OPEN

AIDS, Publish Ahead of Print

DOI: 10.1097/QAD.0000000000002780

Interactive digital interventions for prevention of sexually transmitted HIV: systematic review and meta-analyses

Julia V Bailey (1), Sonali Wayal (1,2,3) Catherine RH Aicken (3,4), Rosie Webster (1), Catherine H Mercer (3), Irwin Nazareth (5), Greta Rait (5), Richard Peacock (6), Elizabeth Murray (1)

1.e-Health Unit, Research Department of Primary Care and Population Health, University College London, London, UK

2. Development Media International, London, UK

3. Centre for Population Research in Sexual Health and HIV, Institute for Global Health, University College London, London, UK

4. School of Health Sciences, University of Brighton, Falmer, Brighton, UK

5. Research Department of Primary Care and Population Health, University College London, London, UK

6. Whittington Health Library, The Whittington Hospital, London, UK

Corresponding author

Julia V Bailey PhD

eHealth Unit,

Research Department of Primary Care and Population Health,

University College London
Upper Third Floor, Royal Free Hospital
Rowland Hill Street
London, UK
NW3 2PF
julia.bailey@ucl.ac.uk

@juliavbailey

Abstract

Background Digital technology offers good opportunities for HIV prevention. This systematic review assesses the effectiveness of interactive digital interventions (IDIs) for prevention of sexually transmitted HIV.

Methods We conducted a systematic search for randomised controlled trials (RCTs) of IDIs for HIV prevention, defining 'interactive' as producing personally tailored material. We searched databases including the Cochrane Central Register of Controlled Trials, MEDLINE, EMBASE, CINAHL, PsycINFO, grey literature, reference lists, and contacted authors if needed.

Two authors screened abstracts, applied eligibility and quality criteria and extracted data. Meta-analyses used random-effects models with standardised mean differences for continuous outcomes and odds ratios for binary outcomes, assessing heterogeneity using the I^2 statistic.

Results We included 31 RCTs of IDIs for HIV prevention. Meta-analyses of 29 RCTs comparing IDIs with minimal interventions (e.g. leaflet, waiting list) showed a moderate increase in knowledge (SMD 0.56, 95% CI: 0.33 to 0.80), no effect on self-efficacy (SMD 0.13, 95% CI 0.00 to 0.27), a small improvement in intention (SMD 0.16, 95% CI 0.06 to 0.26), improvement in HIV prevention behaviours (OR 1.28, 95% CI 1.04 to 1.57) and a possible increase in viral load, but this finding is unreliable.

We found no evidence of difference between IDIs and face-to-face interventions for knowledge, self-efficacy, intention, or HIV-related behaviours in meta-analyses of five small RCTs. We found no health economic studies.

Conclusions There is good evidence that IDIs have positive effects on knowledge, intention and HIV prevention behaviours. IDIs are appropriate for HIV prevention in a variety of settings.

*Supplementary Video Abstract, http://links.lww.com/QAD/B934

Keywords

Human immunodeficiency virus; HIV; Behavior change; eHealth; Digital Health; Sexually transmitted infection; Meta-analysis; Systematic Review

Introduction

The global annual HIV incidence has been relatively constant since 2005, but with marked differences between countries,[1] strong deprivation gradients,[2] and disproportionate impact in groups such as men who have sex with men (MSM), sex workers, prisoners, transgender people and injecting drug users.[3] HIV incurs substantial personal, social and economic costs.[1]

Interventions to prevent sexually transmitted HIV have historically focused on behaviour change to increase safer sex,[4-7] but attention has turned to treatment as prevention (viral suppression with antiretroviral therapy (ART)).[8] Global U=U campaigns (Undetectable equals Untransmissible)[9] have fast-track targets to end the AIDS epidemic by 2030.[10]

There has been good progress towards meeting 95-95-95 targets: in 2018, an estimated 79% of HIV positive people worldwide knew their status, 78% of those were accessing treatment, and 86% were virally suppressed.[3] Alongside scaling up access to ART, the success of this campaign depends upon socio-cultural and behavioural change including increased awareness; tackling myths, stigma and shame; increased uptake of HIV testing; and adherence to ART.[5,10] HIV prevention through safer sex remains essential (e.g. condom use, negotiated safety).[11]

Access to the Internet and mobile phones is increasing globally, although large inequalities remain.[12,13] Digital interventions offer private, convenient access, which is particularly useful for stigmatised sexual health issues.[14] Multi-media formats such as audio and video can help to reach people with poor literacy, and digital interventions can increase engagement by offering individualised feedback.[15]

There is a wealth of sexual health information online, but information alone is not usually enough to prompt behaviour change.[16] Interactive digital interventions (IDIs) are theory-based behaviour change interventions that provide information and tailored, personalised feedback to support decisions, for behaviour change, or for emotional support.[4] Tailoring increases the relevance of material, to enhance engagement, learning, and behaviour change.[15,17,18] This systematic review establishes the effectiveness of tailored IDIs for prevention of sexually transmitted HIV.

Methods

Objectives

1) To determine the effectiveness of IDIs for prevention of sexually transmitted HIV in comparison to minimal interventions (e.g. waiting list, leaflet)

2) To determine whether IDIs for HIV prevention are as effective as face-to-face interventions

3) To determine cost-effectiveness

Search strategy

We followed Cochrane collaboration methods to update our 2010 Cochrane review of interactive computer-based interventions for sexual health promotion,[4] and then selected studies focusing solely on HIV prevention (Supplemental Digital Content 1 – PRISMA

Diagram, http://links.lww.com/QAD/B935). In 2013 we searched the same databases as for the Cochrane review,[19] and updated the review again in 2017, searching fewer databases from 2014 to June 2017 in light of the vast number of citations (Supplemental Digital Content 2 – Search terms, http://links.lww.com/QAD/B936). We searched databases of published literature including the Cochrane Central Register of Controlled Trials, MEDLINE, EMBASE, CINAHL, PsycINFO, grey literature, conference abstracts and trials registers. We also searched reference lists of included studies and databases of sexual health interventions.

The search strategy comprised three concepts: 1) RCT design filter[20] or health economic evaluation AND 2) Computer-based/digital interventions AND 3) Sexual health, including HIV prevention (See search terms - Supplemental Digital Content 2, http://links.lww.com/QAD/B936).

Inclusion and exclusion criteria

Eligible studies were RCTs or health economic evaluations of IDIs for prevention of sexually transmitted HIV. IDIs were defined as 'programmes that provide information and one or more of decision support, behaviour-change support, or emotional support for health issues, requiring contributions from users to produce tailored, personally relevant feedback, delivered by any digital media'.[4] IDIs may be for self-guided use, or with remote or face-to-face human support to enhance engagement.

We sought interventions intended to prevent acquisition or transmission of HIV through sexual risk-reduction, e.g. using condoms for penetrative sex; reduction in partner numbers; sero-sorting; or uptake of pre-exposure prophylaxis (PrEP). We included any populations in any setting, and any HIV status.

We excluded non-interactive interventions; electronic healthcare communication; composite interventions which combine an IDI with an *active* human component; interventions to optimise healthcare delivery; and interventions addressing clinical management of HIV (e.g. adherence to ART) since people receiving care are likely to also receive face-to-face health promotion, and we wished to assess the effect of self-directed IDIs.[4,21]

Group 1 compared IDIs with **minimal interventions** (e.g. being on a waiting list, receiving a leaflet, measurement only), to assess whether IDIs are effective. **Group 2** compared IDIs with **face-to-face interventions**, to assess whether IDIs are equally effective.

Screening and data extraction

Two review authors (JB and SW, RW or CA) independently screened titles, abstracts and full texts of candidate studies using Reference Manager™ or Covidence™ software. We independently extracted data, resolving disagreements through discussion or by seeking a third opinion (EM). We contacted authors of included studies where necessary, to clarify details of study design and for missing data, making multiple attempts to contact co-authors. JB, SW and CA transferred data into Review Manager™ software, double-checking the accuracy.

Study characteristics and outcomes

We categorised outcomes as follows:

- **Cognitive outcomes:** HIV related knowledge; self-efficacy (a person's belief in their capacity to carry out a specific action); behavioural intention
- **Behavioural outcomes:** e.g. condom use; partner numbers; HIV testing; negotiation/communication skills.
- **Biological outcomes:** e.g. HIV or STI acquisition; viral load
- **Health economic outcomes:** e.g. costs of developing and implementing IDIs; costs and savings for health services and/or users/consumers.

Where multiple outcomes were reported in one study, we selected one outcome only from each outcome category, prioritising (in order): authors' primary outcomes, outcomes reflecting the intervention's main aim, sexual health outcomes in preference to other domains, condom-related outcomes, laboratory measured outcomes, and data from the longest measured follow-up period.[4] We recorded any adverse effects attributable to an intervention.

Assessment of risk of bias, sensitivity analyses and subgroup analyses

We assessed study quality using the Cochrane risk of bias tool. Studies at high risk of bias due to inadequate sequence generation or concealment of allocation were excluded. Studies with <80% retention were deemed 'high risk of bias', but retained. We assessed the effect of study quality by repeating the analyses including only studies at low risk of bias due to randomisation procedures and loss to follow-up, comparing the results with the main meta-analyses. Other quality factors were considered in interpretation of the findings (e.g. selective reporting, blinding, and other sources of bias) (Supplemental Digital Content 3 - Included Studies, http://links.lww.com/QAD/B937; Supplemental Digital Content 4 -Figure: Risk of Bias, http://links.lww.com/QAD/B938).

We explored heterogeneity by conducting post-hoc subgroup analyses by **Setting** (educational, healthcare, online); **Population Targeted** (MSM, other at-risk adults, general populations), and **HIV status** (HIV positive; or HIV negative, unknown or any status).

Data syntheses

We sought numerators and denominators for dichotomous (yes/no) variables, and means, standard deviations and participant numbers for continuous variables. When no standard deviation was available, we calculated this using the F statistic. Where necessary to combine data, we expressed odds ratios (ORs) as standardised mean differences (SMDs) or vice versa.[22]

We pooled results of RCTs using a random-effects model, which allows combination of outcomes measured using different scales (e.g. study-specific knowledge tests). We comment on the size of SMDs using Cohen's rules of thumb, judging <0.40 to be 'small'; 0.4 to 0.70, 'moderate'; and >0.70 a 'large' effect.[23] We assessed statistical heterogeneity by using the I^2 statistic to estimate variance between studies and Chi^2 test for heterogeneity, interpreting the I^2 statistic as follows: 0% to <25% might not be important; 25% to <50%: moderate heterogeneity; 50% to <75%: substantial; 75% to 100%: considerable.

Results

A total of 29,606 citations were screened (Supplemental Digital Content 1 – PRISMA Diagram, http://links.lww.com/QAD/B935). The full texts of 411 publications were screened, yielding 38 potentially eligible RCTs of IDIs for HIV prevention (reported in 37 papers). We found no health economic evidence.

We subsequently excluded seven studies: two RCTs which compared different designs of IDI,[24,25] three that were at high risk of bias in their method of randomisation:[26-28] one for which control arm data were unavailable,[29] and one which reported a large loss to follow-up with insufficient data for analysis.[30]

We therefore included 31 RCTs (reported in 30 papers), with 29 RCTs addressing IDI effectiveness (**Group 1**) and five RCTs comparing IDIs with face-to-face interventions (**Group 2**). In total 11,293 people were randomised, 10,423 in Group 1 and 870 in Group 2.

Description of studies

Most studies were conducted in the USA (27/31), and one each in the Netherlands,[31] Uganda,[32] Zambia[33] and Sweden[34] (Supplemental Digital Content 3 – Included Studies, http://links.lww.com/QAD/B937). Twelve studies targeted young people,[32,35-45] ten targeted MSM,[31,34,35,38,46-51] and five targeted HIV positive people.[49,52-55] One study targeted adults at risk of HIV (including MSM and intravenous drug users),[56] and another targeted African American women.[57] Participants were recruited online;[34-36,38,46-48,51,58] through educational settings;[32,40,41,43] health care settings;[36,37,42,44,50,52-56,59-61] and other institutions including social care,[39] a drug court,[62] and the military.[60]

Aims and design of interventions

Most interventions focused on behavioural change for prevention of HIV and other STI, or HIV alone (Supplemental Digital Content 3 –Included Studies, http://links.lww.com/QAD/B937). One intervention promoted voluntary male circumcision,[33] and one addressed drug use, alcohol and safe sex in combination.[63]

Programmes offered tailored material in a variety of ways: by participant characteristics and/or behaviour (age,[44] gender and ethnicity,[36] ethnicity and sexual experience,[42] gender and sexual experience,[32] sexual orientation,[54] sexual risk and/or drug use and alcohol use[25,47,52,54]), and by intervention targets (knowledge, motivation and behavioural skills,[31,43] stage of change,[37,51] feedback on knowledge tests,[39,43,48,53,56,60,64] interactive texts and virtual peers sharing experiences,[51] feedback following virtual decisions or scenarios,[38,48,50] rehearsal of communication skills and decisions,[53,59] appraising 'dysfunctional thoughts',[56] visualisation of a social support network,[53] and personal goals with feedback on achievement.[43,53,54])

Risk of bias in included studies

Seventeen out of the 31 studies were judged low risk of bias in terms of random sequence generation and concealment of allocation (Supplemental Digital Content 4 – Figure: Risk of Bias, http://links.lww.com/QAD/B938). Retention at follow-up was at least 80% without differential loss to follow-up in 16/31 studies. Outcomes had been selectively reported in one study, with data unavailable from authors.[60]

Group 1: Are IDIs effective?

29 studies examined the effectiveness of IDIs compared to minimal interventions. A total of 5,277 people were randomised to receive an IDI, and 5,146 received minimal interventions (e.g. waiting list, leaflet, or measurement only) (Supplemental Digital Content 5 – Table: Summary of Findings, Group One, http://links.lww.com/QAD/B939).

Do IDIs improve HIV-related knowledge?

We combined data from 12 out of 14 studies which reported HIV-related knowledge. One additional study reported no difference in knowledge,[60] and one reported significant improvements,[44] but data suitable for analysis were unavailable. Meta-analysis showed an SMD of 0.56 for knowledge (95% CI: 0.33 to 0.80), which is a moderate effect (Figure 1). We were not able to adjust for clustering effects in one study:[39] adjustment would probably have widened the confidence intervals. There was considerable heterogeneity (I^2=82%, p<0.0001).

Do IDIs improve HIV prevention self-efficacy?

We combined data from 14 out of 16 studies which reported self-efficacy. Two additional studies found no difference between intervention and control for self-efficacy, with data unavailable from authors.[44,50] Meta-analysis showed an SMD of 0.13 (95% CI 0.00 to 0.27) (Figure 2). We were not able to adjust for clustering effects in one study.[39] There was substantial heterogeneity (I^2=68%, p=0.0001).

Do IDIs impact on HIV prevention intention?

We combined data from 9 out of 12 studies which measured behavioural intention. Meta-analysis showed a small effect on HIV-related intentions for IDIs compared to minimal interventions (SMD 0.16, 95% CI 0.06 to 0.26); heterogeneity I^2=0% (Figure 3). Two additional studies found no difference between intervention and control for intention, but data for analysis were unavailable.[44,50] Another study reported significant improvement in readiness to change condom use,[60] but data were unavailable.

Do IDIs improve HIV prevention behaviours?

21 out of 23 studies contributed to meta-analyses of behavioural outcomes. Suitable data were unavailable for three studies.[44,50,60] Meta-analysis showed a combined odds ratio of 1.28 (95% CI 1.04 to 1.57) for HIV prevention behaviours (Figure 4). There was considerable heterogeneity (I^2=66, p<0.0001).

Do IDIs affect biological outcomes?

Four RCTs out of 7 contributed to a meta-analysis of biological outcomes, measuring HIV viral load,[55] and other STIs (e.g. chlamydia, gonorrhoea, syphilis).[36,49] Perry et al. (1991) reported no new diagnoses of HIV[56] so could not be included in the meta-analysis, and data were unavailable for one study (self-reported HIV status).[31] One study specifically aimed to increase testing, so we excluded this from the meta-analysis since STI/HIV detection could increase as consequence of increased testing.[35] Meta-analysis of three studies showed no impact on STI diagnoses (OR 1.48, 95% CI: 0.96 to 2.28), with one study reporting an

increase in detectable HIV viral load (OR 1.61, 95% CI: 1.01 to 2.55) (Figure 5). There was no overall heterogeneity (I^2=0%).

Does study quality affect results?

Excluding studies at unclear risk of bias due to their methods of randomisation did not substantially alter effect sizes. Excluding studies at high risk of bias due to retention <80% tended to increase overall effect sizes, implying that those who drop out may also be those who would benefit from interventions (analyses available from authors). The outcome measurements for biological outcomes (STI diagnoses and HIV viral load) were prone to bias: the event rate for self-reported STI (Bull 2009, online RCT results) was very small, with wide confidence intervals;[36] Milam 2016 was a small trial (49 participants); and viral load data were not available for 48% of McKinstry 2017's sample;[55] so the finding that an IDI appeared to increase HIV viral load should be treated with caution.

Effects by Setting, Population Targeted, and HIV Status

There were no subgroup differences for **IDIs offered in different settings** (educational settings, healthcare, or online) for knowledge, self-efficacy, intention, or HIV prevention behaviours, and setting did not account for heterogeneity (Supplemental Digital Content 7 – Forest plots, Figures 9 to 12, http://links.lww.com/QAD/B941).

There were no subgroup differences by **population targeted** (MSM, other adults at risk of HIV, and general populations) for knowledge, self-efficacy or intention, and targeting did not account for heterogeneity for these outcomes. IDIs showed more impact on behavioural outcomes for adults at risk of HIV than for MSM or general populations (Supplemental Digital Content 7 – Forest plots, Figures 13 to 16, http://links.lww.com/QAD/B941).This analysis reduced some of the heterogeneity.

There were no significant differences in effects by **HIV status** for knowledge, self-efficacy, intention or behaviour, and HIV status did not account for heterogeneity (Supplemental Digital Content 7 – Forest plots, Figures 17 to 20, http://links.lww.com/QAD/B941).

There were too few studies to explore subgroups for biological outcomes.

Summary: Are IDIs effective?

We found that IDIs had moderate effects on HIV-related knowledge and HIV prevention behaviours, with no clear effect on self-efficacy, and a small effect on intention. The meta-analysis of biological outcomes (STI diagnoses/HIV viral load) is unreliable because of potential bias in outcome measurement. There were no significant differences by setting, population targeted, or HIV status, except for a greater impact on behavioural outcomes for IDIs delivered to risk groups other than MSM. This group included African-American women at risk through sexual behaviour and/or injecting drug use,[57] adults in a drug court[62] and HIV positive adults.[52-55]

Group 2: Are IDIs as effective as face-to-face interventions?

Five RCTs compared IDIs with non-digital, face-to-face HIV prevention (Supplemental Digital Content 6 – Group Two Outcomes, http://links.lww.com/QAD/B940). 434 people

were randomised to receive an IDI, and 436 to face-to-face interventions (e.g. HIV education, counselling, or a lecture). These trials are equivalence trials, which test whether one intervention is as effective as another (i.e. whether there is evidence of no difference).

Knowledge

We combined data from 3 out of 4 small studies which measured knowledge.[40,45,56] Meta-analysis showed no evidence of difference between IDIs and face-to-face comparators (SMD 0.12, 95% CI -0.39 to 0.63), although the total sample size was small (Supplemental Digital Content 7 – Figure 6, http://links.lww.com/QAD/B941). One further study reported no difference in knowledge between an IDI and a face-to-face intervention,[60] but data were unavailable.

Self-efficacy

We combined data from three studies which measured self-efficacy.[37,40,45] Meta-analysis showed no evidence of difference between IDIs and face-to-face comparators (SMD 0.15, 95% CI -0.05 to 0.36) although the total sample size was small (Supplemental Digital Content 7 – Figure 7, http://links.lww.com/QAD/B941).

Intention

We combined data from 3 of the 4 studies which measured HIV-related behavioural intention.[37,40,45] Meta-analysis showed no evidence of difference between IDIs and face-to-face comparators (SMD 0.12, 95% CI -0.31 to 0.56), although the total sample size was small (Supplemental Digital Content 7 – Figure 8, http://links.lww.com/QAD/B941). One additional study reported readiness to change (condom use), with greater improvement at 2 weeks for the face-to-face intervention,[60] but 2-month outcome data were unavailable.

HIV prevention behaviours

Two studies measured behavioural outcomes. Data were not available for Jenkins et al.[60] (condom use with risky partners), so meta-analysis was not possible. Marsch et al. found no evidence of difference between an IDI and a face-to-face intervention for unprotected sex, but this was a small study (74 participants).[45]

Biological outcomes

Only one study reported a biological outcome (HIV seroconversion),[56] but could not evaluate impact on HIV acquisition since there were no new diagnoses.

Summary: Are IDIs as effective as face-to-face interventions?

We found no evidence of difference between IDIs and face-to-face interventions for knowledge, self-efficacy, intention, or HIV-related behaviours. Outcomes for both IDIs and face-to-face interventions generally improved from baseline, pointing towards these being equally effective rather than equally ineffective, although the body of evidence is small and stronger evidence is needed. We could not evaluate biological outcomes.

Discussion

This systematic review provides compelling evidence that IDIs have positive effects on knowledge and HIV prevention behaviours. The meta-analysis of biological outcome measures (STI diagnoses/HIV viral load) is unreliable because of potential bias in outcome measurement. We found no evidence of difference in effectiveness between IDIs and face-to-face interventions, and no evidence on cost-effectiveness.

Quality of the review

This review synthesises 31 RCTs conducted over nearly 30 years. Whilst technology has changed over time, the review evaluates the impact of tailored IDI for specific target populations, regardless of technology or mode of delivery. Study quality was mixed, with large, mostly unexplained heterogeneity. There was often insufficient detail to judge risk of bias: we made considerable effort to contact authors but many assessments remain unclear. However, our sensitivity analyses were reassuring since effect sizes were unchanged or increased when we removed lower quality studies.

Interventions reached populations at risk of HIV, including young people, MSM, intravenous drug users, soldiers, and socio-economically deprived communities, but most trials were conducted in high income countries (mostly the USA). There was considerable heterogeneity, but this was not accounted for by study quality, setting, HIV status, or by population targeted (except for behavioural outcomes). IDIs are complex interventions with many components, and they vary across many dimensions (e.g. informational content, theoretical basis, multi-media features, mode of delivery etc.).

Implications of findings

There is strong evidence from RCTs conducted in a variety of settings that IDIs are effective for improving HIV-related knowledge, and this supports the roll-out of IDIs for HIV education. We found a significant overall impact on HIV-related behaviour, but individual study results were mixed: further research is needed to find out what works for whom in what circumstances,[5] the cost-effectiveness of IDIs,[19,65] and to establish whether IDIs are as effective as face-to-face interventions.

IDI were effective for people living with HIV, which is an important finding as attention turns to treatment as prevention.[11] Our findings support targeting MSM as well as adults in other HIV risk groups.

Biological outcomes are regarded as gold standard to evaluate STI/HIV prevention interventions, but there are considerable measurement challenges, including low STI or HIV event rates (particularly over short follow-up periods),[56] and the costs and practical challenges of biological sampling.[4] Better quality outcome measurement is needed to explore the impact of IDIs on biological outcomes, differentiating increased detection from STI/HIV acquisition (e.g. testing all participants instead of relying on self-report or medical records).

Digital interventions for HIV to date favour education and behaviour change over linkage to care and medication adherence.[11] Behaviour change interventions for safer sex and earlier HIV detection remain extremely important globally, and biomedical interventions (such as male circumcision, PrEP, PEP, and treatment as prevention) need to address psychosocial and behavioural dimensions to be effective.[10,21,38] Mobile phone (SMS) interventions are acceptable and feasible and can impact on clinic attendance, ART adherence and time from testing to treatment, but do not impact on risk behaviour.[65] The next generation of IDIs need to address the behavioural dimensions of uptake of care and treatment as prevention.[11] We also need to know the effectiveness and cost-effectiveness of composite interventions for HIV prevention (IDIs offered together with face-to-face education or clinical care).

Digital interventions are highly scalable,[19] and dissemination of self-administered IDIs can be fast and relatively cheap,[66] Some at-risk populations may seek sexual partners online (e.g. MSM, young people, sex workers), and apps and websites for dating, porn, and buying sex offer an opportunity for online sexual health promotion.[13,14] Sexual health services such as online self-testing also present an important opportunity for sexual health promotion.[67,68]

Conclusions

There is good evidence that IDIs have positive effects on knowledge and sexually transmitted HIV prevention behaviours. IDIs are very appropriate for HIV prevention globally, for a range of populations, in different settings including schools and further education, in clinics and/or online.

Contributions of authors

- Drafting the protocol: Julia Bailey, Sonali Wayal, Elizabeth Murray, Greta Rait, Richard Peacock, Irwin Nazareth.
- Developing a search strategy: Julia Bailey, Richard Peacock, Sonali Wayal.
- Searching for trials: Sonali Wayal, Rosie Webster, Catherine Aicken, Julia Bailey.
- Selecting trials for inclusion: Julia Bailey, Sonali Wayal, with Catherine Aicken as arbiter.
- Extracting data from trials: Julia Bailey, Sonali Wayal, Catherine Aicken
- Entering data into Review Manager software: Julia Bailey, Sonali Wayal, Rosie Webster, Catherine Aicken.
- Performing the analysis: Julia Bailey, Sonali Wayal, Catherine Aicken, with statistical advice from Cath Mercer.
- Interpreting the results: All co-authors
- Writing the review: Julia Bailey, Sonali Wayal, Catherine Aicken.
- Editing and approving the final paper: all co-authors

Conflicts of interest

There are no conflicts of interest to declare.

Funding

NIHR Public Health Research Programme 11/3009: Sexual health promotion delivered by digital media: Scoping Exercise (2013–14, for SW and JB). No other funding source.

Role of the funding source

The NIHR had no role in the review protocol design, data collection, analysis, interpretation or writing, or in the decision to submit the paper for publication.

Acknowledgements

We wish to thank Dr Bronwen Merner, Dr Dianne Lowe, Dr Rebecca Ryan, Louisa Walsh from the Cochrane Consumers and Communication Group, for their comments on review methods and quality.

References

1. Wang H, Wolock TM, Carter A, et al. Estimates of global, regional, and national incidence, prevalence, and mortality of HIV, 1980-2015: the Global Burden of Disease Study 2015. *The Lancet HIV* 2016; **3**(8): e361-e87.

2. Control ECfDPa. Continuum of HIV care Monitoring implementation of the Dublin Declaration on Partnership to Fight HIV/AIDS in Europe and Central Asia: 2018 progress report, 2019.

3. UNAIDS. Global HIV & AIDS statistics — 2019 fact sheet. 2019. https://www.unaids.org/en/resources/fact-sheet (accessed 25th October 2019).

4. Bailey JV, Murray E, Rait G, et al. Interactive computer-based interventions for sexual health promotion (Review). *Cochrane Database of Systematic Reviews* 2010; (9): Art. No.: CD006483. DOI:10.1002/14651858.CD006483.pub2.

5. Krishnaratne S, Hensen B, Cordes J, Enstone J, Hargreaves JR. Interventions to strengthen the HIV prevention cascade: a systematic review of reviews. *The Lancet HIV* 2016; **3**(7): e307-e17.

6. Noar SM, Black HG, Pierce LB. Efficacy of computer technology-based HIV prevention interventions: a meta-analysis. *AIDS 23(1):107-15*, 2009.

7. Noar SM, Pierce LB, Black HG. Can computer mediated interventions change theoretical mediators of safer sex? A meta-analysis. *Human Communication Research* 2010; **36**(3): 261-97.

8. Cohen MS, Chen YQ, McCauley M, et al. Antiretroviral Therapy for the Prevention of HIV-1 Transmission. *New England Journal of Medicine* 2016; **375**(9): 830-9.

9. Eisinger RW, Dieffenbach CW, Fauci AS. HIV Viral Load and Transmissibility of HIV Infection: Undetectable Equals Untransmittable. *JAMA* 2019.

10. UNAIDS. Fast-Track: ending the AIDS epidemic by 2030 2014.

11. Maloney KM, Bratcher A, Wilkerson R, Sullivan PS. Electronic and other new media technology interventions for HIV care and prevention: a systematic review. *Journal of the International AIDS Society* 2020; **23**(1): e25439.

12. ITU. Country ICT data (to 2018). 2018. https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (accessed 22/10/2019.

13. Campbell BR, Ingersoll KS, Flickinger TE, Dillingham R. Bridging the digital health divide: toward equitable global access to mobile health interventions for people living with HIV. *Expert Review of Anti-infective Therapy* 2019; **17**(3): 141-4.

14. Bailey JV, Mann S, Wayal S, Abraham C, Murray E. Digital media interventions for sexual health promotion-opportunities and challenges. *BMJ* 2015; **350**: h1099.

15. Lustria MA, Cortese J, Noar SM, Glueckauf RL. Computer-tailored health interventions delivered over the web: Review and analysis of key components. *Patient Education & Counseling* 2009; **74**: 156-73.

16. Stephenson JM, Imrie J, Bonell C. Effective Sexual Health Interventions. Issues in experimental evaluation. Oxford, New York: Oxford University Press; 2003.

17. Noar SM, Benac CN, Harris MS. Does tailoring matter? Meta-analytic review of tailored print health behavior change interventions. *Psychological Bulletin 133(4):673-93,* 2007.

18. Noar SM, Grant Harrington N, Van Stee SK, Shemanski Aldrich R. Tailored Health Communication to Change Lifestyle Behaviors. *American Journal of Lifestyle Medicine* 2011; **5**(2): 112-22.

19. Bailey JV, Mann S, Wayal S, et al. Sexual health promotion for young people delivered via digital media: a scoping review, 2015.

20. Robinson KA, Dickersin K. Development of a highly sensitive search strategy for the retrieval of reports of controlled trials using PubMed. *International Journal of Epidemiology* 2002; **31**(1): 150-3.

21. Chaiyachati KH, Ogbuoji O, Price M, Suthar AB, Negussie EK, Bärnighausen T. Interventions to improve adherence to antiretroviral therapy: a rapid systematic review. *AIDS* 2014; **28**: S187-S204.

22. Chinn S. A simple method for converting an odds ratio to effect size for use in meta-analysis. *Statistics in Medicine* 2000; **19**: 3127-31.

23. Cohen J. Statistical Power Analysis in the Behavioral Sciences. 2nd edition ed. Hillsdale (NJ); 1988.

24. Mikolajczak J, van Breukelen GJP, Kok G, Hospers HJ. Evaluating the effects of an online HIV-prevention intervention to promote HIV-testing among Men who have Sex with Men (MSM). 2008.

25. Mustanski B, Garofalo R, Monahan C, Gratzer B, Andrews R. Feasibility, acceptability, and preliminary efficacy of an online HIV prevention program for diverse young men who have sex with men: the keep it up! intervention. *AIDS & Behavior* 2013; **17**(9): 2999-3012.

26. Klein CH, Card JJ. Preliminary efficacy of a computer-delivered HIV prevention intervention for African American teenage females. *AIDS Education & Prevention* 2011; **23**(6): 564-76.

27. Cortese J, Lustria LA. Can tailoring increase elaboration of health messages delivered via an adaptive educational site on adolescent sexual health and decision making? *Journal of the American Society for Information Science & Technology* 2012; **63**(8): 1567-80.

28. Roberto AJ, Zimmerman RS, Carlyle KE, Abner EL. A computer-based approach to preventing pregnancy, STD, and HIV in rural adolescents. *Journal of Health Communication* 2007; **12**(1): 53-76.

29. Chib AI, Lwin MO, Lee Z, Ng VW, Wong PHP. Learning AIDS in Singapore: examining the effectiveness of HIV/AIDS efficacy messages for adolescents using ICTs. *Knowledge Management & E-Learning: an International Journal* 2010; **2**(2): 169-87.

30. Bull SS, Lloyd L, Rietmeijer C, McFarlane M. Recruitment and retention of an online sample for an HIV prevention intervention targeting men who have sex with men: the Smart Sex Quest Project. *AIDS Care 16(8):931-43*, 2004.

31. Davidovich U, de Wit J, Stroebe W. Using the Internet to reduce risk of HIV infection in steady relationships. A randomized controlled trial of a tailored intervention for gay men.; 2006.

32. Ybarra, M L, Bull, et al. Adolescent Abstinence and Unprotected Sex in CyberSenga, an Internet-Based HIV Prevention Program: Randomized Clinical Trial of Efficacy. *PLOS one* 2013; **8**(8): e70083-e.

33. Leiby K, Connor A, Tsague L, et al. The impact of SMS-based interventions on VMMC uptake in Lusaka province, Zambia: A randomized controlled trial. *Journal of Acquired Immune Deficiency Syndrome* 2016; **72**(Supplement 4): S269-S77.

34. Schonnesson Ln Bowen AM, Williams ML. Project SMART: preliminary Results From a Test of the Efficacy of a Swedish Internet-Based HIV Risk-Reduction Intervention for Men Who Have Sex With Men. *Archives of sexual behavior* 2016; **45**(6): 1501-11.

35. Bauermeister JA, Pingel ES, Jadwin-Cakmak L, et al. Acceptability and preliminary efficacy of a tailored online HIV/STI testing intervention for young men who have sex with men: the Get Connected! program. *AIDS and Behavior* 2015; **19**(10): 1860-74.

36. Bull SS, Pratte K, Whitesell N, Rietmeijer C, McFarlane M. Effects of an internet-based intervention for HIV prevention: the Youthnet trials. *AIDS & Behavior* 2009; **13**(3): 474-87.

37. Calderon Y, Cowan E, Leu CS, et al. A Human Immunodeficiency Virus Posttest Video to Increase Condom Use Among Adolescent Emergency Department Patients. *Journal of Adolescent Health* 2013.

38. Christensen JL, Miller LC, Appleby PR, et al. Reducing shame in a game that predicts HIV risk reduction for young adult MSM: a randomized trial delivered nationally over the Web. *Journal of the International AIDS Society* 2013; **16**(Suppl 2): 18716-.

39. Di Noia J, Schinke SP, Pena JB, Schwinn TM. Evaluation of a brief computer-mediated intervention to reduce HIV risk among early adolescent females. *Journal of Adolescent Health35(1):62-4* 2004.

40. Evans AE, Edmundson-Drane EW, Harris KK. Computer-assisted instruction: an effective instructional method for HIV prevention education? *Journal of Adolescent Health 26(4):244-51*, 2000.

41. Fiellin LE, Hieftje KD, Pendergrass TM, et al. Video Game Intervention for Sexual Risk Reduction in Minority Adolescents: Randomized Controlled Trial. *J Med Internet Res* 2017; **19**(9): e314-e.

42. Ito KE, Kalyanaraman S, Ford CA, Brown JD, Miller WC. "Let's Talk About Sex": pilot study of an interactive CD-ROM to prevent HIV/STIS in female adolescents. *AIDS Education & Prevention* 2008; (1): 78-89.

43. Kiene SM, Barta WD. A brief individualized computer-delivered sexual risk reduction intervention increases HIV/AIDS preventive behavior. *Journal of Adolescent Health 39(3):404-10*, 2006.

44. Marsch LA, Grabinski MJ, Bickel WK, et al. Computer-assisted HIV prevention for youth with substance use disorders. *Substance Use & Misuse* 2011; (1): 46-56.

45. Marsch LA, Guarino H, Grabinski MJ, et al. Comparative Effectiveness of Web-Based vs. Educator-Delivered HIV Prevention for Adolescent Substance Users: A Randomized, Controlled Trial. *Journal of Substance Abuse Treatment* 2015; **59**: 30-7.

46. Bowen A, Horvath K, Williams M. A randomized control trial of Internet-delivered HIV prevention targeting rural MSM. *Health education research* 2007; **22**(1): 120-7.

47. Carpenter KM, Stoner SA, Mikko AN, Dhanak LP, Parsons JT. Efficacy of a web-based intervention to reduce sexual risk in men who have sex with men. *AIDS & Behavior* 2010; **14**(3): 549-57.

48. Hightow-Weidman LB, Pike E, Fowler B, et al. Feasibility and acceptability of delivering an internet intervention to young Black men who have sex with men. *AIDS Care - Psychological and Socio-Medical Aspects of AIDS/HIV* 2012; **24**: 01-.

49. Milam J, Morris S, Jain S, et al. Randomized Controlled Trial of an Internet Application to Reduce HIV Transmission Behavior Among HIV Infected Men Who have Sex with Men. *AIDS Behav* 2016; **20**(6): 1173-81.

50. Read S, Miller L, Appleby P, et al. Socially Optimized Learning in a Virtual Environment: Reducing Risky Sexual Behavior Among Men Who Have Sex With Men. *Human Communication Research* 2006; **32**(1): 1-34.

51. Rosser BR, Oakes JM, Konstan J, et al. Reducing HIV risk behavior of men who have sex with men through persuasive computing: results of the Men's INTernet Study-II. *AIDS* 2010; **24**(13): 2099-107.

52. Gilbert P, Ciccarone D, Gansky Sa et al. Interactive "Video Doctor" counseling reduces drug and sexual risk behaviors among HIV-positive patients in diverse outpatient settings. *PLoS ONE [Electronic Resource]* 2008; **3**: e1988-e.

53. Klein CH, Lomonaco CG, Pavlescak R, Card JJ. WiLLOW: Reaching HIV-Positive African-American Women Through a Computer-Delivered Intervention. *AIDS and Behavior* 2013.

54. Kurth AE, Spielberg F, Cleland CM, et al. Computerized counseling reduces HIV-1 viral load and sexual transmission risk: findings from a randomized controlled trial. *Journal of acquired immune deficiency syndromes* 2014; **65**(5): 611-20.

55. McKinstry LA, Zerbe A, Hanscom B, et al. A Randomized-Controlled Trial of Computer-based Prevention Counseling for HIV-Positive Persons. *J AIDS Clin Res* 2017; **8**(7).

56. Perry S, Fishman B, Jacobsberg L, Young J, Frances A. Effectiveness of psychoeducational interventions in reducing emotional distress after human immunodeficiency virus antibody testing. *Archives of General Psychiatry* 1991; **48**(2): 143-7.

57. Billings DW, Leaf Sl Spencer J, Crenshaw T, Brockington S, Dalal RS. A Randomized Trial to Evaluate the Efficacy of a Web-Based HIV Behavioral Intervention for High-Risk African American Women. *AIDS and Behavior* 2015; **19**(7): 1263-74.

58. Davidovich U, Uhr-Dall H. Reducing sexual risk behaviour among youth: The development and effect evaluation of an interactive online intervention for individuals and their sexual network. *Sexually Transmitted InfectionsConference: 19th Biennial Conference of the International Society for Sexually Transmitted Diseases Research Quebec City, QC CanadaConference Start: 20110710 Conference End: 20110713Conference Publication: (varpagings* 2011; **87**(pp A58): July.

59. Downs JS, Murray PJ, Bruine de BW, Penrose J, Palmgren C, Fischhoff B. Interactive video behavioral intervention to reduce adolescent females' STD risk: a randomized controlled trial. *Social Science & Medicine 59(8):1561-72,* 2004.

60. Jenkins PR, Jenkins RA, Nannis ED, McKee KT, Jr., Temoshok LR. Reducing risk of sexually transmitted disease (STD) and human immunodeficiency virus infection in a military STD clinic: evaluation of a randomized preventive intervention trial. *Clinical Infectious Diseases 30(4):730-5,* 2000.

61. Merchant RC, Clark MA, Langan TJ, Mayer KH, Seage GR, III, DeGruttola VG. Can computer-based feedback improve emergency department patient uptake of rapid HIV screening? *Annals of Emergency Medicine* 2011; **58**(1:Suppl 1): Suppl-9.

62. Festinger DS, Dugosh Kl Kurth Ae Metzger DS. Examining the efficacy of a computer facilitated HIV prevention tool in drug court. *Drug and alcohol dependence* 2016; **162**: 44-50.

63. Gilbert LK, Temby JR, Rogers SE. Evaluating a teen STD prevention Web site. *Journal of Adolescent Health 37(3):236-42,* 2005.

64. Mikolajczak J, van Breukelen GJP, Kok G, Hospers HJ. Evaluating the effects of an online HIV-prevention intervention to promote HIV-testing among Men who have Sex with Men. *Netherlands Journal of Psychology* 2012; **67**(2): 21-35.

65. Daher J, Vijh R, Linthwaite B, et al. Do digital innovations for HIV and sexually transmitted infections work? Results from a systematic review (1996-2017). *BMJ Open* 2017; **7**(11): e017604.

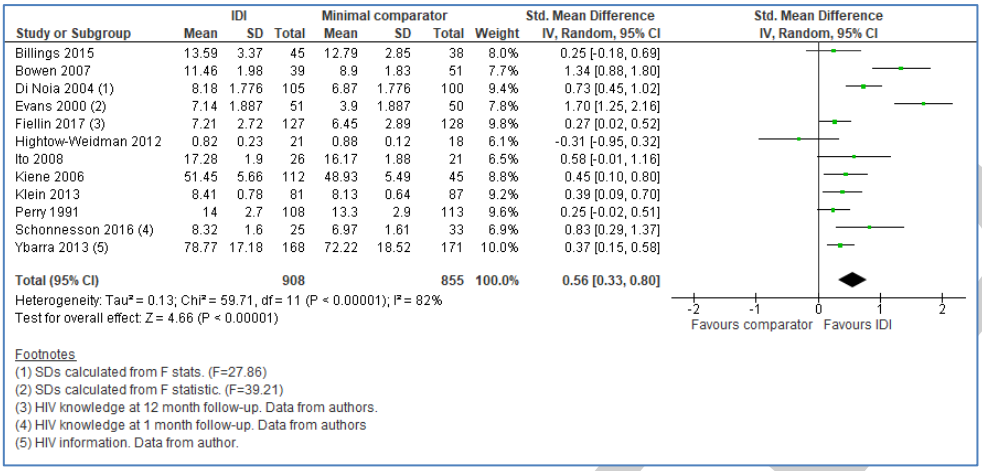
66. Asiimwe C, Gelvin D, Lee E, et al. Use of an innovative, affordable, and open-source short message service-based tool to monitor malaria in remote areas of Uganda. *The American Journal of Tropical Medicine and Hygiene* 2011; **85**(1): 26-33.

67. Estcourt CS, Gibbs J, Sutcliffe LJ, et al. The eSexual Health Clinic system for management,prevention, and control of sexually transmitted infections: exploratory studies in people testing for Chlamydia trachomatis. *Lancet Public Health* 2017; **2**: 182-90.

68. Baraitser P, Holdsworth G, Joia DS, Free C. Technology for Patient-Centred Innovation - a Mixed Method Evaluation in Sexual Health. *International Journal for Quality in Health Care* 2017; **29**(suppl_1): 54-.

Interactive digital interventions for prevention of sexually transmitted HIV – Forest plots

Figure 1 Forest plot: IDIs versus minimal interventions: KNOWLEDGE

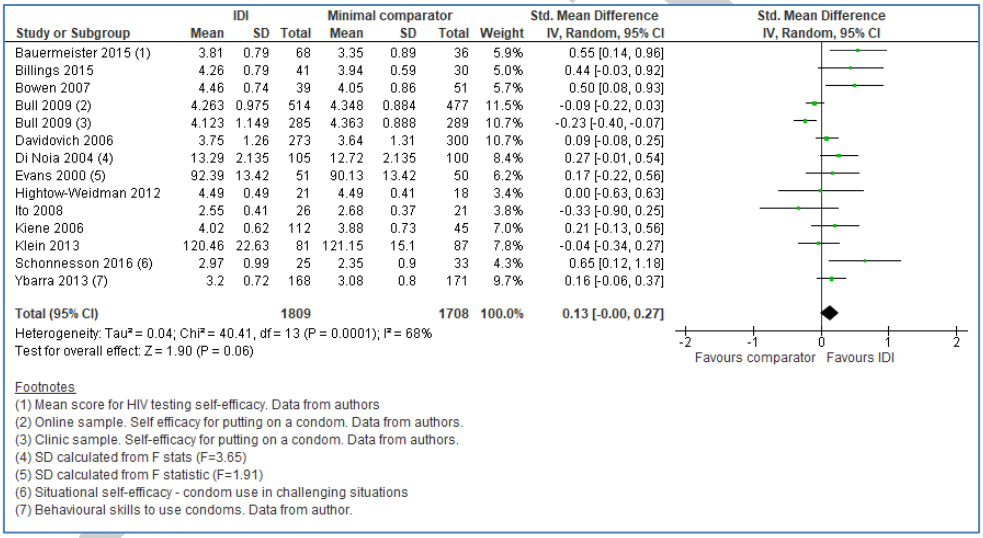


Study or Subgroup	IDI Mean	IDI SD	IDI Total	Minimal comparator Mean	Minimal comparator SD	Minimal comparator Total	Weight	Std. Mean Difference IV, Random, 95% CI
Billings 2015	13.59	3.37	45	12.79	2.85	38	8.0%	0.25 [-0.18, 0.69]
Bowen 2007	11.46	1.98	39	8.9	1.83	51	7.7%	1.34 [0.88, 1.80]
Di Noia 2004 (1)	8.18	1.776	105	6.87	1.776	100	9.4%	0.73 [0.45, 1.02]
Evans 2000 (2)	7.14	1.887	51	3.9	1.887	50	7.8%	1.70 [1.25, 2.16]
Fiellin 2017 (3)	7.21	2.72	127	6.45	2.89	128	9.8%	0.27 [0.02, 0.52]
Hightow-Weidman 2012	0.82	0.23	21	0.88	0.12	18	6.1%	-0.31 [-0.95, 0.32]
Ito 2008	17.28	1.9	26	16.17	1.88	21	6.5%	0.58 [-0.01, 1.16]
Kiene 2006	51.45	5.66	112	48.93	5.49	45	8.8%	0.45 [0.10, 0.80]
Klein 2013	8.41	0.78	81	8.13	0.64	87	9.2%	0.39 [0.09, 0.70]
Perry 1991	14	2.7	108	13.3	2.9	113	9.6%	0.25 [-0.02, 0.51]
Schonnesson 2016 (4)	8.32	1.6	25	6.97	1.61	33	6.9%	0.83 [0.29, 1.37]
Ybarra 2013 (5)	78.77	17.18	168	72.22	18.52	171	10.0%	0.37 [0.15, 0.58]
Total (95% CI)			**908**			**855**	**100.0%**	**0.56 [0.33, 0.80]**

Heterogeneity: Tau² = 0.13; Chi² = 59.71, df = 11 (P < 0.00001); I² = 82%
Test for overall effect: Z = 4.66 (P < 0.00001)

Footnotes
(1) SDs calculated from F stats. (F=27.86)
(2) SDs calculated from F statistic. (F=39.21)
(3) HIV knowledge at 12 month follow-up. Data from authors.
(4) HIV knowledge at 1 month follow-up. Data from authors
(5) HIV information. Data from author.

Figure 2 Forest plot: IDIs versus minimal interventions: SELF-EFFICACY

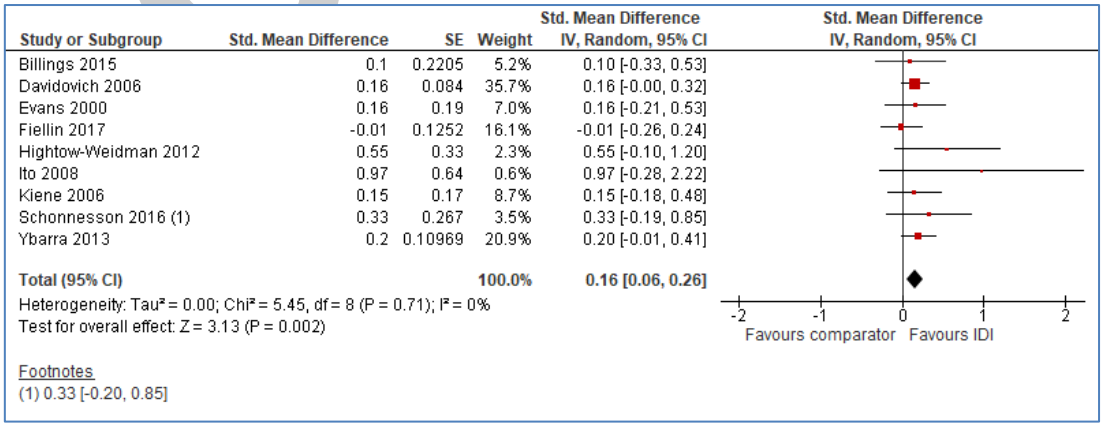


Study or Subgroup	IDI Mean	IDI SD	IDI Total	Minimal comparator Mean	Minimal comparator SD	Minimal comparator Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bauermeister 2015 (1)	3.81	0.79	68	3.35	0.89	36	5.9%	0.55 [0.14, 0.96]
Billings 2015	4.26	0.79	41	3.94	0.59	30	5.0%	0.44 [-0.03, 0.92]
Bowen 2007	4.46	0.74	39	4.05	0.86	51	5.7%	0.50 [0.08, 0.93]
Bull 2009 (2)	4.263	0.975	514	4.348	0.884	477	11.5%	-0.09 [-0.22, 0.03]
Bull 2009 (3)	4.123	1.149	285	4.363	0.888	289	10.7%	-0.23 [-0.40, -0.07]
Davidovich 2006	3.75	1.26	273	3.64	1.31	300	10.7%	0.09 [-0.08, 0.25]
Di Noia 2004 (4)	13.29	2.135	105	12.72	2.135	100	8.4%	0.27 [-0.01, 0.54]
Evans 2000 (5)	92.39	13.42	51	90.13	13.42	50	6.2%	0.17 [-0.22, 0.56]
Hightow-Weidman 2012	4.49	0.49	21	4.49	0.41	18	3.4%	0.00 [-0.63, 0.63]
Ito 2008	2.55	0.41	26	2.68	0.37	21	3.8%	-0.33 [-0.90, 0.25]
Kiene 2006	4.02	0.62	112	3.88	0.73	45	7.0%	0.21 [-0.13, 0.56]
Klein 2013	120.46	22.63	81	121.15	15.1	87	7.8%	-0.04 [-0.34, 0.27]
Schonnesson 2016 (6)	2.97	0.99	25	2.35	0.9	33	4.3%	0.65 [0.12, 1.18]
Ybarra 2013 (7)	3.2	0.72	168	3.08	0.8	171	9.7%	0.16 [-0.06, 0.37]
Total (95% CI)			**1809**			**1708**	**100.0%**	**0.13 [-0.00, 0.27]**

Heterogeneity: Tau² = 0.04; Chi² = 40.41, df = 13 (P = 0.0001); I² = 68%
Test for overall effect: Z = 1.90 (P = 0.06)

Footnotes
(1) Mean score for HIV testing self-efficacy. Data from authors
(2) Online sample. Self efficacy for putting on a condom. Data from authors.
(3) Clinic sample. Self-efficacy for putting on a condom. Data from authors.
(4) SD calculated from F stats (F=3.65)
(5) SD calculated from F statistic (F=1.91)
(6) Situational self-efficacy - condom use in challenging situations
(7) Behavioural skills to use condoms. Data from author.

Figure 3 Forest plot: IDIs versus minimal interventions: INTENTION

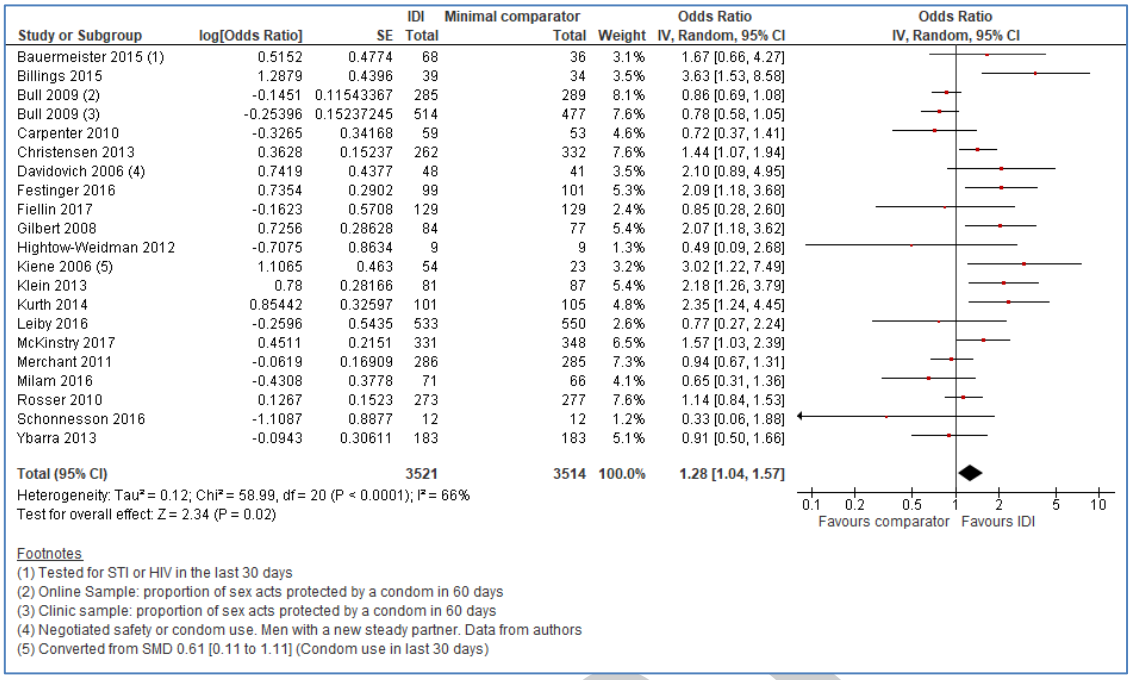


Study or Subgroup	Std. Mean Difference	SE	Weight	Std. Mean Difference IV, Random, 95% CI
Billings 2015	0.1	0.2205	5.2%	0.10 [-0.33, 0.53]
Davidovich 2006	0.16	0.084	35.7%	0.16 [-0.00, 0.32]
Evans 2000	0.16	0.19	7.0%	0.16 [-0.21, 0.53]
Fiellin 2017	-0.01	0.1252	16.1%	-0.01 [-0.26, 0.24]
Hightow-Weidman 2012	0.55	0.33	2.3%	0.55 [-0.10, 1.20]
Ito 2008	0.97	0.64	0.6%	0.97 [-0.28, 2.22]
Kiene 2006	0.15	0.17	8.7%	0.15 [-0.18, 0.48]
Schonnesson 2016 (1)	0.33	0.267	3.5%	0.33 [-0.19, 0.85]
Ybarra 2013	0.2	0.10969	20.9%	0.20 [-0.01, 0.41]
Total (95% CI)			**100.0%**	**0.16 [0.06, 0.26]**

Heterogeneity: Tau² = 0.00; Chi² = 5.45, df = 8 (P = 0.71); I² = 0%
Test for overall effect: Z = 3.13 (P = 0.002)

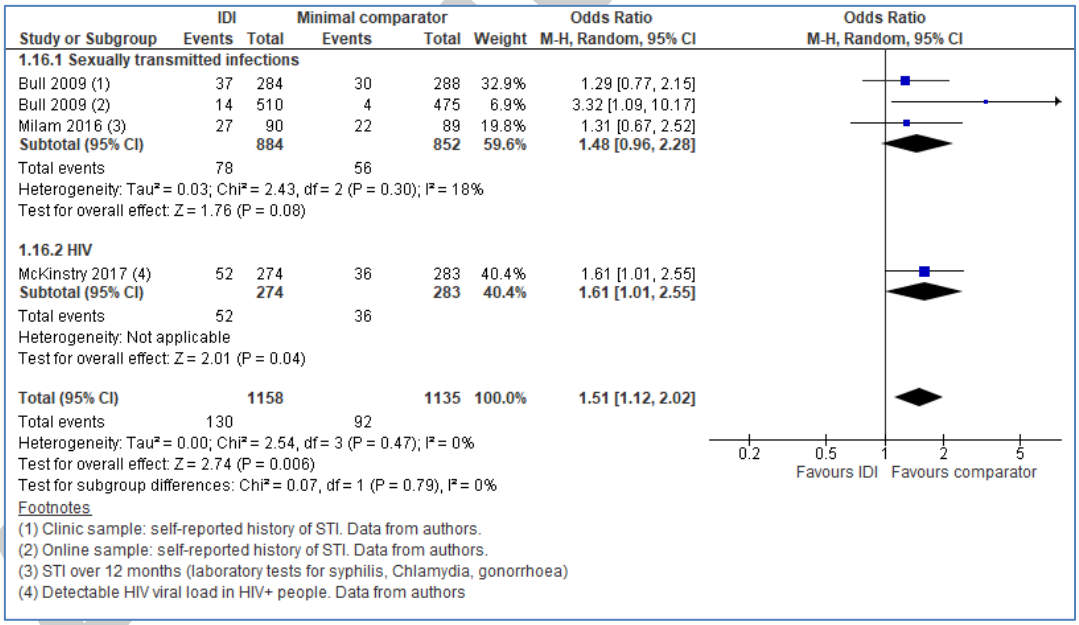
Footnotes
(1) 0.33 [-0.20, 0.85]

Figure 4 Forest plot: IDIs versus minimal interventions: BEHAVIOUR



Footnotes
(1) Tested for STI or HIV in the last 30 days
(2) Online Sample: proportion of sex acts protected by a condom in 60 days
(3) Clinic sample: proportion of sex acts protected by a condom in 60 days
(4) Negotiated safety or condom use. Men with a new steady partner. Data from authors
(5) Converted from SMD 0.61 [0.11 to 1.11] (Condom use in last 30 days)

Figure 5 Forest plot: IDIs versus minimal interventions: BIOLOGICAL OUTCOMES



Footnotes
(1) Clinic sample: self-reported history of STI. Data from authors.
(2) Online sample: self-reported history of STI. Data from authors.
(3) STI over 12 months (laboratory tests for syphilis, Chlamydia, gonorrhoea)
(4) Detectable HIV viral load in HIV+ people. Data from authors