heterosexual social network, which is in agreement with the Check It data (76% of partners were reported as social contacts from school, work, the neighbourhood and so on).

Chlamydia epidemic on dynamic sexual networks

We modelled the infection status of each individual using the Susceptible-Infectious-Susceptible (SIS) framework. All uninfected individuals are susceptible to being infected, and all infected people recover to this susceptible state after either spontaneous recovery or treatment. A susceptible person can be infected by his/her infectious partner. The force of infection is the probability (per day) that a susceptible person will be infected. This probability was estimated by considering risk factors of how many partners the person has, the type of partnership with each partner, the probability of having sexual contact per partner per day (contact rate) and the probability of using a condom.

We estimated the sexual contact rates for the primary and casual partnerships from the data sets (see table A.3). We observed that the contact rate was higher for primary partnerships than for casual partnerships, and there was a decreasing trend in the per partner contact rate when the number of partners increases. Moreover, the data sets gave a higher probability of using a condom with a casual partner than with a primary one (table 2). We introduced a condom failure rate to include cases when the condom is not used properly.

The details on the configuration of the epidemic model over networks are fully described in (online supplemental appendix A.2).

Modelling the intervention strategies

Our goal was to investigate the net impact of screening men through the Check It programme given the existing screening policy for women and the ongoing endemic Ct epidemic. To this end, we outlined the intervention strategies for both women and men in separate flow charts in figure 1. The baseline scenario accounts for Ct screenings completed at women's annual exams as part of regular preventive healthcare. We also included the Ct screenings prompted by symptomatic infections (clinical visits) in the baseline scenario for both men and women.

Existing intervention strategies

The current (baseline) Ct mitigation efforts for women (the right side of figure 1) include Ct screening during routine annual exams and clinical visits for symptomatic infections. The model assumes that the same fraction (σ_a^w) of women return for a physical exam each year (more details in online supplemental appendix A.3). Symptoms can appear in a small fraction of infected women (σ_s^w), and we assumed that a fraction θ_s of these women get medical care within an average of τ_s days, including incubation period and appointment scheduling process, after infection.[10] After the diagnostic test, we assumed that all the positive cases get index treatment in an average of τ_t^w days. Moreover, the CDC recommends EPT for infected women by providing treatment to the patient to bring to her partner(s) without first examining the partner(s).[11] We assumed that a fraction θ_p^w of the partners are treated with an average delay of τ_p^w days. The EPT fraction θ_p^w is the product of (1) the fraction of the physicians practising EPT as recommended and (2) the fraction of compliance from the notified partners. Last, women diagnosed with Ct infection should be retested after the initial treatment.[12] Thus, we assumed a fraction θ_r^w of treated women are retested for infection τ_r^w days after the initial treatment.

Since routine male-screening is not recommended and is rarely practised,[13] we only account for screenings prompted by symptomatic infections. Similar to the process in women, we assumed that there is a small fraction (σ_s^m) of infected men that develop symptomatic Ct infections, and, with a delay of τ_s days, a fraction θ_s of them get screening and treatment. Moreover, follow-up

Table 2 Model parameters for the AA population aged 15–24

	Description	Baseline	Range for 95% Confidence Interval	Reference
β^{m2w}	Transmissibility from men to women per contact	0.30	0.04 to 0.5*	15 16
β^{w2m}	Transmissibility from women to men per contact	0.10	0.04 to 0.25	15 16
τ_n	Average time to recovery without treatment (years)	1.32	exponential	18
τ_t	Average time to recovery after treatment (days)	7	exponential	21
c_p	Fraction of condom use for primary partners	0.54	–	online supplemental appendix A.6.1
c_c	Fraction of condom use for casual partners	0.66	–	online supplemental appendix A.6.1
c_ϵ	Condom failure rate	0.1	–	22
θ_s	Fraction of symptomatic infections screened	0.7	0.6 to 0.8	10
τ_s	Time lag in screening for symptomatic infection (days)	21	14 to 28	23
	Intervention parameters among young AA women			
σ_a^w	Fraction of the target women who are screened annually	0.6	0.56 to 0.65	24 25
σ_s^w	Fraction of symptomatic infection in women	0.3	–	10
θ_p^w	Fraction of partner treatment for index women	0.24	–	Derived
	- Fraction of physicians practicing partner treatment	0.4	0.3 to 0.5	26
	- Fraction of compliance for partner treatment	0.6	0.4 to 0.8	27 28
θ_r^w	Fraction of treated women who are rescreened	0.2	0.17 to 0.28	29
τ_t^w	Time lag in treatment for screened women (days)	2	–	30
τ_p^w	Time lag in partner treatment for treated women (days)	6	0 to 15	27
τ_r^w	Time lag in rescreening for treated women (days)	105	80 to 130	12 29
	Intervention parameters among young AA men			
σ_e^m	Fraction of target population enrolled per year	0.075		online supplemental appendix A.6.2
	- Fraction of non-peer VBS-enrolment	0.76		online supplemental appendix A.6.2
	- Fraction of SNPR enrolment	0.24		online supplemental appendix A.6.2
ρ	Number of peer-recruited men per VBS-enrolled man	0.32		Derived
σ_s^m	Fraction of symptomatic Ct infection in men	0.11		10
θ_t^m	Fraction of screened positive men treated (EIT)	0.76	0.1 to 0.9	online supplemental appendix A.6.3
θ_p^m	Fraction of partner treatment for index men (EPT)	0.27	0.1 to 0.9	online supplemental appendix A.6.3
θ_r^m	Fraction of treated men with rescreening	0.12	0.1 to 0.9	online supplemental appendix A.6.3
τ_t^m	Time lag in treatment for screened men (days)	12	–	online supplemental appendix A.6.3
τ_n^m	Time lag in screening for men enrolled via SNPR (days)	7	–	Assume
τ_p^m	Time lag in partner treatment for treated men (days)	2	–	online supplemental appendix A.6.3
τ_r^m	Time lag in rescreening for treated men (days)	102	–	online supplemental appendix A.6.3

Continued

Table 2 Continued

Description	Baseline	Range for 95% Confidence Interval	Reference

*For the disease transmissibility parameters (β^{m2w} and β^{w2m}), the estimated ranges come from the mathematical modelling papers. In our study, we estimated the baseline values for these transmission rates by calibrating the model to the Ct prevalences in the AA population within the age range (10.2% in men and 13.5% in women).
AA, African American; Ct, *Chlamydia trachomatis*; EIT, expedited index treatment; EPT, expedited partner treatment; SNPR, social network peer referral; VBS, venue-based screening.

interventions, such as partner treatment or rescreening after the index treatment, are not commonly implemented in clinics for men.[13] Therefore, follow-up interventions for men were not included in the model.

Check It intervention strategies

The Check It programme recruited participants in community venues, including community colleges, historically black colleges and universities, barbershops and other community-based organisations. This venue-based enrolment is enhanced with marketing strategies (distribution of flyers, web education, social media and informational cards) and enrols a fraction σ_e^m of the target male population for Ct screenings.

Some participants learnt about the programme through their social networks, such as text messages and information cards sent by friends or word-of-mouth. We accounted for this peer impact as SNPR and included it as a source of enrolment (see table A.4). On average, the proportion between the non-peer enrolled men and peer-recruited men is 1:ρ, and we assumed that peer-referred men are enrolled in the programme with an average delay of τ_n^m days from the time the referring man enrolled.

We modelled the non-peer enrolment process as a random sampling from the entire male population. Meanwhile, we modelled the peer-referred enrolment (SNPR) by searching the background social network of each non-peer enrolled man and randomly sampling among the eligible candidates.

The rest of the intervention practice was modelled similarly to women's cases: a fraction θ_t^m of the screened and infected men receive EIT after a delay of τ_t^m days. A fraction θ_p^m of these men's partners receive EPT with a delay of τ_p^m days. Finally, a fraction θ_r^m of the index men return for rescreening τ_r^m days after the initial infection.

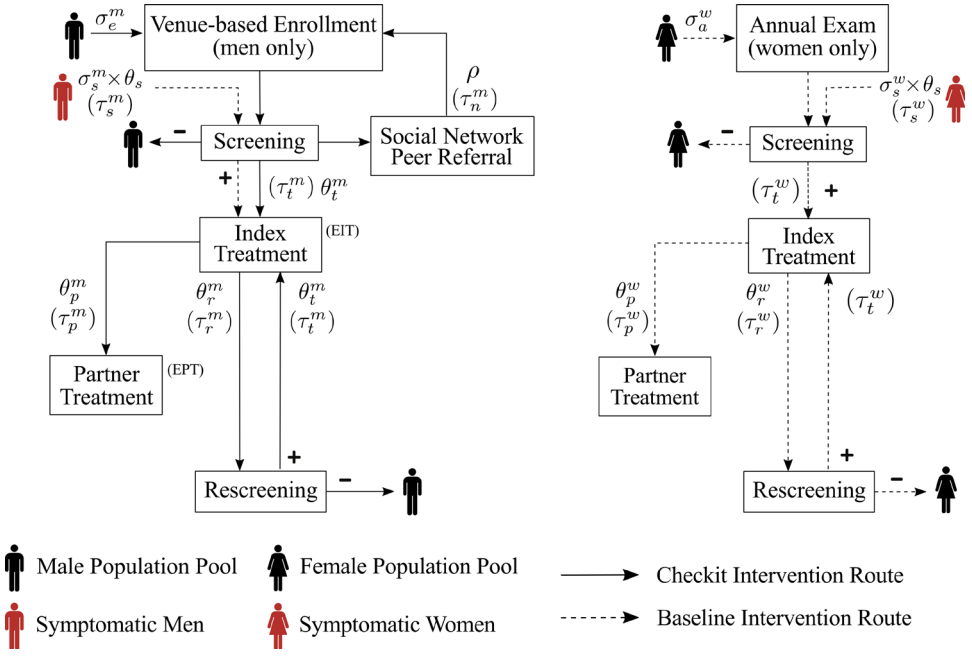

Figure 1 Flowchart for Ct intervention strategies in men and women. The solid lines are the new practices incorporated in the male-screening programme, Check It, and the dashed lines are the existing interventions implemented in the healthcare system. These current interventions include women's annual screening and screenings prompted by symptomatic infections in both men and women. Our modelling effort assessed the net impact of the male-screening programme to help control the Ct epidemic. The Check It programme targets the male population and uses venue-based enrolment, expedited index treatment, expedited partner treatment, rescreening and social network peer referral (see table 1). The intervention parameters are marked along the routes indicating the rates of compliance and delays, obtained from either literature or Check It data (see table 2). Ct,*Chlamydia trachomatis*.

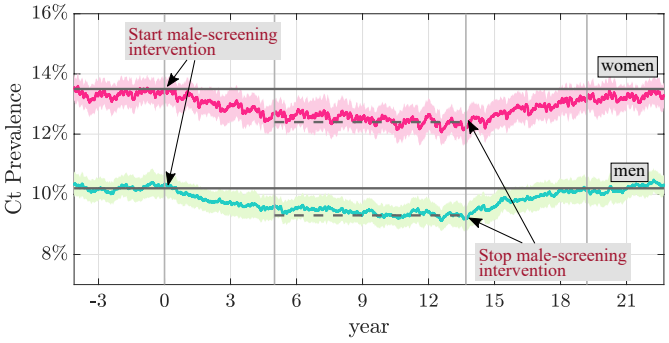

Figure 2 Impact of male-screening programme implemented at the existing intervention level. The curves are the mean of 50 stochastic simulations, and the bands around the curves indicate the one SD. The baseline Ct prevalences (before year 0) are 13.5% and 10.2% in women and men, respectively. At year 0, the male-screening intervention is turned on. Around year 5, the Ct prevalences reach quasi-steady states, which are 12.4% in women and 9.3% in men. The prevalences are reduced by 8.1% in women and 8.8% in men relatively. When the male-screening programme is stopped around year 14, the Ct prevalences return to the baseline levels in about 5.5 years. Ct,*Chlamydia trachomatis*.

If the rescreened men are infected with Ct, then they are treated as index cases, and the intervention process is repeated. Details on the estimates of compliance rates and delays were summarised in table A.5 and A.6.

Model parameters and calibration

The model parameters used in the simulations (table 2) represent our best knowledge of the current Ct epidemic and mitigation efforts among the AA population in the age range 15 to 24 in the USA. The values for the parameter Ct transmission probabilities per sexual contact between men and women (β^{m2w} and β^{w2m}) are not clear in the current biological literature. Quinn *et al*[14] gives the estimate of infection frequency per partnership. There are modelling studies[15 16] that provide rough estimates with large variations on the probability of transmission per contact. Because of the large uncertainty with these two parameters, they may vary in a wide range and are treated as tuning parameters for model calibration.

We calibrated the model to fit the current Ct prevalence in New Orleans among the AA population aged 15 to 24 (10.2% in men and 13.5% in women).[17] This prevalence reflects both the high infection rate in the region and the ongoing mitigation efforts among women. To have a realistic initial infection within the sexual network, we set the initial infection population to be consistent with the distribution of an emerging epidemic. We obtained such a quasi-steady-state balanced initial condition by starting a small epidemic in the past and letting it grow to the current (pre-Check It) Ct endemic state (online supplemental appendix A.4). This initialisation process considered the existing (baseline) combination of Ct interventions (dashed routes in figure 1) to give a comprehensive approximation of the current Ct control before the launch of Check It.

Approximately half of the Ct infections in women are cleared naturally by the first year after being infected and 80% are cleared after 2 years.[18] We fitted an exponential distribution for the average time of natural recovery τ_n days to the data from,[18] and we assumed the same distribution for men and women. Our numerical simulations suggest that the model results are not sensitive to this assumption (see Discussion and online supplemental appendix A.5). We also assumed the recovery time with treatment also follows an exponential distribution $\tau_t \sim exp\,(1/7)$ in days.

Sensitivity analysis

The model parameters in table 2 represent the best-guess estimates for practical scenarios, and we used local and extended sensitivity analysis to quantify the most significant model parameters.[19] To check the impact of each component of the Check It intervention bundle one-at-a-time, we conducted the extended sensitivity analysis by varying each intervention parameter (the parameter of interest), while fixing the other parameters. We then checked its corresponding impact on the Ct prevalence for women, men and the overall population (the quantities of interest).

For the local sensitivity analysis, we defined the relative local sensitivity index of a quantity of interest, q, with respect to the parameter of interest, p, as $S_p^q = p/q \times \partial q/\partial p$. This normalised sensitivity index, S_p^q, measures the percentage change in an output quantity given the percentage change in an input parameter. If an input parameter, p, changes by x%, then the output quantity, q, changes by $S_p^q \times x$%.

To further investigate the synergistic effect of the intervention components beyond the current levels, which could be limited by the protocols and available resources of Check It, we conducted the global sensitivity analysis by varying two intervention parameters together while fixing all other parameters. We then predicted the impact under different combinations of intervention parameters.

Patient and public involvement

There was no patients or public involvement in designing, conducting, reporting on or dissemination of information related to our modelling study.

RESULTS

Impact of male-screening programme at existing intervention level

We quantified the impact of the male-screening programme implemented at the current level of intervention intensity (as shown in table 2). Figure 2 shows the change in Ct prevalences after the launch of the male-screening intervention for men at year 0 with a balanced initial condition (online supplemental appendix A.4). Around year 5 of the programme, the Ct prevalences are controlled at much lower levels (quasi-steady states):

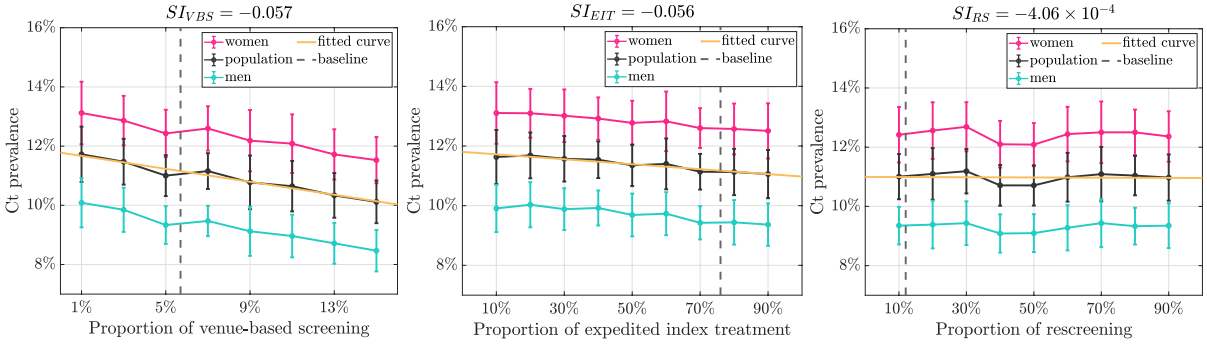

Figure 3 Local and extended sensitivity analysis on Check It intervention parameters (on the x-axis) against the Ct prevalence (y-axis). For each plot, the parameter of interest is varied while the other model parameters are fixed as in table 2. The Ct prevalences for men, women and the entire population are plotted, which are averaged over the time-frame year 4.5~5.5 of 30 simulations. The error bars give the one SD above and below the average. The local sensitivity indices (q=quantity of interest is Ct prevalence) are given in the titles. Ct,*Chlamydia trachomatis;* EIT,expedited index treatment; VBS, venue-based screening.

12.4% (95% CI 12.1% to 12.7%) in women and 9.3% (95% CI 9.1% to 9.5%) in men, which are reduced relatively by 8.1% (95% CI 5.9% to 10.4%) in women and 8.8% (95% CI 6.9% to 10.8%) in men. When stopping the male-screening programme later around year 14, the Ct prevalences return back to the baseline scenario in about 5.5 years.

In fact, near the lower quasi-steady states, our model predicts the following annual statistics from the programme based on a population of 5000:

- Each year, the programme conducts in total 174 screenings, including 42 from peer-recruited participants (SNPR), and achieves 13 treatments for index men (EIT) and 8 treatments for partners of those men (EPT).
- Among all the screened men found to be Ct-positive, the average number of partners within the past 2 months is 2.30 (95% CI 2.25 to 2.35).
- Compared with the scenario without Check It, the programme prevents 10.8 (95% CI 5.3 to 16.3) cases in men and 35.6 (95% CI 24.8 to 46.4) cases in women per year.
- Roughly, for each man screened, it could prevent 0.062 (95% CI 0.030 to 0.094) cases in men and 0.204 (95% CI 0.143 to 0.267) cases in women.

Significance of the components of the intervention

The sensitivity analysis quantified the relative significance of the intervention components in the programme. In the results presented below, we have considered the quantity of interest to be Ct prevalence and omit the upper index in the sensitivity index for the simplicity of the presentation.

From figures 3 and 4 (left), the Ct prevalences have an almost linear response to the intervention parameters, and the sensitivity at the current level of Check It intensity

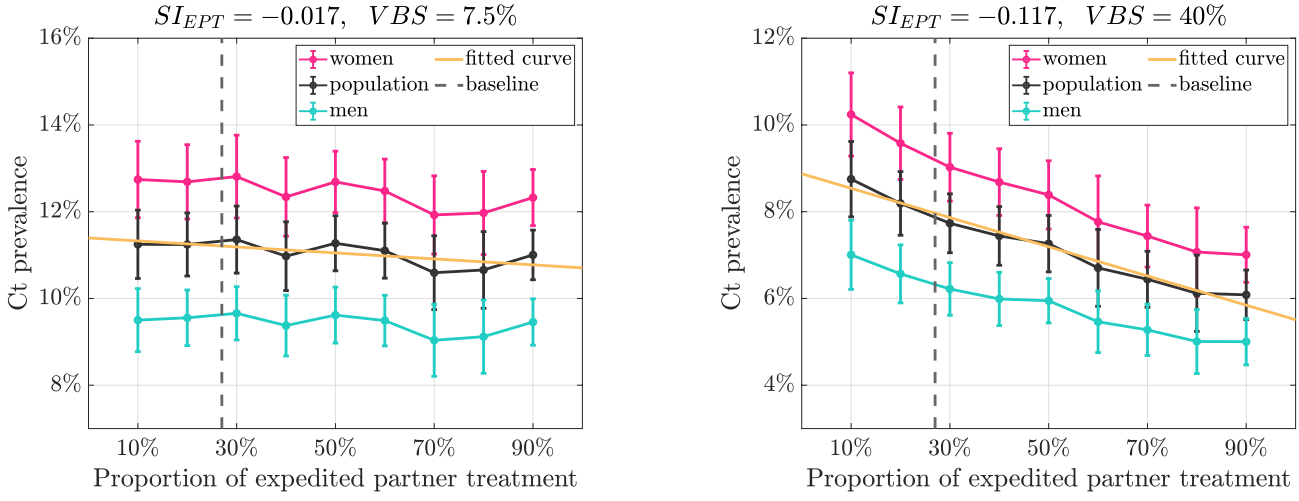

Figure 4 Local and extended sensitivity analysis on expedited partner treatment (on the x-axis) against the Ct prevalence (y-axis). Left: the analysis at the current level of Check It intervention intensity, screening 7.5% of the target male population. Together with the results in figure 3 and at the current Check It level, the significance of intervention components is ranked as venue-based screening ≈expedited index treatment >expedited partner treatment >rescreening. Right: the analysis at a much higher 40% male-screening rate while fixing other intervention parameters. The magnitude of the local sensitivity index is almost seven times larger (-0.117 vs –0.017), which suggests that the partner treatment becomes more important in reducing prevalence when increasing the screening coverage in men. Ct,*Chlamydia trachomatis;* EIT,expedited index treatment.

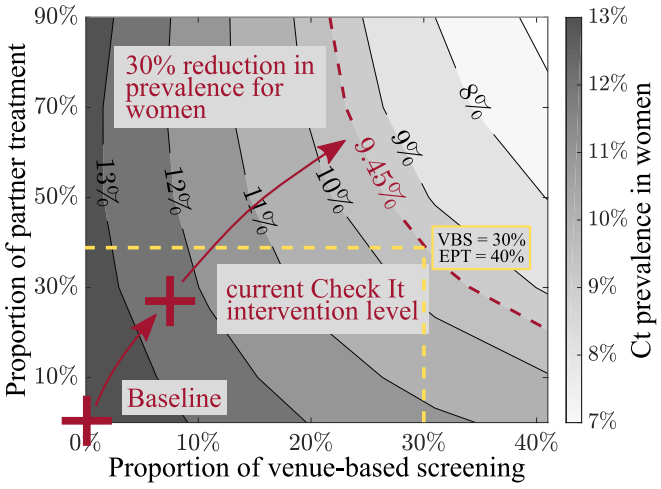

Figure 5 Global sensitivity analysis of Ct prevalence in women (marked in contour lines) against two intervention parameters: venue-based screening (VBS, x-axis) and expedited partner treatment (EPT, y-axis) on a uniform 5× 5 grid. At each grid point, the Ct prevalence is averaged over the time-frame year 4.5~5.5 of 10 simulations, and the contour surface is smoothed by a least-square fit of a two-dimensional quadratic polynomial to the grid values. The baseline scenario (VBS=0% and EPT=0%) and current intervention level (VBS=7.5% and EPT=27%) are marked in crosses, which shows an 8.1% relative reduction in women's prevalence. To achieve a 30% relative reduction in women's Ct prevalence, the combined intervention levels required are marked by the dashed contour line. For example, with a coverage of 30% male-screening and 40% partner treatment, the model predicts that the Ct prevalence in AA women will be reduced to 9.45%. AA,African American; Ct, *Chlamydia trachomatis*.

is ranked from high to low as VBS, EIT, EPT, rescreening, where the sensitivity of VBS is close to EIT. Moreover, when increasing the coverage of VBS from 7.5% to 40% (figure 4), the magnitude of the corresponding sensitivity index for EPT becomes seven times larger (-0.117 vs −0.017), which suggests that EPT would be much more effective in reducing the prevalence with high male-screening coverage.

We then conducted a global sensitivity analysis using the two most significant parameters from the local and extended sensitivity analysis: VBS and EPT. The response plot for women's Ct prevalence (figure 5) shows that the male-screening strategy has the potential to reduce the Ct prevalence in women substantially, and it predicts the effectiveness under different combinations of intervention intensities. For example, the model estimates the combination of VBS=30% of the target men and EPT=40% of their partners will give a 30% reduction in Ct prevalence among women after 5 years of intervention.

DISCUSSION

Our model provides a framework for public health workers to ask 'what if' questions that are hard to evaluate in the field. We simulated the Ct epidemic over sexual networks based on a young AA population in New Orleans, where the ongoing female-screening interventions are not sufficient to bring down the high Ct prevalence in women. From the simulation results at the current intervention level (figure 2), by annually screening men in the target population (AA, sexually active, aged 15 to 24), together with other best practices in Ct control, there is the potential to further mitigate Ct prevalence from the baseline (female-screening intervention only) among this high-prevalence cohort. Moreover, once the male-screening programme is suspended, the prediction shows that the prevalence will return to the baseline level given no significant changes in the underlying force of infection in the population. This suggests that, similar to the existing recommendation of annual screening policy for high-risk women, the male-screening intervention also requires long-term efforts to maintain its effectiveness over time. With the joint force of the interventions for both men and women, Ct could be controlled at much lower prevalences.

From the local and extended sensitivity analysis (figure 3), we quantified the impact of each intervention component. For all the intervention components involved, the Ct prevalences have linear responses to the variation of each intervention parameter. The sensitivity indices quantify the impact and show that the two most significant intervention parameters are (1) the coverage of venue-based screening for men, which identifies and treats the Ct-positive men, and (2) the coverage of expedited partner treatment, which prevents the potential reinfection between the couple. Figure 4 shows the impact of partner treatment on the Ct prevalences but with much higher coverage of male-screening among the target population (increase from 7.5% to 40%). The larger magnitude in the sensitivity index implies that the expedited partner treatment will be much more effective in reducing Ct prevalence when increasing the screening coverage in men.

By using the global sensitivity analysis on these two most significant intervention parameters, the model further explores the potential impact on a larger parameters space. Figure 5 gives the prediction of the Ct prevalences under different combinations of intervention parameters. At the current Check It intervention level, the impact could be limited by the resources and the capacity of the programme and the policy imposed on the protocol. In the adapted Check It protocol (as of February 2020), the expedited partner treatment incorporated the practices of patient delivered partner therapy and mail delivery, which improved the fraction of partner treatment from 27% to nearly 40%. Moreover, if male-screening could be part of the standard recommendation as it is for women and if a moderate compliance rate of 30% could be achieved, then the model predicts that this joint screening programme will result in 30% relative reduction in the Ct prevalence for the AA young women. After three decades of routinely screening women with no improvement in Ct

rates, alternative interventions must be considered. This model provides support for changing the recommendations to include routine screening for men in addition to the current recommendations and best Ct control practices like EPT.

Our model considered a comprehensive picture of the current Ct epidemic in a young AA community and the control strategies implemented in men and women, separately. The model is parametrised using the survey data from the target population in New Orleans. This allows a detailed reconstruction of the assortative sexual mixing among the population and gives realistic predictions on the spread of the Ct epidemic and assessments on the mitigation efforts.

Although the model is parametrised based on the data sets from New Orleans, they represent similar cities that have high Ct rates (urban, southern and largely impoverished AA community) in many ways. Our study presented a robust and flexible model framework that could be adapted for the Ct epidemics in other similar populations. Nevertheless, the quantitative results presented in this study can only be interpreted for other cities after carefully examining the differences between sexual behaviour and assortative mixing patterns in two populations.

Many of our model limitations are associated with the scope of the available data sets. The uncertainty and bias in the model parameters and model assumptions can affect the reliability of the quantitative predictions. For example, due to the ethical challenges, rigorous estimates from longitudinal studies on the natural history of chlamydia are not available.[20] We have assumed the same natural recovery period for men and women, and we studied the impact of this uncertainty in the (online supplemental Appendix A.5). Our assumptions on the partner updating frequency were made due to a lack of longitudinal data on the subject. Still, our numerical simulations (in online supplemental appendix A.1.3) suggested that, on the model recalibration, the relative ranking of the responses in the sensitivity analysis and the trend in prediction pattern is robust and insensitive. Also, Check It is still an ongoing study, and some of our model parameters may be further refined using the incoming data.

The dynamic sexual networks approximated the sexual behaviour between the high-risk age cohorts from Check It and YGG studies (men 15 to 24 and women 18 to 19). Meanwhile, we noticed a minority of women (6%) in the YGG study reported partners from different age cohort (>24 years old). These partnerships, which may serve as a residual reservoir, could not be detected by Check It programme that targets age range 15 to 24. However, due to the lack of further data on quantifying these sexual behaviours, we did not include the intergenerational partnership with large age differences.

In the current study, we did not incorporate the demographic characteristics of the individual. This may lead to some bias in modelling the mixing (eg, age-mixing) structure for the sexual partnership. We reduced this bias by embedding the sexual networks into a grand social network, which considers an individual's age, ethnicity, social groups, economic status and geographical location. When updating the sexual networks, people will be more likely to establish sexual partnerships with their frequent social contacts. Another model assumption due to the lack of age is we didn't include the ageing effect: people will not be removed as they get older than eligible age range, and no new susceptible young people will come into the population. Thus, the caveat is the model will only be a good approximation for a limited time, and it is not suitable for simulations over a long period. Our future modelling study will be focussed on improving the model, such as considering the ageing process in the population and accounting for sexual partnerships outside the current range. These improvements will help us better quantify the impact of a male-screening programme.

We recognise that mathematical models are a simplistic representation of the real world. The quantitative predictions from our model may need further validation using incoming data stream on Ct prevalences, however, the qualitative results of our analysis adds to the evidence that male-screening interventions, together with other best practices in Ct control, has the potential to further mitigate the Ct prevalence among women in a high-prevalence community. Our future work will include further model calibration and validation using the incoming data from the Check It programme and evaluating the cost-effectiveness of the male-screening programme.

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Acknowledgements We thank William Geisler (University of Alabama at Birmingham) for his helpful insight into the natural history of Chlamydia in men and women. We are also grateful to M Jacques Nsuami (Louisiana State University Health Sciences Center) whose comments and suggestions helped improve and clarify this manuscript.

Contributors All authors meet the ICMJE criteria for authorship. ZQ, AA and JH contributed to the design of the mathematical model. ZQ conducted data analysis, undertook numerical simulations and visualisation and interpreted results. NS and MCC-K contributed to data collection and analysis and reviewed model design and interpretation. CS reviewed the model design and interpretation. JH and PK contributed to the study, reviewed the model, data analysis and results interpretations and oversaw and coordinated the investigation. ZQ wrote the first draft of the article. All authors contributed to the writing and review of the draft and approved final manuscripts.

Funding This work was supported by the grants from the National Institutes of Health National Institute of Child Health and Human Development (R01HD086794) and the endowment for the Evelyn and John G Phillips Distinguished Chair in Mathematics at Tulane University. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Tulane University Institutional Review Board.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

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APPENDIX: NUMERICAL IMPLEMENTATIONS AND PARAMETERS

A.1. Generation of dynamic sexual network

We modelled the sexual behaviour of the target population through a series of simulated sexual networks, which were embedded in a grand social network. The sexual networks characterised the sexual behavior among a 5000-member synthetic population. We generated these networks using the data inputs from two studies in New Orleans: "You Geaux Girl!" (YGG)[1] and "Check It"[2], where 473 African-American women and 1318 African-American men were enrolled to survey their sexual behaviour and complete an intervention process. The social network was generated using Simfrastructure agent-based modelling and simulation system[3], which simulated the social activities among a population of 150,000 in New Orleans.

We present the details on network configurations and parametrization below. For further technical algorithms on the network generation, we refer readers to Azizi et al.[4].

A.1.1. Degree and joint-degree distributions

We extracted the information of degree distributions (number of partners one reports) and joint-degree distributions (number of partners one thinks his/her partner has) for women and men from the YGG and Check It data sets. These distributions were then used to generate sexual networks.

Based on the degree distributions from the self-reported data (see fig. A.1 first row), we truncated the distribution at a maximum degree = 12 for men and max degree = 6 for women. We then smoothed the extracted joint-degree distribution using LOESS with second degree polynomials, which was implemented by `fit` (method = `'loess'`, span = 0.25) in MATLAB. Lastly, we normalised the distribution to unity. Table A.1 shows the estimate of the joint-degree table on a 5000 population size, where the (i, j) entry in the table gives the total number of partnerships that exist between degree i women and degree j men on the sexual network. Figure in table A.1 shows the smoothed surface of the joint-degree probability distribution. We then recalculated the estimated degree distributions from the updated joint-degree distribution, and we compared it with the reported ones in the second row of fig. A.1. Overall, the estimated degree distributions still in good agreement with the ones from the self-report data.

A.1.2. Primary and casual partnership

We categorised the partnership into primary (long-term) and casual (short-term) to distinguish the dominant sexual partners from the other temporary partners based on participants' self-reported sexual behaviour. The casual partners may be replaced every two months, which is the time frame that the Check It survey asks about recent sexual behaviour, and the primary partners are more likely to stay in the sexual network.

For women, the YGG survey reported partner type as "main" and "casual", thus, we considered the main partner is our primary partner class. For men, the Check It survey has several questions that characterise the relationship from different perspectives, including the duration of the partnership, where they met (school, neighbourhood, club, dating site, etc), the best description of the relationship (girlfriend, wife, close friend, one-night stand), feeling

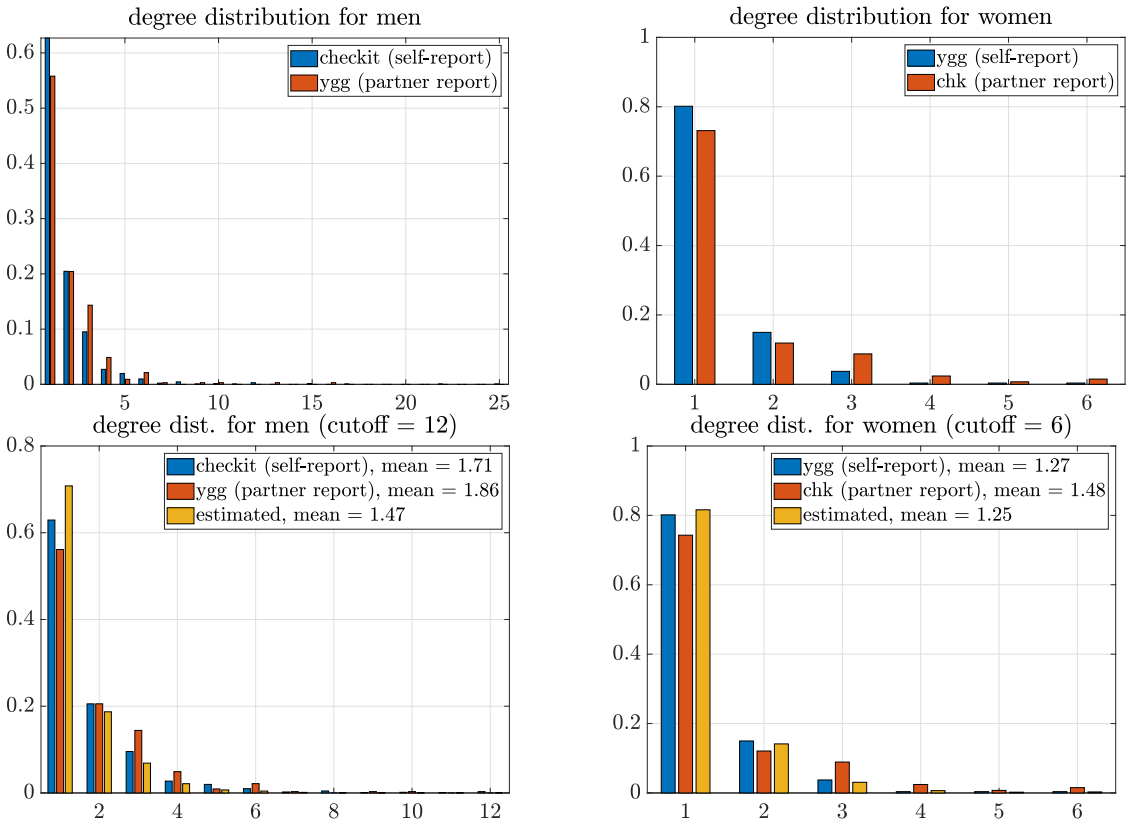

Figure A.1: Degree distributions for the number of partners for men and women. Blue bars: self-report data; Red bars: partner report data; Yellow bars: estimated distributions, which are used as model inputs to generate sexual networks. Top row: original degree distributions for men and women; Bottom row: processed degree distributions with cutoff at max degree = 12 for men and max degree = 6 for women, respectively.

		# of partners for men (degree of men)											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	1	1102	608	273	109	42	29	15	6	5	4	6	6
	2	425	163	100	34	14	14	2	1	1	3	3	3
women	**3**	77	57	52	32	17	6	2	1	2	2	0	1
degree	**4**	17	16	20	13	2	2	0	0	1	0	0	1
	5	0	3	14	0	3	7	2	0	0	0	0	1
	6	6	13	15	8	2	2	0	0	0	0	2	0

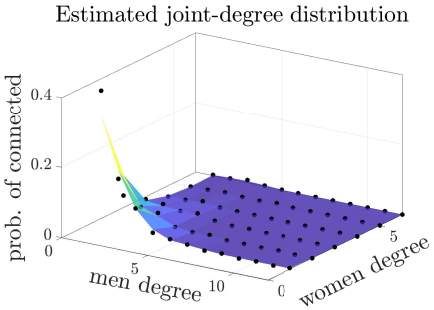

Table A.1: **Left Table**: Joint-degree table for a population of size 5000. The entry at (i, j) location represents the total number of partnerships between degree i women and degree j men in the sexual network. **Right Figure**: Plot of the corresponding joint-degree probability distribution.

committed or not and level of closeness. For Check It data, there are in total 2052 partners for 1318 men, and the partnership types were assigned using the following ordered criteria:

1. If the relationship is best described by an ex-girlfriend (n=234), someone who I might want to have a relationship with (n=70), one-night stand (n=136), someone I paid to have sex with (n=10), internet hook up (n=14), or other (such as stranger, coworker and random answers, n=55), refuse to answer, or don't know on relationship type (n=137) → casual partner.

2. If the relationship is best described by: girlfriend (n=596), wife (n=65) → primary partner.

3. For other relationship types, including a good friend of mine, a friend with benefits, someone I have sex with but not necessarily a friend:

   (a) if consider oneself committed (n=54) → primary partner

   (b) If reporting refuse to answer or don't know on the duration of the sexual relationship (n=64), or times of vaginal sex in the past 2 months (n=15) → casual partner.

   (c) * If times of vaginal sex ≥ 5 (n=133) → primary partner.

   (d) * If times of vaginal sex ≤ 1 (n=236) → casual partner.

   (e) * If times of vaginal sex $2-4$:

      i. If the duration of sexual relationship greater than six months (n=54) → primary partner.

      ii. In the remaining undefined partners: if the level of closeness or strength of your relationship (on a scale 1-10, 1 being not close or strong at all and 10 being extremely close) is greater than six (n=88) → primary partner.

      iii. In the remaining undefined partners: if meeting with the partner before first had sex with her at a club or other event and didn't know her before (n=3), meet her online through a dating site or social media (n=1) and other (party, work, college, etc, n=3) → casual partner.

4. Among all the remaining undefined partnerships, if the man

   (a) already has exactly one primary partner (25 men have exactly one primary partner following the rules above), then consider all other partner(s) (n=26) → casual partner;

   (b) already has exactly two primary partners (four men have exactly two primary partners following the rules above), then consider all other partner(s) (n=6) → casual partner;

   (c) (no more than two primary partners defined for all the men in Check It data)

(d) has exactly one partner, who is undefined (n=3), both the level of closeness is less than two → casual partner;

5. all other undefined partners (n=49) → casual partner.

* Notice that in step 3 (c)-(e), we have included the criteria on the frequency of the sexual contacts to categorise the partnership, and it may happen that one may be considered as the primary partner if there are more than five vaginal sexual contacts in two months, even if the relationship is not described as girlfriend/wife/committed. That is, when categorising the partnership, we consider both one's subjective perception of the relationship (typical definition in social science) and the actual sexual behaviour pattern. This is because the design of the sexual networks is to model the sexual behaviour dynamic in the population, which may or may not be consistent with the subjective perception of the relationship for each individual.

We used our best guess to categorise each partnership based on the process described above, and we summarised the resulting distributions in table A.2, which is not sensitive to the perturbation of the classification criteria. For each table, the (i, j) entry gives the fraction of degree i person who has exactly j primary partner(s), and the last column is the accumulative probability for having at least one primary partner.

		# of primary partners				
		1	**2**	**3**	**4**	$\geq$ **1**
degree of men	**1**	0.66	0	0	0	0.66
	2	0.44	0.15	0	0	0.59
	3	0.37	0.23	0.09	0	0.69
	4	0.36	0.14	0.11	0.08	0.69
	5	0.15	40.19	0.08	0.08	0.5
	6	0.46	0.23	0.08	0	0.77
	7	0	0.33	0	0	0.33
	8	0.33	0.17	0	0	0.5
	9	1	0	0	0	1
	10	0	0	0	0	0
	11	1	0	0	0	1
	12	0.75	0.25	0	0	1

		# of primary partners			
		1	**2**	**3**	$\geq$ **1**
degree of women	**1**	0.9	0	0	0.9
	2	0.7	0.08	0	0.77
	3	0.8	0.1	0	0.9
	4	0	1	0	1
	5	1	0	0	1
	6	1	0	0	1

Table A.2: Distributions of the number of primary partners for men (left) and women (right): the (i, j) entry gives the probability that a degree i man/women has (self-report) j primary partners. The last column gives the accumulative probabilities for having at least a primary partner.

A.1.3. Dynamic sexual networks

Given the distributions estimated in appendix A.1.1 and appendix A.1.2, we could generate a sexual network embedded in the social network, that is on average, the individual has a fraction p of the casual partners from his/her connected social network, and a fraction

$1-p$ are chosen randomly from the rest of the 5000 population. Moreover, to simulate the partner changing process in the population, we implemented dynamic sexual networks: every two months, with 50% probability, the casual partners were replaced by either individuals from his/her social network or the rest of the population. The fraction p was estimated from the Check It survey data, which is $p = 0.82$.

We used two months for the partnership updates since this is the time frame covered by the Check It survey: the Check It survey asked questions about participant's sexual behaviour within the past two months. There is no data available to infer the actual partner replacements period. Moreover, the fraction 50% is an assumption, not backed by survey data. To investigate the impact of these two parameters on the prediction, we ran simulations using two sets of different parameters, as shown in fig. A.2. For all the simulations, we have calibrated the model using transmission parameters β^{m2w} and β^{w2m} to the current Ct prevalence in men and women, as described in appendix A.4. By increasing the dynamic period and decreasing the fraction of causal partner replacement, the sexual mixing in the population is lowered. This also results in higher calibrated transmission parameters to match the same baseline Ct prevalence. Also, due to the lower sexual mixing level, it takes much longer for the program intervention to bring the epidemic down to a lower quasi-steady state. Overall, the effectiveness of the intervention, measured by the amount of (asymptotic) reduction in prevalence, is comparable to the baseline configuration and is relatively insensitive across different levels of sexual mixing in the population.

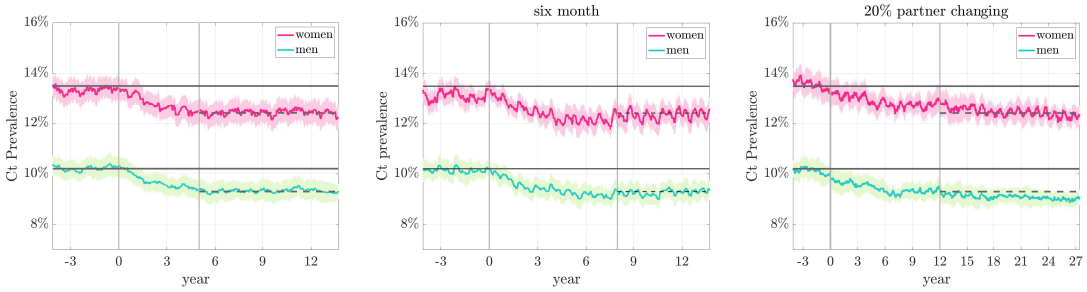

Figure A.2: Dynamic sexual networks with different configurations. Left: configuration used in the model, (50%, 2 months, $\beta^{m2w} = 0.3, \beta^{w2m} = 0.1$); Middle: (50%, six month, $\beta^{m2w} = 0.34, \beta^{w2m} = 0.113$); right: (20%, two month, $\beta^{m2w} = 0.34, \beta^{w2m} = 0.107$). It takes five, eight, and twelve years for Ct prevalence to achieve a lower quasi-steady state, respectively.

A.2. Chlamydia transmission SIS model over a dynamic sexual network

We updated the changes of infection statuses for the individuals daily, following the SIS framework, where each individual is either susceptible (S) or infected (I).

A.2.1. Force of infection: $S \to I$

On each day, we modelled the force of infection, the ability for the infected individuals to spread Ct to their susceptible partners as follows:

$$\begin{matrix}\text{Trasmission}\\ \text{or not}\end{matrix} = \begin{bmatrix}\text{Prob. of having a sexual}\\ \text{contact per day per partner}\end{bmatrix} \cdot \begin{bmatrix}\text{Prob. of transmission}\\ \text{per contact}\end{bmatrix} \times \left(1 - \begin{matrix}\text{Prob. of effective}\\ \text{condom use}\end{matrix}\right),$$

where each bracket gives a zero or one value with the specified probability contained inside.

From the datasets, we summarised the probability of having sexual contact per day per partner for men and women with different degrees in table A.3. This probability depends on both how many partners the individual has (degree of men/women) and the type of the partnership (primary or casual). In general, the probability of having contact with the primary partner is higher than with the casual one.

		Type of partnership		
		Primary	Casual	Mix-type
degree of men (Check It)	**1**	0.14	0.06	0.11
	2	0.11	0.06	0.08
	3	0.12	0.05	0.08
	4	0.18	0.06	0.11
	5	0.15	0.04	0.07
	6	0.07	0.03	0.05
	7	0.08	0.03	0.04
	8	0.04	0.03	0.03
	10	0.03	0.02	0.02
	11	0.03	0.02	0.02
	12	0.07	0.06	0.06

		Type of partnership		
		Primary	Casual	Mix-type
degree of women (YGG)	**1**	0.12	0.02	0.11
	2	0.07	0.05	0.06
	3	0.08	0.02	0.04
	4	0.02	0.03	0.03
	5	0.01	0.01	0.01
	6	0.02	0.02	0.02

Table A.3: Probability of having contact per partner per day. For both tables, entries in row i give the probability that a degree i person has sexual contact with a primary (column one) or casual partner (column two), respectively. The last column gives the average probability of contact regardless of the partnership.

The probability of effective condom use depends on two factors, the probability of condom use and the probability of condom-use failure. From the data sets, we estimated that the values for condom use for primary and casual partners are $c_p = 0.54$ and $c_c = 0.66$, respectively. The condom use failure rate was fixed as $c_\epsilon = 0.1$[5].

In the case of asymmetric primary-casual relationship, we modelled both the condom use probability and the contact frequency as a compromise between the couple, and we took the harmonic average of the values from two sides.

Lastly, the probability of transmission per contact (β^{m2w} and β^{w2m}) can have a wide range in different scenarios. We considered the maximum likelihood estimates by solving a nonlinear least-square optimisation problem and matching the Ct prevalence to the current prevalence in New Orleans (10.2% in men and 13.5% in women).

A.2.2. Temporary immunity: $I \rightarrow S$

Meanwhile, the infected individual could recover (without lasting immunity) and become susceptible again. The recovery could be due to either the natural clearance of the pathogen or medical treatment. We modelled the time to recovery as exponential distributions with different means (see the baseline values in table 2 main text). We also assumed that no one recovers naturally within the first three months of infection (Molano et al.[6]), which was incorporated as a shift in the corresponding distribution.

Moreover, both natural and treated recovering process could be interrupted and start over again if the individual has an infectious contact with the partner before fully recovered. The natural recovery process could be updated as a treated recovery process once the individual gets treatment, either from the enrolment in the Check It program (men), annual screening (women), or screening due to symptomatic infection.

A.3. Modelling annual screening for women

The Centers for Disease Control and Prevention recommends annual Ct screening for all sexually active women younger than 25 as well as older women with risk factors, which is a standard preventive strategy to identify most of the asymptomatic infections in women. We considered this intervention strategy as part of the baseline scenario and implemented a simple model to simulate the women's annual screening process in practice.

We assumed that a fraction σ_a^w of the women in the target population receives annual Ct screening. In reality, most women return for screening following an annual routine schedule (regular annual screening), and there is also a small fraction of women receive screening on a casual basis (opportunistic screening). For the former case, we pre-generated an annual screening schedule for the regular screening group. For the latter case, we randomly sampled the opportunistic screening group from the rest of the women.

Figure A.3 presents the simulations at the initial calibration stage for two extreme scenarios: all the screened population belongs to one group: either the regular screening group (left plot) or the opportunistic screening group (right plot). Two cases show similar trends and prevalence at the quasi-steady state. We observed that the random screening case has a significantly slower convergence to the quasi-steady state. The slower convergence is a result of random screening targets different populations from year to year rather than a fixed population and, therefore, it takes a longer time to converge to a stable status. In our model, since there is no further information on the proportion of the population within each group, we assumed that all the screenings belong to the regular screening group. Moreover, since we only studied the Ct scenario after the quasi-steady state is achieved, the difference at the initial convergence speed does not affect our conclusion.

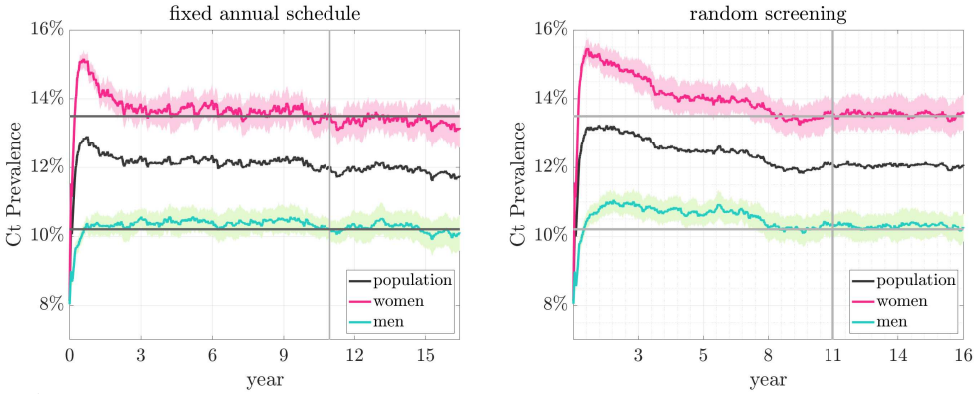

Figure A.3: Modelling the annual Ct screening as a preventive strategy in women under two scenarios: a constant population gets regular annual screenings following a fixed schedule (left), or randomly screen the same number of women but different populations from year to year (right). The Ct prevalence for the random screening case converges much slower to a quasi-steady state than the fixed annual schedule case.

A.4. Model initialisation - balanced initial condition

We initiated the model to represent the current baseline Ct epidemic in New Orleans. Since the distribution of the current infected population depends on the history of the Ct epidemic, the initial infections are distributed across the sexual network as they would be as part of an emerging epidemic (fig. A.4). To identify a physically relevant initial condition, we started by an epidemic infecting a small fraction of the population at $t = 0$, and let the infection be internally redistributed in time until a quasi-steady-state is achieved. We started with 8% of infections, and for most situations, the simulations took about fourteen years. We then reset the time to be zero and use this infection status as the initial condition for the rest of the simulations. We have infected 8% of the men and women with most sexual partners initially to speed up the process, as they are more likely to be infected in a balanced scenario.

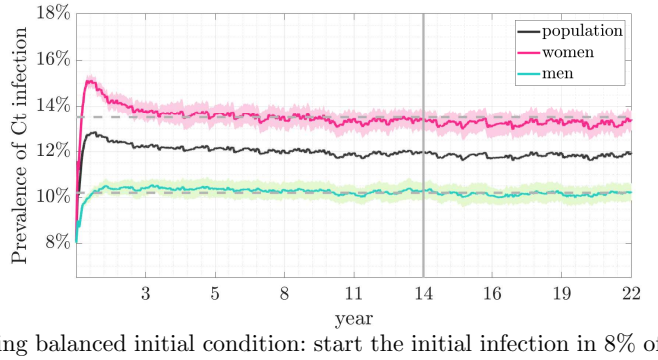

Figure A.4: Generating balanced initial condition: start the initial infection in 8% of men and 8% of women with the highest sexual degree, and a quasi-steady-state is achieved around year 14. We then reset the time to be zero and use this infection status as the initial condition for the rest of the simulations. The background lighter curves are the one standard deviation bands for 50 stochastic simulations, and the thicker curves in the middle are the mean of the simulations. The standard deviation of the prevalence is 0.0092 and 0.0075 for women and men, respectively. We calibrate the model to fit the current prevalence from data, which is 10.2% in men and 13.5% in women.

A.5. Discussion on natural recovery time without treatment – τ_n^w and τ_n^m

To understand how the uncertainty in natural recovery time will impact the modelling results, we repeated the numerical simulations in the main text using another set of parameters from Lewis et al.[7], where the estimate for the men (τ_n^m) was much longer than what we used in the baseline setting.

We followed the results in Lewis et al.[7] and used much longer natural recovery time for men, which is 2.33 years. We update the parameter τ_n^m in the baseline setting (table 2 in the main text), and we recalibrated model: the transmissibility parameters were updated as $\beta^{m2w} = 0.3580$ and $\beta^{w2m} = 0.0597$.

The updated baseline simulations is given in fig. A.5. Comparing to the baseline scenario in the main text, the Ct prevalences reach slightly lower quasi-steady states, which correspond to a bit larger impact of the male-screening program. We noticed that by having a longer natural recovery time, to maintain the same baseline Ct prevalences, the transmissibility parameters has to decrease. That is, although people have a longer infectious period to pass infection, the probability of transmission per infectious contact is much lower.

We also re-investigated the (local and extended) sensitivity analysis using the updated natural recovery distributions, which are given in fig. A.6. Comparing to the baseline setting in the main text, the magnitude of the local sensitivity indices remain on the same scale, and the order of the significance remains unchanged: from high to low, venue-based screening (VBS), index treatment (EIT), expedited partner treatment (EPT), and rescreening (RS).

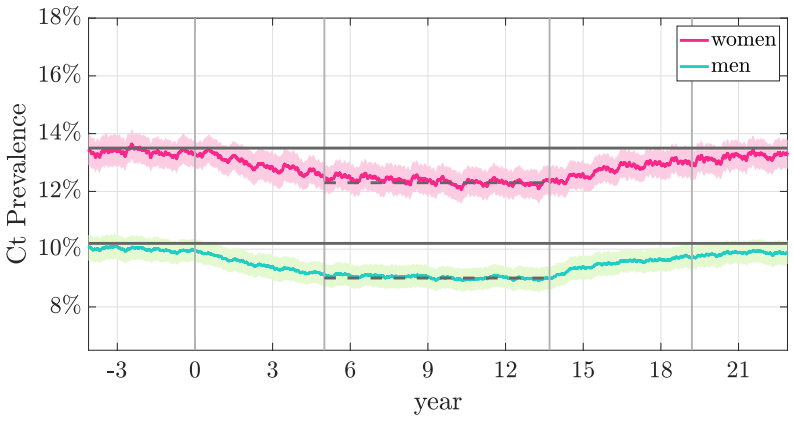

Figure A.5: Impact of male-screening program using updated natural recovery parameters (same simulation configurations as fig. 2 in the main text). The baseline Ct prevalences (before year zero) are 13.5% and 10.2% in women and men. Under the male-screening program, the Ct prevalences reach quasi-steady states: 12.3% in women and 9.0% in men, which are slightly lower than the baseline scenario in the main text.

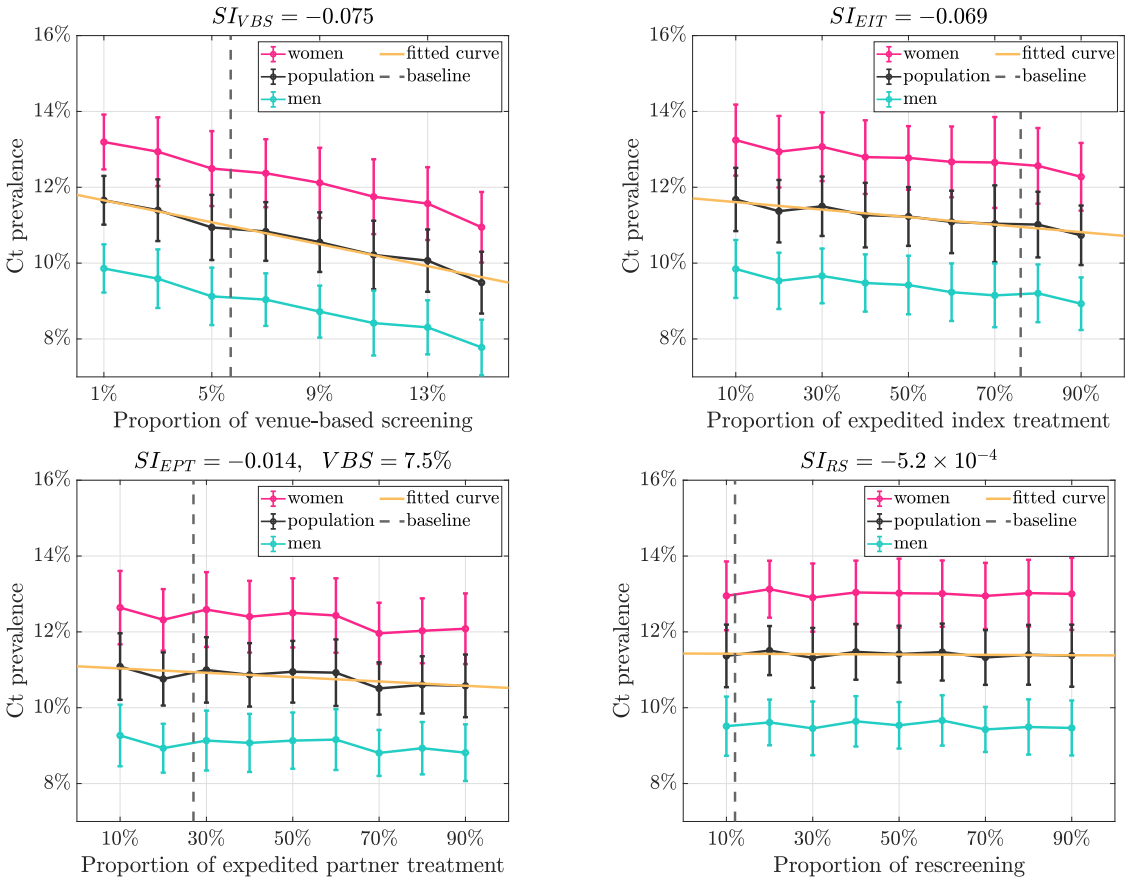

Figure A.6: Local and extended sensitivity analysis on Check It intervention parameters, using the updated recovery parameters. Same configuration as in the main text (fig. 3 and fig. 4).

A.6. Derivation of model parameters

A.6.1. Fraction of condom use – c_p and c_c

For each participant in Check It study, the number of vaginal sexual contacts and number of condom uses for those contacts are self-reported for each of the listed partner. We calculated the probability of using condom for all the partnerships (n=1744), including 913 primary partnership and 831 casual partnership, and the distributions are given in fig. A.7. The average fraction of condom use is higher among the casual partnership than casual one ($c_c = 0.66$ vs. $c_p = 0.54$).

A.6.2. Check It participants enrolment venues.

Check It recruited participants in various community venues. As of April 2019, there were 1318 participants enrolled. We categorised the enrolments into non-peer venue-based enrolments and peer-referred enrolments (the Social Network Peer Referral or SNPR component in the model). The survey questions on the enrolment venues were update on 03/06/2018,

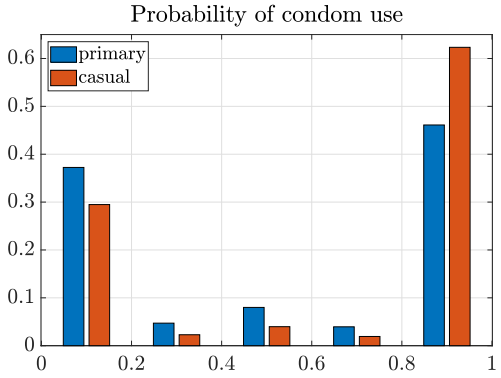

Figure A.7: The distributions of probability of condom use for primary partners and causal partners. The average probability of condom use are $c_p = 0.54$ for primary partner and $c_c = 0.66$ for casual partner.

	Old survey n=516	New survey n=802	Total n = 1318 (100%)
Word of mouth from friend	141	171	peer-referred = 319 (24%)
Text message from friend	7		
Informational card	69	-	non-peer referred = 999 (76%)
Word of mouth from non-friend	80	428	
Flyer	203	73	
Dont know/refuse to answer	16	130	

Table A.4: Check It participant enrolment venues. The survey questions were updated on 03/06/2018. For parametrisation, the numbers have been processed so that the options are mutually exclusive. In total, 24% of the enrolled participants learned about Check It through their contacts in the social circle, and 76% of the participants were enrolled through non-peer venue-based venues.

and we summarised the results for both the old and new surveys in table A.4. There are 24% of the participants enrolled through their social peers and 76% were enrolled through non-peer venue-based venues. Thus, on average, each non-peer referred participant could bring in about 0.32 peer-recruited men ($\rho = 0.32$).

A.6.3. Compliance rates and time lags for Check It intervention stages

At each stage of the intervention process (as illustrated in fig. 1 in the main text), the intervention may not be implemented as planned, which depends on the compliance of the participants. There are also different time lags at each stage, which depends on the program workflow and response time from the participants. We considered fractional compliance rates and the time lags at three stages: expedited index treatment (EIT), expedited partner treatment (EPT), and rescreening (RS), and the results are summarised in tables A.5 and A.6. We have marked out the model parameters that were used in bold, and the corresponding parameter notations, as defined in table 2 in the main text, are included in the parentheses after parameter values for readers' convenience.

	n	%
Total participants enrolment	1318	100
Positive/index participants (Ct prevalence in men)	135	**10.2**
Index men successfully contacted	119	
Treated men (EIT) among contacted	91	**76** ($\theta_{\mathbf{t}}^{\mathbf{m}}$)
Treated men (EIT) among contacted before 08/30/2018*	60	
Index rescreening among the treated before 08/30/2018*	7	**12** ($\theta_{\mathbf{r}}^{\mathbf{m}}$)
Partners of positive men notified	154	100
Partners complete the treatment upon notified	42	**27** ($\theta_{\mathbf{p}}^{\mathbf{m}}$)
- Patient-Delivered Partner Therapy (PDPT)	23	
- Contacted by Check It staff/OPH	19	

Table A.5: Fractional compliance at Check It intervention stages. *Check It program started incentives for three-month rescreening after 08/30/2018. We only consider the treated men before the change (n=60) to eliminate the impact of incentives.

	n	mean	median	std
Time lag from index enrolment to notification	119	11.7	10	7.5
Time lag from index notification to treatment	91	4.4	2	9.9
Time lag from index enrolment to treatment	91	14.9	**12** ($\tau_{\mathbf{t}}^{\mathbf{m}}$)	10.2
Time lag from index treatment to partner treatment	42	**2** ($\tau_{\mathbf{p}}^{\mathbf{m}}$)	0	7.3
- Patient-Delivered Partner Therapy (PDPT)	23	1	0	1.8
- Contacted by Check It staff/OPH	19	4	0	10.6
Time lag from index initial treatment to rescreening	7	**102** ($\tau_{\mathbf{r}}^{\mathbf{m}}$)	96	27.7

Table A.6: Time lags between Check It intervention stages.

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