Efficacy of e-health interventions for smoking cessation management in smokers: a systematic review and meta-analysis

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Summary

Background Smoking is one of the major risk factors for shortened lifespan and disability, while smoking cessation is currently the only guaranteed method to reduce the harm caused by smoking. E-health is a field that utilizes information and communication technology to support the health status of its users. The emergence of this digital health approach has provided a new way of smoking cessation support for smokers seeking help, and an increasing number of researchers are attempting to use e-health for a wide range of effective smoking cessation interventions. We conducted a systematic review and meta-analysis of studies that used e-health as a smoking cessation support tool.

Methods This systematic review and meta-analysis searched the PubMed, Embase, and Cochrane Library databases until December 2022. The included studies were randomized controlled trials (RCTs) comparing the use of e-health interventions and traditional offline smoking cessation care interventions. The primary outcome of the studies was the point smoking cessation rate (7-day and 30-day), and the secondary outcome was sustained smoking cessation rates. Studies were excluded if there was no clear e-health intervention described or if standard-compliant cessation outcomes were not clearly reported. Fixed-effects meta-analysis and meta-regression analyses were performed on the included study data to evaluate the effectiveness of the interventions. The meta-analysis outcome was the risk ratio (RR) and a 95% confidence interval. The study was registered with PROSPERO, CRD42023388667.

Findings We collectively screened 2408 articles, and ultimately included 39 articles with a total of 17,351 eligible participants, of which 44 studies were included in the meta-analysis. The meta-analysis revealed that compared to traditional smoking cessation interventions, e-health interventions can increase point quit rates (RR 1.86, 95% CI 1.69–2.04) as well as sustained quit rates in the long-term (RR 1.79, 95% CI 1.60–2.00) among smokers. Subgroup analysis showed that text and telephone interventions in e-health significantly improved short-term quit rates for up to 7 days (RR 2.10, 95% CI 1.77–2.48). Website and app interventions also had a positive impact on improving short-term quit rates for up to 7 days (RR 1.74, 95% CI 1.56–1.94). The heterogeneity of the study results was low, demonstrating the significant smoking cessation advantages of e-health interventions.

Interpretation We have found that personalized e-health interventions can effectively help smokers quit smoking. The diverse remote intervention methods of e-health can provide more convenient options for further customization. Additionally, further follow-up research is needed to evaluate the sustained effectiveness of interventions on smokers' continuous abstinence over a longer period (greater than one year). In the future, e-health can further optimize smoking cessation strategies.

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Keywords: eHealth; Smoking cessation; Meta-analysis; Intervention

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Research in context

Evidence before this study

Our systematic review and meta-analysis strictly followed the PRISMA guidelines. We searched PubMed, Embase, and Cochrane Library from the start of the period since the establishment of these databases to December 31, 2022, retrieving 2408 published RCTs using digital health interventions and usual care methods of smoking cessation. Analysis performed by Sarah and colleagues in 2018 demonstrated that digital interventions (particularly text-message and computer-delivered) could be effective for smoking cessation in pregnancy. Huyen and colleagues reviewed 108 studies including 110,372 participants and found that smoking cessation interventions using web-based and mobile health platforms resulted in significantly greater smoking abstinence. However, these studies did not examine whether different types of e-health interventions present effectiveness compared with traditional approaches.

Added value of this study

For the first time, our study comprehensively distinguishes e-health into mobile devices (including SMS and telephone) and telemedicine (primarily the use of the Internet) and identifies significant differences in their self-intervention effects on smoking cessation. Interventions through SMS and telephone show significantly better results than websites and applications. We believe this finding is not aligned with our expectations for the current state of e-health and provides valuable insights for the future development of e-health applications. Our analysis is an important step forward in collecting evidence on the effectiveness of e-health interventions, which has practical guiding value for the further development of group programs and the selection of intervention methods for smoking cessation programs in particular groups.

Implications of all the available evidence

We believe that the proportion of e-health interventions in the smoking cessation market will increase over time. By combining superior e-health interventions with traditional approaches (e.g. NRT), we are confident that better smoking cessation outcomes can be achieved. From this analysis, we believe that further research should focus on assessing the sustained cessation effects over a longer period (>1 year). Exploring further clinical trials to evaluate the effectiveness of multiple low-cost intervention combinations is also worthwhile.

Introduction

Smoking is a persistent unhealthy behavior sustained by nicotine dependence and is one of the major risk factors for shortened lifespan and disability, making it an exceedingly important global public health issue. Currently, around 100 million people worldwide use tobacco products, with over 3% residing in low and middle-income countries. Smoking can cause cancer, cardiovascular disease, and respiratory system diseases, with nearly 90% of lung cancer cases attributed to smoking.[1] Any degree of tobacco use is associated with increased health risks, with approximately 60,000 people dying each year due to smoking-related complications.[1] In the United States, smoking causes more deaths each year than any other preventable cause.[2]

However, smoking cessation is currently the only guaranteed method of reducing the risks associated with smoking.[3] For smokers, quitting at any point in time is beneficial. If successful, it even can prolong life by up to 10 years.[4] Studies show that around 70% of smokers intend to quit, but due to their physiological dependence on nicotine, it is a challenging task. Individuals who succeed in quitting smoking typically attempt to do so an average of 6 times before achieving long-term abstinence.[5] For those seeking to quit smoking, there are now numerous smoking cessation interventions available, including pharmacological and behavioral interventions. Strong evidence demonstrates that pharmacological and behavioral interventions, whether used alone or in combination, effectively increase smoking cessation rates in adults.[6,7] The distribution of small brochures detailing the hazards of smoking at general outpatient clinics or health promotion centers remains one of the traditional interventions, which has not demonstrated significant efficacy.[8] Moreover, the widespread use of medication, face-to-face smoking cessation support, or other interventions is associated with high economic costs.[8,9] Thus, we require a convenient, effective, high-security, low-cost, and widely applicable smoking cessation intervention method to better address this global public health problem.

In 2021, "*Global strategy on digital health 2020–2025*" released by the World Health Organization (WHO) defined e-health as "The cost-effective and secure use of information and communications technologies in support of health and health-related fields." E-health is an innovative healthcare service that encompasses mobile health (m-health) and telemedicine.[10,11] A wide range of information and communication technologies such as mobile devices and the Internet are utilized in prompting and maintaining health.[12] Compared to face-to-face medical technology, e-health can more, efficiently, and with higher quality respond to the increase in healthcare expenditure, changes in population structure, and increasingly complex health conditions.[13] The rise of e-health has provided a new way for smokers to seek smoking cessation support.[14] E-health extends smoking cessation counseling beyond hospitals and professional smoking cessation care facilities, covering smokers who have never received support from these

sources, and providing an opportunity for behavior support to those who do not have the conditions for face-to-face smoking cessation support.[15] Moreover, compared to face-to-face intervention, e-health intervention is more easily accessible anytime and anywhere. Researchers around the world are increasingly trying to use e-health for extensive and effective smoking cessation interventions.[16]

However, evidence of the effectiveness of e-health as a smoking cessation intervention and provide have not been extensively and systematically evaluated with large samples. Therefore, our meta-analysis aims to evaluate the evidence of e-health as a smoking cessation support intervention tool effectiveness and provide reference to individual smoking cessation management of future e-health smoking cessation interventions.

Method

Search strategy and selection criteria

Our systematic review and meta-analysis strictly followed the PRISMA guidelines. We searched PubMed, Embase, and Cochrane library from the start of the period since the establishment of these databases to 31 December 2022, retrieving 2408 published randomized controlled trials (RCTs) using digital health interventions and usual care methods of smoking cessation. Key words and specific subject headings for each database connecting to the terms 'smoking cessation', 'e-health' (including Telemedicine, Internet, telemedicine, mobile health, mHealth, tele-health, e-health, m-health, e-health, etc.) and 'randomised control trial' were searched. Boolean logic using AND, OR and NOT was applied to provide an exhaustive search strategy. This meta-analysis was based on individual participant data from RCTs included in the study. Risk ratios (RRs) and their confidence intervals (95% CI) were calculated for the different interventions based on the reported outcomes data from each randomized controlled trial. The point quit rate (7 days and 30 days) was the primary outcome of this meta-analysis. The secondary outcome was participants' sustained quit rates only. We also found that some studies reported on participants' adherence to different interventions. However, these articles assessed without a uniform methodology, making it difficult to quantitatively analyze adherence results. Inclusion criteria for this study were: participants were aged 18 years or older and volunteered to participate in the trial; each study had to be a randomized controlled trial with more than 15 participants in both the control and intervention groups; the study conducted a comparison of the e-health intervention and offline usual care intervention (including drug treatment, cessation brochures, and face-to-face cessation support) with data on the outcomes; and no other factors interfered with the outcome of the trial: e.g. monetary rewards.

Yiyang Li conducted the data search and Shen Li and Zhan Qu independently screened all abstracts and screened all full-text articles. The selection of articles was entirely reviewed and screened by two independent individuals, and any discrepancies in results were discussed with a third party, Xuelei Ma, the corresponding author of the study, for final judgment. The risk of bias and certainty of the evidence for articles were assessed independently using the Cochrane Risk of Bias tool.

Bias and quality analysis

Two reviewers (LS and QZ), following the guidance of the Cochrane Handbook for Systematic Reviews of Interventions and the Cochrane Tobacco Addiction Group, independently conducted risk of bias assessments. The Cochrane risk of bias tool, comprising seven items, was used by both reviewers to assess the risk of bias in each included study: (1) bias due to random sequence generation, (2) selection bias, (3) bias due to deviations from intended interventions, (4) bias in the measurement of outcomes, (5) bias due to incomplete outcome data, (6) bias in the selection of the reported result, and (7) bias from other sources. After data extraction, each reviewer judged the risk for each domain as low, high, or unclear. Disagreements were resolved with the presence of the third author. Based on the risk of bias, the quality of evidence was rated as very low, low, moderate, or high. The quality assessment of this study follows the GRADE (Grading of Recommendations, Assessment, Development, and Evaluation) framework.

Data analysis

We utilized Stata 14 software to calculate the total risk ratio (RR) and 95% confidence interval (CI) for e-health intervention and conventional offline care intervention. After a comprehensive assessment of the included articles, considering their similar research questions and study designs that suggest high clinical homogeneity and potentially low variability in true effects, we plan to employ the fixed-effects model and subsequently conduct sensitivity analyses for validation. If we discover that the fixed-effects model fails to account for potential heterogeneity, we will utilize the random-effects model to mitigate any bias introduced by true effect variations. We calculated I^2 to assess the extent of heterogeneity in the results, with I^2 values less than or equal to 25% indicating low heterogeneity, values between 25% and 75% indicating moderate heterogeneity, and values above 75% indicating strong heterogeneity. We also used a funnel plot to evaluate publication bias, and if the visual inspection indicated asymmetry, we conducted an Egger regression test to detect bias. We presented forest plots to show the total RR of participants' quit rates and sustained quit rates between the e-health and conventional care interventions, illustrating the effect of digital health interventions on smoking cessation event rates compared to the control group. Meta-regression assessed the impact

of one or more potential variables on the intervention effect size. We conducted regression tests on the included covariates, including country of origin, the gender ratio and age of participants, different measures of e-health intervention and usual care, intervention time, use of medication-assisted smoking cessation, and use of biochemical validation smoking cessation, to explore the possible reasons for heterogeneity and to construct a more precise model. When significant effects of mobile device methods such as text messaging and phone calls, and telemedicine e-health interventions such as websites and apps were found, we conducted subgroup analyses of specific e-health methods to further explore the effectiveness and impact of different e-health interventions on smoking cessation. The study was registered with PROSPERO, CRD42023388667.

Role of the funding source
There was no funding source for this study.

Result
We retrieved a total of 2408 articles through a literature search, including 1122 from the Cochrane Library and 1286 from other databases such as PubMed and Embase. The majority of the studies retrieved were in English, with very few articles in other languages that did not meet the inclusion criteria. After the duplicate screening, 1264 articles were excluded. From the remaining articles, we excluded 404 non-randomized controlled trial articles, 167 experimental design articles, and 512 articles that were not consistent with our study objectives based on the abstract reading. We then conducted full-text reading and eligibility assessment on the remaining 60 articles, with two reviewers independently reviewing and a third reviewer conducting a re-review on uncertain articles. Finally, we included a total of 39 articles. The inclusion process can be seen in Fig. 1.

Of the 39 articles we included, five studies involved three parallel experimental groups (one control and two intervention groups). We divided each of these five groups into two separate controlled trials, resulting in a total of 44 studies included in the analysis. This systematic review extracted and analyzed data from 17,351 participants. Ten studies (22.7%) did not provide the gender ratio of participants; two studies (4.5%) only included male participants, while the remaining studies included both male and female participants, and one study included transgender participants. Among the 44 studies, 15 were conducted in the United States, 17 in Europe (including two in Norway, two in Netherlands, and five in the United Kingdom), and eight in Asia (including six in China). One study was conducted in Australia, two in Brazil, and one in Argentina, and the characteristics of each study can be seen in Table 1.

We define traditional usual care methods as those that do not involve the use of mobile phones, websites, or electronic mobile devices (such as printed brochures, face-to-face counseling, and medication such as NRT treatment, among others). The included studies all used e-health interventions to intervene with smokers, and the e-health interventions took various forms. Among them, 17 studies used text messaging and phone calls as the intervention method, while 27 studies used websites and mobile applications. Most interventions (61.4%) involved regular smoking cessation education and health counseling provided through websites and software programs.

The intervention duration varied from 21 days to 12 months across all studies, with short to medium term studies (21 days–3 months) accounting for 52.3% of the total. Three studies (6.8%) had intervention durations of 12 months, and the rest were between 3 and 12 months. Sixteen studies (36.4%) employed combined drug interventions, including nicotine patches, NRT, and varenicline. The results of 34 studies (77.3%) were confirmed through biochemical validation, ensuring the accuracy of the outcomes.

Main outcome
A total of 34 studies reported the point smoking cessation rates (7-day and 30-day). We initially intended to distinguish between the 7-day point quit rate and the 30-day point quit rate. However, since only three articles reported the 30-day point quit rate, which makes results lack representativeness and cause potential bias. Considering the greater challenge in achieving a 30-day smoking cessation, we decided to combine the results for 7 days and 30 days together without exaggerating the results of the point quit rate. The analysis demonstrated that the e-health intervention group had a higher rate of smoking cessation compared to the control group (RR 1.86, 95% CI 1.69–2.04). The data analysis report revealed no heterogeneity (I^2 = 0%, 95% CI 0–34.9%, p = 0.565) (Fig. 2).

Secondary outcome
We hypothesized that participants who achieved sustained cessation achieved good smoking cessation outcomes. Statistical analysis of the data showed that 13 studies reported sustained cessation rates, of which 1 study reported a 60-day cessation rate, 2 studies reported a 3-month cessation rate, 7 studies reported a 6-month cessation rate, 1 study reported a 36-week cessation rate, and 2 studies reported a 12-month cessation rate. The results showed that compared to the control group using traditional smoking cessation methods, the e-health intervention group had better-sustained quit rates for two month or more (RR 1.79, 95% CI 1.60–2.00). The results showed low heterogeneity (I^2 = 0%, 95% CI 0–47.4%, p = 0.565) (Fig. 3).

Subgroup analysis
We conducted a meta-regression analysis on covariates that may affect the statistical results. The results of the

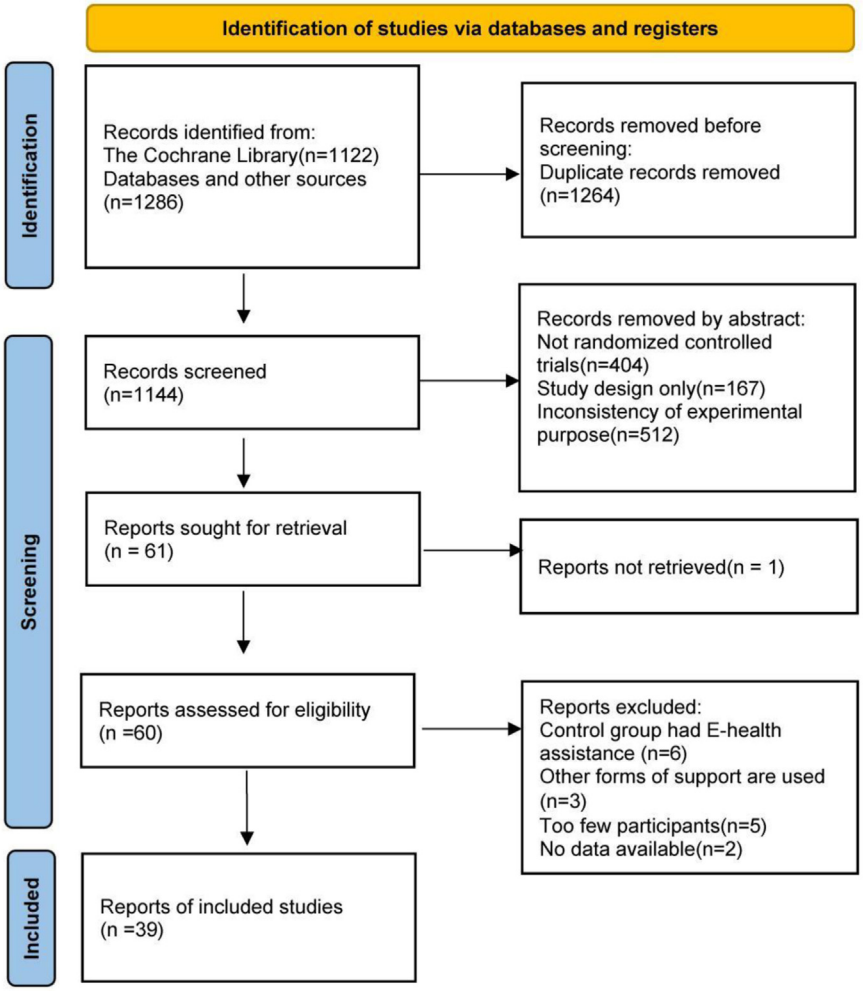

Fig. 1: **Study selection.**

point quit rate showed that the use of different e-health intervention measures did affect the statistical results. However, to explore this further, we grouped interventions into two types based on the scope of e-health defined by the WHO. One uses text message and telephone interventions (mobile device health) and the other uses websites and software programs (telemedicine). Both types of interventions had a positive impact on successful smoking cessation. Of the 34 studies that reported point prevalence of smoking cessation, 13 studies used mobile device health interventions (phone calls and text messages), and 21 used telemedicine interventions (websites and software programs). Among them, the effect of using text or telephone interventions was stronger (RR 2.10, 95% CI 1.77–2.48), while the positive intervention effect of website and software programs was slightly weaker (RR 1.74, 95% CI 1.56–1.94). Subgroup analysis showed no heterogeneity in both groups (Tex and Tel: I^2 = 0%, p = 0v522; Web and APPs: I^2 = 0%, p = 0.700, overall I^2 = 0%, p = 0.565) (Fig. 4). We also conducted meta-regressions of sustained quit rates, but we did not find any correlates.

Of the 13 studies that reported continuous cessation rates, 6 studies were categorized in the mobile device group and 7 studies in the telemedicine group. The results showed stronger smoking cessation effects in the former (RR 2.01, 95% CI 1.72–2.36) than in the latter (RR 1.54, 95% CI 1.32–1.81). Subgroup analysis showed no heterogeneity in both groups (Tex and Tel: I^2 = 0%, p = 0.506; Web and APPs: I^2 = 0%, p = 0.965, overall I^2 = 0%, p = 0.565) (Fig. 5).

Risk of bias in studies

All included studies underwent bias risk assessment following guidelines recommended by the Cochrane Handbook for Systematic Reviews of Interventions. Assessment of blinding-related bias was uniformly designated as low risk, as the Cochrane Tobacco

Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
Bernstein 2016[17]	USA	30:30	43.9 ± 11.2:36.3 ± 10.8	30:30	SmokeFreeTXT	A brochure describing the state smokers' quitline	No	No	7-day point prevalence abstinence at 3 months	30.0%:13.0%		SmokeFreeTXT	The proportion of subjects engaging in quitline services for the intervention and control subjects was 9/30 (30%) and 1/30 (3%) respectively (p = 0.005)
Brendryen 2008[18]	Norway	145:146	35.9 ± 10.0:36.4 ± 10.5	199:197	Happy Ending (HE)	Self-help booklet	Yes	No	7-day point prevalence abstinence at 6 months	37.1%:21.6%		Happy Ending (HE)	
Brendryen 2008[19]	Norway	145:145	39.5 ± 11.0:39.7 ± 10.8	144:146	Happy Ending (HE)	Self-help booklet	No	No	7-day point prevalence abstinence at 6 months	29.0%:14.0%		Happy Ending (HE)	
Brunette 2018[20]	USA	39:19	24.2 ± 3.6	30:28	Let's Talk About Smoking	Computerized version of an education pamphlet from the National Cancer Institute (NCI)	No	Yes	7-day point prevalence abstinence at 14 weeks	14.8%:0%		Let's Talk About Smoking	
Brunette 2020[21]	USA	108:54	45.91 ± 11.32	84:78	Let's Talk About Smoking	Computerized version of an education pamphlet from the National Cancer Institute (NCI)	No	Yes	7-day point prevalence abstinence at 6 months	7.1%:1.3%		Let's Talk About Smoking	Satisfaction: 8.9 [SD 1.3] vs 8.3 [SD 2.1]; p = 0.045 Dropout rate: 25/84, 30% vs 36/78, 46%
Bui 2022[22]	Cambodia	50:0	44.9 ± 6.9:43.4 ± 7.6	25:25	Automated Messaging (AM)	Standard care	No	Yes	7-day point prevalence abstinence at 2 months	40.0%:8.0%		Automated Messaging (AM)	81% delivered messages and assessments were read or completed as indicated by digital date/time stamp
Burford 2013[23]	Australia	60:100	25.1 ± 4.1:24.2 ± 4.1	80:80	The APRIL Face Aging software	Standardized smoking cessation advice	No	Yes	self-reporting to have successfully quit smoking at 6 months	13.8%:1.3%		The APRIL Face Aging software	
Calhoun 2016[24]	USA	345:63	42.9 ± 13.9	205:203	Free, lifetime membership to the full, enhanced version of QuitNet (www.QuitNet.com)	Standard specialty-clinic based treatment	Yes	No	7-day point prevalence abstinence at 3 months	17.4%:12.7%		Free, lifetime membership to the full, enhanced version of QuitNet (www.QuitNet.com)	

(Table 1 continues on next page)

Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
(Continued from previous page)													
Chen 2021[25]	Taiwan. China	121:0	55.95 ± 6.99:56.81 ± 8.68	57:64	行動社群網路支持介入	Regular care and a smoking cessation booklet	No	Yes	smoking cessation rate at 3 months	35.1%:17.2%		行動社群網路支持介入	The utilization rate of mobile social network support is obviously low, with 9 people actually reading and replying, and most of the rest have not read or replied.
Cheung 2015[26]	Hongkong, China	75:21	40.5 ± 9.9	42:54	WhatsApp Online Social Groups	Self-help booklet on smoking cessation	No	No	7-day point prevalence abstinence at 6 months	64.3%:38.9%		WhatsApp Online Social Groups	
Cheung 2015[26]	Hongkong, China	72:22	40.5 ± 9.9	40:54	Facebook Online Social Groups	Self-help booklet on smoking cessation	No	No	7-day point prevalence abstinence at 6 months	47.5%:38.9%		Facebook Online Social Groups	
Chulasai 2022[27]	Thailand	164:109	21.06 ± 1.62	137:136	Smartphone Application for Smoking Cessation (Quit with US)	Pharmacists' smoking cessation counseling	No	No	7-day point prevalence abstinence at 12 weeks	58.4%:30.9%		Smartphone Application for Smoking Cessation (Quit with US)	119 participants in the Quit with US intervention group were satisfied with the overall design and the overall content with a mean (SD) score of 4.06 (0.82) and 4.16 (0.80) (scale of 1–5), respectively. They also expressed confidence in using the smartphone app with a mean (SD) score of 4.33 (0.74) (scale of 1–5)
Cobos 2017[28]	Spain	179:141	45 ± 9.1	160:160	A combined program that includes health advice and text messaging to mobile phone (SMSalud®)	Usual clinical practice	No	Yes			6 month continuous quit rate 24.4%:11.9%	A combined program that includes health advice and text messaging to mobile phone (SMSalud®)	The satisfaction ratings were very high on all items, more than 80% of patients stating that they were satisfied or totally satisfied.
Cruvinel 2019[29]	Brazil	34:32	47.7 ± 11.5	44:22	SmokeFreeTXT	A brochure describing the state smokers' quitline	Yes	No	7-day point prevalence abstinence at 1 month	25.0%:9.3%		SmokeFreeTXT	Most TXT participants (80.4%) reported that the text message content was "helpful". Similarly, most (80.5%) reported that the number of text messages received was "enough". Nearly all (95.1%) found calls to be "just the right length."

(Table 1 continues on next page)

Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
(Continued from previous page)													
Dezee 2013[30]	USA	127:90	40.5 ± 1.3:40.4 ± 5.7	173:44	Happy Ending (HE)	Self-help booklet	Yes	Yes	7-day point prevalence abstinence at 12 weeks	20.8%:18.2%		Happy Ending (HE)	
Durmaz 2019[31]	Turkey	80:52	39.3 ± 12.1	44:88	Happy Ending (HE)	Self-help booklet	No	No	30-day point prevalence abstinence rate at 1st month post target quit day	65.9%:40.9%	3 month continuous quit rate 50.0%:30.7%	Happy Ending (HE)	
Elfeddali 2012[32]	Netherlands	150:242	40.88 ± 11.80	190:202	Let's Talk About Smoking	Computerized version of an education pamphlet from the National Cancer Institute (NCI)	No	Yes			12 month continuous quit rate 33.2%:22.3%	Let's Talk About Smoking	
Elfeddali 2012[32]	Netherlands	145:231	40.88 ± 11.80	174:202	Let's Talk About Smoking	Computerized version of an education pamphlet from the National Cancer Institute (NCI)	No	Yes			12 month continuous quit rate 30.5%:22.3%	Let's Talk About Smoking	
Free 2011[33]	UK	3193:2599	36.8 ± 11.0:36.9 ± 11.1	2911:2881	Automated Messaging (AM)	Standard care	No	Yes			6 month continuous quit rate 9.2%:4.3%	Automated Messaging (AM)	
Goldenhersch 2020[34]	Argentina	63:57	43.20 ± 9.50	60:60	The APRIL Face Aging software	Standardized smoking cessation advice	No	Yes	1 day after the end of the program	23.3%:5.0%		The APRIL Face Aging software	Intervention adherence was analyzed only in the TG, and 93% (56/60) of participants finished the 21-day program. Of those who finished, 41% (23/56) were fully adherent to the program (ie, completed all daily sessions and nightly reflections 21 days in a row) and 59% (33/56) were regularly adherent (ie, completed the program in >21 days), completing the program in 28.56 days on average.

(Table 1 continues on next page)

Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
(Continued from previous page)													
Humfleet 2013[35]	USA	Male: Female: Transgender 114:21:5		58:69	Computer-Based Internet Treatment (CBI)	Individual counseling	Yes	Yes	7-day point prevalence abstinence at 24 weeks	26.7%:15.1%		Computer-Based Internet Treatment (CBI)	
Mehring 2014[36]	Germany	75:91	42.2 ± 12.6:45.8 ± 12.8	86:82	Web-based coaching program	Usual care	No	Yes	biochemically confirmed smoking status at 12 weeks	5.8%:7.3%		Web-based coaching program	
Naughton 2012[37]	UK			96:102	MiQuit	Nontailored self-help leaflet	No	Yes	7-day point prevalence abstinence at 12 weeks	22.9%:19.6%		MiQuit	
Naughton 2014[38]	UK	285:317	41.8 ± 13.0	299:303	iQuit system	Usual care	No	No	2-week point prevalence abstinence at 8 weeks	15.1%:8.9%	6 month continuous quit rate 11.4%:6.3%	iQuit system	The majority of intervention participants reported that 79.2% found the information useful, 88.0% found the reports easy to understand, 65.2% found the reports effective in helping them quit smoking, 11.4% felt the reports were too long, and 69.6% read all the reports at least once.
Naughton 2017[39]	UK		26.5 ± 5.8	203:204	MiQuit	Usual care	No	Yes			continuous abstinence from 4 weeks post-randomisation until 36 weeks gestation 5.4% 2.0%	MiQuit	62% rated the text messages as quite or extremely helpful but 14% considered them annoying. 81% would either "probably" or "definitely" recommend MiQuit support to a friend or relative.
Olano 2022[16]	Spain	209:304	49.8 ± 10.82	242:271	Dejal@bot	Usual care	Yes	Yes			6 month continuous quit rate 26.0%:18.8%	Dejal@bot	In terms of variables related to intervention intensity, the mean total interaction time with the patients was 21.2 min (SD 18.3; 95% CI 19.0–23.4) in the CG and 121 min (SD 157.5; 95% CI 121.1–140.0) in the IG ($p < 0.001$), and the mean number of contacts was 2.92 (SD 1.89) in the CG and 45.56 (SD 36.32) in the IG ($p < 0.001$)

(Table 1 continues on next page)

Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
(Continued from previous page)													
Pechmann 2017[40]	USA	42:118	35.7 ± 9.9	65:70	Tweet2Quit	Usual care	Yes	No			sustained abstinence out to 60 days post-quit date 40.0%:20.0%	Tweet2Quit	Participants randomised to Tweet2Quit averaged 58.8 tweets/ participant and the average tweeting duration was 47.4 days/participant.
Sanchez 2019[41]	European	49:46	50.3 ± 9.08	52:45	Smartphone application	Usual care	Yes	Yes	7-day point prevalence abstinence at 12 months	64.7%:40.9%		Smartphone application	
Schwaninger 2021[42]	Switzerland	89:73	31.3 ± 10.9	81:81	Dyadic Buddy App	Usual care	No	Yes			6 month continuous quit rate 22.2%:13.6%	Dyadic Buddy App	
Shuter 2014[43]	USA	76:60	45.9 ± 10.0:45.4 ± 9.9	69:69	Website	Standard care	Yes	Yes	7-day point prevalence abstinence at 3 months	10.1%:4.3%		Website	PSFW subjects logged into a mean of 5.5 of 8 sessions and 26.2 of 41 pages. They executed a mean of 10 interactive clicks during a mean total of 59.8 min logged in.
Simmons 2013[44]	USA	99:66	20.45 ± 1.97	81:84	Web-Smoke	Didactic smoking intervention	No	Yes	7-day point prevalence abstinence at 6 months	32.1%:22.6%		Web-Smoke	
Skov 2016[45]	Denmark		51 (42–60):53 (41–62)	452:451	Active and effective telephone	Self-help booklet	No	Yes		14.8%:8.7%	6 month continuous quit rate 8.6%:4.2%	Active and effective telephone	
Skov 2016[45]	Denmark		52 (42–59):53 (41–62)	452:451	E-quit	Self-help booklet	No	Yes		11.5%:8.7%	6 month continuous quit rate 6.6%:4.2%	E-quit	
Tang 2018[15]	China			674:411	Happy Quit (HFM)	Usual care	No	Yes	7-day point prevalence abstinence at 4 weeks	13.1%:5.8%		Happy Quit (HFM)	
Tang 2018[15]	China			284:411	Happy Quit (LFM)	Usual care	No	Yes	7-day point prevalence abstinence at 4 weeks	11.6%:5.8%		Happy Quit (LFM)	

(Table 1 continues on next page)

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Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
Teixeira 2022[46]	Brazil	98:145	54.8 ± 11.9	26:19	Pare de Fumar Conosco	Standard care	No	No	7-day point prevalence abstinence at 4 weeks	15.4%:15.8%		Pare de Fumar Conosco	At Week 4, the median motivation level was 10, and seven of the 24 participants who completed the fourth week of treatment quit smoking. At Week 4, eleven participants used smoking cessation medications (43% in the intervention group and 50% in the control group). Sessions adherence of the in-person smoking cessation counseling group decreased over time.
Tseng 2017[47]	USA			53:52	Text	Regular care and a smoking cessation booklet	Yes	Yes	7-day point prevalence abstinence at 4 weeks	18.5%:11.3%		Text	Varenicline adherence rate (SC + TM: SC): 38.9% (n = 21):54.7% (n = 29)
Tseng 2017[47]	USA			54:52	Text + Phone	Regular care and a smoking cessation booklet	Yes	Yes	7-day point prevalence abstinence at 12 weeks	15.7%:5.7%		Text + Phone	Varenicline adherence rate (SC + TM + ABT: SC): 29.4% (n = 15): 34.0% (n = 18)
Vidrine 2015[48]	USA	245:105	45 ± 8.1	178:172	Phone	Self-help booklet	Yes	Yes	7-day point prevalence abstinence at 3 months	15.7%:4.7%		Phone	
Vidrine 2019[49]	USA			110:108	Text + Phone	Self-help booklet	Yes	Yes	30-day point prevalence abstinence at 6 months	25.5%:12.0%		Text + Phone	
Villanti 2022[50]	USA		25.6 ± 3.3	172:153	Text + Web	Self-help booklet	No	No	30-day point prevalence abstinence at 12 weeks	39.5%:14.4%		Text + Web	
Wang 2019[51]	Hongkong, China	918:267	41.5 ± 14.0	591:594	WhatsApp	Self-help booklet	No	Yes	7-day point prevalence abstinence at 6 months	7.6%:4.0%		WhatsApp	Smoking cessation service use at 3 months (WhatsApp: Control): 91 (15%): 13 (2%) p < 0.0001

(Table 1 continues on next page)

Study (Year)	Country	Sex ratio (Male: Female) (N)	Age (mean ± SD)	Number (E-health:Control) (N)	Intervening measure	Control condition	Pharmacotherapy	Biochemical verification	Intervention period	Point Quit Rate(E-health:Control)	Continuous quit rate (E-health:Control)	Intervening measure	Compliance (Satisfaction/ Acceptability)
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Webb 2020[52]	UK	142:123	40 ± 12	265:265	Quit Genius	Self-help booklet	Yes	Yes	7-day point prevalence abstinence at 4 weeks	44.5%:28.3%		Quit Genius	In the per-protocol analysis, which included only participants that completed their week 4 outcomes, several secondary outcomes were significantly better in treatment compared with control; confidence improved more (risk ratio 1.33, 95% CI 1.02–1.74), as did self-efficacy (p = 0.04).
Ybarra 2013[53]	USA	92:72	21.6 ± 2.1	101:63	Text	Self-help booklet	No	No	7-day point prevalence abstinence at 4 weeks	35.6%:20.6%	3 month continuous quit rate 39.6%:30.2%	Text	

Table 1: **Summary of smoking cessation studies.**

Addiction Group noted that blinding is unattainable in intervention-focused smoking cessation research. We categorized 30 studies as having a low risk of bias (30/44, 68.2%), indicative of low bias risk across all domains. Seven studies exhibited some lower risk (7/44, 15.9%), suggesting minor concerns in at least one domain but without a high-risk determination. Six studies carried a higher risk (6/44, 13.6%), identified as having a high bias risk in at least one domain. Only one study presented a high risk (1/44, 2.3%), indicating a high bias risk in more than one domain. The bias risk for each domain is outlined in the Supplementary materials. Incomplete outcome data was the primary cause of non-low bias risk (9/14, 64%). The high-risk study was due to inadequate randomization. However, we meticulously reviewed their experimental procedures and conducted relevant sensitivity analyses, concluding that it do not affect the overall bias risk of the studies. We also conducted an Egger test for the point quit rate group, with an overall p-value of 0.026. After conducting meta-regression to find the covariate of e-health intervention modality, the Egger test was conducted after grouping the groups separately, and none of them were found to be biased. This suggests that different e-health intervention modalities are indeed important variables in digital health interventions for smoking cessation. We also conducted an Egger test for sustained cessation rate and found no significant bias.

Discussion

Our research shows that e-health interventions for smoking cessation are effective for smokers in different countries. Compared to traditional offline methods, the smoking cessation rate increased by 1.86 times. This fact suggests that e-health interventions perform better in terms of intervention outcomes compared to standard care. This is due to the fundamental difference in the intervention methods between the two of them. E-health interventions are tailored for mainstream electronic device usage, reminding smokers to quit through health education on web pages and apps, as well as sending smoking cessation message prompts via SMS and calls. E-health is undoubtedly a good intervention method in terms of the outcome of smoking cessation rates. However, we found that e-health interventions had slightly lower sustained quit rates than point quit rates. This also reflects a commonality in smoking cessation approaches, which is that sustained cessation is difficult to achieve, whether through e-health or usual care. There is also a lack of long-term clinical follow-up studies (more than one year) to demonstrate that the effects of smoking cessation can be sustained for a significant period, and we may need more research trials to improve the validity of the evidence as far as sustained cessation rates are concerned.

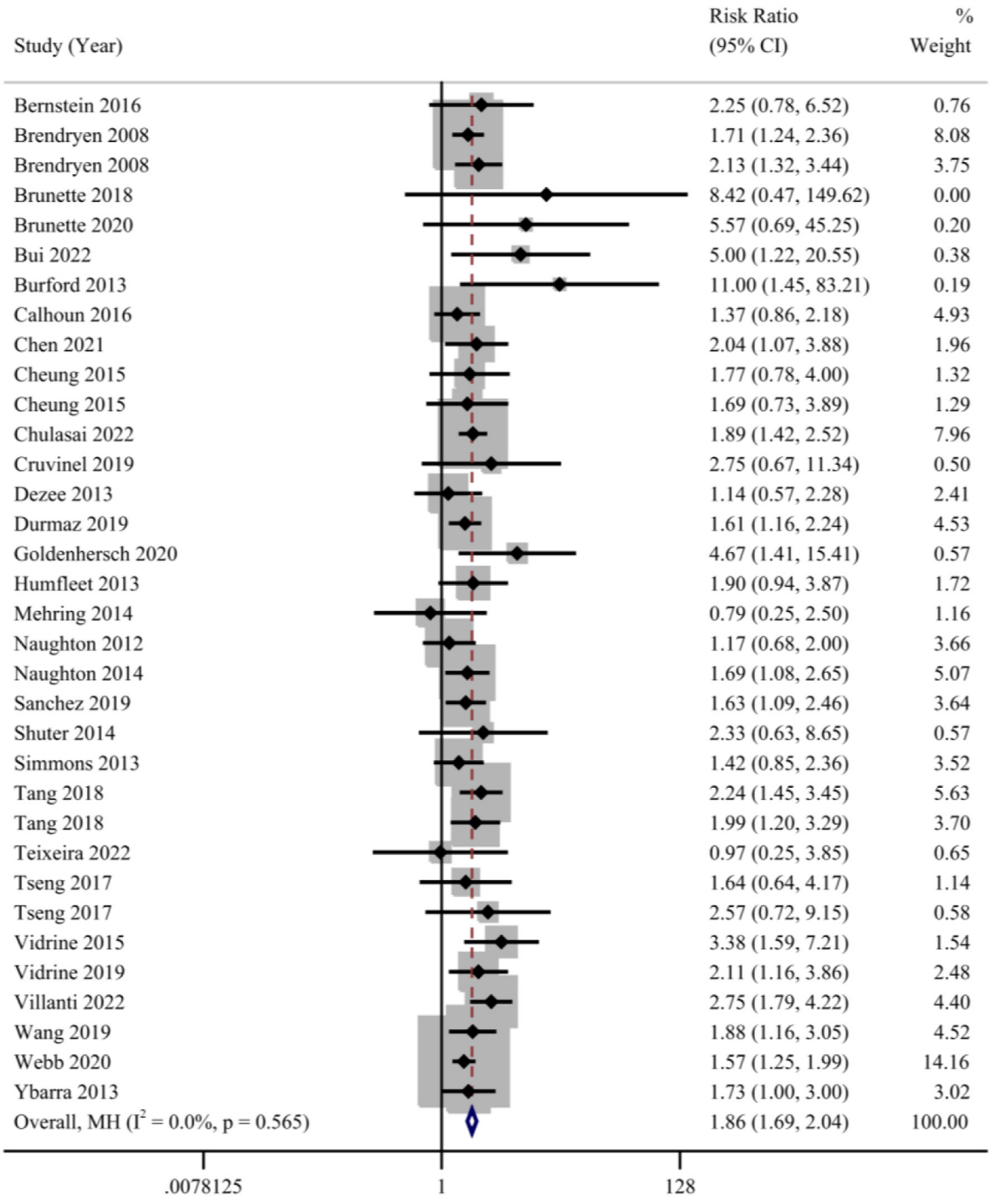

Fig. 2: **E-health interventions compared with control care in smokers. Outcome was point smoking cessation rate on the 7th or 30th day.**

Interestingly, when we categorize e-health interventions into m-health and telemedicine. The RR value for m-health interventions is 2.10. Considering the diverse definitions of e-health, m-health might not be universally considered as mainstream e-health, we only focus on the effectiveness of using telemedicine. The RR value is 1.74. The efficacy was still remarkable, which demonstrated that the differences in definitions won't diminish the recommended use of e-health in smoking cessation. However, we believe this finding is

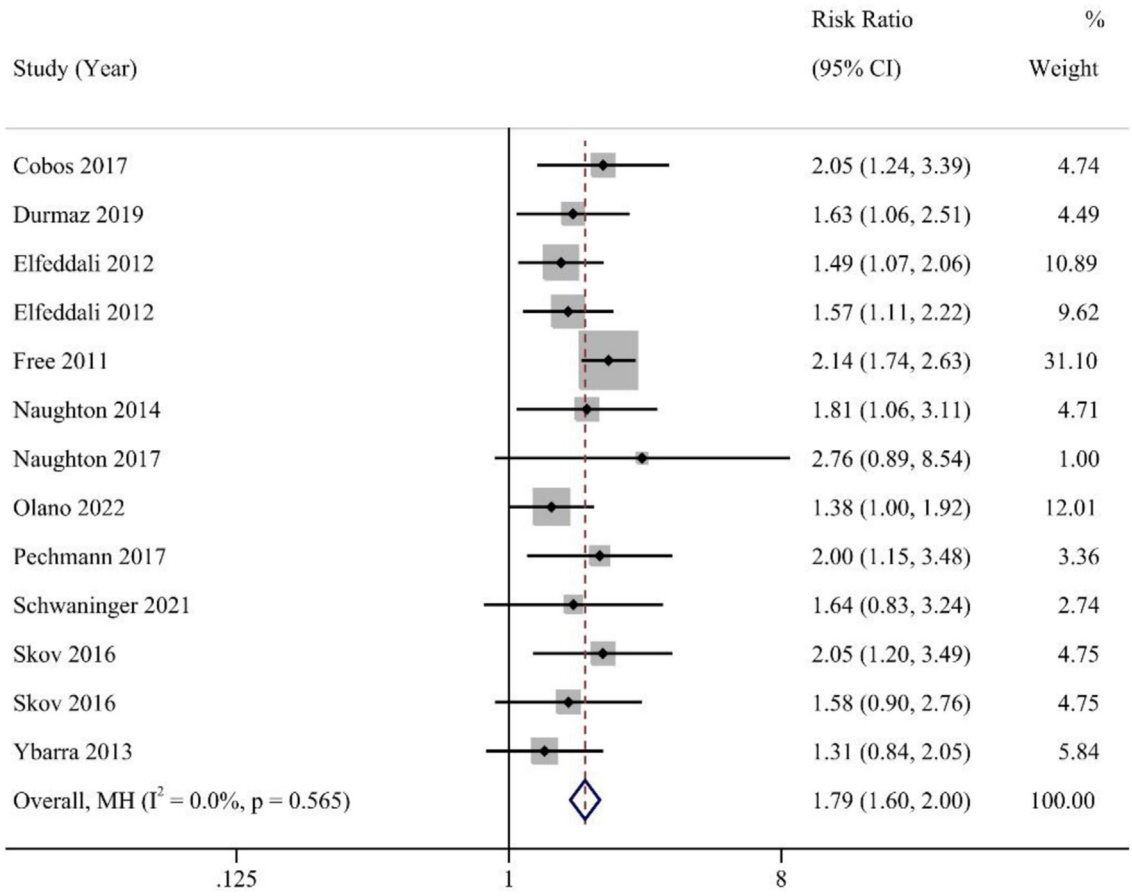

Fig. 3: **E-health interventions compared with control care in smokers. Outcome was sustained quit rate**.

not aligned with our expectations for the current state of e-health and provides valuable insights for the future development of e-health applications.

Due to the absence of any previously reported findings indicating such results, we speculate that this noticeable difference may be attributed to varying levels of acceptance of different intervention modalities. In this era of information overload, people might be less responsive to message prompts from websites and mobile applications (given the numerous messages received daily). In the past, when the internet was less developed, participants may have considered phone calls or text messages as more immediate reminders. Simultaneously, we observed a relatively limited number of studies on telephone interventions compared to other eHealth modalities (4/44). This could be attributed to more research personnel and time costs that telephone interventions require than others, such as text messaging. However, considering excellent performance in intervention outcomes and advancements in automatic telephone reminder methods, more research on telephone interventions is anticipated.

In our research, due to the lack of a standardized methodological approach in assessing compliance across articles reporting compliance results, it was challenging to perform a quantitative or qualitative analysis of compliance outcomes of different types. Such an analysis could introduce significant bias and uncertainty. Therefore, we have presented the reported compliance results in Table 1 for reference. However, based on the content reported in these studies, e-health remains a method with higher compliance and satisfaction than regular care.

The outcomes of compliance and satisfaction will be greatly affected by different interfaces, interactive forms, and intervention strategies (especially the rapidly developing smoking cessation websites and mobile applications). How participants receive intervention and feedback information is different (including but not limited to SMS replies, questionnaire filling, website clicks, tweet sending times, etc.). We observed in some articles that when participants browsed websites or apps more times, their smoking cessation success rate might increase.[54] Villanti et al.'s research indicates that for

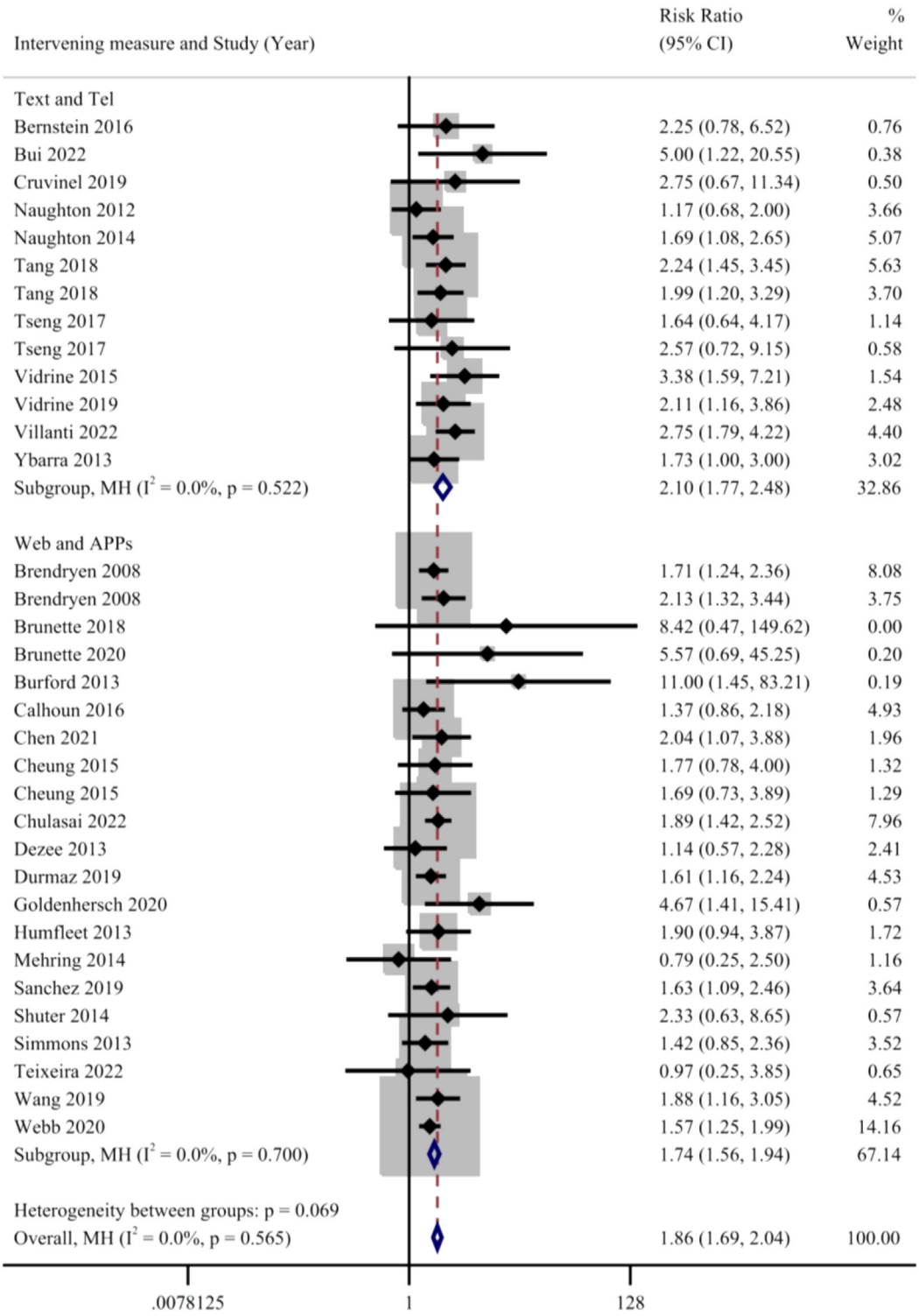

Fig. 4: **Subgroup analysis of Text and Tel interventions compared with Web and APPs interventions. Outcome was point smoking cessation rate on the 7th or 30th day.**

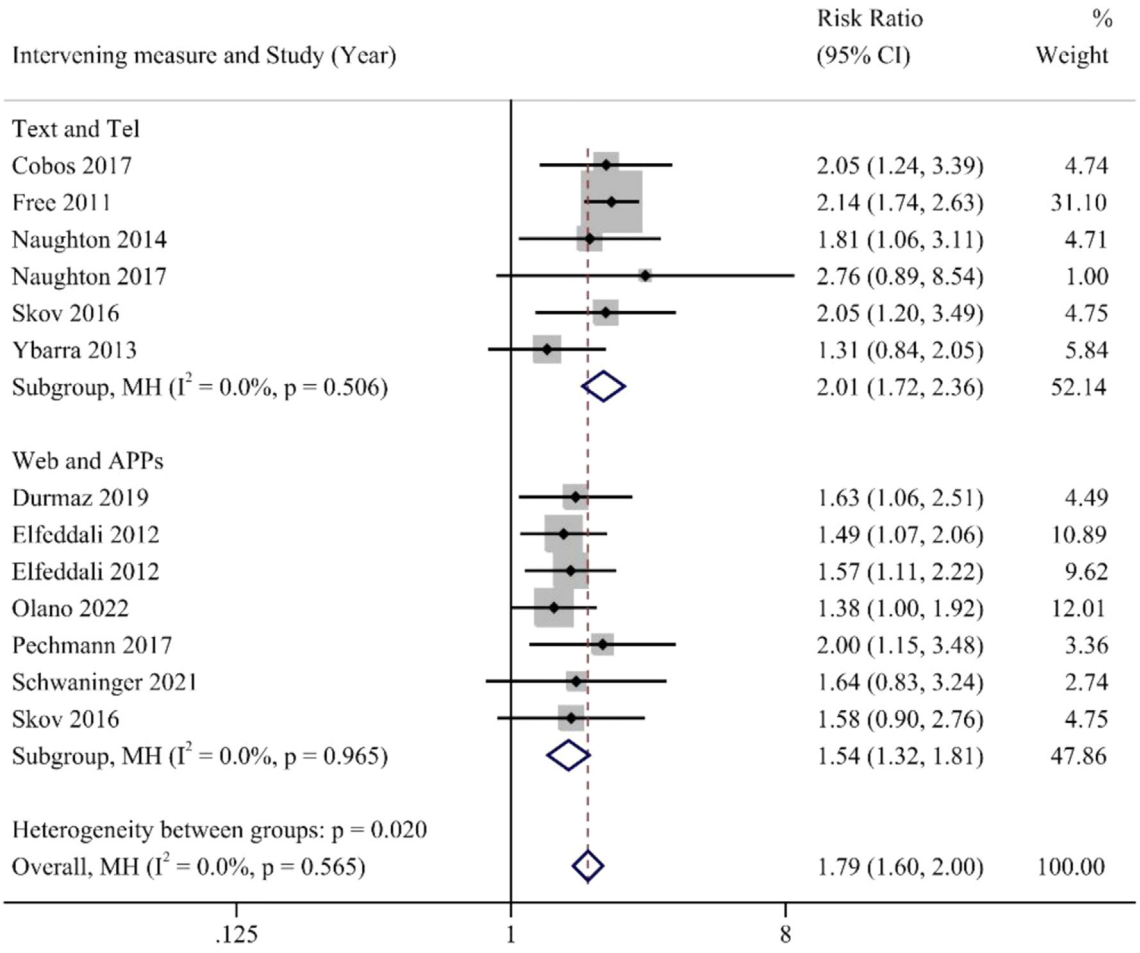

Fig. 5: **Subgroup analysis of Text and Tel interventions compared with Web and APPs interventions. Outcome was sustained quit rate.**

each additional registration completed by participants, the 7-day smoking cessation rate increases by 7%, and the 30-day point prevalence abstinence increases by 9%.[50] Multiple studies have also demonstrated that successful quitters tend to spend more time using websites and apps, with higher levels of engagement than those who are unsuccessful. Shuter et al.'s study shows that the quit rate for participants who completed all sessions was 17.9%, compared to only 5% for those who did not complete all sessions.[43] This provides a potential direction for future smoking cessation efforts focusing on exploring methods to enhance user engagement and encourage prolonged participation in these programs.

The potential of these new digital health smoking cessation interventions, based on mobile phones or widely used electronic products, is not only their effectiveness but also their simplicity, convenience, and ease of dissemination. Villanti et al. achieved above-average results by using a combination of text messaging and websites for interventions.[50] Future clinical studies in this area are worth looking forward to. In the context of the rapid development of the internet, low-cost e-health interventions that are not limited to a single method (such as a combination of software and text messaging) may further improve user acceptance.

These types of methods also offer possibilities for addressing this global issue in public health-challenged areas or environments with unequal medical resources. The involvement of e-health interventions offers the possibility of addressing the global issue of smoking in areas or contexts with uneven medical resources. We believe that more applicable and optimized smoking cessation strategies can be implemented through smoking cessation applications to achieve better outcomes. Relevant future research should go further to explore strategies tailored to smoking populations with special needs, such as pregnant women, people living with HIV, and people with depression. Additionally, a cost-effectiveness analysis of e-health interventions and how to integrate them effectively into a daily workflow to further

transform healthcare services into a health-centered model is also necessary.

Although most studies indicate that e-health interventions have a stronger positive effect, some studies suggest that the difference in quit-smoking rates between intervention and traditional groups is not significant.[30,36,45] The effectiveness of e-health in helping smokers quit is influenced by a variety of factors, and the heterogeneity we found in e-health interventions in helping smokers achieve sustained abstinence may be influenced by factors we have not yet identified. This will require us to conduct more clinical studies in different scenarios to determine their effectiveness.

Although this systematic review and meta-analysis indicate that e-health self-management interventions have demonstrated excellent performance in promoting smoking cessation, this study still has several limitations. Such as the included studies have differences in participant population selection, age, ethnicity, sample size, assessment tools, intervention period, control group intervention type, and e-health intervention type, which may lead to heterogeneity and bias (e.g. higher expectations of smoking cessation in certain patient populations). Therefore, the results of this systematic review should be interpreted with caution. Secondly, study participants were usually recruited at only one location or focused on a particular population in certain cases; thus, the resulting samples may not be representative of the entire smoking population, limiting the generalizability of the study results.

This meta-analysis provides a comprehensive review of the new smoking cessation intervention approach, e-health. We found that e-health interventions showed high efficacy of smoking cessation management in smokers. Although e-health still requires more clinical research in various scenarios to prove its effectiveness in helping smokers quit smoking, its convenience and effectiveness can be widely used in various settings, especially in public health and economically underdeveloped areas. We believe that with the development and popularization of e-health self-management smoking cessation interventions, there will be significant improvements in smoking cessation, a global public health issue.

Contributors

Xuelei Ma and Shen Li contributed to the conception and design of the study. Shen Li, Zhan Qu and Yiyang Li contributed to the literature search, screening and data extraction. Xuelei Ma, Shen Li and Zhan Qu contributed to data access and verification. Shen Li and Zhan Qu contributed to data visualization and analysis. All authors wrote the first draft of the manuscript and edited the manuscript. All authors contributed to critical revision of the manuscript. All authors approved the final manuscript.

Data sharing statement

For the sake of transparency and reproducibility of the study, study data and other additional documents will be provided in the appendix upon request of the corresponding author. If additional detailed data are required, interested researchers can email the corresponding author to ask for them. Data sharing applies only to academic research and not to other objectives.

Declaration of interests

All authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2023.102412.

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