

Digital technology-based HIV prevention interventions for men who have sex with men in China: A systematic review and meta-analysis.

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Wenting Huang¹ PhD; Daniel Stegmüller² PhD; Jason J. Ong^{3,4} PhD; Susan Schlueter Wirtz⁵ MPH; Kunru Ning⁵ MPH; Yuqing Wang⁵ MPH; Guodong Mi⁶ PhD; Fei Yu⁶ MPH; Chenglin Hong⁷ PhD, MSW, MPH; Jessica M. Sales¹ PhD; Yufen Liu⁸ MPH; Stefan D. Baral⁹ MD, MPH; Patrick S. Sullivan⁵ PhD, DVM; Aaron J. Siegler⁵ MHS, PhD

¹Behavioral, Social, and Health Education Sciences Rollins School of Public Health Emory University Atlanta US

²Department of Political Science Duke University Durham US

³Melbourne Sexual Health Centre Alfred Health Melbourne AU

⁴Central Clinical School, Faculty of Medicine Nursing and Health Sciences Monash University Melbourne AU

⁵Department of Epidemiology Rollins School of Public Health Emory University Atlanta US

⁶Danlan Beijing Media Limited Beijing CN

⁷School of Social Work University of Connecticut Hartford US

⁸National Center for AIDS/STD Control and Prevention Chinese Center for Disease Control and Prevention Beijing CN

⁹Department of Epidemiology Johns Hopkins School of Public Health Baltimore US

Corresponding Author:

Wenting Huang PhD

Behavioral, Social, and Health Education Sciences

Rollins School of Public Health

Emory University

1518 Clifton Rd

Atlanta

US

Abstract

Background: There remain unmet HIV prevention needs in China, particularly among gay, bisexual, and other men who have sex with men (MSM). Technology-based interventions are increasingly used in HIV prevention globally.

Objective: To perform a systematic review and meta-analysis of studies to assess the effectiveness of technology-based HIV prevention interventions to improve HIV testing and consistent condom use in China.

Methods: We searched in English (PubMed/MEDLINE, Embase, and Web of Science) and Chinese (Wanfang, WEIPU, and CNKI) databases for technology-based HIV prevention studies published between January 1, 2004 to September 30, 2021. Eligible studies were technology-based HIV prevention intervention studies with outcomes of HIV testing and/or condom use among MSM and/or transgender women using randomized controlled or non-randomized pretest-posttest designs in China. Intervention technologies identified apps, web pages, and other types of electronic communications (e.g., email, short message services, and video messages). Two researchers screened and extracted data independently for each study. Bayesian meta-analysis was conducted to estimate the pooled effect size and 95% credible interval (CrI). We added study and intervention features as covariates to explore their associations with the study effects. Study quality was assessed using the Integrated Quality Criteria for Review of Multiple Study Designs. Publication bias was assessed by funnel plots and Robust Bayesian Meta-Analyses.

Results: We identified 1214 and 1691 records from English and Chinese databases, respectively. A total of 141 records entered the full-text screening and, 24 studies were eligible for the review. About half of the interventions (n=14) were delivered through social media platforms, predominantly using message-based communication. The remaining studies used email and web-based platforms. The pooled effect sizes estimated were an absolute increase of 20% (95%CrI: 0.10-0.30) in HIV testing uptake and an absolute increase of 15% (95%CrI: 0.05-0.26) in consistent condom use. The pooled point estimate of effect from RCT studies was smaller than non-randomized studies for HIV testing uptake (16% vs. 23%) and consistent condom use (10% vs. 19%), but their CrIs were largely overlapping. Interventions lasting more than six months were associated with a 35% greater uptake of HIV testing (95%CrI: 0.19, 0.51) compared to those lasting six months.

Conclusions: Technology-based HIV prevention interventions are promising strategies to improve HIV testing uptake and

consistent condom use among MSM in China, with significant effects found across a broad array of studies and study designs. However, many studies in the review did not include randomized designs or include a control group. More rigorous study designs, such as RCT, are needed for this evidence base, with outcome measurements that address the limitation of self-report outcomes, to inform the development and implementation of future intervention programs.

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Original Manuscript

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Conclusions:

Technology-based HIV prevention interventions are promising strategies to improve HIV testing uptake and consistent condom use among MSM in China, with significant effects found across a broad array of studies and study designs. However, many studies in the review did not include randomized designs or include a control group. More rigorous study designs, such as RCT, are needed for this evidence base, with outcome measurements that address the limitation of self-report outcomes, to inform the development and implementation of future intervention programs.

Keywords: HIV; MSM; telemedicine; systematic review; Bayesian; meta-analysis



Introduction

HIV remains an important health concern and an area of public health efforts in China, with a particular focus on HIV transmission among gay, bisexual, and other men who have sex with men (MSM) due to high and sustained risk for HIV infection. A cross-sectional survey of 47,000 MSM from 61 cities in China in 2008-2009 found an overall HIV prevalence of 4.9% [1]. Since 2010, the HIV prevalence among MSM has emerged as the highest population-specific prevalence in China, increasing from 5.7% to 7.8% by 2014 according to China's National HIV Sentinel Surveillance System [2]. Studies have suggested that transgender women may face an even higher HIV prevalence (over 10%) than cisgender MSM [3-6].

Applying technology-based approaches to deliver HIV prevention information has been proposed as a critical part of engaging sexual minority populations that are disproportionately missed in HIV prevention and care in China [7]. These technology-based interventions include social media messaging [8], web-based HIV referral service [9], Chatbot [10], and gay social networking apps [11-13]. Given that more than 80% of MSM did not disclose their sexual orientation to healthcare providers in China [14], technology-based approaches allow for both improved targeting of interventions to this hidden population and represent an opportunity offer MSM and transgender women easier access to HIV prevention and care services while reducing fears related to stigma and discrimination. A literature review published in 2019 found multilevel technology-based interventions in China were effective in delivering HIV prevention and care services [15]. In addition to the various modes of technology, there is a popular "all-in-one" smartphone app in China, WeChat, providing opportunities to develop innovative interventions. WeChat offers multiple functions, including group chat messaging, voice and video calls, gaming, wallet and payments, and location sharing, in a single platform. WeChat has billions of monthly active users in China [16]. WeChat offers developers tools to make WeChat-based mini-apps which are not required to be downloaded and installed from app store [12]. These mini-apps can include different functions and features in WeChat and can deliver complex eHealth interventions like secondary distribution of HIV self-testing kits [17].

Globally, several systematic reviews have identified increased use of technology-based HIV interventions over the past two decades and have documented mixed evidence regarding the efficacy of such interventions across the world. Reviewing studies published in 2007-2019, a systematic review of technology-based HIV interventions described the trend of increasing eHealth modalities. Interventions were reported to be efficacious in increasing safe sex behaviors in the short term; only a quarter of the interventions reported maintaining the behavior change over a year [18]. Another systematic review from 2015-2020 found more pilot or quasi-experimental study designs than efficacy randomized control trials (RCTs). The review found promising feasibility and acceptability outcomes among pilot studies, and some efficacious outcomes among RCTs [19]. In addition to describing the types of technology used to deliver intervention and the reported behavior changes, a few recent meta-analyses assessed the effect sizes of technology-based interventions. A meta-analysis of eHealth interventions among MSM found a small but significant effect size for all three behavioral outcomes over reviewed study period, any condomless anal intercourse with nonpaying male partners (Cohen's $d=-0.21$, $p<0.001$),

HIV testing (Cohen's $d=0.38$, $p<0.001$) and having multiple sex partners (Cohen's $d=-0.26$, $p=0.02$) [20]. Another meta-analysis reviewing studies published in 2010-2018 estimated that the proportion of HIV testing uptake among study participants who exposed to technology-based interventions meant to increase testing was 1.5 times higher than that among unexposed study participants [21]. Across the two reviews, a number of intervention features were associated with greater impact on HIV testing, including interventions delivered through mainstream social media, providing self-testing kits or HIV test referral services, placing interventions on interactive platforms, involving target users, and providing longer periods of intervention exposure [20, 21]. Both meta-analyses reported high heterogeneity across their reviewed studies ($I^2=83.3\%$ [20], $I^2=65.2\%$ [21]). So far, all these systematic reviews have included technology-based HIV prevention interventions globally, but no one restricted to China. Given the numerous technology-based interventions and the unique WeChat platform in China, there is a need for a systematic assessment to document these intervention strategies and intervention effects. We aimed to describe technology-based HIV prevention interventions among MSM and transgender women in China, to document the intervention strategies, to estimate intervention effects, and to explore the relationships between intervention features and effect size. This review is narrower in geographic focus than prior reviews, allowing for understanding of local intervention effects in China. In prior reviews, small sample size and high heterogeneity across studies were often the major concerns given the use of conventional meta-analysis. Therefore, we conducted a Bayesian meta-analysis instead of the conventional frequentist meta-analysis to improve the precision of the pooled effect size estimation and provide the probability of the intervention effect being greater than zero [22-24].

Methods

The protocol for this review was registered on PROSPERO (Registration number CRD42021270856). This review was conducted following the guidance of the Cochrane Handbook and was reported following the guidance of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [25].

Eligibility criteria

The summary of eligibility criteria for this systematic review is presented in Table 1. In this review, we used a broad definition of technology to include Internet (e.g., webpage, social media platform, and smartphone applications) and other types of electronic communication (e.g., short message services (SMS), and video messages). Inclusion criteria and the search strategy were informed by the Population, Intervention, Comparison, Outcome (PICO) framework [26], including appropriate populations for the reviews' goals (e.g., HIV negative MSM and/or transgender women residing in China, including Taiwan, Hong Kong and Macau), use of an technology-based intervention, an eligible study type (e.g., RCT, and non-randomized designs like one group pretest-posttest, pretest-posttest with a non-equivalent comparison group), eligible study outcomes (e.g., HIV seroconversion, HIV testing, condom use, pre-exposure prophylaxis (PrEP) initiation, PrEP awareness and willingness), and eligible data collection timeframe (January 1, 2004 to September 30, 2021) and publication timeframe (January 1, 2004 to September 30, 2021).

Exclusion criteria were studies that exclusively used phone calls or in-person interventions; that focused on persons living with HIV; or that did not have quantitative HIV prevention outcome (e.g., qualitative outcomes).

Study identification and selection

We searched the PubMed (including PubMed Central and MEDLINE), Embase, Web of Science, Wanfang, WEIPU (including CSJD-VIP), China Academic Journals Full-text Database (CJFD)/China National Knowledge Infrastructure (CNKI), and Chinese Biomedical Literature Database (CMB) for studies published between January 1, 2004 to September 30, 2021. Conference abstracts were searched from the online archives of the International AIDS Society (IAS) Conference and the Conference on Retroviruses and Opportunistic Infections (CROI) for English publications, as well as the Chinese National Conference of HIV/AIDS for Chinese publications. Search terms were first developed in English and then translated into academic Chinese terminology for searching Chinese-language databases. A full description of the search terms can be found in Supplement 1.

Records identified from the keywords search were managed in Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia). The selection procedure followed the guideline of PRISMA (Figure 1). Duplicate records were checked across English and Chinese literature and were removed (n=371). Two researchers screened titles and abstracts independently to exclude records that clearly did not meet the inclusion criteria or clearly met the exclusion criteria. The eligibility of the remaining records was assessed using full-text articles. During the full-text review, all included articles were retrieved (n=141) and reviewed by two researchers independently. Discrepancies were solved through discussion between the two researchers and a senior researcher. After 115 articles were removed according to exclusion criteria, a total of 24 articles (11 articles in English, 12 articles in Chinese, and 1 abstract in English) were included in the final review.

Study quality assessment

Study quality was assessed using the Integrated Quality Criteria for Review of Multiple Study Designs (ICROMS), a tool developed for a wide range of study designs, including RCTs, pre-post studies, cohort studies, and interrupted time series analyses [27]. The ICROMS consists of two components: (1) a scoring system for quality of study design, and (2) a “decision matrix”, which provides mandatory criteria and minimum requirement scores for specific study designs relating to the robustness of the study. The assessment of ICROMS has seven dimensions, ranging from study aims to managing bias. Each dimension has three to seven specific criteria for quality assessment. This measure has been used in previous systematic reviews of eHealth interventions [18, 28]. Each study was assessed by two researchers independently. Discrepancies were solved by discussion between the two researchers.

Data extraction

Data extraction for each study was performed by two coders (WH, SW, KN, YW) independently. Studies published in Chinese were only extracted by bilingual coders (WH, KN, YW). A standard, Excel-based tool was used to extract data on publication year,

language (English or Chinese), study design, sample size, technology mode, behavioral theory applied, intervention development, intervention delivery, outcome measurement (e.g., the length of recalled period), and results and analyses (e.g., number of consistent condom uses, number of HIV tests, effect size measurement, and reported effect size). Several intervention features were further coded for use as covariates. These features included whether the intervention was theoretically based (i.e., developed based on a behavioral change theory); whether it had active engagement with users (e.g., using interactive dialogue box, motivational interviewing, and one-on-one counseling session); whether it was an intervention designed to have more than a one-time interaction; whether the intervention development and delivery involved target population; the length of intervention (e.g., less than six months, six months, and more than six months); and the length of study follow-up (e.g., three months, six months, and twelve months). Studies did not report these features were coded as “no”. Extracted data were compared and discrepancies were discussed with a third coder until reaching consensus.

Data synthesis

The primary outcomes for the review were HIV testing uptake and consistent condom use. We defined HIV testing uptake as the proportion of participants who reported receiving a facility-based HIV test during the study period or who used an HIV test kit in the study period. Consistent condom use was defined as the proportion of participants with no condomless anal sex with any partners in the study period. When articles reported multiple follow-up assessments, longest follow-up interval was used for the outcomes of interest. Effect sizes were calculated as mean differences either between intervention and control/comparison groups or between pretest and posttest depending on the study design. The uncertainty assessed with their standard errors. Standard errors were extracted from studies that reported it; for studies that did not report standard errors, we manually calculated them by comparing either intervention and control groups for RCTs, or between pretest and posttest outcomes or between intervention and comparison groups for non-randomized studies. Therefore, one HIV testing uptake outcome and/or one consistent condom use outcome were produced for each study. Studies using noninferiority designs ($n=2$) were excluded from the meta-analysis given the goal of the review to estimate overall effect sizes. We decided to use absolute effect instead of relative effect because absolute effect is easier to interpret for clinical practice; in contrast, relative measures sometimes provide misleading estimates [29].

Given the expected heterogeneity across studies, a Bayesian random effects model were used to estimate the pooled effect size and 95% credible interval (CrI) for behavioral changes in HIV testing uptake and consistent condom use associated with interventions [23]. This model assumes that reported study estimates, γ , follow a normal distribution with mean equal to the true study effect, and standard deviation (SD) equal to the reported standard error. The true study effects, θ , were assumed to arise from a normal distribution with mean equal to the overall meta-analytic estimate, μ , and study heterogeneity, τ . In a robust version of this hierarchical model, we specified the true study effects as arising from a t-distribution (with estimated degrees of freedom) to increase robustness against potential outliers. We chose vaguely informative default priors for all model parameters and conducted prior sensitivity analyses. For details, see Supplement 3. All models were estimated using Hamiltonian Monte Carlo sampling [30]. We ran four Markov chains for

20,000 iterations, dropping the first 10,000 iterations as burn-in phase. Forest plots were used to display the estimates.

To explore relevant study and intervention features that could be associated with the study effect sizes, we added the study and intervention features as covariates to the Bayesian model. Heterogeneity and potential publication bias were evaluated qualitatively through examining contour-enhanced funnel plots, which included the statistical significance of study estimates, and quantitatively through examination of the Bayes factor with robust Bayesian meta-analysis. We also conducted subgroup analysis to estimate the pooled effect sizes and 95%CrIs by RCT and non-randomized designed studies. All analysis was performed using brms and RoBMA package in R 4.3.1 (version 2.20.4).

Results

Study Characteristics

We identified 1214 records from English databases and 1691 records from Chinese databases, published between January 1, 2004 to September 30, 2021. Removing 371 duplicate records, 2534 records were screened with titles and abstracts, and a total of 141 records were included in the full-text screening. After the full-text screening, 24 studies were included in the final review. The study selection process and reasons for exclusion were presented in Figure 1. Table 2 presents the characteristics of each reviewed study, including study design (with dates and sample size), technology type, intervention, theoretical framework and intervention development, intervention delivery and frequency, and reported results. Half of the reviewed studies (n=12) were published in English and half (n=12) were published in Chinese. Most study sites were in mainland China (n=19). Other study sites included Hong Kong (n=3) [31-33] and Taiwan (n=2) [34, 35]. Although transgender women were included in our search strategy, eligible studies were restricted to MSM. Over half (n=13) of studies were RCTs. Among the RCTs, eight studies were two-group parallel RCTs, two studies were three-group parallel RCTs [32, 36], two studies were noninferiority RCTs [37, 38], and one was stepped-wedge cluster RCT [39]. Among the non-randomized studies (n=11), one study used pretest-posttest design with a nonequivalent comparison group [35], five used one-group pretest-posttest designs [40-44], and five studies used pretest-posttest designs with repeated cross-sectional surveys [45-49].

Intervention Features

The development of about one-quarter of study interventions (n=7) was informed by a behavioral theory [12, 13, 32-35, 50]. All studies guided by behavioral theories were published in English. The theories used included conventional behavioral theories like the Health Belief Model (HBM) [33], the Theory of Planned Behavior (TPB) [50], Diffusion of Innovations (DOI), information-motivation-behavioral skills model (IMB) [12, 34], and parallel-response model [32], as well as an HIV specific model – the AIDS Risk Reduction Model (ARRM) [13]. Regarding intervention content, over half of the studies (n=15) used a comprehensive intervention package rather than a single intervention [12, 13, 31, 33-36, 39, 40, 46-48, 50-52]. Most of these comprehensive interventions (14/15) included back-and-forth interaction with participants, such as screening for HIV-related risk behaviors, peer counseling, motivational interviewing, CBO-led activities, online-to-offline HIV counseling and testing, etc. [12, 13, 31, 33-36, 39, 40, 46-48, 50, 51]. Most of these

interactions (12/15) were live conversations with a research team member or a trained volunteer [12, 31, 33-35, 39, 40, 46-48, 50, 51]. A few studies used automatic reply text-based messages [13, 36, 50].

Over half of the studies (n=14) delivered intervention content through social media platforms and direct message functionality, among which half were WeChat-based [12, 13, 39, 40, 42, 51, 52]. A quarter of the studies (n=7) used text, video message, or email to deliver intervention content [12, 31, 32, 37, 38, 41, 45]. Five studies' interventions were delivered through web pages [13, 32, 45, 47, 50]. Six studies used two types of technologies in their interventions [12, 13, 31, 32, 45, 47]. Three quarters of studies (n=18) delivered their intervention multiple times; a third of those (n=6) did not report the frequency of intervention delivery. Among studies reporting their intervention delivery frequency, weekly (n=5) [12, 35, 41, 50, 52] and biweekly (n=4) [31, 34, 39, 42] were the most common frequencies. The length of intervention varied from a single time to a year, and the most frequent length of intervention was 6 months (n=9) [12, 31, 34, 35, 40-44]. In terms of community engagement, less than half of the studies (n=10) reported involving MSM in intervention development [12, 32-35, 37-40, 50] and a third of studies (n=9) reported engaging the MSM community in intervention delivery [31, 35, 39, 40, 42, 43, 46-48]. Only three studies reported engaging MSM community in both intervention development and delivery process [12, 35, 50].

Study Quality

Assessing quality with the ICROMS global quality scores, over two-thirds of studies (17/24) met the score requirement (Table S4). When considering the mandatory criteria, only 6 studies met the criteria, all of which were RCTs. Reviewing the quality by study design, for RCTs, one study did not meet the score requirement [36] and six trials did not meet the mandatory criteria of managing bias between groups with random allocation [12, 31, 33, 34, 51, 52]. The controlled pretest-posttest design study did not meet either the score requirement or the mandatory criteria [35]. For uncontrolled pretest-posttest design studies (n=10), half of the studies did not meet the minimum requirement [40, 42, 45, 47, 48] and none of them met the mandatory criteria of mitigating the effect of no control group.

Publication Bias

The contour-enhanced funnel plots in Figure 2 and 3 revealed an asymmetrical distribution of studies for both HIV testing uptake and consistent condom use, indicating possible publication bias. Particularly, three studies for HIV testing uptake [33, 46, 48] and two studies for consistent condom use [41, 46] seems reported a much larger effect sizes compared to the rest studies. The asymmetry regarded non-significant results suggested the asymmetrical distribution was probably caused by publication bias based on statistical significance. The Robust Bayesian Meta-Analyses (RoBMA) results document evidence for publication bias, with a Bayes factor of 21.04 and 4.37 indicating that the likelihood of publication bias was 21.04 and 4.37 times the likelihood of no publication bias for HIV testing uptake and consistent condom use, respectively. The Egger's test indicated no small-study effects for HIV testing uptake, as the result was not statistically significant with a z statistic of 0.24 and a p-value of 0.81; as well as for consistent condom use, as the result

was not statistically significant with a z statistic of 0.37 and a p-value of 0.71.

Bayesian Meta-analysis

For the meta-analysis, 15 studies were included for the HIV testing uptake outcome and 13 studies for the consistent condom use outcome. Among the 15 studies, most studies (n=13) reported an improvement of HIV testing uptake, while two studies reported no significant change. Only five studies estimated the effect size [12, 13, 33, 34, 39]; other studies performed chi-square tests to assess significance. For condom use behavior, most (10/13) reported an improvement in consistent condom use, three studies reported no significant change, and only three studies estimated an effect size.

The overall effect size estimated from the Bayesian random effects model were 0.20 (95%CrI: 0.10, 0.30) for HIV testing uptake and 0.15 (95%CrI: 0.05, 0.26) for consistent condom use. The probability that the mean difference exceeded zero was >99% for both HIV testing uptake and consistent condom use, despite the effect sizes for a few studies being estimated close to zero. In the HIV testing uptake model, the effect sizes of three studies seemed much larger than others [33, 46, 48]. However, after using a robust model with t-distributed random effects, the pooled effect size was 0.19 (95%CrI: 0.10, 0.30), similar to the estimates from the original model. The probability of that the mean difference exceeded zero was still >99%. Likewise, adjusting the two studies with large effect sizes [41, 46] in the robust model for consistent condom use yielded close estimates, 0.12 (95%CrI: 0.05, 0.23), compared to the original model.

The overall effect sizes were also estimated separately by study design (RCT and non-randomized design), given their difference in study quality assessment. Figure 4 presents the estimated effect sizes for HIV testing uptake by RCT and non-randomized designs. The pooled effect point estimate from RCT studies (0.16, 95%CrI: -0.02, 0.33) was smaller than non-randomized studies (0.23, 95%CrI: 0.07, 0.38), but the credible intervals were largely overlapping. The 95% credible interval for RCT was slightly wider than non-randomized studies, but they were largely overlapping. Similarly, the pooled effect point estimate for consistent condom use among RCTs (0.10, 95%CrI: -0.02, 0.21) was also smaller than non-randomized designed studies (0.19, 95%CrI: -0.00, 0.37) studies, but these credible intervals were largely overlapping (Figure 5). Detailed model results are presented in Table S1 in Supplement 2.

Covariates analysis

We explored the association between behavioral change outcomes (HIV testing uptake and consistent condom use) and study characteristics and intervention features (Table 3). Among the study characteristics and intervention features we assessed, the only characteristic that associated with the behavioral change outcome was the length of intervention and study follow-up. Intervention lasting more than six months was associated with a 35% greater uptake of HIV testing (95%CrI: 0.19, 0.51) compared to six months. Studies followed up for twelve months was associated with a 2% greater uptake of HIV testing (95%CrI: 0.01, 0.39) compared to those followed up for six months.

Sensitivity analysis

We conducted sensitivity analysis using different priors such as a non-informative prior (μ

$\sim N(0, 10000)$) and an informative prior ($\mu \sim N(0.38, 1)$ for HIV testing uptake, $\mu \sim N(0.21, 1)$ for consistent condom use) on meta-analytic means, as well as an alternative heterogeneity prior ($\tau \sim \text{Half-Cauchy}(0, 1)$) (Supplement Table S2 and S3). For both HIV testing uptake and consistent condom use models, the effect estimates across models were similar to the original models, suggesting that the estimated effects from the original models are stable.

Discussion

Reviewing a total of 24 eligible studies published in the last two decades, we found promising intervention effects for technology-based interventions designed to support HIV testing uptake and consistent condom use among MSM in China. The estimated pooled effect sizes from our primary Bayesian meta-analysis found a promising absolute effect on increasing both HIV testing and condom use: a 20% increase of HIV testing uptake and a 15% increase in consistent condom use. The probability that the effect size exceeds zero is over 99% for both HIV testing uptake and consistent condom use. To address potential outlier studies reporting larger effects compared to other reviewed studies, we performed robust models for both outcomes which estimated pool effect sizes similar to the original models. These promising behavior changing effects among interventions in China align with findings from other meta-analyses world widely. A previous global meta-analysis which identified a significant effect in increasing HIV testing uptake (Cohen's $d=0.38$) and reducing condomless anal intercourse (Cohen's $d=0.21$) [20]. Another meta-analysis of computer-based interventions also estimated a significant effect in increasing condom use (Cohen's $d=0.26$) [53]. To address concerns with prior selection, we conducted sensitivity analysis with different types of priors for both HIV testing uptake and consistent condom use. These models produced similar estimates to the original models. Therefore, we propose that technology-based interventions were likely to be effective in changing these two behaviors based on the reviewed studies.

We conducted sub-group analysis to explore the difference of estimated effect sizes across study designs to account for the varied quality of study, despite the benefit of Bayesian random effects model is allowing combination of the effect sizes from studies with different designs. We found that the estimated pool effect sizes for non-randomized studies were slightly larger than RCT studies, in both outcomes of HIV testing uptake and consistent condom use. The effect sizes dispersion of consistent condom use among RCTs seems lower than non-randomized studies. However, these 95% CrIs were largely overlapped, indicating the effect size differences between study designs were not significant or substantial. Previous meta-analyses examined the effect size difference in study design reported a significant estimated effect size difference in unprotected anal intercourse reduction across RCT and non-randomized designs, while not significant in HIV testing uptake improvements [20, 21]. These inconsistent findings suggest that study designs should be explored as an essential factor that could impact on the intervention effect size in future meta-analysis. It also urges more rigorous study designs like RCT to fully demonstrate the effects of these technology-based interventions.

Previous reviews and meta-analyses indicate several intervention features might be associated with the intervention effect, including involvement of users in the design process, interactive intervention, multiple intervention sessions, longer treatment duration,

and the use of combined technology modalities to deliver intervention [20, 21]. However, we did not find any significant association between these intervention features and the effect size, which could be due to the known issue of small sample size for specific features (i.e., the small number of studies included with these traits). Although our meta-regression analysis shows that the intervention lasting over 6 months seems to have a significant greater impact on HIV testing uptake compared to the interventions lasting 6 months, it could be a coincidence since the two studies that delivered intervention over 6 months are those reported a much larger effect sizes compared to the rest studies [46, 48]. Moreover, we did not find any other intervention features, such as theory-based intervention content, back-and-forth interactions, multiple intervention sessions, and community engagement, that could possibly explain the association between intervention duration and effects on HIV testing uptake.

One of the unique features of these mHealth interventions in China is leveraging the same mainstream all-in-one social networking app, WeChat. As mHealth becomes a more important and efficient tool to deliver health interventions, there are lingering questions regarding how to tailor interventions for target populations and how to scale up efficacious interventions to a boarder range of populations [19, 54]. Technology-based intervention modes have expanded from web-based, to short messages, to social media [18, 55, 56]. Having 1.3 billion monthly active users (over 80% of the population) in China [57], WeChat is a convenient platform to distribute direct message with text, pictures, and videos to specific users. It also offers a platform for people to develop WeChat-based applications which are less costly compared to developing a standard smartphone application [16]. Additionally, using a mainstream social networking app instead of an MSM-focused app may reduce the concern of stigma avoiding unanticipated “outing” or labeling. In our review, despite that most studies that used WeChat only used its direct messaging function to deliver interventions, several studies developed an official account or a mini-app to provide risk assessment and HIV self-testing kit distribution [12, 42, 51, 52]. Some researchers are also exploring approaches to leverage the social media platform to provide more comprehensive services together with MSM focused community-based organization and public opinion leaders [58-60]. Employing this social networking platform, researchers may be able to enhance community engagement and provide more comprehensive health services to a larger target population.

Despite the meta-regression showing no significant finding between effect size and intervention features, some patterns in the intervention development and delivery can still be observed descriptively. For example, theory-based interventions have been reported to be more effective than non-theory-based ones [61]. In our review, less than a third of the studies reported using a health behavior theory when developing the intervention. This low utilization of behavior change theory aligns with a prior review on mHealth studies in low- and middle-income countries [62]. This is not surprising, because most of the health behavior theories were developed in the context of high-income countries, and some of the constructs like self-efficacy could be difficult to apply without tailoring for the target population and local context. The insufficient utilization of health behavior change theories in the development of mHealth interventions highlights an opportunity to further improve the intervention effects with theory-guided intervention development, and reinforces the need to develop or tailor these existing theories into culturally and contextually appropriate theories.

Our analysis is limited by publication bias, given that significant and positive intervention results are more likely to be published. Non-significant findings should be encouraged to be published. All reviewed studies were conducted in the context of China. Despite that technology-based interventions in general found to be effective in HIV testing and condom use behavior, the application of technology and intervention contents should be tailored based on culture, context, and the needs of targeted populations in different countries. Additionally, the data available for analysis from original study reports was limited. Future intervention studies should be encouraged to report more details about the intervention features to allow further analysis or scale up. Moreover, we did not identify any study that targeted on transgender women in China in this review. This indicates a lack of technology-based HIV prevention intervention research for transgender women in China. The lack of research and high HIV prevalence among transgender women globally indicate a need for HIV prevention efforts tailored to this key population [6]. Finally, this review searched for studies published before 2021. There could be a risk for excluding relevant studies published during 2022-2024. These studies could be included in future reviews.

Conclusions

Existing social networking platforms in China provides great opportunities for technology-based intervention development and distribution in HIV prevention. Technology-based HIV prevention interventions were found to have significant effects on health behavior change of both HIV testing uptake and consistent condom use among MSM in China across a broad array of studies and study designs. However, many study designs in the review were less rigorous without a randomized design or a control group. More rigorous study designs, such as RCT, and measurement of outcomes that address limitation of self-report, such as picture verification of HIV self-tests, are needed to build up a more robust evidence base for the development and implementation of future technology-based intervention programs.

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Data Availability

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Conflicts of interest

None declared.

Abbreviation

ARRM: AIDS Risk Reduction Model

CrI: credible interval

CROI: Conference on retroviruses and opportunistic infections

DOI: diffusion of innovation

HBM: health belief model

HIV: human immunodeficiency virus

IAS: International AIDS society

ICROMS: integrated quality criteria for review of multiple study designs

IMB: information-motivation-behavioral skill model

MSM: men who have sex with men

PRISMA: preferred reporting items for systematic reviews and meta-analyses

RCT: randomized controlled trial

SMS: short message service

TPB: theory of planned behavior



Table 1. Summary of the inclusion/exclusion criteria for the systematic review of digital technology-based HIV prevention interventions for men who have sex with men in China, 2004-2021.

	Inclusion criteria	Exclusion criteria
Article or study type	• Randomized controlled trials • Non-randomized trials with pretest and posttest.	• Reviews, narratives, commentaries, and editorials. • Qualitative studies.
Study population	• HIV negative MSM • Transgender women	• Other populations
Study setting	• China (including Taiwan, Hong Kong, and Macau)	• Outside China
Study intervention	• Internet (e.g., webpage, social media platform, and smartphone applications) • Electronic communication (e.g., short message services (SMS), and video messages)	• Interventions that are not using any forms of Internet or electronic communication.
Main outcomes	• HIV seroconversion • HIV testing • Condom use • Pre-exposure prophylaxis (PrEP) initiation • PrEP awareness and willingness	• Studies that exclusively use phone calls or in-person interventions.
Quality criteria	• Peer-reviewed journal article • Conference abstracts of the International AIDS Society (IAS) Conference and the Conference on Retroviruses, Opportunistic Infections (CROI), or Chinese National Conference of HIV/AIDS	• Studies that are not published in a peer-reviewed journal • Conference abstracts that are not presented in the IAS, CROI, or Chinese National Conference of HIV/AIDS.
Language	• English or Chinese	• All other non-English or Chinese languages
Data collection period	• January 1, 2004, to September 30, 2021	• All periods outside January 1, 2004, to September 30, 2021
Publication period	• January 1, 2004, to September 30, 2021	• All periods outside January 1, 2004, to September 30, 2021

Table 2. Study design and intervention features in reviewed studies in China, 2004-2021 (n=24).

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Traditional RCTs with one intervention and one control group (n=8: 6 in English, 2 in Chinese)						
Cheng et al., 2019; Mainland China	Non-blind RCT; 9/2010-6/2011; n=1100	Webpages	I: Online interactive scenarios about HIV-related risk behaviors and health messages. C: Standard HIV referral service only.	Theory of Planned Behavior (TPB). Developed via mixed method formative research.	A total of 4 weeks: - one-time delivery of 5 scenarios via Web-based interactive dialogue box. - weekly health messages sent via email for 3 weeks;	I vs. C, BL to 6-month FU: • Condomless anal sex in the past 3 months decreased (Difference in proportion: 9.3%, 95%CI: 1.1-17.5%).
Chiou et al., 2020; Taiwan	RCT; 8/2015-5/2017; n=300	App – developed by the research team for MSM	I: A multifunction safe behavior and screening (SBS) app use for 6 months. C: No intervention.	Information-Motivation-Behavioral skills model (IMB). Developed through a qualitative study soliciting MSM's demand, MSM users review, and expert review on content validity.	A total of 24 weeks: - a message reminding user of the app's function was sent every 2 weeks. - a quiz and 2 activities related to HIV test, safe sex, and recreational drug use was sent every 3 weeks.	I vs. C, BL to 6-month FU: • HIV and syphilis testing frequency increased (mean difference: 0.217, SE=0.08). • Percentage of condom uses during anal sex in the past 3 months increased (Difference: 20.7%, SE=0.06). • Other outcomes: Disease and safe behavior knowledge increased (Difference: 2.13, SE=0.21).
Lau et al., 2008; Hong Kong	RCT; Not specified study dates; n=477	Email	I: Graphic health messages, HIV-related risk behaviors log-form with feedback, and peer counselors. C: No intervention.	Did not report any theory was used. Developed by a panel consisting of the authors.	A total of 6 months: - health message was sent via email every 2 weeks. - an e-log-form with feedback ('report card') was sent every month.	I vs. C, BL to 6-month FU: • No change in HIV testing in the past 6 months. • No change in condom uses during anal sex in the past 6 months. • Other outcomes: No change in HIV/STD-related knowledge and perceptions.

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Wang et al., 2018; Hong Kong	Non-blind RCT; Not specified study dates; n=430	App – a live-chat app	I: An online video promoting HIV testing, another online video and a motivational interviewing (MI) promoting HIV self-testing with online real-time instructions and pre-test/post-test counseling (HIVST-OIC), and a free-HIVST kit. C: An online video promoting HIV testing.	Health Belief Model (HBM). Developed through literature review and a stakeholder panel discussion.	One-time: - Online HIV testing promotion video: 3 minutes. - Online HIVST-OIC promotion video: 4 minutes. - A brief MI: 15 min.	I vs. C, BL to 6-month FU: • HIV testing rate increased (Relative risk (RR): 1.77, 95%CI: 1.54-2.03; absolute risk reduction (ARR): 39.1%, 95%CI: 31.3-46.9).
Yun et al., 2021; Mainland China	Double-blind RCT; 10/2017-6/2018; n=192	App – WeChat	I: A comprehensive intervention package includes 4 components: HIV risk assessment, HIV testing facilities recommendation, free condoms and HIV self-testing kit, and health education website. C: A link to a HIV health education webpage.	AIDS Risk Reduction Model. Did not report the process of intervention development.	A total of 3 months: - information related to the intervention was sent every 4 weeks.	I vs. C, BL to 3-month FU: • No change in HIV testing in the past 3 months. • Condom usage among casual partners in the past 3 months increased (Odds ratio (OR):2.81, 95%CI: 1.23-6.39).
Zhu et al., 2019; Hefei	RCT; 9/2017-6/2018; n=100	App – WeChat	I: WeTest program, plus watching a brief video demonstrating the use of HIVST kit and result interpretation, and two oral HIVST kits with standard information about regular HIV testing. C: Only the demonstration video watch, and two oral HIVST kits with standard information about regular HIV testing.	IMB model. Developed through formative in-depth interviews for intervention content, cognitive interviews for refining content, and pilot test of the beta-version WeTest program.	A total of 6 months: - Two health messages weekly about personal stories, data of HIV/STI infections among MSM, national policies, and general health concern stories of MSM. - One-time instruction of oral HIVST kit use.	I vs. C, BL to 6-month FU: • HIV testing in the past 6 months increased (adjusted RR: 1.99, 95%CI: 1.03-3.84). • Oral HIV self-test in the past 6 months increased (adjusted RR: 2.17, 95%CI: 1.08-4.37). • No change in consistent condom use in the past 6 months.

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Li et al., 2020; Mainland China	RCT; 3/2017-4/2019; n=600	App – WeChat	I: WeChat-based counseling, HIV testing, and test result notification; HIV infection risk evaluation and personal change suggestions. C: On-site intervention, including regular distribution of HIV education materials, in-person education class, counseling and HIV testing.	Did not report any theory was used. Did not report the process of intervention development.	Did not report the length of the intervention: - The HIV infection risk evaluation was sent every week.	I vs. C, BL to 6-month FU: • Condomless anal sex in the past 6 months decreased (I reduced from 42% to 16%; C reduced from 41% to 31%; $\chi^2=18.04$, $p<.05$).
Xiao et al., 2020; Shanghai	Double-blind RCT; 7/2017-6/2018; n=200	App – WeChat	I: MSM-focused HIV prevention message plus regular HIV prevention message. C: Regular HIV prevention message.	Did not report any theory was used. Did not report the process of intervention development.	A total of 12 months: - a weekly regular HIV prevention message. - a weekly MSM-focused HIV prevention message.	I vs. C, at 12-month FU: • No change in consistent condom use in the past 6 months. • Other outcomes: Knowledge increased in several AIDS knowledge items.
RCT with 2 intervention groups, and non-traditional RCT (n=5: all in English)						

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Lau et al., 2016; Hong Kong	Non-blind Three-group parallel RCT; Not specified study dates; n=402	Email and webpage	I₁: Sexually transmitted disease (STD)-related cognitive approach (SC): a video about STD prevention (Video I) and a video about MSM unprotected anal sex (UAI) prevention (Video II). I₂: STD-related cognitive plus fear appeal imagery approach (SCFI): an additional movie with fear appeal and visual imagery (Video III) plus Video I and Video II. C: HIV-related information-based approach: receive factual HIV-related text information but no video.	Parallel-Response model. Developed by an inter-disciplinary panel with MSM meetings.	One-time videos: - Video I: 5 minutes. - Video II: 5 minutes. - Video III: 10 minutes.	I₁ vs. I₂, I₁ vs. C, I₂ vs. C, at 3-month FU: • No change of unprotected anal sex (UAI) in the past 3 months post-intervention across the three groups. • Other outcomes: No significant association between immediate fear-related emotional responses and UAI.
Luo et al., 2021; Beijing China	Three-group parallel RCT; 10/2017-9/2018; n=9280	App – Blued	I₁: HIV risk assessment and tailored feedback plus the routine HIV education. I₂: HIV risk assessment plus the routine HIV education. C: Routine HIV education.	Did not report any theory was used. Did not report the process of intervention development.	Did not report the length of the intervention and delivery frequency.	I₁ vs. C, BL to 12-month FU: • Mean number of HIV tests in the past 12 months increased (Incident rate ratio (IRR): 1.32, 95%CI: 1.09-4.58). I₁ vs. I₂, I₁ vs. C, I₂ vs. C, BL to 12-month FU: • No statistical difference in the proportion of UAI among the three groups.

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Tang et al., 2016; Mainland China	Noninferiority RCT; Not specified study dates; n=721	Video message	I ₁ : A crowdsourced video promoting HIV testing. I ₂ : A health marketing video promoting HIV testing. C: No controlled or comparison group.	Did not report any theory was used. The 1-minute crowdsourced video was developed via a crowdsourcing contest. The health marketing video was developed by a marketing company with public health professional guidance.	One-time videos: - Both videos were 1 minute long.	I ₁ vs. I ₂ , at 3-week FU: • No difference in the first-time HIV testing with a noninferiority margin of -3%.
Tang et al., 2019; Mainland China	Noninferiority single-blind RCT; 11/2015-2/2016; n=1173	Video message	I ₁ : A crowdsourced video promoting condom use. I ₂ : A social marketing video promoting condom use.	Did not report any theory was used. The 1-minute crowdsourced video was developed via a crowdsourcing contest. The social marketing video was shot by a marketing company following a script by social marketing experts and approved by young MSM.	One-time: - Both videos were 1 minute long.	I ₁ vs. I ₂ , at 3-week FU: • No difference in proportions of condomless sex with a noninferiority margin of +10%. • No difference in HIV testing in the past 3 weeks with a noninferiority margin of +10%. I ₁ vs. I ₂ , at 3-month FU: • No difference in proportions of condomless sex with a noninferiority margin of +10%.

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Tang et al., 2018; Guangdong and Shandong	Stepped wedge cluster RCT; 7/2016-8/2017; n=1381	App – WeChat and other social media platforms	I: Routine CDC and CBO promotional efforts; HIV testing promotional image; a free HIVST kit; local CBO-led contest for HIV testing stories. C: Routine CDC and CBO promotional efforts.	Did not report any theory was used. Developed through a nationwide open context, a regional strategy designathon, and local participatory contests.	A total of 3 months: - Six HIV testing. promotional image was sent via WeChat biweekly. - One-time access to a free HIVST kit. - One-time local CBO-led contest.	I vs. historical C, BL to 12-month FU: • The proportion of HIV testing increased (Difference in proportion: 8.9%, 95%CI: 2.2-15.5). • The proportion of HIVST increased (RR: 1.89%, 95%CI: 1.50-2.38). • No change in facility-based HIV testing. • No change in condom use. • No change in syphilis testing, or anticipated HIV stigma.
Non-randomized pretest-posttest design (n=11: 1 in English, 10 in Chinese)						
Ko et al., 2013; Taiwan	Pretest-posttest design with nonequivalent group using repeated cross-sectional survey; 10/2010-11/2011; n=1008 at baseline and n=1037 at posttest	Webpage - Facebook	I: Trained Internet popular opinion leaders (iPOLs) share and exchange news, video clips, reports, and opinions, and connect with others for advice and support on an online iPOL platform built on Facebook uses the Web 2.0 2-way communication format. C: Another non-equivalent controlled website with no intervention.	The Diffusion of Innovation (DOI) theory. Did not report the process of intervention development.	A total of 6 months: - No regular schedule - Frequent sharing of information and 2-way conversations. - A total of 432 posts, 503 comments, and 804 likes on the iPOL platform. - Estimated 959,088 people viewed the posts on the iPOL platform.	I vs. C, BL to 6-month FU: • Increased HIV tests in the past 6 months (43.89% vs. 22.31%, $\chi^2=54.8$, $p<.01$). • Increased condom uses during anal sex with online sex partners (34.15% vs 26.19%, $\chi^2=13.4$, $p<.01$).
Liu et al., 2012; Mainland China	Pretest-posttest design using repeated cross-sectional survey; Not specified study dates; n=1293 at BL and n=1014 at posttest	Webpage and email	I: HIV prevention messages about risk of HIV infection, safe sex practice, and HIV tests through webpage and email. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 2 months: - Three sessions of HIV prevention education messages. - Did not report the intervention frequency.	BL to 3-month FU: • The proportion of lifetime HIV testing increased (49% to 54%, $p<.05$). • The proportion of last time condom use in sex with men increased (65% vs 71%, $p<.05$). • Other outcomes: Knowledge increased in several AIDS knowledge items.

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Xie et al., 2018; Dongguan	Pretest-posttest design using repeated cross-sectional survey; Not specified study dates; n=1510 at BL and n=1321 at posttest	App – ZANK	I: HIV prevention intervention. Did not report any intervention details. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 2 months: - Did not report the intervention delivery and frequency.	BL to 3-month FU: • The proportion of lifetime HIV testing increased (49% vs. 55%, $\chi^2=7.65$, $p<.05$). • Consistent condom uses in anal sex with men in the last 6 months increased (50% vs. 55%, $\chi^2=9.81$, $p<.05$). • The proportion of last time condom use in anal sex with men increased (67% vs. 73%, $\chi^2=10.8$, $p<.05$) • Other outcomes: Knowledge increased in several AIDS knowledge items.
Liu et al., 2014; Jining	One-group pretest-posttest design; 7/2012-12/2012; n=213	App – QQ and WeChat	I: CBO volunteers one-on-one HIV prevention intervention session via QQ or WeChat, set up a hotline for HIV and HIV testing counseling. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 6 months: - Each monthly intervention session last 30 minutes.	BL to 6-month FU: • The proportion of lifetime HIV testing increased (62% vs. 76%, $\chi^2=9.51$, $p<.05$). • Consistent condom uses in anal sex with men in the last 6 months increased (47% vs. 61%, $\chi^2=7.34$, $p<.05$). • The proportion of last time condom use in anal sex with men increased (56% vs 68%, $\chi^2=5.58$, $p<.05$).

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Song et al., 2017; Guangxi	One-group pretest-posttest design; 9/2014-12/2014; n=212	Short message services	I: Text messages about HIV knowledge, condom knowledge, and HIV testing information. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 6 months: - Two messages every week.	BL to 6-month FU: • No change in the proportion of HIV testing in the past 3 months. • Consistent condom uses in anal sex with men in the last 3 months increased (27% vs. 57%, $p<.05$) • The proportion of last time condom use in anal sex with men increased (38% vs 73%, $p<.05$)
Zhang et al., 2014; Shandong	One-group pretest-posttest design; 8/2013-5/2014; n=468	App – QQ	I: HIV prevention intervention about HIV knowledge, risk of infection, condom use and safe sex practice, and HIV testing. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 6 months: - Did not report the intervention delivery and frequency.	BL to 6-month FU: • The proportion of lifetime HIV testing increased (30% vs. 51%, $\chi^2=39.3$, $p<.01$). • Consistent condom uses in anal sex with men in the last 6 months increased (45% to 60%, $\chi^2=21.7$, $p<.01$). • Other outcomes: HIV knowledge increased (88% vs. 94%, $\chi^2=9.12$, $p<.01$).
Yan et al., 2013; Heilongjiang	One-group pretest-posttest design; 10/2011-12/2012; n=400	App – QQ	I: CBO volunteers one-on-one HIV prevention intervention session via QQ. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 6 months: - Did not report the intervention delivery and frequency.	BL to 6-month FU: • The proportion of lifetime HIV testing increased (57% vs. 68%, $p<.01$). • Consistent condom uses in anal sex with men in the last 3 months increased (45% vs. 60%, $p<.01$). • The proportion of last time condom use in anal sex with men increased (66% vs 82%, $p<.05$).

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Tao et al., 2020; Shaoxing	One-group pretest-posttest design; 4/2018-6/2018; n=209	App – WeChat	I: Health messages delivered by CBO. A free oral fluid based HIVST kit. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 6 months: - Health messages were delivered biweekly.	BL to 6-month FU: • Consistent condom uses in anal sex with regular partners in the past 6 months increased (52% to 64%, $\chi^2=4.42$, $p<.05$) • Consistent condom uses in anal sex with online casual partner in the past 6 months increased (67% to 85%, $\chi^2=8.50$, $p<.05$) • Consistent condom uses in anal sex with venue casual partner in the past 6 months increased (58% to 89%, $\chi^2=5.56$, $p<.05$) • Other outcomes: Knowledge increased in several AIDS knowledge items.
Wang et al., 2014; Chengdu	Pretest-posttest design using repeated cross-sectional survey; 10/2012-09/2013; n=370 at baseline and n=236 at posttest	Webpage and app	I: Multidimensional intervention model includes online- and venue-based interventions. Trained peer educators conducted online counseling and introduced MSM from online to offline to receive condom, lubricant, and HIV testing. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 12 months: - Did not report the intervention delivery frequency.	BL to 12-month FU: • Consistent condom uses in anal sex in the past 6 months increased (46% to 64%, $p<.01$)

Reference, Date; Location	Study Design Study Date Study Sample Size	Intervention Technology	Intervention (I), Control (C)	Theoretical Framework Intervention Development	Intervention Delivery and Frequency	Reported results ¹
Wang et al., 2011; Yingtan	Pretest-posttest design using repeated cross-sectional survey; 8/2009-8/2010; n=135 at baseline and n=134 at posttest	App – QQ	I: Peer education through QQ groups and on-site counseling. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 12 months: - Did not report the intervention delivery frequency.	BL to 12-month FU: • The proportion of lifetime HIV testing increased (10% vs 75%, $\chi^2=48.4$, $p<.01$). • Consistent condom uses in anal sex with men in the last 6 months increased (24% vs 78%, $\chi^2=78.2$, $p<.01$). • The proportion of last time condom use in anal sex with men increased (50% vs 90%, $\chi^2=35.8$, $p<.01$). • Other outcomes: Knowledge increased in several AIDS knowledge items.
Wang et al., 2009; Mianyang	Pretest-posttest design using repeated cross-sectional survey; 12/2006-1-/2008; n=201 at baseline and n=203 at posttest	Unclear	I: POL delivered online and offline peer education. C: No controlled or comparison group.	Did not report any theory was used. Did not report the process of intervention development.	A total of 12 months: - Did not report the intervention delivery frequency.	BL to 12-month FU: • HIV testing in the past 6 months increased (13% vs 54%, $\chi^2=76.5$, $p<.01$)

I, intervention; C, control; BL, baseline; FU, follow-up;
¹ Results were reported by the study authors. Point estimates for non-significant outcomes are left out.

Table 3. Association between study and intervention characteristics and study effect sizes in China, 2004-2021.

Study and intervention characteristics		HIV testing uptake (n=15)		Consistent condom use (n=13)	
		n(%)	coefficient (95%CrI)	n(%)	coefficient (95%CrI)
Publication year (median, range)		2014, 2008-2021	-0.01 (-0.03, 0.01)	2016, 2011-2020	-0.01 (-0.04, 0.02)
Publication language	English	7 (46.7)	Ref	4 (30.8)	Ref
	Chinese	8 (53.3)	0.04 (-0.12, 0.20)	9 (69.2)	0.10 (-0.07, 0.27)
Outcome measure	HIV testing in the lifetime	6 (40)	Ref	-	-
	HIV testing in the last 3 months	4 (27)	-0.04 (-0.24, 0.15)	-	-
	HIV testing in the last 6 months	5 (33)	0.09 (-0.11, 0.27)	-	-
	Consistent condom use in the last sex	-	-	1 (7.7)	Ref
	Consistent condom use in the last month	-	-	1 (7.7)	-0.04 (-0.50, 0.42)
	Consistent condom use in the last 3 months	-	-	5 (38.5)	0.10 (-0.24, 0.43)
	Consistent condom use in the last 6 months	-	-	6 (46.2)	0.10 (-0.24, 0.43)
Intervention based on a behavioral change theory	No	10 (66.7)	Ref	9 (69.2)	Ref
	Yes	5 (33.3)	0.05 (-0.12, 0.21)	4 (30.8)	-0.10 (-0.27, 0.07)
Intervention included back-and-forth interactions	No	4 (26.7)	Ref	5 (38.5)	Ref
	Yes	11 (73.3)	0.09 (-0.08, 0.27)	8 (61.5)	0.07 (-0.09, 0.24)
More than one time intervention session	No	4 (26.7)	Ref	8 (61.5)	Ref
	Yes	11 (73.3)	-0.05 (-0.21, 0.11)	5 (38.5)	-0.02 (-0.20, 0.15)
Intervention development involved target population	No	9 (60.0)	Ref	8 (61.5)	Ref
	Yes	6 (40.0)	0.04 (-0.13, 0.19)	5 (38.5)	-0.10 (-0.27, 0.06)
Intervention delivery engaged target population	No	8 (53.3)	Ref	8 (61.5)	Ref
	Yes	7 (46.7)	0.04 (-0.12, 0.21)	5 (38.5)	0.07 (-0.10, 0.25)
Length of intervention	Six months	8 (53.3)	Ref	5 (38.5)	Ref
	Less than six months	5 (33.3)	-0.06 (-0.17, 0.06)	5 (38.5)	-0.09 (-0.27, 0.10)
	More than six months	2 (13.3)	0.35 (0.19, 0.51)	3 (23.1)	0.08 (-0.15, 0.31)
Length of study follow-up	Six months	9 (60.0)	Ref	7 (53.8)	Ref
	Three months	3 (20.0)	-0.14 (-0.30, 0.02)	3 (23.1)	-0.10 (-0.29, 0.09)
	Twelve months	3 (20.0)	0.02 (0.01, 0.39)	3 (23.1)	0.10 (-0.12, 0.33)

Note: univariate meta-regression was performed for each characteristic.

Figure 2. Contour-enhanced funnel plot for correlation between probability of publication and magnitude of effect for HIV testing uptake in China, 2004-2021.

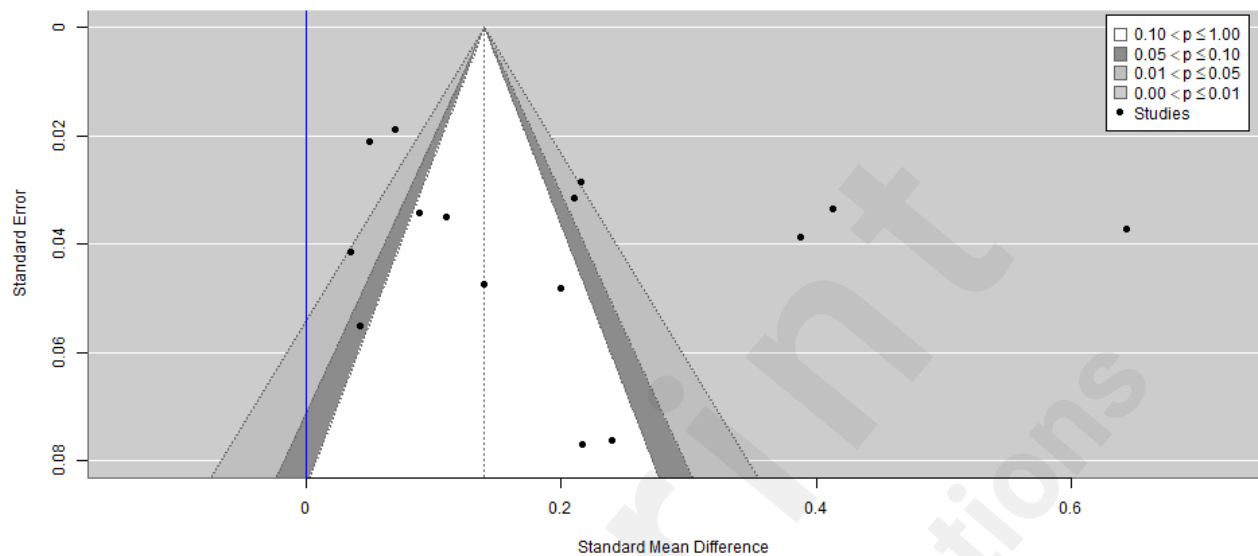


Figure 3. Contour-enhanced funnel plot for correlation between probability of publication and magnitude of effect for consistent condom use in China, 2004-2021.

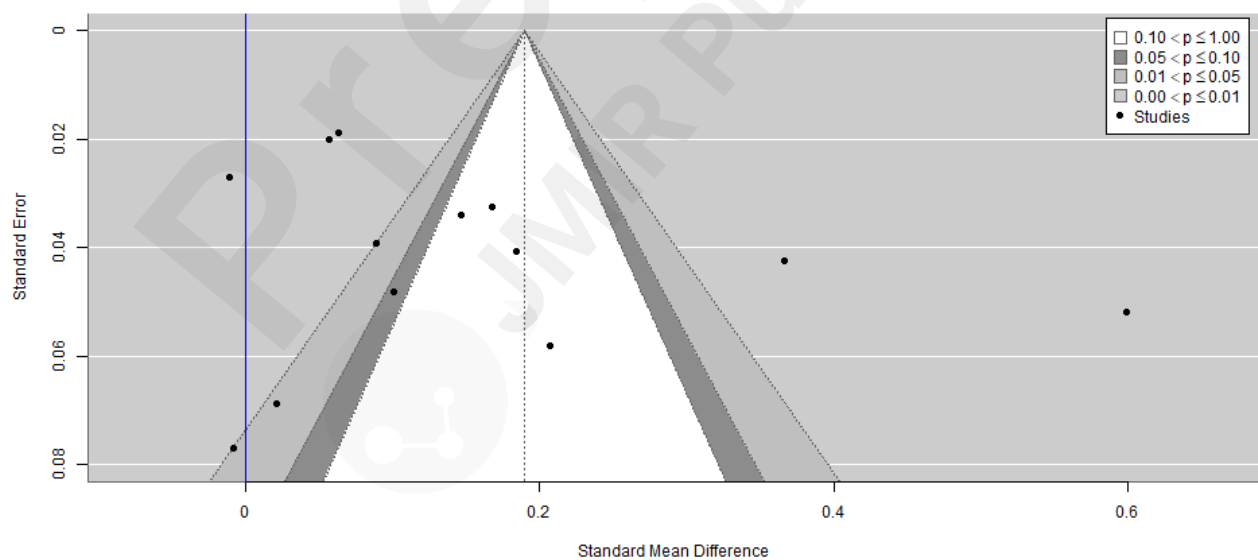


Figure 4. Forest plots of intervention effect on HIV testing uptake from Bayesian random effects meta-analysis in China, 2004-2021.

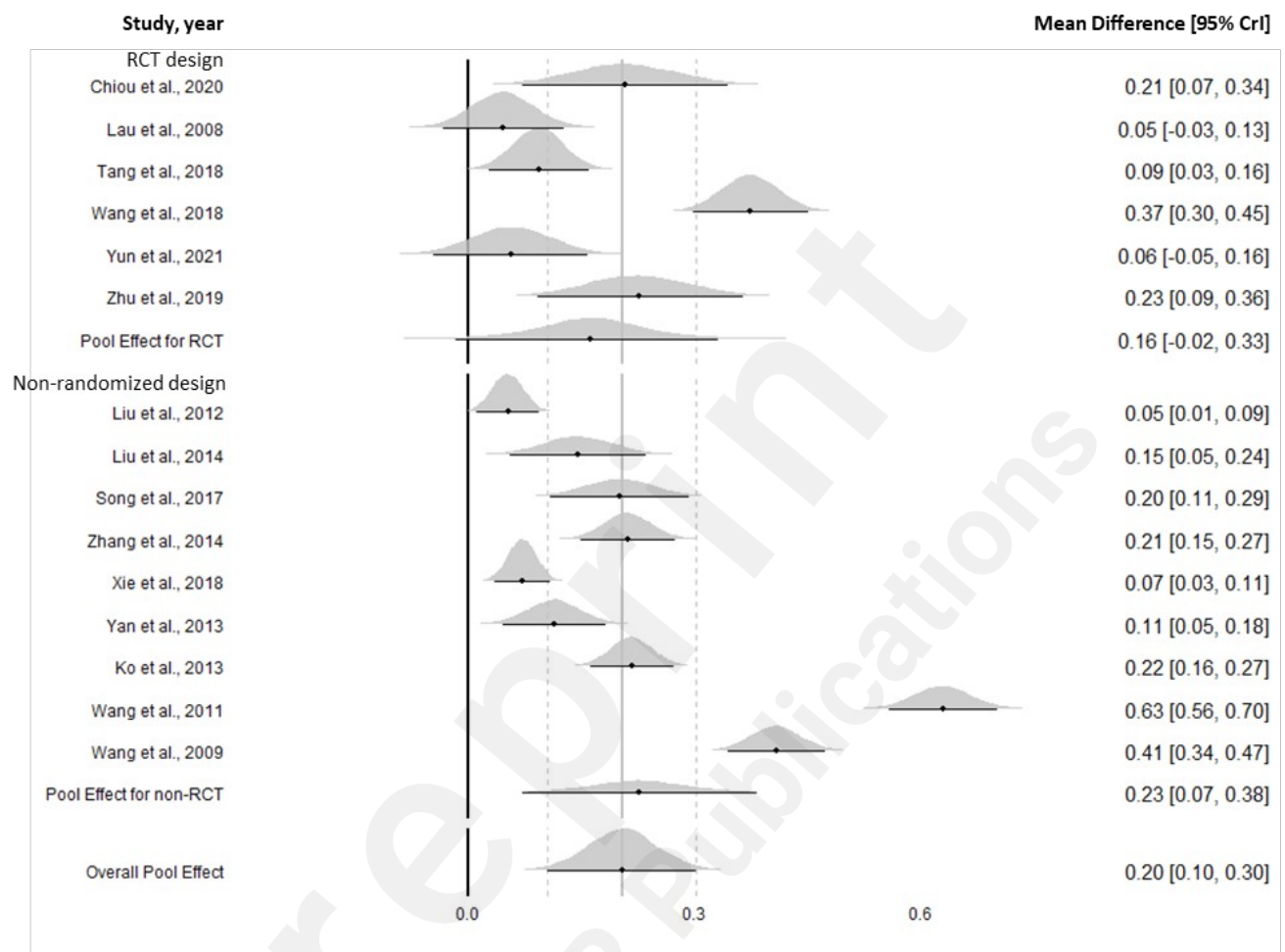
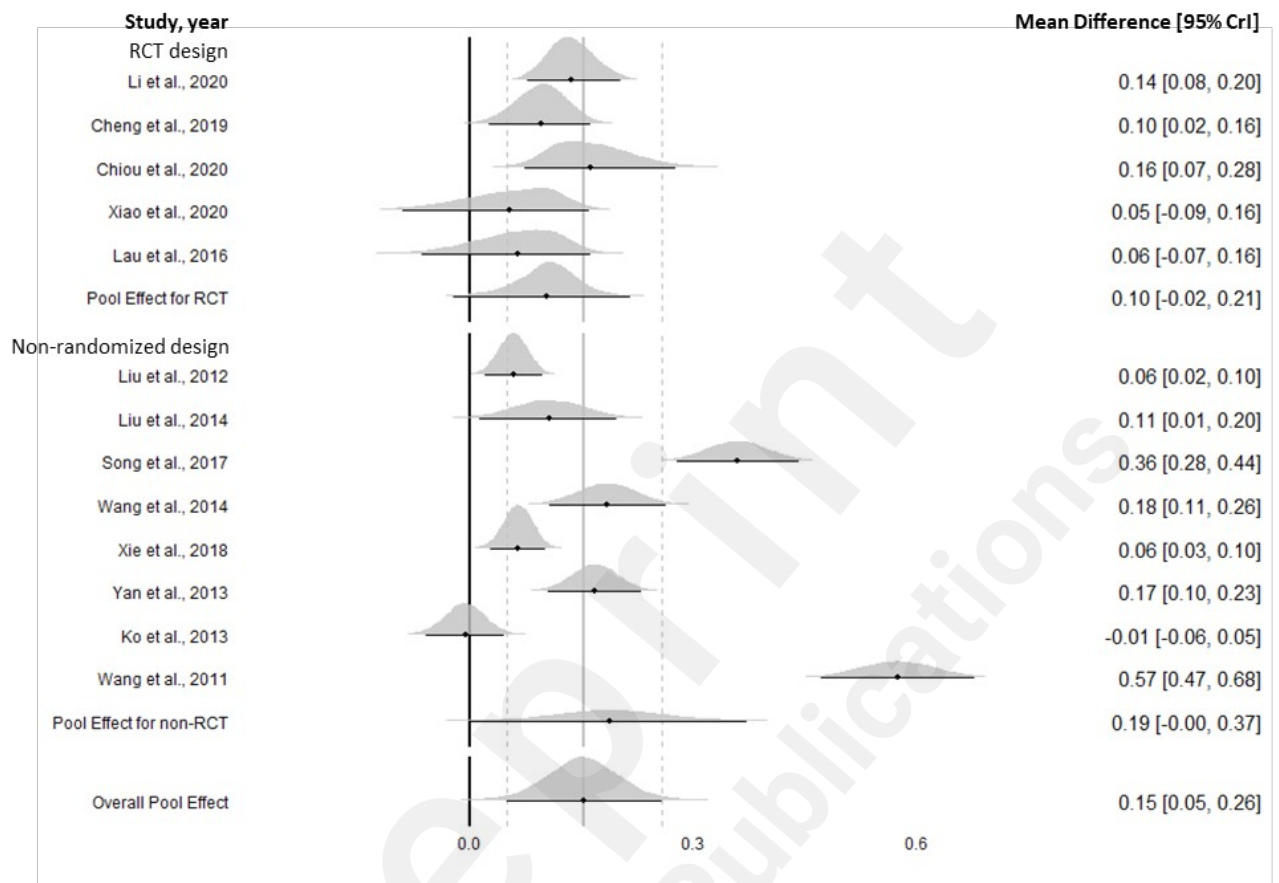


Figure 5. Forest plots of intervention effect on consistent condom use from Bayesian hierarchical random effects model in China, 2004-2021.



Supplement 1. Search strategy**Search terms used for English databases**

Database	Search terms	Date and Results
PubMed	(China[All Fields] or "Hong Kong"[All Fields] or "Macau"[All Fields] or "Taiwan"[All Fields]) AND (Tongzhi[tw] or "Male"[Mesh] or male[tw] or "Homosexuality, Male"[Mesh] or "Homosexual*" [tw] or msm[tw] or "men who have sex with men"[tw] or "transgender women"[tw] or "assigned male at birth"[tw] or AMAB[tw] or "transsexual women"[tw] or "gay men"[tw] or "gay male*" [tw] or "bisexual men"[tw] or "bisexual male*" [tw]) AND ("Acquired Immunodeficiency Syndrome"[Mesh] or "Acquired Immunodeficiency Syndrome"[tw] or "HIV Infections"[Mesh] or "HIV Infections"[tw] or HIV[tw] or AIDS[tw] or "Unsafe Sex"[Mesh] or "Risk-Taking"[Mesh] or "Risk-Taking"[tw] or "Unsafe Sex"[tw]) AND ("Telemedicine"[Mesh] or "Telemedicine"[tw] or "Internet"[Mesh] or "Internet"[tw] or "Online Systems"[Mesh] or "Online Systems"[tw] or "Online Social Networking"[Mesh] or "Online Social Networking"[tw] or "Smartphone"[Mesh] or "Smartphone*" [tw] or "Text Messaging"[Mesh] or "Text Messaging"[tw] or "mobile device*" [tw] or "Social Media"[Mesh] or "Social Media"[tw] or Facebook[tw] or Facetime[tw] or "Social media"[tw] or Wechat[tw] or Weibo[tw] or "web based"[tw] or online[tw] OR mHealth[tw] OR eHealth[tw] OR "mobile health"[tw] or web[tw] or "Web Browser"[Mesh] or "Mobile Applications"[Mesh] or "Mobile Applications"[tw] or app[tw] or "Cell Phone"[Mesh] or "Cell Phone"[tw])	10/18/2021 577 results
Embase	#1 'china'/exp OR 'china' OR 'hong kong'/exp OR 'hong kong' OR 'macau'/exp OR macau OR 'taiwan'/exp OR Taiwan #2 tongzhi OR 'male'/exp OR male OR 'homosexuality, male'/exp OR 'homosexuality, male' OR 'homosexual*' OR msm OR 'men who have sex with men'/exp OR 'men who have sex with men' OR 'transgender women' OR 'assigned male at birth' OR amab OR 'transsexual women' OR 'gay men'/exp OR 'gay men' OR 'gay male*' or "bisexual men" or "bisexual male*" #3 'acquired immunodeficiency syndrome'/exp OR 'acquired immunodeficiency syndrome' OR 'hiv infections'/exp OR 'hiv infections' OR 'hiv'/exp OR hiv OR 'aids'/exp OR aids OR 'risk-taking'/exp OR 'risk-taking' OR 'unsafe sex'/exp OR 'unsafe sex' #4 ('telemedicine'/exp OR 'telemedicine' OR 'internet'/exp OR 'internet' OR 'online systems'/exp OR 'online systems' OR 'online social networking'/exp OR 'online social networking') AND ('online social networking'/exp OR 'online social networking') OR 'smartphone'/exp OR 'smartphone' OR 'smartphone*' OR 'text messaging'/exp OR 'text messaging' OR 'mobile device*' OR 'facebook'/exp OR facebook OR facetime OR 'social media'/exp OR 'social media' OR 'wechat'/exp OR wechat OR weibo OR 'web based' OR 'online'/exp OR online OR 'mhealth'/exp OR mhealth OR 'ehealth'/exp OR ehealth OR 'mobile health'/exp OR 'mobile health' OR 'web'/exp OR web OR 'web browser'/exp OR 'web browser' OR 'mobile applications'/exp OR 'mobile applications' OR app OR 'cell phone'/exp OR 'cell phone' #5 #1 AND #2 AND #3 AND #4 #6 #1 AND #2 AND #3 AND #4 AND ([chinese]/lim OR [english]/lim)	10/19/2021 622 results
Web of Science	TOPIC: ((Tongzhi or male or "Homosexuality, Male" or "Homosexual*" or msm or "men who have sex with men" or "transgender women" or "assigned male at birth" or AMAB or "transsexual women" or "gay men" or "gay male*" or "bisexual men" or "bisexual male*")) AND TOPIC: (("Acquired Immunodeficiency Syndrome" or "HIV Infections" or HIV or AIDS or "Unsafe Sex" or "Risk-Taking" or "Unsafe Sex")) AND TOPIC: (("Telemedicine" or	10/19/2021 334 results

	"Internet" or "Online Systems" or "Online Social Networking" "Online Social Networking" or "Smartphone" or "Smartphone*" or "Text Messaging" or "Text Messaging" or "mobile device*" or "Social Media" or "Social Media" or Facebook or Facetime or "Social media" or Wechat or Weibo or "web based" or online OR mHealth OR eHealth OR "mobile health" or web or "Web Browser" or "Mobile Applications" or "Mobile Applications" or app or "Cell Phone")) AND PUBLICATION YEARS: (2021 OR 2016 OR 2011 OR 2007 OR 2020 OR 2015 OR 2010 OR 2006 OR 2019 OR 2014 OR 2009 OR 2005 OR 2018 OR 2013 OR 2008 OR 2017 OR 2012) AND LANGUAGES: (ENGLISH) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
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Search terms used for Chinese databases

"□□" or "□□" or "□□" or "□□" AND "□□" or "MSM" or "□□□" or "□□" or "□□□□□" or "□□□" AND "□□□" or "AIDS" or "HIV" AND "□□" or "□□" or "intervention" AND "□□□" or "□□□□" or "□□□□" or "□□" or "□□" or "eHealth" or "□□□□" or "□□□□□" or "□□" or "□□" or "□□□□" or "□□□□" or "□□"

Supplement 2. Bayesian hierarchical random effects model results

Model:

Observation level model

$$y_j \mid \theta_j, \sigma_j \sim N(\theta_j, \sigma_j^2)$$

Study effects model

$$\theta_j \mid \mu, \tau \sim N(\mu, \tau^2) \quad \mu \sim N(0, 1) \quad \tau \sim t_3(0, 1)$$

Study effects model (with robust random effects distribution)

$$\theta_j \mid \mu, \tau \sim t_\nu(\mu, \tau^2) \quad \mu \sim N(0, 1) \quad \tau \sim t_3(0, 1) \quad \nu \sim G(2, 0.1)$$

Estimation:

HMC using four chains run for 20,000 iterations with 10,000 removed as burn-in. We conducted standard diagnostics for absence of convergence and checked for divergent transitions and found no obvious issues.

Table S1. Bayesian hierarchical random effects model results.

Parameter	Posterior mean	SD	Lower CrL	Upper CrL
Model for HIV testing uptake (both RCT and non-randomized studies)				
μ	0.20	0.05	0.12	0.28
τ	0.18	0.04	0.13	0.26
Liu et al., 2012	-0.15	0.05	-0.24	-0.07
Liu et al., 2014	-0.06	0.07	-0.17	0.05
Song et al., 2017	0	0.07	-0.11	0.10
Zhang et al., 2014	0.01	0.06	-0.09	0.10
Chiou et al., 2020	0.01	0.08	-0.13	0.15
Xie et al., 2018	-0.13	0.05	-0.22	-0.05
Yan et al., 2013	-0.09	0.06	-0.19	0.01
Ko et al., 2013	0.01	0.06	-0.08	0.10
Lau et al., 2008	-0.16	0.06	-0.26	-0.06
Wang et al., 2011	0.42	0.06	0.32	0.52
Tang et al., 2018	-0.11	0.06	-0.21	-0.01
Wang et al., 2018	0.17	0.06	0.08	0.27
Yun et al., 2021	-0.15	0.07	-0.26	-0.03
Zhu et al., 2019	0.03	0.08	-0.10	0.16
Wang et al., 2009	0.20	0.06	0.11	0.30
Model for HIV testing uptake (RCT only)				
μ	0.16	0.09	0.03	0.30
τ	0.19	0.10	0.09	0.36
Chiou et al., 2020	0.05	0.10	-0.11	0.21
Lau et al., 2008	-0.12	0.09	-0.27	0.03
Tang et al., 2018	-0.07	0.09	-0.21	0.08
Wang et al., 2018	0.21	0.09	0.07	0.36
Yun et al., 2021	-0.10	0.10	-0.26	0.04
Zhu et al., 2019	0.06	0.10	-0.10	0.24
Model for HIV testing uptake (non-randomized studies only)				

μ	0.23	0.08	0.10	0.35
τ	0.22	0.07	0.14	0.36
Liu et al., 2012	-0.17	0.08	-0.30	-0.05
Liu et al., 2014	-0.08	0.09	-0.22	0.06
Song et al., 2017	-0.03	0.09	-0.17	0.12
Zhang et al., 2014	-0.02	0.08	-0.15	0.12
Xie et al., 2018	-0.15	0.08	-0.28	-0.03
Yan et al., 2013	-0.11	0.08	-0.25	0.02
Ko et al., 2013	-0.01	0.08	-0.14	0.12
Wang et al., 2011	0.40	0.08	0.27	0.54
Wang et al., 2009	0.18	0.08	0.05	0.32
Model for consistent condom use (both RCT and non-randomized studies)				
μ	0.15	0.05	0.07	0.24
τ	0.18	0.05	0.12	0.26
Liu et al., 2012	-0.09	0.06	-0.18	0
Liu et al., 2014	-0.05	0.07	-0.16	0.06
Song et al., 2017	0.20	0.06	0.10	0.31
Li et al., 2020	-0.01	0.06	-0.10	0.09
Cheng et al., 2019	-0.06	0.06	-0.16	0.04
Chiou et al., 2020	0.05	0.07	-0.07	0.17
Wang et al., 2014	0.03	0.06	-0.07	0.13
Xiao et al., 2020	-0.13	0.08	-0.27	0
Xie et al., 2018	-0.09	0.06	-0.18	0
Yan et al., 2013	0.01	0.06	-0.08	0.11
Ko et al., 2013	-0.16	0.06	-0.25	-0.07
Lau et al., 2016	-0.11	0.08	-0.24	0.02
Wang et al., 2011	0.41	0.07	0.29	0.53
Model for consistent condom use (RCT only)				
μ	0.10	0.06	0.01	0.18
τ	0.09	0.07	0.01	0.23
Li et al., 2020	0.03	0.06	-0.05	0.14
Cheng et al., 2019	-0.01	0.06	-0.10	0.09
Chiou et al., 2020	0.06	0.07	-0.03	0.19
Xiao et al., 2020	-0.05	0.07	-0.18	0.04
Lau et al., 2016	-0.04	0.07	-0.17	0.05
Model for consistent condom use (non-randomized studies only)				
μ	0.19	0.09	0.04	0.33
τ	0.24	0.09	0.14	0.41
Liu et al., 2012	-0.13	0.09	-0.28	0.02
Liu et al., 2014	-0.08	0.10	-0.24	0.08
Song et al., 2017	0.17	0.10	0.02	0.33
Wang et al., 2014	0	0.10	-0.16	0.16
Xie et al., 2018	-0.12	0.09	-0.27	0.03
Yan et al., 2013	-0.02	0.10	-0.17	0.14

Ko et al., 2013	-0.19	0.09	-0.35	-0.04
Wang et al., 2011	0.39	0.10	0.23	0.56
Models for HIV testing uptake, controlling for study quality				
μ	0.21	0.05	0.13	0.30
τ	0.16	0.04	0.10	0.24
Good quality ¹	-0.14	0.14	-0.37	0.07
Liu et al., 2012	-0.16	0.06	-0.25	-0.07
Liu et al., 2014	-0.07	0.07	-0.18	0.04
Song et al., 2017	-0.01	0.07	-0.12	0.10
Zhang et al., 2014	0	0.06	-0.10	0.09
Chiou et al., 2020	0	0.08	-0.13	0.14
Xie et al., 2018	-0.14	0.05	-0.23	-0.05
Yan et al., 2013	-0.10	0.06	-0.20	0
Ko et al., 2013	0	0.06	-0.09	0.10
Lau et al., 2008	-0.17	0.06	-0.27	-0.06
Wang et al., 2011	0.41	0.06	0.31	0.52
Tang et al., 2018	0.02	0.12	-0.18	0.22
Wang et al., 2018	0.16	0.06	0.06	0.27
Yun et al., 2021	-0.02	0.12	-0.23	0.18
Zhu et al., 2019	0.02	0.08	-0.11	0.15
Wang et al., 2009	0.19	0.06	0.09	0.29
Models for consistent condom use, controlling for study quality				
μ	0.16	0.06	0.07	0.25
τ	0.16	0.05	0.09	0.25
Good quality ¹	-0.10	0.14	-0.33	0.13
Liu et al., 2012	-0.10	0.06	-0.20	0
Liu et al., 2014	-0.05	0.07	-0.16	0.06
Song et al., 2017	0.20	0.07	0.09	0.31
Li et al., 2020	-0.01	0.06	-0.11	0.09
Cheng et al., 2019	0.03	0.13	-0.18	0.24
Chiou et al., 2020	0.04	0.07	-0.08	0.16
Wang et al., 2014	0.03	0.07	-0.08	0.13
Xiao et al., 2020	-0.13	0.09	-0.28	0.01
Xie et al., 2018	-0.09	0.06	-0.19	0
Yan et al., 2013	0.01	0.06	-0.09	0.11
Ko et al., 2013	-0.16	0.06	-0.26	-0.06
Lau et al., 2016	-0.03	0.13	-0.24	0.18
Wang et al., 2011	0.41	0.08	0.29	0.54

Supplement 3. Sensitivity analysis.**Table S2. Model estimates for sensitivity analysis for HIV testing uptake.**

	Posterior Mean	SD	Lower CrL	Upper CrL	Original Posterior Mean	% Deviation
Non-informative prior on meta analytic mean: μ prior ~ N(0, 10000)						
μ	0.21	0.05	0.12	0.28	0.19	8.08
τ	0.18	0.04	0.13	0.26	0.16	11.70
Informative priors on meta analytic mean: μ prior ~ N(0.38, 1)						
μ	0.20	0.05	0.13	0.28	0.19	7.49
τ	0.18	0.04	0.13	0.25	0.16	10.37
Alternative heterogeneity prior: τ prior ~ HC(0, 1)						
μ	0.20	0.05	0.12	0.28	0.19	-74.10
τ	0.18	0.04	0.13	0.26	0.16	-75.23

Note: The intercept prior N(0.38, 1) was based on findings from a previous meta-analysis study [20]. The “original posterior mean” column presents estimates from the robust model (Table 2). CrL = 95% credible interval; ESS = Effective sample size; % Deviation=(Mean – Original Mean)/ Original Mean*100; Tau represents the between-study heterogeneity.

Table S3. Model estimates for sensitivity analysis for consistent condom use

	Posterior Mean	SD	Lower CrL	Upper CrL	Original Posterior Mean	% Deviation
Non-informative priors on meta analytic mean: μ prior ~ N(0, 10000)						
μ	0.15	0.05	0.07	0.24	0.14	11.10
τ	0.18	0.05	0.12	0.26	0.15	18.18
Informative priors on meta analytic mean: μ prior ~ N(0.21, 1)						
μ	0.15	0.05	0.07	0.24	0.14	10.93
τ	0.18	0.04	0.12	0.26	0.15	16.22
Alternative heterogeneity prior: τ prior ~ HC(0, 1)						
μ	0.15	0.05	0.06	0.24	0.14	10.45
τ	0.18	0.05	0.12	0.27	0.15	17.8

Note: The intercept prior N(0.38, 1) was based on findings from a previous meta-analysis study [20]. The “original posterior mean” column presents estimates from the robust model (Table 2). CrL = 95% credible interval; ESS = Effective sample size; % Deviation=(Mean – Original Mean)/ Original Mean*100; Tau represents the between-study heterogeneity.

Supplement 4. Quality assessment**Table S4. Study quality assessment using ICROMS.**

Author, year	Study design	Global quality score	Minimum score met	Mandatory criteria met
Li et al., 2020	RCT	24	Yes	No
Cheng et al., 2019	RCT	28	Yes	Yes
Chiou et al., 2020	RCT	27	Yes	No
Xiao et al., 2020	RCT	27	Yes	No
Lau et al., 2008	RCT	29	Yes	No
Lau et al., 2016	RCT	30	Yes	Yes
Luo et al., 2021	RCT	19	No	No
Tang et al., 2016	RCT	31	Yes	Yes
Tang et al., 2018	RCT	31	Yes	Yes
Wang et al., 2018	RCT	29	Yes	No
Yun et al., 2021	RCT	31	Yes	Yes
Zhu et al., 2019	RCT	31	Yes	No
Tang et al., 2019	RCT	30	Yes	Yes
Ko et al., 2013	CBA	16	No	No
Liu et al., 2012	NCBA	20	No	No
Liu et al., 2014	NCBA	21	No	No
Song et al., 2017	NCBA	25	Yes	No
Zhang et al., 2014	NCBA	22	Yes	No
Wang et al., 2014	NCBA	16	No	No
Xie et al., 2018	NCBA	23	Yes	No
Yan et al., 2013	NCBA	22	Yes	No
Tao et al., 2020	NCBA	21	No	No
Wang et al., 2011	NCBA	22	Yes	No
Wang et al., 2009	NCBA	19	No	No

* The minimum required global quality scores are 22 for both randomized controlled trial (RCT) and non-controlled before-after (NCBA) studies, and 18 for controlled before-after (CBA) study based on integrated quality criteria for review of multiple study designs (ICROMS).

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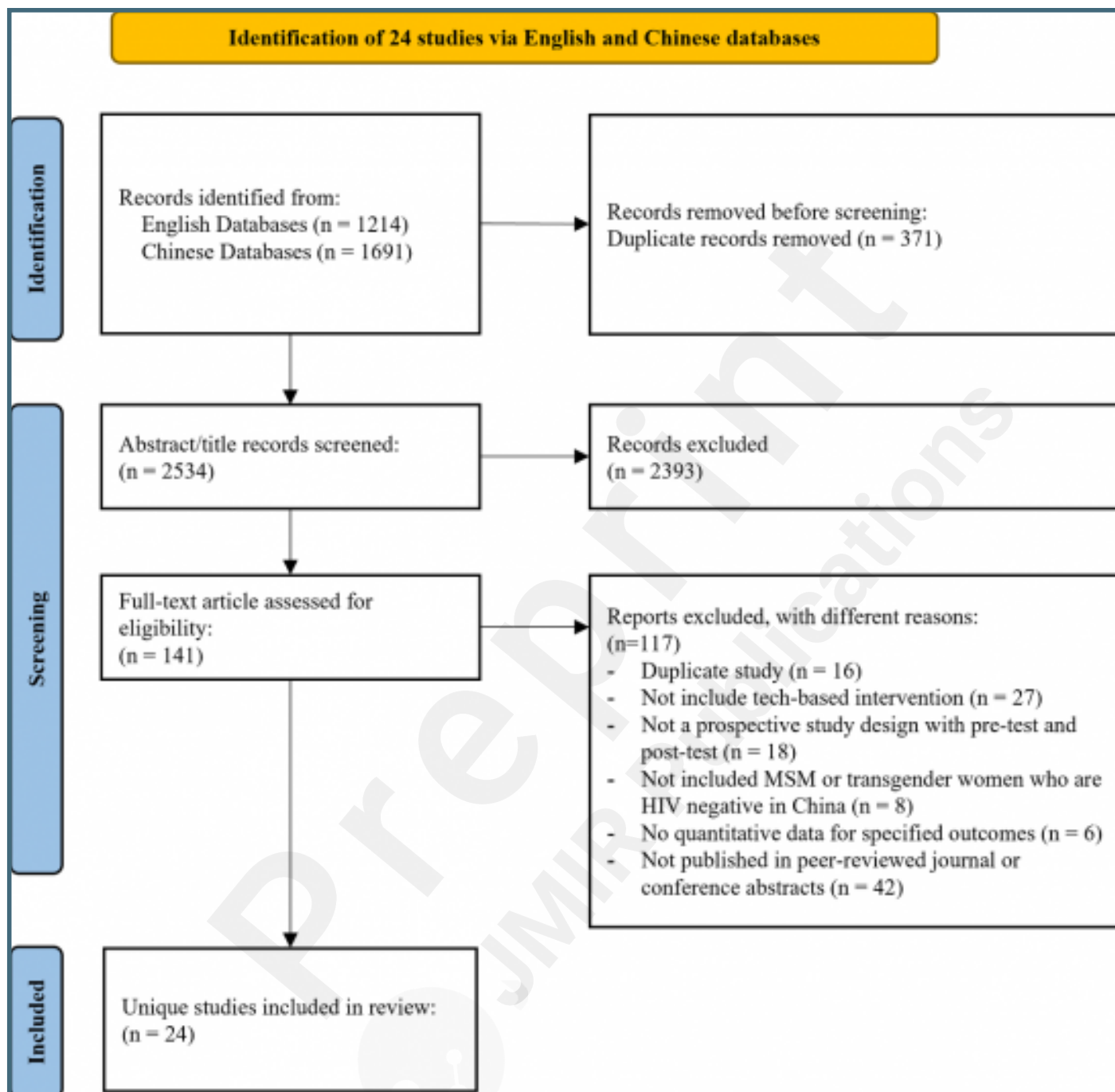
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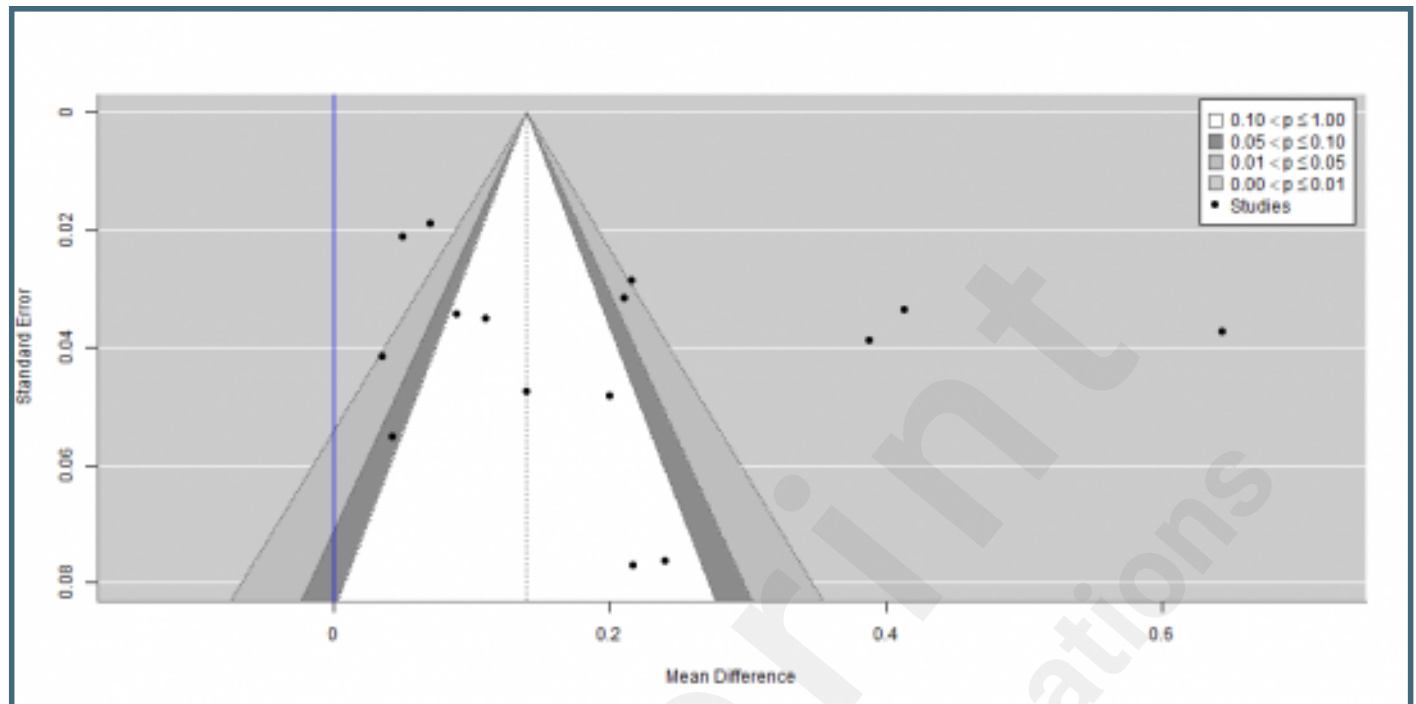
Supplementary Files

Figures

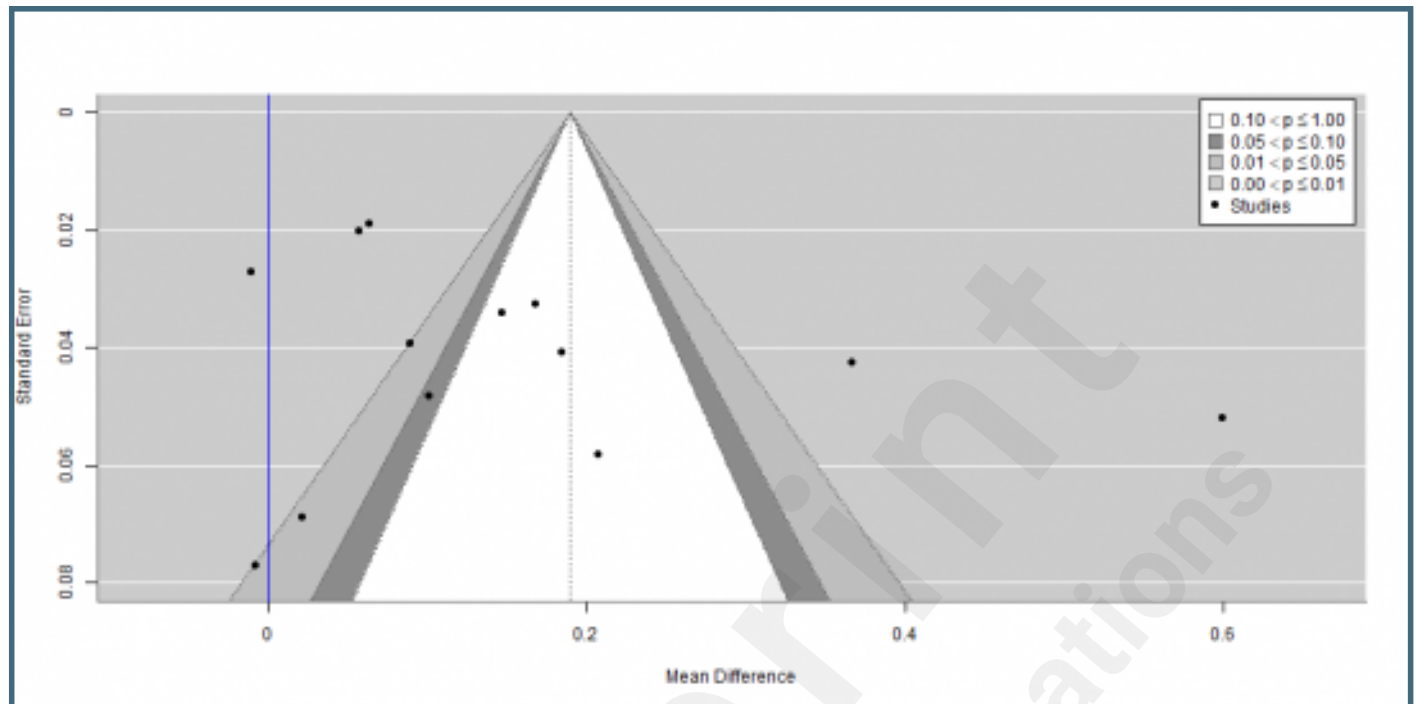
Flow chart of the study search and selection process.



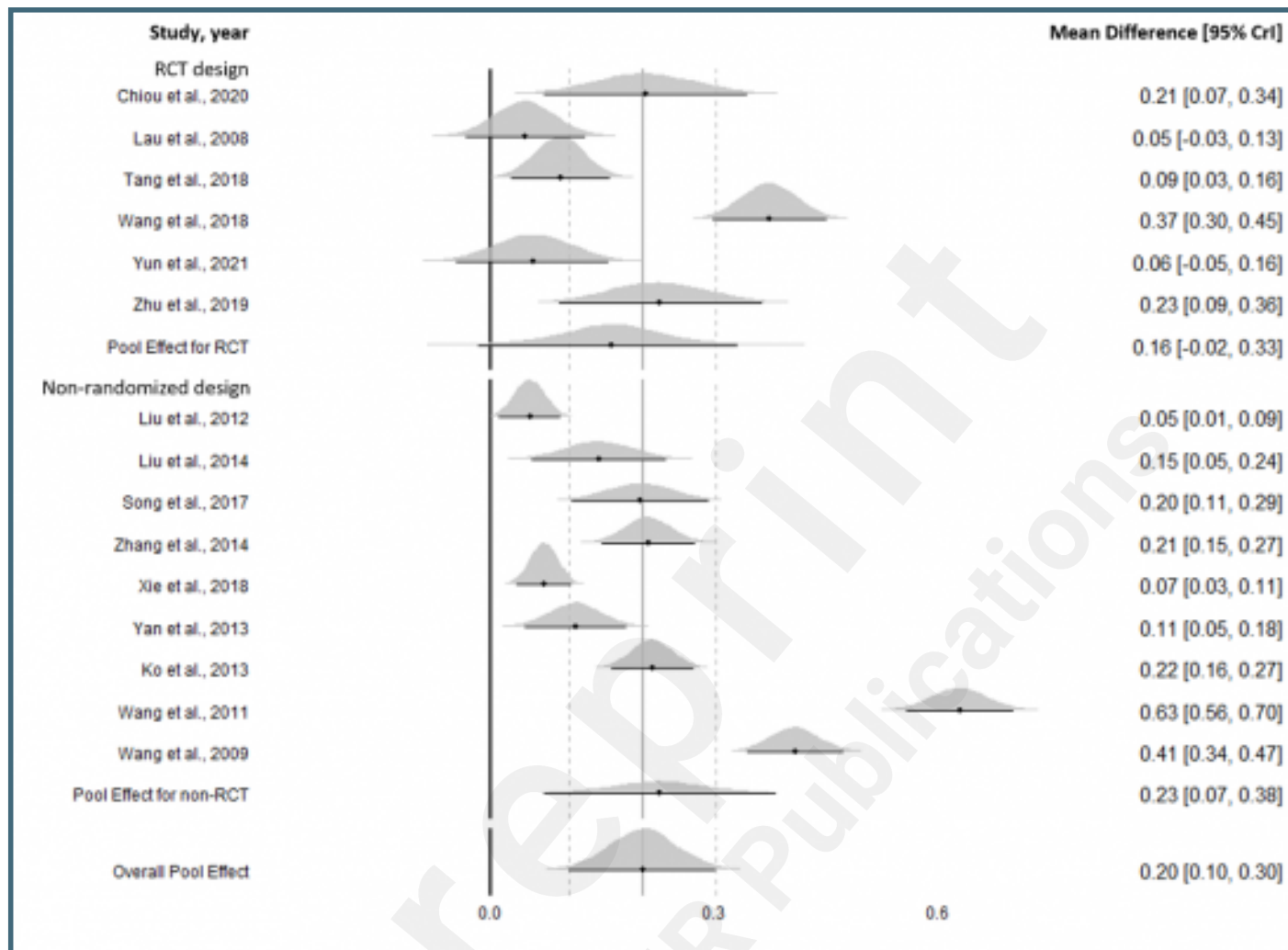
Contour-enhanced funnel plot for correlation between probability of publication and magnitude of effect for HIV testing uptake in China, 2004-2021 (n=15).



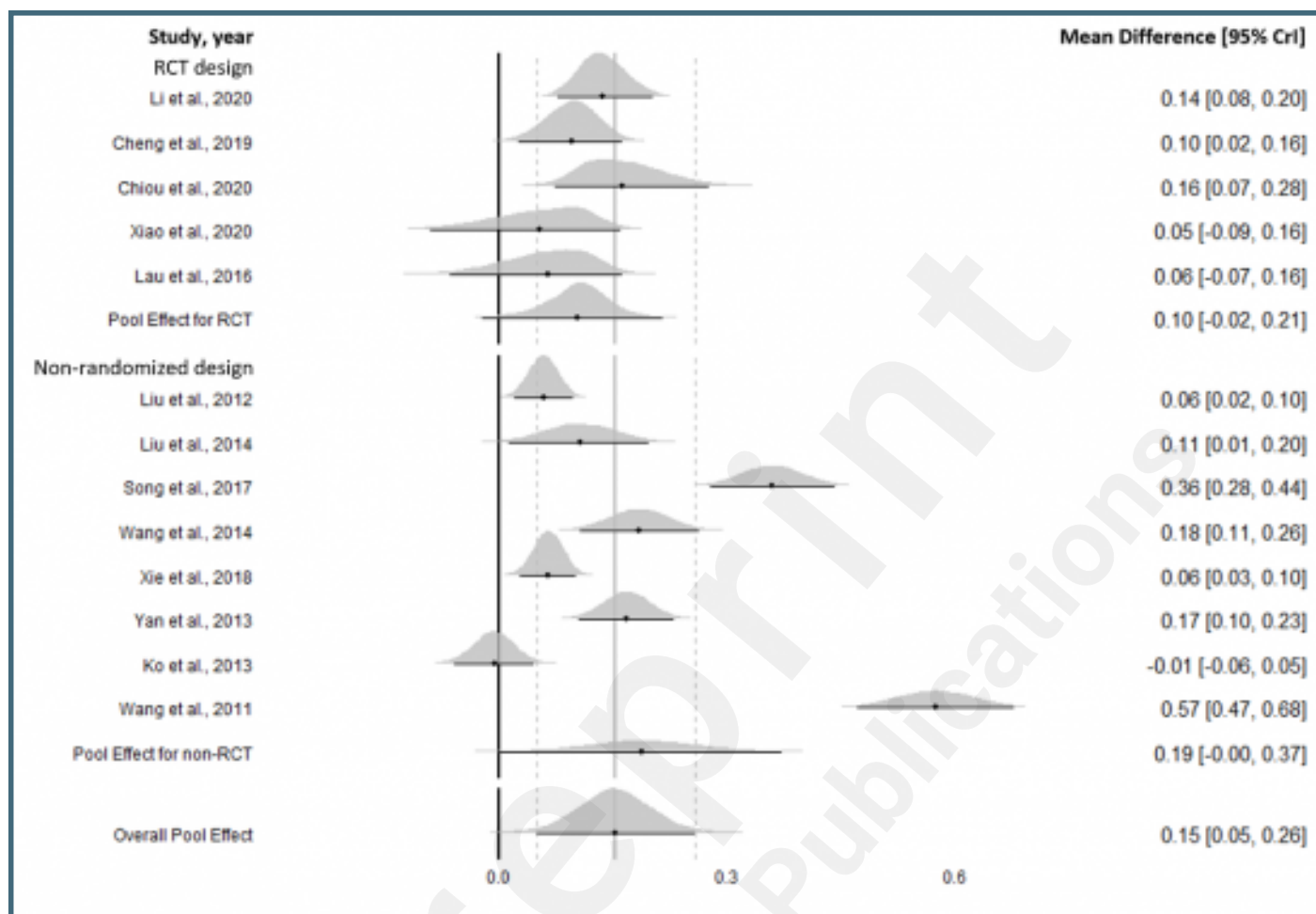
Contour-enhanced funnel plot for correlation between probability of publication and magnitude of effect for consistent condom use in China, 2004-2021 (n=13).



Forest plots of intervention effect on HIV testing uptake from Bayesian random effects meta-analysis in China, 2004-2021 (n=15).



Forest plots of intervention effect on consistent condom use from Bayesian hierarchical random effects model in China, 2004-2021 (n=13).



Multimedia Appendixes

Supplement 1.

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Supplement 2.

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CONSORT (or other) checklists

PRISMA abstract checklist.

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