Interactive digital interventions for prevention of sexually transmitted HIV

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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 randomized 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 standardized mean differences (SMD) for continuous outcomes and odds ratios (OR) 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.

Conclusion: 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

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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 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 2019, an estimated 81% of HIV-positive people worldwide knew their status, 82% of those were accessing treatment, and 88% were virally suppressed [3]. Alongside scaling up access to ART, the success of this campaign depends upon sociocultural 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 stigmatized sexual health issues [14]. Multimedia formats such as audio and video can help to reach people with poor literacy, and digital interventions can increase engagement by offering individualized 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, personalized 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 constituted three concepts: RCT design filter [20] or health economic evaluation AND Computer-based/digital interventions AND 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, for example, 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 optimize healthcare delivery; and interventions addressing clinical management of HIV (e.g. adherence to ART) as 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 (J.B. and S.W., R.W. or C.A.) 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 (E.M.). We contacted authors of included studies wherever necessary, to clarify details of study design and for missing data, making multiple attempts to contact authors. J.B., S.W., and C.A. transferred data into Review Manager software, double-checking the accuracy.

Study characteristics and outcomes

We categorized outcomes as follows:

(1) Cognitive outcomes: HIV-related knowledge; self-efficacy (a person's belief in their capacity to carry out a specific action); behavioural intention.
(2) Behavioural outcomes: for example, condom use; partner numbers; HIV testing; negotiation/communication with a partner.
(3) Biological outcomes: for example, HIV or STI acquisition; viral load.
(4) Health economic outcomes: for example, 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 because of inadequate sequence generation or concealment of allocation were excluded. Studies with less than 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 because of 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 standardized 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 less than 0.40 to be 'small'; 0.4–0.70, 'moderate'; and greater than 0.70 a 'large' effect [23]. We assessed statistical heterogeneity by using the I^2 statistic to estimate variance between studies and chi-square test for heterogeneity, interpreting the I^2 statistic as follows: less than 25% might not be important; 25 to less than 50%: moderate heterogeneity; 50 to less than 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 articles). 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 randomization [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 articles), 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 randomized, 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], 10 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]; healthcare 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, tailoring by 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 offering tailored feedback according to users' knowledge, motivation and behavioural skills [31,43]; stage of change [37,51], or knowledge [39,43,48,53,56,60,64]. Other interventions offered 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]; visualization 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 of 31 studies. Outcomes had been selectively reported in one study, with data unavailable from authors [60].

Group 1: Are interactive digital interventions effective?

Twenty-nine studies examined the effectiveness of IDIs compared with minimal interventions. A total of 5277 people were randomized to receive an IDI, and 5146

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 interactive digital interventions 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% confidence interval (CI) 0.33–0.80], which is a moderate effect (Fig. 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 interactive digital interventions 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 0.00–0.27) (Fig. 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 interactive digital interventions impact on HIV prevention intention?

We combined data from nine out of 12 studies which measured behavioural intention. Meta-analysis showed a small effect on HIV-related intentions for IDIs compared with minimal interventions (SMD 0.16, 95% CI 0.06–0.26); heterogeneity $I^2 = 0\%$ (Fig. 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 interactive digital interventions improve HIV prevention behaviours?

Twenty-one out of 23 studies contributed to a meta-analysis 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 1.04–1.57) for HIV prevention behaviours (Fig. 4). There was considerable heterogeneity ($I^2 = 66\%$, $P < 0.0001$).

Do interactive digital interventions affect biological outcomes?

Four RCTs out of seven contributed to a meta-analysis of biological outcomes, measuring HIV viral load [55], and other STIs (e.g. chlamydia, gonorrhoea, syphilis) [36,49]. One study [56] reported no new diagnoses of HIV so
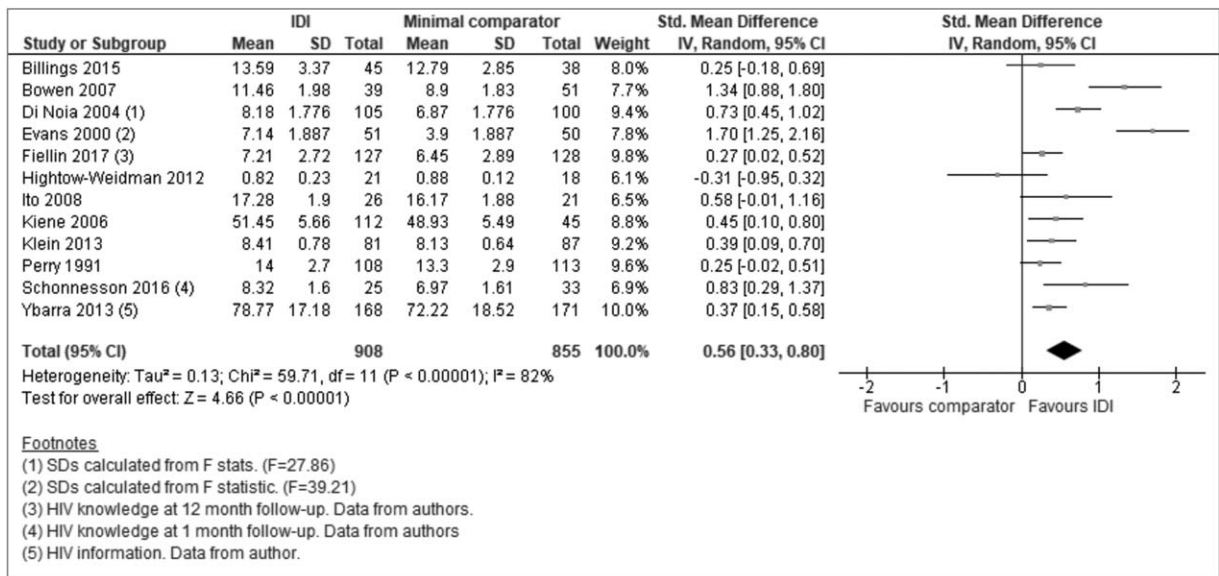
Study or Subgroup	IDI Mean	SD	Total	Minimal comparator Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Std. Mean Difference IV, Random, 95% CI
Billings 2015	13.59	3.37	45	12.79	2.85	38	8.0%	0.25 [-0.18, 0.69]	
Bowen 2007	11.46	1.98	39	8.9	1.83	51	7.7%	1.34 [0.88, 1.80]	
Di Noia 2004 (1)	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.

Fig. 1. Forest plot: interactive digital interventions versus minimal interventions: knowledge.

could not be included in the meta-analysis, and data were unavailable for another study (self-reported HIV status) [31]. One study specifically aimed to increase testing, so we excluded this from the meta-analysis as 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 0.96–2.28), with one study reporting an increase in detectable HIV viral load (OR 1.61, 95% CI 1.01–2.55) (Fig. 5). There was no overall heterogeneity ($I^2 = 0$%).

Does study quality affect results?
Excluding studies at unclear risk of bias because of their methods of randomization did not substantially alter effect sizes. Excluding studies at high risk of bias because of less than 80% retention 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 *et al.* 2009, online RCT results) was very small, with wide
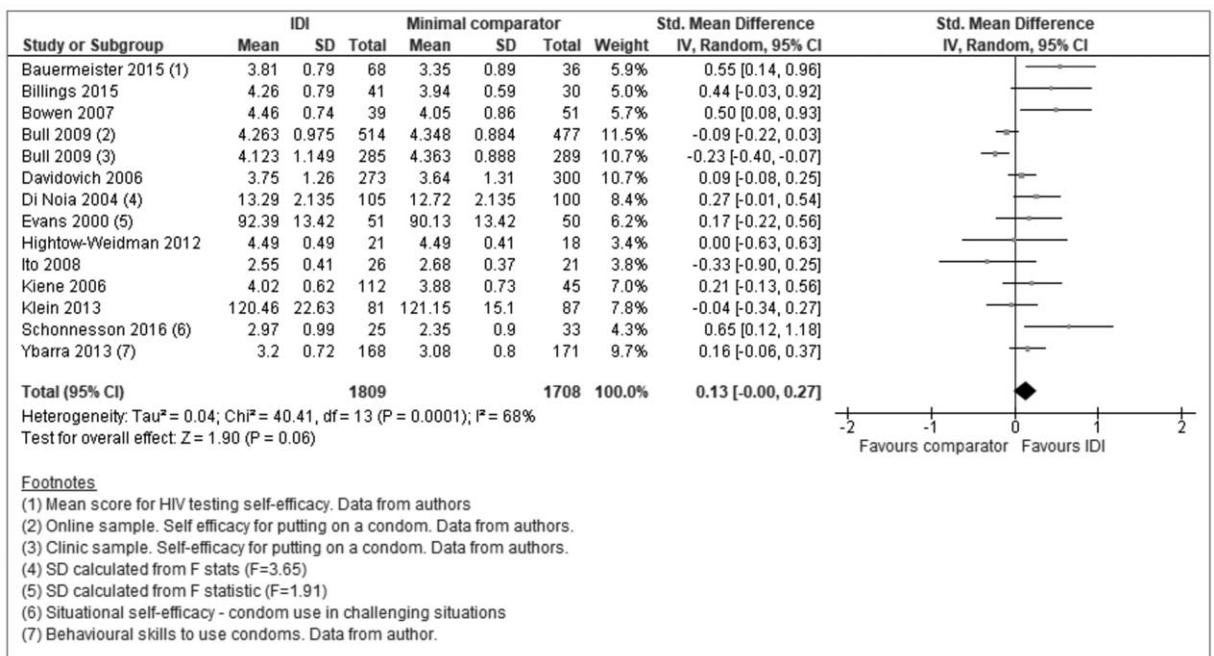
Study or Subgroup	IDI Mean	SD	Total	Minimal comparator Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Std. Mean Difference IV, Random, 95% CI
Bauermeister 2015 (1)	3.81	0.79	68	3.35	0.89	36	5.9%	0.55 [0.14, 0.96]	
Billings 2015	4.26	0.79	41	3.94	0.59	30	5.0%	0.44 [-0.03, 0.92]	
Bowen 2007	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.

Fig. 2. Forest plot: interactive digital interventions versus minimal interventions: self-efficacy.

Study or Subgroup	Std. Mean Difference	SE	Weight	Std. Mean Difference IV, Random, 95% CI	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]

Fig. 3. Forest plot: interactive digital interventions versus minimal interventions: intention.

confidence intervals [36]; Milam *et al.* 2016 was a small trial (49 participants) [49]; and viral load data were not available for 48% of McKinstry *et al*'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 9–12, 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 13–16, 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
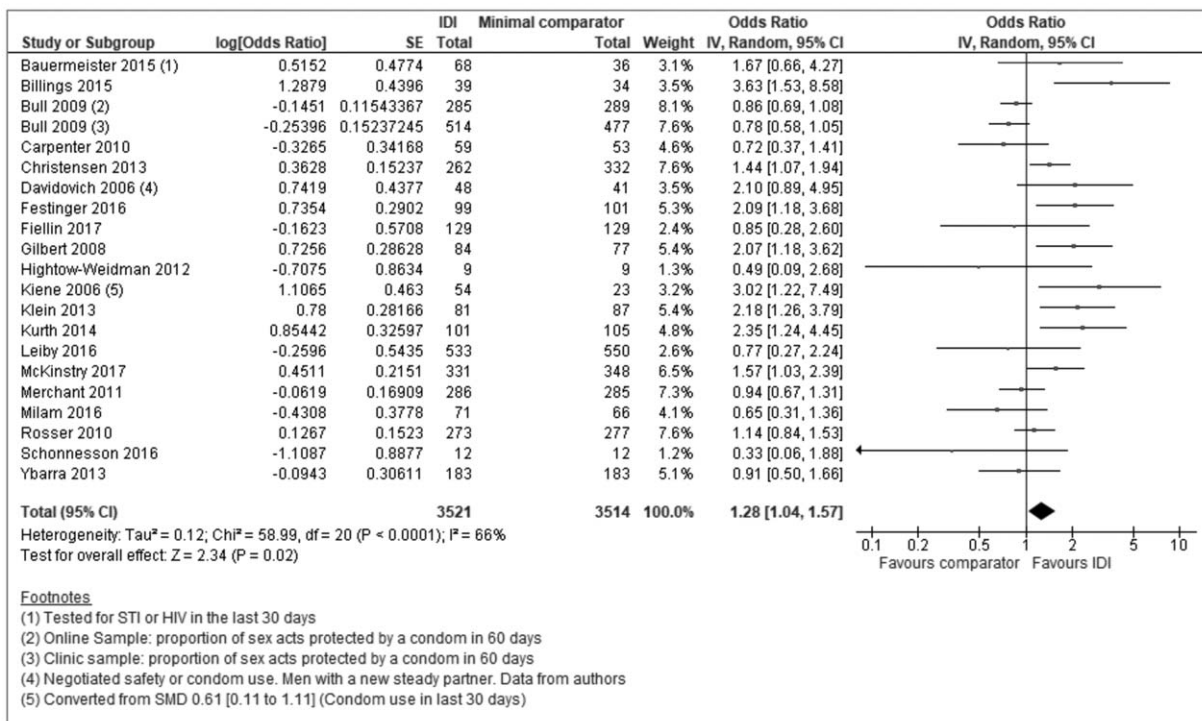
Study or Subgroup	log[Odds Ratio]	SE	IDI Total	Minimal comparator Total	Weight	Odds Ratio IV, Random, 95% CI	Odds Ratio IV, Random, 95% CI
Bauermeister 2015 (1)	0.5152	0.4774	68	36	3.1%	1.67 [0.66, 4.27]	
Billings 2015	1.2879	0.4396	39	34	3.5%	3.63 [1.53, 8.58]	
Bull 2009 (2)	-0.1451	0.11543367	285	289	8.1%	0.86 [0.69, 1.08]	
Bull 2009 (3)	-0.25396	0.15237245	514	477	7.6%	0.78 [0.58, 1.05]	
Carpenter 2010	-0.3265	0.34168	59	53	4.6%	0.72 [0.37, 1.41]	
Christensen 2013	0.3628	0.15237	262	332	7.6%	1.44 [1.07, 1.94]	
Davidovich 2006 (4)	0.7419	0.4377	48	41	3.5%	2.10 [0.89, 4.95]	
Festinger 2016	0.7354	0.2902	99	101	5.3%	2.09 [1.18, 3.68]	
Fiellin 2017	-0.1623	0.5708	129	129	2.4%	0.85 [0.28, 2.60]	
Gilbert 2008	0.7256	0.28628	84	77	5.4%	2.07 [1.18, 3.62]	
Hightow-Weidman 2012	-0.7075	0.8634	9	9	1.3%	0.49 [0.09, 2.68]	
Kiene 2006 (5)	1.1065	0.463	54	23	3.2%	3.02 [1.22, 7.49]	
Klein 2013	0.78	0.28166	81	87	5.4%	2.18 [1.26, 3.79]	
Kurth 2014	0.85442	0.32597	101	105	4.8%	2.35 [1.24, 4.45]	
Leiby 2016	-0.2596	0.5435	533	550	2.6%	0.77 [0.27, 2.24]	
McKinstry 2017	0.4511	0.2151	331	348	6.5%	1.57 [1.03, 2.39]	
Merchant 2011	-0.0619	0.16909	286	285	7.3%	0.94 [0.67, 1.31]	
Milam 2016	-0.4308	0.3778	71	66	4.1%	0.65 [0.31, 1.36]	
Rosser 2010	0.1267	0.1523	273	277	7.6%	1.14 [0.84, 1.53]	
Schonnesson 2016	-1.1087	0.8877	12	12	1.2%	0.33 [0.06, 1.88]	
Ybarra 2013	-0.0943	0.30611	183	183	5.1%	0.91 [0.50, 1.66]	
Total (95% CI)			**3521**	**3514**	**100.0%**	**1.28 [1.04, 1.57]**	

Heterogeneity: Tau² = 0.12; Chi² = 58.99, df = 20 (P < 0.0001); I² = 66%
Test for overall effect: Z = 2.34 (P = 0.02)

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)

Fig. 4. Forest plot: interactive digital interventions versus minimal interventions: behaviour.
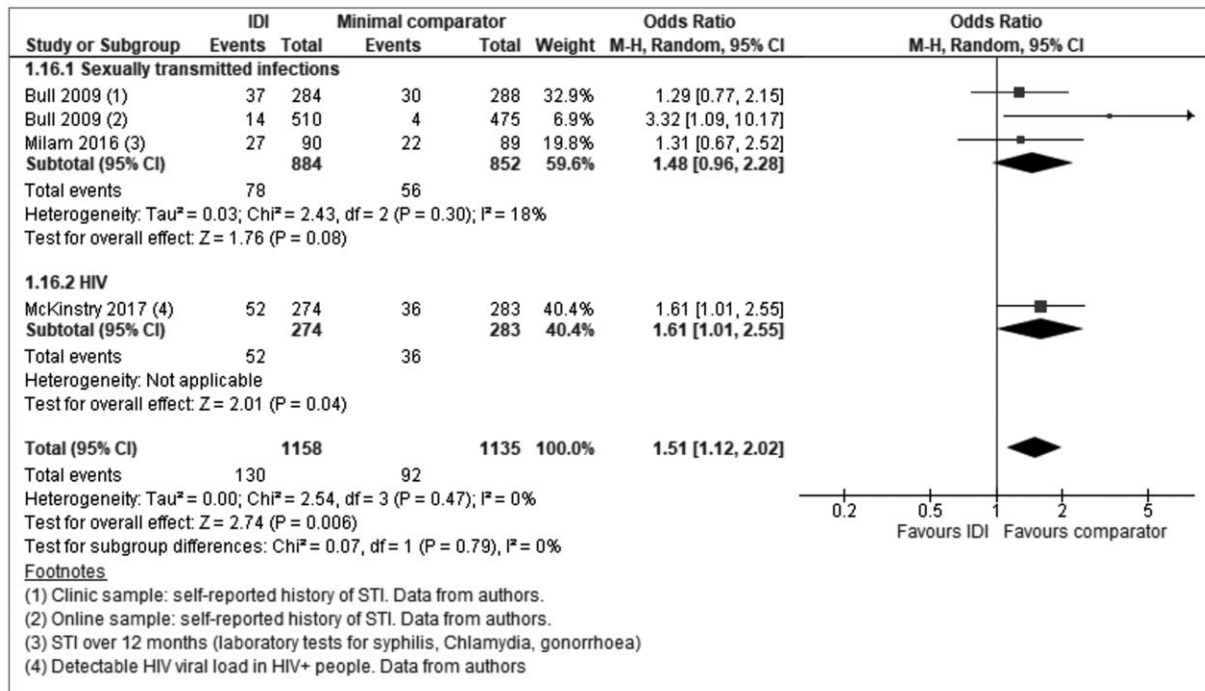
Fig. 5. Forest plot: interactive digital interventions versus minimal interventions: biological outcomes.

(Supplemental Digital Content 7 – Forest plots, Figures 17–20, http://links.lww.com/QAD/B941).

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

Summary: Are interactive digital interventions 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 interactive digital interventions as effective as face-to-face interventions?

Five RCTs compared IDIs with nondigital, face-to-face HIV prevention (Supplemental Digital Content 6 – Group Two Outcomes, http://links.lww.com/QAD/B940). Four hundred and thirty-four people were randomized 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 three out of four 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 three of the four 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.* [45] 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).

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

Summary: Are interactive digital interventions 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 synthesizes 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 as 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 socioeconomically 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, multimedia features, mode of delivery, etc.) [19].

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.

IDIs 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 increased 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].

Conclusion

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.

Conflicts of interest

There are no conflicts of interest.

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