



# The effectiveness of eHealth-based cardiovascular disease risk communication: a systematic review and meta-analysis



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This study aimed to systematically review and meta-analyze the effectiveness of eHealth-based cardiovascular disease (CVD) risk communication and its impact on health-related outcomes. Twenty-three RCTs were included. The eHealth-based CVD risk communication showed significant improvements in controlling systolic blood pressure ( $P = 0.03$ ), low-density lipoprotein ( $P = 0.02$ ), physical activity ( $P = 0.003$ ), smoking cessation ( $P = 0.004$ ), disease awareness ( $P = 0.002$ ), and quality of life ( $P = 0.03$ ). No significant effects were found for other outcomes, including diastolic blood pressure, total cholesterol, and overall risk scores. These findings provide valuable insights into the potential role of eHealth-based risk communication in CVD prevention. In addition, existing risk communication interventions are multicomponent, and future research could standardize intervention components and optimize intervention elements using the Behavior Change Techniques Taxonomy and factorial designs, while developing targeted risk communication strategies for different populations to improve health outcomes.

Cardiovascular disease (CVD), including heart disease, cerebrovascular conditions, and disorders of the blood vessels, accounts for approximately one-third of global mortality and remains a major public health challenge worldwide<sup>1,2</sup>. A core strategy for CVD prevention is the management of modifiable risk factors<sup>3</sup>. Central to this strategy is the effective communication of individual risk factors and guidance on how to manage them, an approach known as 'risk communication'. The World Health Organization defines risk communication as the real-time exchange of information, advice and opinions between experts or officials and people facing threats to their survival, health, or social wellbeing<sup>4</sup>. Risk communication generally includes risk assessment, the selection of appropriate communication strategies and tools, and the implementation of those strategies in clinical practice<sup>5</sup>. When implemented effectively, CVD risk communication can enhance patients' understanding of their personal risk, improve awareness, promote informed decision-making, and enhance healthier lifestyle

behaviors<sup>6</sup>. Importantly, mental health, both a known determinant of CVD outcomes and a critical enabler of health behavior change, is essential to consider in evaluating the broader impact of these communication strategies<sup>7,8</sup>.

Existing reviews have predominantly focused on the format of risk information presentation<sup>9,10</sup>, the effectiveness of communication strategies<sup>11</sup>, and the perceptions and experiences of both healthcare providers and patients regarding risk communication<sup>12</sup>. Although these reviews generally conclude that risk communication can reduce CVD risk factors, some scholars have noted that failing to distinguish between interventions focused solely on CVD risk communication and those integrating additional components may undermine the accuracy of these findings<sup>6,13</sup>. For example, Bakhit et al.<sup>6</sup> included a broad range of both digital and non-digital interventions without clearly differentiating between them, which may have obscured the specific contribution of electronic health (eHealth)-based

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communication. Building on this observation, this study focuses specifically on the application of eHealth technologies for CVD risk communication. We seek to clearly define the technical modalities that underpin the intervention, thereby mitigating the potential bias introduced by their conflation. The focus on eHealth is further justified by increasing pressure on healthcare systems and limited resources, which underscore the increasing need to enhance the efficiency and reach of risk communication<sup>14</sup>. eHealth technologies refer to the secure and cost-effective use of digital tools and communication platforms to deliver health services and exchange medical information, presenting a promising solution<sup>15</sup>. Their growing value in patient education and CVD risk communication has attracted increasing attention from healthcare professionals<sup>16–18</sup>.

This review aims to systematically examine and quantify the effectiveness of eHealth technologies in CVD risk communication, and to assess their impact on patients' health outcomes. Findings are expected to address existing research gaps and provide an evidence base for optimizing clinical practice and informing relevant policy development.

## Results

A total of 2992 records were identified initially from seven databases. After removing duplicates and undertaking screening, twenty-three trials were included in the systematic review and meta-analysis. The literature screening process is detailed in Fig. 1. The excluded trials along with the reasons for exclusion are provided in Supplementary Table S1.

The twenty-three included trials, published between 2006 and 2024, covered data from thirteen countries. The United States contributed the most trials (n = 6). Among these trials, eleven focused on primary prevention of CVD, ten on secondary prevention, and two on both. The total sample size across the trials was 11,311 participants.

Seven types of eHealth technologies were used across the twenty-three trials, including smartphone applications (n = 9), websites (web-based tool, website, computer-based program) (n = 8), telephone calls (n = 4), email (n = 4), decision support systems (n = 2), electronic health records (n = 2), and short message service (SMS) (n = 1). In six trials, two or more types of eHealth technologies were combined. The functions of eHealth technologies in CVD risk communication included risk assessments, risk presentation, personalized suggestions, tracking or reminding. Further details of the interventions are presented in Table 1.

All trials were rated as having a low risk of bias for random sequence generation. Low risk of bias was also observed for allocation concealment in seventeen out of twenty-three trials (74%), blinding of participants and study personnel in seven trials (30%), and blinded outcome assessment in eighteen trials (78%). Sixteen trials were assessed as having a high risk of bias, primarily due to the absence or inadequacy of blinding procedures. Five trials were rated as having an unspecified risk of bias due to insufficient information. For incomplete outcome data and selective reporting, all trials were rated as low risk of bias. As no outcome included in the meta-analysis had data from more than ten trials, funnel plots were not used to assess potential publication bias, in line with current methodological recommendations<sup>19</sup> (Fig. 2 and Supplementary Fig. S1).

Use of eHealth-based CVD risk communication showed a significant reduction (seven trials, SMD = -0.16, 95% CI: -0.30 to -0.02; I<sup>2</sup> = 39%; P = 0.03) in systolic blood pressure (SBP) (Fig. 3). Subgroup analysis revealed that the intervention showed a stronger effect in the primary prevention (SMD = -0.33, 95% CI: -0.61 to -0.05; I<sup>2</sup> = 0%; P = 0.02), compared to the secondary prevention (SMD = -0.21, 95% CI: -0.35 to -0.07; I<sup>2</sup> = 0%; P = 0.004) and combined group (incorporating both prevention levels) (SMD = 0.06, 95% CI: -0.09 to 0.21; P = 0.44). Both the short-term follow-up (≤3 months, SMD = -0.32, 95% CI: -0.69 to 0.05; I<sup>2</sup> = 0%; P = 0.09) and long-term follow-up (>3 months, SMD = -0.14, 95% CI: -0.30 to 0.02; I<sup>2</sup> = 52%; P = 0.08) subgroups showed a small reduction without statistically significant changes. Moreover, no significant difference was observed between these two subgroups (P = 0.38) (Supplementary Fig. S2).

The eHealth group showed a modest but non-significant reduction in diastolic blood pressure (DBP) compared to the control group (seven trials, SMD = -0.07, 95% CI: -0.17 to 0.03; I<sup>2</sup> = 0%; P = 0.18) (Fig. 3). Similarly, subgroup analysis revealed no significant differences in intervention effects across levels of prevention (primary prevention (SMD = -0.10, 95% CI: -0.38 to 0.18; I<sup>2</sup> = 0%; P = 0.48), secondary prevention (SMD = -0.05, 95% CI: -0.19 to 0.10; I<sup>2</sup> = 0%; P = 0.53), combined group (SMD = -0.08, 95% CI: -0.23 to 0.07; P = 0.31)) or follow-up time (≤3 months (SMD = -0.05, 95% CI: -0.41 to 0.30; I<sup>2</sup> = 0%; P = 0.76), >3 months (SMD = -0.07, 95% CI: -0.17 to 0.03; I<sup>2</sup> = 0%; P = 0.17)) (Supplementary Fig. S3).

Data from five trials were meta-analyzed to evaluate the impact of eHealth-based CVD risk communication on total cholesterol (TC). The results showed no significant difference between the intervention

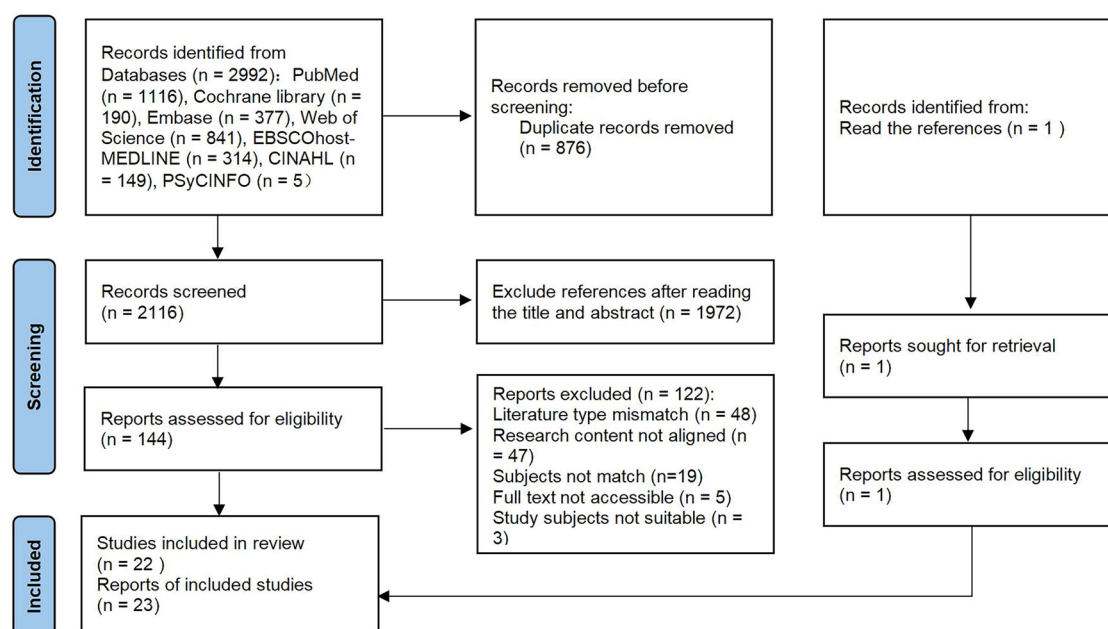


Fig. 1 | PRISMA flow diagram. 2992 records were initially identified from seven databases, and 23 trials were ultimately included in the meta-analysis.

**Table 1 | Characteristics of included trials**

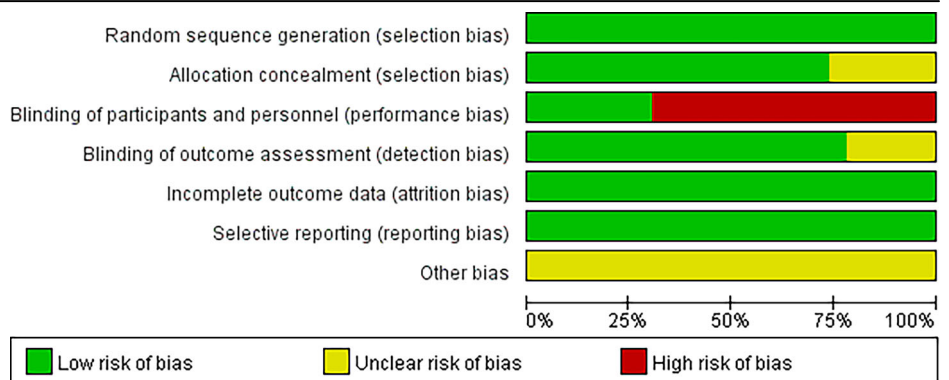
Authors (year)	Country	Groups	Levels of prevention	Sample size (female %)	Providers	eHealth technologies	Interventions	Outcomes
Persell et al. <sup>50</sup>	USA	2 arms	P	646 (11)	lay health workers, physicians, nurses	EHR, telephone, email	①②③	g, j
Persell et al. <sup>51</sup>	USA	2 arms	P	435 (23)	researchers, physicians	EHR, email	①②	b, c, j
Sheridan et al. <sup>52</sup>	USA	2 arms	P	75 (59)	researchers	decision support system	①②③	f, g, h
Sheridan et al. <sup>53</sup>	USA	2 arms	P	160 (28)	researchers	decision support system	①②③	b, c, e, h, i
Ruffin et al. <sup>54</sup>	USA	2 arms	P	3786 (70)	researchers	a web-based tool	①②③	a, b, c, d, h
Silarova et al. <sup>55</sup>	UK	4 arms	P	953 (44)	researchers	a web-based tool	①②③	a, b, c, d
Soureti et al. <sup>56</sup>	UK	4 arms	P	781 (NR)	researchers	website	①②③	a, b, e, h
Sarfo et al. <sup>57</sup>	Nigeria	2 arms	P	100 (62)	researchers, clinical providers	app	①②③④	a, b, c, e, i
Lee et al. <sup>58</sup>	New Zealand	4 arms	P	80 (79)	researchers	computer-based program	①②	a, c, d
Beratarrechea et al. <sup>59</sup>	Argentina	2 arms	P	755 (69)	community health workers	app, SMS	①②③④	c, h, g
Hussin et al. <sup>60</sup>	Malaysia	2 arms	P	75 (65)	researchers, nurses, physicians	app	①②③④	b, c, i
Jaspers et al. <sup>61</sup>	Netherlands	3 arms	S	303 (16)	researchers	telephone	①②③	a, c, f
Greving et al. <sup>62</sup>	Netherlands	2 arms	S	330 (25)	nurses, physicians	website, email	①②③④	c, e
Vernooij et al. <sup>63</sup>	Netherlands	2 arms	S	330 (25)	nurses, physicians	website, email	①②③④	i
Guo et al. <sup>64</sup>	China	2 arms	S	209 (44)	researchers	app	①②③④	a, c, d, e
Su et al. <sup>65</sup>	China	2 arms	S	43 (16)	nurses	website	①②③④	b, c, d
Athilingam et al. <sup>22</sup>	USA	2 arms	S	18 (56)	nurses	app, telephone	①②③④	a, c, d, e
Mirshahi et al. <sup>66</sup>	Iran	2 arms	S	50 (40)	nurses	website	①②③④	b
Achury-Saldana et al. <sup>67</sup>	Colombia	2 arms	S	140 (29)	nurses	app	①②③④	a, b, c, d, e
Bernal-Jiménez et al. <sup>21</sup>	Spain	2 arms	S	128 (28)	nurses	app	①②③④	a, b, c, e
Cruz-Cobo et al. <sup>20</sup>	Spain	2 arms	S	300 (31)	researchers	app	①②③④	b, c
Redfern et al. <sup>68</sup>	Australia	2 arms	Both	934 (23)	researchers	app	①②③④	a, c, d, e
Nolan et al. <sup>69</sup>	Canada	2 arms	Both	680 (49)	physicians, nurses, PhD students in clinical psychology	telephone	①②③	c, d, e

P primary prevention, S secondary prevention, EHR electronic health record, NR not Reported.

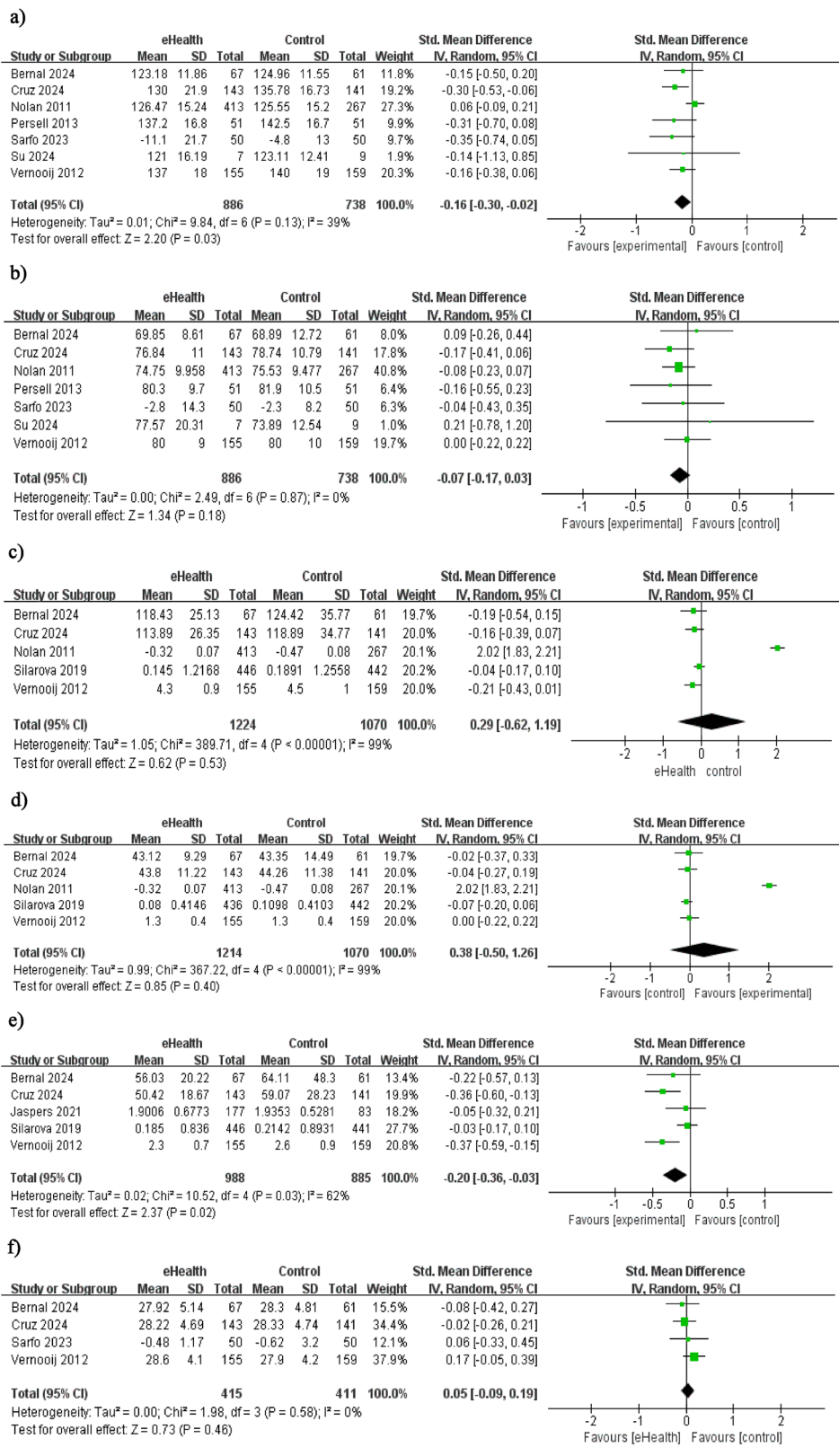
Intervention components: ①risk assessment; ②risk presentation; ③personalized suggestions; ④tracking or reminding.

Outcome indicators: a: risk perception (risk perception/risk knowledge, etc.); b: physiological indicators (blood pressure/lipids/blood sugar/hemoglobin, etc.); c: lifestyles (diet/physical activity/smoking/medication/quality of life, etc.); d: mental health indicators; e: feasibility evaluation (feasibility/acceptability/satisfaction, etc.); f: decision related; g: doctor-patient communication; h: intention (information seeking intention, treatment intention, etc.); i: risk score (cardiovascular basic risk score, coronary heart disease risk score, etc.); j: medication prescription.

**Fig. 2 | Risk of bias of the included studies.** Created using Review Manager 5.4.1.



**Fig. 3 | Results of meta-analysis for the effects of eHealth-based CVD risk communication on health-related outcomes.** **a** Presents the overall effect for systolic blood pressure; **b** presents the overall effect for diastolic blood pressure; **c** presents the overall effect for total cholesterol; **d** presents the overall effect for high-density lipoprotein; **e** presents the overall effect for low-density lipoprotein; **f** presents the overall effect for body mass index. SD standard deviation. Created using Review Manager 5.4.1.



and control groups (SMD = 0.29, 95% CI: -0.62 to 1.19; I<sup>2</sup> = 99%; P = 0.53) (Fig. 3). Change in TC did not differ by the follow-up time (SMD = 0.29, 95% CI: -0.62 to 1.19; I<sup>2</sup> = 99%; P = 0.53). However, significant differences were observed among groups with different prevention subgroups. For the primary prevention subgroup, the intervention showed a trivial and non-significant trend toward a small

reduction in risk (SMD = -0.04, 95% CI: -0.17 to 0.10; P = 0.60). In contrast, the secondary prevention subgroup exhibited a statistically significant reduction in risk (SMD = -0.19, 95% CI: -0.33 to -0.04; I<sup>2</sup> = 0%; P = 0.01). The combined group demonstrated a substantially larger and highly significant positive effect (SMD = 2.02, 95% CI: 1.83 to 2.21; P < 0.00001). (Supplementary Fig. S4).

Five trials evaluated the effect of eHealth-based CVD risk communication on high-density lipoprotein (HDL). Combined results showed that HDL did not significantly decline among those who received the interventions (SMD = 0.38, 95% CI: -0.50 to 1.26;  $I^2 = 99\%$ ;  $P = 0.40$ ) (Fig. 3). For follow-up time subgroups ( $\leq 3$  months vs.  $>3$  months), both subgroups showed non-significant changes, and there was no inter-subgroup difference ( $P = 0.34$ ), whereas significant differences were found across groups with different prevention levels. The combined group showed a significant improvement in HDL (SMD = 2.02, 95% CI: 1.83 to 2.21;  $P < 0.00001$ ) compared to the primary prevention subgroup (SMD = -0.07, 95% CI: -0.20 to 0.06;  $P = 0.28$ ) and the secondary prevention subgroup (SMD = -0.02, 95% CI: -0.16 to 0.13;  $I^2 = 0\%$ ;  $P = 0.80$ ), neither of which showed significant changes. (Supplementary Fig. S5).

Meta-analysis results showed significant differences in the changes of low-density lipoprotein (LDL) between the two groups (five trials, SMD = -0.20, 95% CI: -0.36 to -0.03;  $I^2 = 62\%$ ;  $P = 0.02$ ) (Fig. 3). Subgroup analysis results showed that significant reductions were observed in the secondary prevention subgroup (SMD = -0.27, 95% CI: -0.42 to -0.12;  $I^2 = 26\%$ ;  $P = 0.0005$ ), while the primary prevention subgroup (SMD = -0.03, 95% CI: -0.17 to 0.10;  $P = 0.62$ ) showed no significant change; by follow-up time, the subgroup with follow-up  $>3$  months showed a significant reduction (SMD = -0.27, 95% CI: -0.42 to -0.12;  $I^2 = 26\%$ ;  $P = 0.0005$ ), whereas the subgroup with follow-up  $\leq 3$  months showed no significant change (SMD = -0.03, 95% CI: -0.17 to 0.10;  $P = 0.62$ ) (Supplementary Fig. S6).

There was no significant difference in body mass index (BMI) (four trials) between intervention and control groups (SMD = 0.05, 95% CI: -0.09 to 0.19;  $I^2 = 0\%$ ;  $P = 0.46$ ). No significant differences were observed between the different subgroups either (Fig. 3, Supplementary Fig. S7).

Meta-analysis of lifestyles, mental health outcomes, disease awareness and quality of life revealed that eHealth-based CVD risk communication was associated with significant improvements in physical activity, disease awareness, and quality of life (Table 2). However, it did not significantly change diet, medication adherence, depression, or anxiety.

Regarding the cardiovascular risk score (CRS), the eHealth group demonstrated a more substantial reduction compared to the control group. However, no significant overall effect was observed between the intervention and control groups (three trials, SMD = -0.18, 95% CI: -0.67 to 0.30;  $I^2 = 92\%$ ;  $P = 0.46$ ). Subgroup analysis indicated significant differences in the intervention effects based on levels of prevention. The primary prevention group showed a significant reduction (SMD = -0.89, 95% CI: -1.30 to -0.48;  $P < 0.001$ ), secondary prevention group showed no significant change (SMD = 0.00, 95% CI: -0.22 to 0.22;  $P = 1.00$ ). For follow-up time subgroups,  $\leq 3$  months group showed a significant reduction (SMD = -0.89, 95% CI: -1.30 to -0.48;  $P < 0.0001$ ),  $>3$  months group showed no significant change (SMD = 0.12, 95% CI: -0.09 to 0.34;  $I^2 = 60\%$ ;  $P = 0.25$ ) (Fig. 4).

Sensitivity analyses, conducted by sequentially removing individual trials, demonstrated that effect sizes for several outcomes remained within acceptable ranges, with confidence intervals (CIs) consistently crossing the null effect value. This suggests a degree of robustness in the overall findings, indicating that the results were not unduly influenced by any single study. However, not all outcomes demonstrated such stability. Measures such as LDL levels, dietary factors, and quality of life exhibited notable fluctuations in effect sizes, warranting cautious interpretation of these specific results. Full details of the sensitivity analysis are presented in Supplementary Fig. S16.

Three trials explored user experiences with eHealth technologies. Due to variations in evaluation methods and the limited number of trials, we conducted a descriptive analysis for this section. Cruz-Cobo et al.<sup>20</sup> found that the intervention group showed significantly improved adherence to a healthy diet ( $P < 0.001$ ) and increased physical activity ( $P < 0.001$ ). Participants also reported high satisfaction ( $42.53 \pm 6.38$ ), rating the application's usability as excellent ( $>80.3$  points), and described it as a promising and innovative tool. Similarly, Bernal-Jiménez et al.<sup>21</sup> found that participants in

the intervention group reported significantly greater satisfaction and app usability compared to those receiving standard care ( $P = 0.002$ ). In the trial by Athilingam et al.<sup>22</sup>, users of the HeartMapp application gave high ratings for ease of use, content accuracy, user-friendly design, problem-solving features, and their confidence in using the app, demonstrating an overall high level of satisfaction.

## Discussion

The increasing global burden of CVD and its associated risk factors underscores the urgent need for more effective risk communication strategies. eHealth technologies have emerged as promising tools, complementing traditional face-to-face education. This systematic review and meta-analysis examined the effectiveness of eHealth-based CVD risk communication across a broad range of health-related outcomes. While several positive effects were identified, overall findings were mixed, with certain outcomes showing limited or no improvement.

Significant benefits were identified in key clinical and behavioral outcomes, particularly SBP, LDL levels, physical activity, smoking cessation, disease awareness, and quality of life. The positive effects on SBP, cholesterol control and disease awareness are consistent with prior meta-analyses<sup>6,23,24</sup>, emphasizing the clinical relevance of eHealth-based risk communication in managing modifiable CVD risk factors. Notably, smoking cessation, often regarded as one of the most difficult behavioral changes, demonstrated significant improvement in the long-term follow-up subgroup. This finding aligns with previous meta-analyses reporting the efficacy of SMS- or app-based interventions in promoting both short-term (3 months) and long-term (6 months) smoking cessation<sup>25</sup>. Similarly, improvements in physical activity reinforce the potential of eHealth technologies in driving lifestyle modifications among at-risk populations. In contrast, the findings regarding physical activity and smoking cessation differ from those reported in another meta-analysis on CVD risk communication<sup>6</sup>. These discrepancies may be attributed to the current review's specific focus on eHealth-based CVD risk communication, where participants were primarily drawn from populations with lifestyle-related CVD risk and risk communication was an essential intervention component in the included trials. By comparison, the previous meta-analysis included broader forms of risk communication and incorporated additional intervention components beyond risk communication itself.

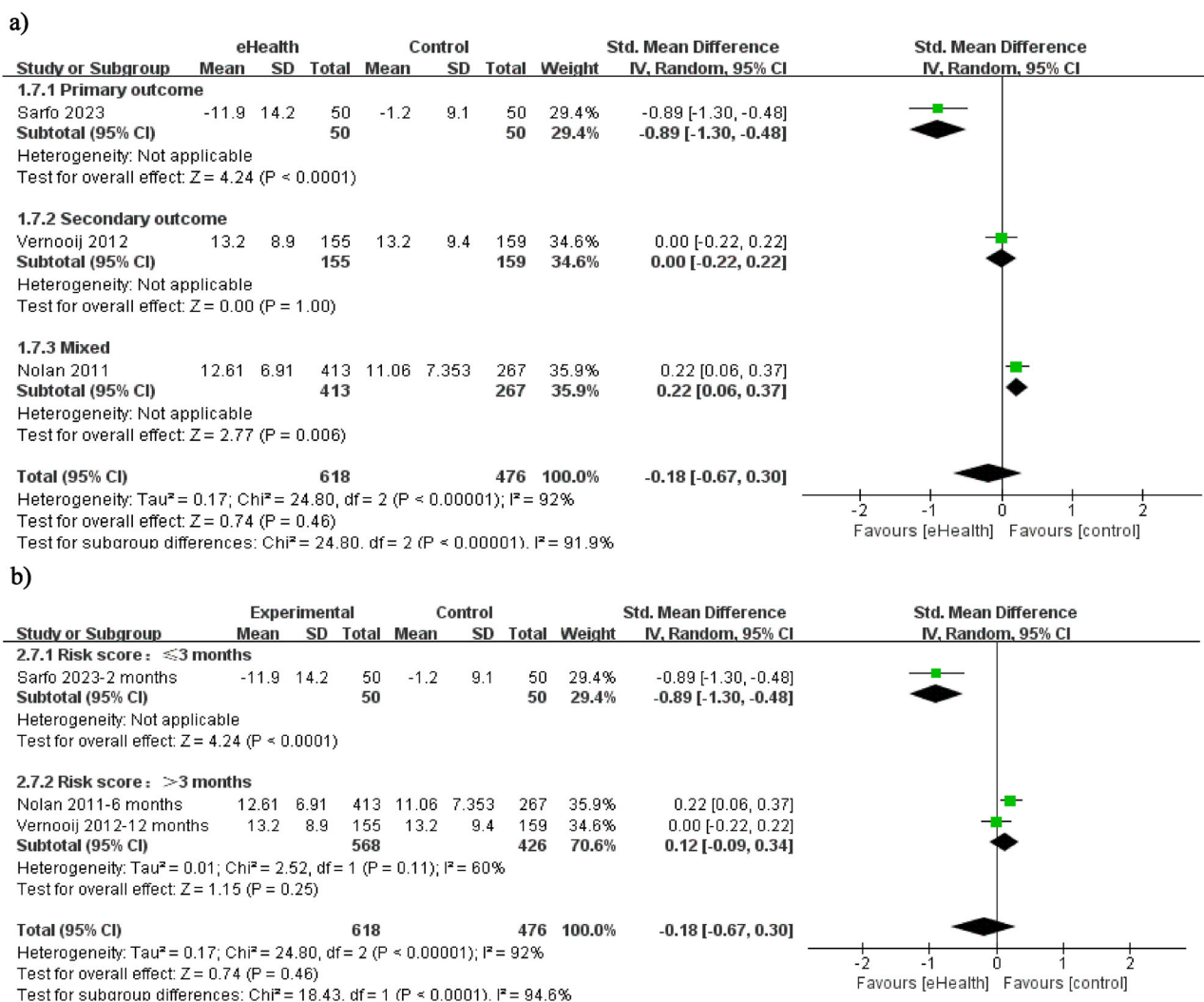
However, not all outcomes demonstrated significant improvement. Mental health, diet, and medication adherence showed limited or inconsistent changes. For example, medication adherence improved in the primary prevention subgroup, while dietary behavior improved in the secondary prevention subgroup, likely due to differences in intervention intensity and personalization. Patients under secondary prevention are typically monitored more closely and receive more intensive medical management, including lipid-lowering therapies<sup>26,27</sup>. Despite the well-established evidence linking mental health and poor CVD outcomes<sup>8</sup>, our results found no significant improvement in mental health measures, possibly because eHealth-based risk communication interventions often focus on health information and rather than psychological support<sup>23</sup>. It must be emphasized that cognitive and affective responses are key determinants in initiating and sustaining health behavior change<sup>7</sup>. Therefore, risk communication strategies must carefully consider their psychological impact on patients. Poorly framed risk information, such as notifications that induce excessive anxiety or feelings of helplessness, may increase psychological distress<sup>28</sup>. This can ultimately counteract the potential benefits of the intervention and undermine long-term behavior maintenance.

As eHealth interventions become increasingly integrated into clinical practice, understanding user experiences is essential<sup>29,30</sup>. Several studies have explored the experiences or insights of patients and providers regarding CVD risk communication<sup>12,31-33</sup>. As noted in prior research, isolated risk assessments are often perceived as meaningless by patients, particularly when the results conflict with their subjective perceptions of their own health status<sup>12</sup>. This highlights the challenge faced by healthcare providers in translating quantified risk data into meaningful, patient-centered

**Table 2 | Results of meta-analyses of trials for lifestyles, mental health, disease awareness and quality of life**

Outcomes	n	Overall results	Levels of prevention		Both	Follow-up time		Index in Supplementary file
			Primary prevention	Secondary prevention		≤3 months	>3 months	
Physical activity-continuous data	5	<b>SMD = 1.35 (95% CI = 0.46, 2.23) <math>f^2 = 97\%</math>; <math>P = 0.003</math></b>	SMD = 3.22 (95% CI = -3.29, 9.72) $f^2 = 99\%$ ; $P = 0.33$ (n = 2)	<b>SMD = 0.60 (95% CI = 0.40, 0.79) <math>f^2 = 0\%</math>; <math>P &lt; 0.00001</math> (n = 3)</b>	No trial	SMD = 2.19 (95% CI = -0.82, 5.20) $f^2 = 98\%$ ; $P = 0.15$ (n = 3)	<b>SMD = 0.62 (95% CI = 0.42, 0.82) <math>f^2 = 0\%</math>; <math>P &lt; 0.00001</math> (n = 2)</b>	S-Fig. S8
Physical activity-dichotomous data	3	<b>OR = 1.35 (95% CI = 1.10, 1.64) <math>f^2 = 13\%</math>; <math>P = 0.003</math></b>	<b>OR = 1.38 (95% CI = 1.08, 1.77) <math>f^2 = \text{not applicable}</math> <math>^a P = 0.01</math> (n = 1)</b>	No trial	OR = 1.35 (95% CI = 0.90, 2.02) $f^2 = 55\%$ ; $P = 0.15$ (n = 2)	No trial	All > 3 months	S-Fig. S8
Diet	4	SMD = 0.63 (95% CI = -0.04, 1.30) $f^2 = 96\%$ ; $P = 0.07$	SMD = 0.12 (95% CI = -0.03, 0.28) $f^2 = 0\%$ ; $P = 0.12$ (n = 2)	<b>SMD = 1.14 (95% CI = 0.70, 1.58) <math>f^2 = 74\%</math>; <math>P &lt; 0.00001</math> (n = 2)</b>	No trial	SMD = 0.12 (95% CI = -0.03, 0.28) $f^2 = 0\%$ ; $P = 0.12$ (n = 2)	<b>SMD = 1.14 (95% CI = 0.70, 1.58) <math>f^2 = 74\%</math>; <math>P &lt; 0.00001</math> (n = 2)</b>	S-Fig. S9
Medication	6	OR = 1.47 (95% CI = 1.00, 2.15) $f^2 = 80\%$ ; $P = 0.05$	<b>OR = 2.07 (95% CI = 1.04, 4.12) <math>f^2 = 87\%</math>; <math>P = 0.04</math> (n = 3)</b>	OR = 1.23 (95% CI = 0.47, 3.21) $f^2 = \text{not applicable}^a$ $P = 0.68$ (n = 1)	OR = 1.09 (95% CI = 0.86, 1.37) $f^2 = 0\%$ ; $P = 0.47$ (n = 2)	<b>OR = 2.62 (95% CI = 1.95, 3.51) <math>f^2 = 0\%</math>; <math>P &lt; 0.00001</math> (n = 2)</b>	OR = 1.13 (95% CI = 0.95, 1.35) $f^2 = 0\%$ ; $P = 0.18$ (n = 4)	S-Fig. S10
Smoking cessation	6	<b>OR = 1.50 (95% CI = 1.14, 1.99) <math>f^2 = 3\%</math>; <math>P = 0.004</math></b>	OR = 0.94 (95% CI = 0.52, 1.72) $f^2 = 0\%$ ; $P = 0.85$ (n = 2)	<b>OR = 1.78 (95% CI = 1.21, 2.62) <math>f^2 = 1\%</math>; <math>P = 0.003</math> (n = 3)</b>	OR = 1.56 (95% CI = 0.94, 2.59) $f^2 = 3\%$ ; $P = 0.09$ (n = 1)	OR = 1.44 (95% CI = 0.67, 3.10) $f^2 = 0\%$ ; $P = 0.35$ (n = 2)	<b>OR = 1.52 (95% CI = 1.11, 2.19) <math>f^2 = 22\%</math>; <math>P = 0.01</math> (n = 5)</b>	S-Fig. S11
Depression	4	SMD = -0.01 (95% CI = -0.28, 0.25) $f^2 = 0\%$ ; $P = 0.91$	No trial	All are secondary prevention	No trial	SMD = 0.03 (95% CI = -0.50, 0.55) $f^2 = 32\%$ ; $P = 0.92$ (n = 3)	SMD = -0.01 (95% CI = -0.25, 0.45) $f^2 = \text{not applicable}^a$ $P = 0.94$ (n = 1)	S-Fig. S12
Anxiety	3	SMD = 0.01 (95% CI = -0.27, 0.29) $f^2 = 0\%$ ; $P = 0.95$	No trial	All are secondary prevention	No trial	SMD = -0.15 (95% CI = -0.62, 0.31) $f^2 = 0\%$ ; $P = 0.52$ (n = 2)	SMD = 0.01 (95% CI = -0.25, 0.45) $f^2 = \text{not applicable}^a$ $P = 0.58$ (n = 1)	S-Fig. S13
Disease awareness	6	<b>SMD = 0.72 (95% CI = 0.26, 1.19) <math>f^2 = 89\%</math>; <math>P = 0.002</math></b>	SMD = 0.45 (95% CI = 0.01, 0.90) $f^2 = \text{not applicable}^a$ $P = 0.05$ (n = 1)	<b>SMD = 0.79 (95% CI = 0.24, 1.33) <math>f^2 = 91\%</math>; <math>P = 0.005</math> (n = 5)</b>	No trial	<b>SMD = 0.53 (95% CI = 0.07, 0.98) <math>f^2 = 52\%</math>; <math>P = 0.02</math> (n = 3)</b>	SMD = 0.87 (95% CI = -0.03, 1.76) $f^2 = 94\%$ ; $P = 0.06$ (n = 3)	S-Fig. S14
Quality of life	6	<b>SMD = 0.36 (95% CI = 0.04, 0.68) <math>f^2 = 72\%</math>; <math>P = 0.03</math></b>	No trial	All are secondary prevention	No trial	SMD = 0.28 (95% CI = -0.29, 0.85) $f^2 = 73\%$ ; $P = 0.33$ (n = 3)	SMD = 0.32 (95% CI = -0.03, 0.67) $f^2 = 80\%$ ; $P = 0.08$ (n = 3)	S-Fig. S815

N: Number of trials; a: Only one trial in the meta-analysis; Bolded: values are significant. OR odds ratio, SMD Standard Mean Difference, S Supplementary file.



**Fig. 4 | The effect of eHealth-based CVD risk communication on CRS. a** Shows the effects grouped by different levels of prevention, categorized as “primary prevention”, “secondary prevention”, “combined group” (incorporating both prevention

levels); **b** shows the effects grouped by follow-up time, classified as “short-term ≤3 months” and “long-term >3 months”. SD standard deviation. Created using Review Manager 5.4.1.

communication<sup>34,35</sup>. eHealth technologies should therefore serve not merely as information transmitters but as active enablers of risk communication, optimizing information presentation, adapting to individual cognitive profiles, and enhancing the precision and impact of clinician-patient interactions. Furthermore, while quantitative studies excel at documenting objective intervention outcomes, their findings risk becoming “information silos” without complementary exploration of underlying mechanisms. Future research could adopt mixed-methods designs that systematically integrate assessments of usability, accessibility, and acceptability of eHealth technologies with traditional measures of behavioral and clinical efficacy to better understand the mechanisms underpinning intervention effects.

Of the 23 included trials, most eHealth-based CVD risk communication interventions incorporated core elements such as risk assessment, risk presentation, personalized advice, dynamic tracking, and follow-up reminders. Given their multi-component nature, positive effects likely resulted from the combined impact of personalized risk communication and accompanying behavior change techniques, such as self-monitoring, action planning, and reminders. Some trials have used factorial designs to identify “active components” from multi-component interventions<sup>36–38</sup>, while optimizing intervention protocols is an iterative process requiring further research. Future research should use standardized frameworks, such as the behavior change techniques taxonomy<sup>39</sup> and optimization strategies

(e.g., factorial designs<sup>40</sup>, Multiphase Optimization Strategy<sup>41</sup>), to isolate active components and refine intervention protocols for maximal effectiveness.

This systematic review has several limitations that should be considered when interpreting the findings. Firstly, this review, constrained by its inclusion and exclusion criteria, only reflects eHealth-based CVD risk communication. However, risk communication is multidimensional, requiring evaluation across psychological, social, and cultural contexts. The findings of this review should be interpreted in conjunction with other relevant reviews on CVD risk communication<sup>5,6,12,42</sup>. Secondly, there was substantial heterogeneity was observed across the trials. Although subgroup analyses were conducted based on different levels of prevention and follow-up duration, significant heterogeneity in outcomes remained. This heterogeneity could be partly explained by differences in eHealth technologies used, intervention providers, intervention time, variations in study populations and settings (Supplementary Table S2). The inclusion of diverse CVD populations with differing baseline characteristics likely contributed to further clinical and methodological heterogeneity. Finally, the relatively small number of eligible trials limited the ability to assess publication bias. Specifically, the number of trials per outcome was insufficient to apply funnel plots or the Egger’s regression asymmetry test with confidence. As a result, the presence of potential publication bias cannot be ruled out.

## Methods

This systematic review and meta-analysis was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Supplementary Table S3)<sup>43</sup>. The protocol has been registered with PROSPERO (CRD42024582906).

Seven electronic databases, including PubMed, Cochrane Library, Embase, Web of Science, EBSCOhost-MEDLINE, CINAHL, and PsycINFO, were searched from inception to 1st October 2024. The search strategy was developed through initial discussions among some of the authors, and in consultation with an academic experienced in evidence-based nursing methods (JNY). Search terms included: “cardiovascular diseases,” “heart disease,” “hypertension,” “heart failure,” “stroke,” “arteriosclerosis,” “electronic health,” “eHealth,” “mobile health,” “telehealth,” “digital health,” “app,” “internet,” “website,” “web,” “phone,” “email,” “SMS,” “MMS,” “electronic health record,” “risk communication,” “risk assessment,” “risk score,” “risk representations,” “risk information/risk management,” “heart age,” “absolute risk,” “relative risk,” and “counseling”. Additionally, reference lists of included trials were manually searched, and authors of eligible trials were contacted to obtain further data. The complete search strategy is detailed in Supplementary Table S4.

Studies were included if they met the following criteria: (a) Population: individuals aged  $\geq 18$  years with (secondary prevention) or without (primary prevention) established CVD, specifically this review was focused on the types of CVD events that have a high incidence and are closely related to healthy lifestyles, such as coronary heart disease, myocardial infarction, and stroke; (b) Intervention: presenting risk score or the risk of CVD events, using eHealth technologies (e.g., web-based browsers, computers, smartphones, and electronic health records) for risk communication; (c) Comparison: blank control, usual care, or an alternate intervention not delivered via eHealth; (d) Outcome: changes in CVD health-related indicators (e.g., physiological health metrics, lifestyles, mental health); (e) Study design: randomized controlled trials; (f) Language: English. Conference abstracts, letters to the editor, and study protocols that lacked adequate data were excluded.

References identified from the databases were imported into EndNote X9.1 for management. Following the removal of duplicates, two independent reviewers (YJJ and BLL) performed an initial screening based on titles and abstracts, applying predefined inclusion and exclusion criteria. A secondary screening of full-text articles followed. Disagreements arising during the screening process were resolved by consensus, with a third researcher (YJQ) consulted as necessary. Two reviewers (YJJ and BLL) independently extracted data by using a custom-designed data extraction form, which captured information, such as first author, publication year, country, groups, levels of prevention<sup>44</sup>, sample characteristics, eHealth technologies, intervention components, outcomes, and quantitative results. Three researchers (YJJ, BLL, and YJQ) independently evaluated the quality of the included RCTs in accordance with the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0)<sup>45</sup>. Discrepancies in quality assessment were addressed through consultation with a fourth researcher (QSZ).

Prior to formal data analysis, raw data extracted from the included studies were subjected to transformation. For example, when studies provided sample size alongside standard error (SE) or 95% confidence interval (CI), these values were converted to standard deviation (SD). Additionally, data from multiple subgroups were consolidated as part of this preprocessing. Review Manager 5.4.1 was used to analyze the extracted data<sup>46</sup>. In cases where measurement approaches for the indicators were inconsistent, data standardization was performed. For continuous data, the standard mean difference (SMD) with 95%CI was selected over the mean difference (MD), as SMD offers better generalizability and external applicability, making it more suitable for comparison across similar populations and less susceptible to over- or underestimation<sup>47</sup>. Dichotomous data were reported using odds ratios (OR) and CI. Heterogeneity among the included studies was assessed with  $I^2$  statistics, with substantial heterogeneity suggested where  $I^2$  is  $\geq 50\%$ . Considering potential heterogeneity between studies, a random-effects model was used to generate more robust results<sup>48</sup>. A p value of  $\leq 0.05$  was

considered statistically significant for meta-analyses. To enhance data availability and align with the characteristics of the studies, subgroup analyses were performed based on levels of prevention (e.g., primary prevention, secondary prevention, and both) and follow-up time (e.g., short-term  $\leq 3$  months vs. long-term  $> 3$  months) to explore heterogeneity and compare effects across different subgroups. Sensitivity analysis was conducted using the leave-one-study-out method to evaluate the robustness and reliability of the pooled results<sup>49</sup>.

## Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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## Author contributions

Y.J. contributed to Writing the Original Draft, Methodology, Formal Analysis, Data Curation, and Visualization. Y.Q. was involved in Writing—Review and Editing and Data Curation. Q.Z. contributed to Methodology, Writing—Review and Editing, and Data Curation. L.P.A. participated in Writing—Review and Editing. K.B. was involved in Writing—Review and Editing. Z.G. contributed to Writing—Review and Editing. M.T.O. participated in Writing—Review and Editing. M.Y. was involved in Writing—Review and Editing and Funding acquisition. D.A.C. contributed to Methodology and Writing—Review and Editing. B.L. was responsible for Conceptualization, Methodology, Data Curation, Supervision, Writing the Original Draft, Writing—Review and Editing, Project Administration, and Funding Acquisition. All authors read and approved the final manuscript.

## Competing interests

The authors declare no competing interests.

## Additional information

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