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Are Digital Health Interventions That Target Lifestyle Risk Behaviors Effective for Improving Mental Health and Wellbeing in Adolescents? A Systematic Review with Meta-analyses

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Abstract
Research has established associations between poor mental health and lifestyle risk behaviors among adolescents, yet gaps exist in understanding whether digital health interventions for adolescents targeting these behaviors will improve mental health and wellbeing. This study aimed to evaluate how effective digital health interventions targeting lifestyle risk behaviors are in improving mental health/wellbeing among adolescents (10–24 years old). We also aimed to understand how effects vary by participant and intervention characteristics, and intervention adherence and engagement. Through systematic review with meta-analysis, 5229 records were identified. 17 studies were included representing 9070 participants (15.3 mean age, 1.2 SD). Interventions had small but statistically non-significant positive effects on physical and psychosocial quality of life, depressive symptoms and anxiety at follow-up compared to usual care controls. Digital health delivery methods included text messaging, mobile applications, websites and email, or a combination of these. Intervention adherence, engagement and satisfaction were measured poorly across studies. Despite small changes, potential exists for digital health interventions to improve mental health or wellbeing outcomes among adolescents due to the shared nature of risk and protective factors for mental health and chronic diseases.

Keywords Adolescent · Digital health · Risk factors · Mental health · Wellbeing · Systematic review · Meta-analysis

Introduction

Adolescence is a critical life-stage for development of physical and mental health. Health promoting behaviors need to be established and maintained to ensure good physical and mental health and wellbeing during adolescence and into adulthood (World Health Organization, 2014). However, due to an increase in unhealthy lifestyle behaviors adolescents are at risk of chronic diseases in adulthood such as cardiovascular disease (Barbaresko et al., 2018) and obesity (Farhat et al., 2010). Rates of mental health conditions among adolescents are increasing, with global estimations that 14% of 10–19-year-olds experience a mental health condition or disorder (World Health Organization, 2021) and half of all mental disorders emerge at the age of 14 (Kessler et al., 2007). Emerging research demonstrates that during the first year of the Coronavirus Disease 2019 (COVID-19) pandemic the prevalence of mental health conditions increased to 25% (Racine et al., 2021), yet whether this increased prevalence will remain and the potential long-term implications of this are still unknown. Research has established associations between poor mental health among adolescents and lifestyle risk behaviors including physical inactivity (Sampasa-Kanyinga et al., 2020), sub-optimal diet (O'Neil et al., 2014), sedentary behavior (Rodriguez-Ayllon et al., 2019), poor sleep hygiene, alcohol intake (Lima et al., 2020) and tobacco/e-cigarette smoking (Javed et al., 2022;

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Lawrence et al., 2022). There is growing evidence that interventions to improve lifestyle risk behaviors are associated with improvements in mental health and wellbeing outcomes (Dale et al., 2014), as well as physical health outcomes, such as obesity (Galani et al., 2007). Yet, most previous research was conducted in adults and only 35% of these studies were conducted in healthy populations (Dale et al., 2014). This study aims to cover existing knowledge gaps in understanding whether interventions targeting lifestyle risk behaviors will improve mental health and wellbeing among adolescents, especially in the context of digital health.

Digital health interventions are increasingly popular for achieving health objectives such as healthy lifestyle management (Chatterjee et al., 2021) and address health system shortcomings (e.g., access issues) (Kang et al., 2018). Healthcare systems need to provide preventive healthcare to adolescents in formats that are acceptable and engaging to them and can be delivered on a large scale. Additionally, given half of all mental disorders are established in adolescence but are undetected for many years (World Health Organization, 2022), digital health interventions may provide an opportunity to reach these young people. Previous systematic reviews have demonstrated that digital health school-based interventions addressing multiple lifestyle risk behaviors were effective for improving physical activity, fruit and vegetable intake and reducing screen time (Champion et al., 2019). Previous systematic reviews have also shown the effectiveness of digital health interventions for diet and physical activity behaviors (Rose et al., 2017) and supporting weight management (Kouvari et al., 2022) among adolescents. Furthermore, there is increasing research into the application of digital health interventions for prevention of mental health conditions among adolescents (Bantjes, 2022; Bergin et al., 2020; Werner-Seidler et al., 2020). However, this is the first study of its kind to specifically focus on the effectiveness of such interventions on improving mental health or wellbeing outcomes.

Current Study

Emerging evidence suggests interventions which aim to improve lifestyle risk behaviors are associated with improvements in mental health and wellbeing outcomes, and digital health interventions provide the opportunity to be delivered at scale to reach adolescents and provide healthy lifestyle management. The current study aimed to investigate the effectiveness of digital health interventions targeting key lifestyle risk behaviors (physical activity, diet, sedentary behavior, sleep, alcohol and/or smoking) on mental health or wellbeing outcomes among adolescents. A second aim is to evaluate how the effects of digital health interventions vary by participant characteristics (e.g., gender, age) intervention characteristics (e.g., delivery method, frequency, duration, type of risk behaviors) and intervention adherence and engagement.

Methods

Protocol and Registration

This systematic review was conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement guidelines (Page et al., 2021) (Supplementary File 1) and followed the predetermined methods documented in a protocol. The review was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; Registration Number: CRD42021247738).

Eligibility Criteria

Studies were included that met the following criteria: (1) randomised controlled trials (RCTs) or cluster randomised controlled trials (cRCTs); (2) participants were adolescents 10–24 years, defined by the Lancet definition of adolescence (Kinghorn et al., 2018), all genders were included who were free from existing mental health diagnosis, not pregnant or post-partum and free of acute illness or other significant chronic disease that requires specific diet and/or physical activity management (e.g. type 1 diabetes mellitus); (3) intervention focused on one or more of the following six lifestyle risk behaviors: dietary behaviors, physical activity, sedentary behaviors, sleep, alcohol and/or tobacco; (4) an outcome of mental health or wellbeing. The list of outcomes was adapted from another systematic review (Melissa Bujtor, 2019) and included both psychological well-being (self-efficacy, self-esteem, self-image, self-concept, quality of life, health related quality of life, positive affect) and psychological ill-being outcomes (stress, anxiety, depressive symptoms, psychological distress, negative affect); (5) digital health intervention of any duration, including mobile technology (mobile phone applications, text messaging), websites, social media, smart watches, activity trackers, email and Personal Digital Assistant use; (6) A comparator group receiving standard or usual care (no intervention); (7) All settings were included including community, home or school-based and health care; (8) published in any language and; (9) studies published after 2005. The cut-off date of 2005 was selected as the current generation of adolescents ('Generation Z') appeared in the population after 1995, and the oldest of this generation were 10 years old in 1995.

Information Sources and Search Strategy

Ten major electronic databases (Pre-Medline, Medline, Cochrane, Cochrane Central Register of Controlled Trials, Embase, CINAHL, AMED, Informit, Scopus and Web of Science) were systematically searched on 25th June, 2021 and updated on August 17, 2022. The database searches were developed in conjunction with an academic librarian. Search terms included combinations, truncations and synonyms of the following (1) digital health (telehealth; eHealth, mHealth, mobile applications, text messaging, internet, social media, smartwatch, fitness tracker, personal digital assistant) (2) physical activity, diet, sedentary behavior, sleep, alcohol and/or smoking (3) mental health and wellbeing (self-esteem, self-efficacy, quality of life, anxiety, depressive symptoms, self-image, resilience, stress) and (4) adolescent. Database RCT filters were applied to maximise the results of RCTs and cRCTs and limits were set to only identify papers published from 2005 to current. The full electronic search strategy for each database is available in Supplementary File 2.

Study Selection

One author (RR) carried out all electronic database searches. Search results across databases were merged using Endnote X9 reference management software and duplicates of the same study were removed. Following merging the results in Endnote, they were then uploaded to the systematic review management tool, Covidence (Veritas Health Innovation Ltd, Melbourne, Australia). Following the Cochrane Handbook of Systematic Reviews and the PRISMA Statement for study selection, two researchers (RR and SSJ) independently screened titles and abstracts against the inclusion and exclusion criteria. Any disagreements were discussed and resolved by consensus between two authors (RR and SSJ). Where a decision was unresolved, a third author (SRP) was consulted.

Data Collection Process

For studies meeting the inclusion criteria, information was extracted using a pre-designed electronic data extraction table in Covidence. Two authors independently extracted the data (RR and SSJ) and a third author independently cross-checked a 20% random sample for accuracy (AT). Extracted data included primary outcome data of interest and information on participant characteristics, study characteristics and intervention characteristics. Corresponding authors were contacted for missing, incomplete or unclear data.

Data Synthesis and Analysis

A qualitative synthesis of baseline participant and overall study and intervention characteristics, as well as primary outcome data of interest and data on intervention satisfaction, engagement and adherence was completed. Primary outcome data were grouped by each mental health or wellbeing outcome for a quantitative synthesis. For example, any data from studies that measured change in anxiety between groups was pooled. Where possible, for all study arms, the mean and standard deviation for the outcome of interest was extracted at baseline, post intervention and any follow-ups. Next, data was entered into Review Manager (RevMan; version 5.4, Cochrane, London, UK) software for meta-analyses. If studies included multiple intervention arms, only the most complex intervention was used in the meta-analyses, defined as having the largest number of intervention components. All outcomes of interest were continuous in distribution. Where two or more studies measured the same continuous outcome, they were combined using an inverse variance random effects model, using the standardised mean difference (SMD) and 95% confidence interval (CI). Results of the meta-analyses are presented using forest plots for each outcome. Heterogeneity between studies was assessed using tau^2 and the I^2 statistic. I^2 statistic of $> 50\%$ indicate substantial heterogeneity between studies. Significance of heterogeneity was identified using the Cochran's Q (χ^2) test ($P < 0.1$). Sensitivity analyses were performed excluding the studies with high risk of bias to elucidate whether this caused any difference in the pooled results. For each outcome, small-study effects were evaluated using funnel plots. The published protocol was adhered to in full, however once data was synthesized the protocol was amended to add the sensitivity analysis to understand whether removing studies at high risk of bias improved precision, reduced possible heterogeneity and improved the reliability of the pooled effects.

Risk of Bias Assessment

The Cochrane Collaboration's tool was used to assess the risk of bias at the individual study level (Sterne et al., 2019). Two Cochrane Risk of Bias tools were used: for randomized trials (RoB 2) and for cRCTs (RoB 2 cRCT). The RoB 2 and RoB 2 cRCT domains for risk of bias assessment included randomization process, deviations from the intended interventions, missing outcome data, measurement of the outcome and selection of the reported result. The judgement within each domain was assessed to produce an overall risk of bias judgement as low risk, some concerns or high risk of bias. Two authors (RR and SJ) independently evaluated

each study for risk of bias. Any discrepancies were resolved by a third author (SRP).

Results

Study Selection

The search found 5362 articles from all electronic database searches. After exclusion of duplicates, 5229 articles were screened by title and abstract and 5089 were excluded. A total of 140 full-text articles were assessed for eligibility and 123 were excluded with reasons listed in Fig. 1. Seventeen full-text articles representing 17 unique studies were included in this review.

Participant and Study Characteristics

Thirteen of the studies were RCTs and four were cRCTs. All were published in English. Seven studies were conducted in the USA, three in the Netherlands, and one each in Hong Kong, Iceland, Spain, Australia, Taiwan, Turkey and Thailand. There was a total of 9070 participants, ranging in age from 10 to 24 years, with a pooled mean age (pooled SD) of 15.3 (1.2). On average, 55.8% of participants were female (range 16–100%). Interestingly, some studies only reported a percentage of how many participants identified as male/female/other and therefore the exact number of participants for each gender is not presented. 12/17 (70.6%) of studies reported ethnicity. Three studies included only participants of one ethnicity (n = 2 Chinese and n = 1 Thai) (Chan et al., 2022; Chen et al., 2018; Likhitweerawong et al., 2021). Five

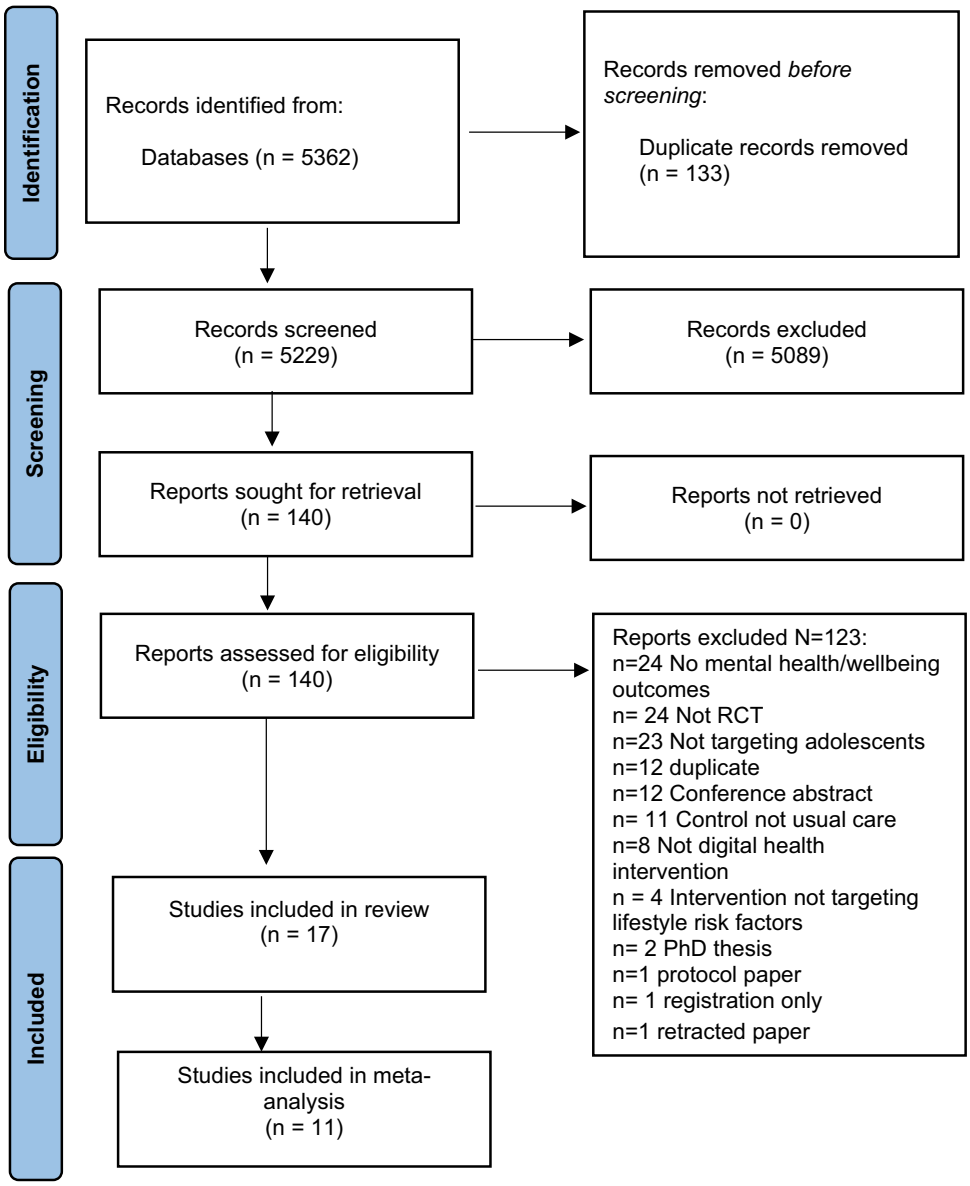


Fig. 1 PRISMA flowchart of study selection

Table 1 Participant characteristics of included studies

Author, year, country	Age range (years)	Mean age, years (SD)	Gender, n (%)	Ethnicity (n/N, %)	Education (n/N, %)	Income/socioeconomic status (n/N, %)	Weight status at baseline	Recruited from school/university/college setting?
Chan et al., 2022, Hong Kong	12–24	ESH: 20.9 (2.5) GT: 19.4 (2.3) WT: 19.7 (2.6)	M: 32.6% F: 67.4%	Chinese (135/135, 100)	Master: (7/135, 5.1) Undergraduate: (97/135, 71.9) Secondary: 31/135 (23.0)	NR	NR	Y – secondary schools and universities
Chen et al, 2018, USA	13–18	14.9 (1.67)	M: 23 (57.5) F: 17 (42.5)	Chinese American (40/40, 100)	NR	95% of study participants reported annual family income < $40,000	BMI ≥ 85th percentile	N—recruited from community clinics
Cremers et al, 2015, Netherlands	10–11	Prompt: 10.36 (0.55) No-prompt: 10.35 (0.54) Control: 10.38 (0.55)	M: 1588 (49.4) F: 1625 (50.6)	Western (2836/3213, 88.2)	NR	SES (high) (1354/3213, 42.1)	NR	Y—primary schools
De Bruin et al, 2016, Netherlands	12–19	IT: 15.3 (1.4) GT: 15.6 (1.7) WL: 15.9 (1.6)	M: 29 (25.0) F: 87 (75.0)	Parent country of birth, Netherlands (93/116, 80.2) Parent country of birth, other (10/116, 8.6) Parent country of birth, missing (13/116, 11.2)	Parent education High school or less (2/116, 1.7) Some college: (35/116, 30.2) College graduate: (30/116, 25.9) Graduate school: (35/116, 30.2) Other: (1/116, 0.9) Missing: (13/116, 11.2)	NR	NR	N—recruited from advertisements, newsletters, lectures at schools and leaflets for healthcare professionals
Egilsson et al, 2021, Iceland	15–16	I: 15.64 (0.25) C: 15.6 (0.26)	M: 24 (58.5) F: 17 (41.5)	NR	Current student (41/41, 100)	NR	BMI Category Underweight (7/41, 17.1%) Healthy weight (25/41, 60.9%) Overweight (1/41, 2.4%) Obesity 1/41, 2.4%) Missing (7/41, 17.1%)	Y – recruited from schools

Table 1 (continued)

Author, year, country	Age range (years)	Mean age, years (SD)	Gender, n (%)	Ethnicity (n/N, %)	Education (n/N, %)	Income/socioeconomic status (n/N, %)	Weight status at baseline	Recruited from school/university/college setting?
Graham et al, 2021, USA	18–24	I: 20.4 (1.7) C: 20.4 (1.7)	M: 1253 (48.4) F: 1303 (50.3) Nonbinary/other: 26 (1.0) Refused: 6 (0.2)	White (2159/2588, 83.4) Asian (128/2588, 4.8) Black (38/2588, 1.5) American Indian/Alaska native (18/2588, 0.7) Multiracial (162/2588, 6.3) Other (50/2588, 1.9) Refused (28/2588, 1.1)	Current student (1932/2588, 74.7)	Lives comfortably (673/2588, 26.0) Meets needs with a little left (1000/2588, 36) Just meets basic expenses (778/2588, 30.1) Does not meet basic expenses (37/2588, 5.3)	NR	N—recruited via advertisements on Facebook and Twitter
Guo et al, 2014, Taiwan	High school students	I: 16.05 (0.91) C: 16.08 (0.68)	M: NR (83.92) F: NR (16.08)	NR	Parent education ≤ 12 years (NR, 94.89) ≥ 12 years (NR, 5.11)	Parent occupation White collar (NR, 18.38) Blue collar (NR, 81.62)	NR	Y—vocational high schools
Jones et al, 2008, USA	High school students	I: 15.0 (1.0) C: 15.2 (1.1)	M: 32 (30.5) F: 73 (69.5)	White (67/105, 63.8) Black (8/105, 7.6) Latino/Hispanic/Mexican (22/105, 21.0) Other (8/105, 7.6)	Mothers' education Less than high school (7/105, 6.7) Finished high school (31/105, 29.5) More than high school (56/105, 53.3) Unknown (11/105, 10.5) Fathers' education Less than high school (9/105, 8.6) Finished high school (22/105, 21.0) More than high school (54/105, 51.4) Unknown (20/105, 19.0)	NR	BMI ≥ 85th percentile	Y—high schools

Table 1 (continued)

Author, year, country	Age range (years)	Mean age, years (SD)	Gender, n (%)	Ethnicity (n/N, %)	Education (n/N, %)	Income/socioeconomic status (n/N, %)	Weight status at baseline	Recruited from school/university/college setting?
Köse and Yıldız, 2021, Turkey	12–18	14.38 (1.53)	M: 25 (39.1) F: 39 (60.9)	NR	Mothers' education Illiterate (3/64, 4.7) Primary school (33/64, 51.6) Secondary school (10/64, 15.6) High school (9/64, 14.1) University (9/64, 14.1) Fathers' education Primary school (28/64, 43.8) Secondary school (12/64, 18.8) High school (13/64, 20.3) University (11/64, 17.2)	Perceived income level Poor (3/64, 4.7) Medium (40/64,62.5) Good (21/64, 32.8)	With overweight or obesity	N—recruited from Adolescence Polyclinic
Likhitweerawong et al, 2021, Thailand	10–15	I: 13.11 (1.99) C: 12.81 (1.79)	M: 48 (68.6) F: 22 (31.4)	Thai (70/70, 100)	NR	NR	BMI ≥ 95th percentile	Y – school and hospital-based settings
Lopez et al, 2021, USA	14–18	15.39 (1.26)	M: 31 (40.79) F: 45 (59.21)	Hispanic (50/76, 65.79) Non-Hispanic (26/76, 34.21)	Parent education High school or less (44/76, 57.89) Trade/vocational (7/76, 9.21) College (22/76, 28.95) Graduate degree (3/76, 3.95)	Household income < $50 k (50/76, 65.79) $50 k–$149,999 (16/76, 21.05) ≥ $150 k (5/76, 6.58) NR (5/76, 6.58)	BMI ≥ 85th percentile	N—recruited from paediatric clinics at hospital, direct mailing campaign and community
Lubans et al, 2012, Australia	8th grade high school students	I: 13.15 (0.44) C: 13.20 (0.45)	F: 357 (100)	Australian (305/357, 85.4) Asian (4/357, 1.1) European (36/357, 10.1) Other (11/357, 3.1)	NR	Socioeconomic position 1–2 (75/357, 21.1 3–4 (87/357, 24.5) 5–6 (183/357, 51.3) 7–8 (9/357, 2.5) 9–10 (1/357, 0.3)	BMI category Underweight (2/357, 0.6) Healthy weight (202/357, 56.6%) Overweight (93/357, 26.1) Obese (60/357, 16.8)	Y—high schools

Table 1 (continued)

Author, year, country	Age range (years)	Mean age, years (SD)	Gender, n (%)	Ethnicity (n/N, %)	Education (n/N, %)	Income/socioeconomic status (n/N, %)	Weight status at baseline	Recruited from school/university/college setting?
Richardson et al, 2021, USA	13–18	NR	M: 168 (56.0) F: 129 (43.0) Trans or nonbinary: 3 (1.0)	I: White: 93 (64.1%) Hispanic: 7 (4.8%) African American: 6 (4.2%) Asian or Pacific Islander: 7 (4.8%) Native American: 1 (0.7%) Other or more than one: 31 (21.4%) C: White: 99 (63.9%) Hispanic: 12 (7.7%) African American: 13 (8.4%) Asian or Pacific Islander: 7 (4.5%) Native American: 0 (0%) Other or more than one: 24 (15.5%)	NR	NR	NR	N—recruited from paediatric clinics
Rodgers et al, 2018, USA	14–19	18.36 (1.34)	M: 26% F: 74%	White (154/274, 56) Asian (51/274, 19) Black (28/274, 10) Hispanic (23/274, 8) Other (18/274, 7)	NR	NR	NR	Y—2 high schools, 2 local youth organisations and 1 university campus
Slootmaker et al, 2010, Netherlands	13–17	Overall: 15.1 I: M: 15.3 (1.1), F: 15.4 (1.1) C: M: 14.8 (1.4), F: 15.0 (1.2)	M: 32 (37) F: 55 (63)	NR	High education: 61% I: M: 87%, F: 54% C: M: 59%, F: 55%	NR	NR	Y—secondary schools

Table 1 (continued)

Author, year, country	Age range (years)	Mean age, years (SD)	Gender, n (%)	Ethnicity (n/N, %)	Education (n/N, %)	Income/socioeconomic status (n/N, %)	Weight status at baseline	Recruited from school/university/college setting?
Thompson et al, 2016, USA	14–17	NR	M: 77 (48.13) F: 83 (51.88)	Hispanic (43/160, 26.88) White (50/160, 31.25) African American (57/160, 35.63) Mixed/Other (10/160, 6.25)	NR	NR	NR	N—recruited through community
Vargas-Martínez et al., 2019, Spain	15–19	I: 16.87 (1.06) C: 16.68 (1.04)	F: 53.01	94.7% Spanish I: 0.954 (0.21) C: 0.936 (0.24)	Mother's schooling years I: 20.39 (27.07) C: 22.68 (29.00) Mean schooling years of mothers: 11.48 Mean schooling years of fathers: 11.17	Good economic situation at home I: 0.45 (0.50) C: 0.49 (0.50) Good or very good 62.27%	NR	Y—secondary or higher secondary schools or first course of vocational training (10th and 11th grade USA equivalent)

BMI body mass index, *C* control, *ESH* Email Self Help, *F* female, *GT* Group Therapy, *I* intervention, *IT* Internet therapy, *M* male, *NR* not reported, *WL* waitlist control, *WT* Waitlist

of the studies were targeted at adolescents who had overweight or obesity (Chen et al., 2018; Jones et al., 2008; Köse & Yıldız, 2021; Likhitweerawong et al., 2021; Lopez et al., 2021). For further participant details please refer to Table 1. Length of follow-up ranged from 1 to 25 months. Nine studies targeted more than one lifestyle risk factor (9/17, 52.9%) (Chen et al., 2018; Egilsson et al., 2021; Jones et al., 2008; Köse & Yıldız, 2021; Lopez et al., 2021; Lubans et al., 2012; Richardson et al., 2021; Rodgers et al., 2018; Slootmaker et al., 2010). Three studies targeted smoking only (Cremers et al., 2015; Graham et al., 2021; Guo et al., 2014), two studies targeted sleep only (Chan et al., 2022; De Bruin et al., 2016) and one each targeted only diet (Likhitweerawong et al., 2021), physical activity (Thompson et al., 2016), and alcohol (Vargas-Martínez et al., 2019). Five studies specifically targeted adolescents with overweight or obesity (Chen et al., 2018; Jones et al., 2008; Köse & Yıldız, 2021; Likhitweerawong et al., 2021; Lopez et al., 2021). Attrition rates across studies varied, with four studies having attrition rates above 30% (Cremers et al., 2015; De Bruin et al, 2016; Egilsson et al., 2021; Vargas-Martínez et al., 2019). Full details of participant and study characteristics are available in Table 1 and 2 respectively.

Intervention Characteristics

The method of delivering digital health interventions varied across the 17 studies. Four interventions used a combination of digital health delivery methods including fitness trackers (Chen et al., 2018), websites (Chen et al., 2018; Cremers et al., 2015; Richardson et al., 2021), mobile phone applications (Chen et al., 2018; Lopez et al., 2021; Richardson et al., 2021) and text messaging (Chen et al., 2018; Cremers et al., 2015; Lopez et al., 2021). Five interventions were delivered via text messaging alone (Graham et al., 2021; Guo et al., 2014; Köse & Yıldız, 2021; Lubans et al., 2012; Thompson et al., 2016), four were delivered through a website (De Bruin et al., 2016; Jones et al., 2008; Slootmaker et al., 2010; Vargas-Martínez et al., 2019), three were mobile phone applications (Egilsson et al., 2021; Likhitweerawong et al., 2021; Rodgers et al., 2018) and one was delivered via email (Chan et al., 2022). Intervention duration ranged from 6 weeks (De Bruin et al., 2016; Egilsson et al., 2021; Rodgers et al., 2018) to 12 months (Cremers et al., 2015; Lubans et al., 2010). Eleven of the interventions had the digital component only (Chan et al., 2022; Cremers et al., 2015; De Bruin et al., 2016; Egilsson et al., 2021; Graham et al., 2021; Jones et al., 2008; Likhitweerawong et al., 2021; Richardson et al., 2021; Rodgers et al., 2018; Slootmaker et al., 2010; Vargas-Martínez et al., 2019), whereas six studies were multicomponent and included the digital component alongside other intervention components e.g. classroom curriculum, interactive workshops (Chen et al., 2018; Guo et al.,

2014; Köse & Yıldız, 2021; Lopez et al., 2021; Lubans et al., 2012; Thompson et al., 2016). Due to the complexity across interventions in terms of duration, components and exposure, the results are unable to be pooled to adequately demonstrate frequency of intervention exposure. There were several behavior change theories underpinning the interventions including cognitive behavioral therapy (CBT) (Chan et al., 2022; De Bruin et al., 2016; Jones et al., 2008), social cognitive theory (SCT) (Chen et al., 2018; Graham et al., 2021; Lubans et al., 2012), I-Change Model (Cremers et al., 2015; Vargas-Martínez et al., 2019), motivational interviewing (Köse & Yıldız, 2021) and self-determination theory (SDT) (Thompson et al., 2016). Five of 17 studies used co-design with adolescents in intervention development (Egilsson et al., 2021; Graham et al., 2021; Guo et al., 2014; Richardson et al., 2021; Thompson et al., 2016). Full details of the intervention characteristics are available in Table 3.

Mental Health or Wellbeing Outcomes

For two of the included studies, the outcome data of interest was not presented in the manuscript and was unavailable after contacting the corresponding author (Cremers et al., 2015; Thompson et al., 2016). All data used in the meta and sensitivity analyses are available in Supplementary File 3. Forest plots for meta-analyses are available in Fig. 2. Forest plots for sensitivity analysis are available in Fig. 3.

Quality of Life

Four studies (4/17, 23.5%) measured quality of life (QOL) (Chen et al., 2018; Köse & Yıldız, 2021; Likhitweerawong et al., 2021; Vargas-Martínez et al., 2019), with all having sufficient data to perform meta-analyses and used two QOL measures that are validated in adolescent populations: Pediatric Quality of Life Inventory (PedsQL) (Chen et al., 2018; Köse & Yıldız, 2021; Likhitweerawong et al., 2021) and EQ-5D-5L (Vargas-Martínez et al., 2019). One study measured QOL as the primary outcome (Vargas-Martínez et al., 2019). Only one study showed significant effects of the intervention (Köse & Yıldız, 2021), which used text messaging to deliver the intervention over 6-months. Two separate meta-analyses were performed due to one paper reporting QOL for the physical and psychosocial subscales separately and not the total summary score. Overall, meta-analyses indicated that compared with usual care controls, interventions increased physical QOL levels but did not reach a significant level (SMD 0.30, 95% CI − 0.05 to 0.66, P = 0.10). There was significant heterogeneity amongst studies ($Tau^2 = 0.09$, $I^2 = 70\%$; P = 0.02). Similarly, interventions increased psychosocial QOL levels but did not reach a significant level compared to control with significant heterogeneity amongst studies (SMD 0.38, 95% CI − 0.08 to 0.83, P = 0.10; $Tau^2 = 0.16$, $I^2 = 82\%$, P = 0.001). One study had high RoB (Köse & Yıldız, 2021) and therefore the sensitivity analysis was performed on the remaining three studies. For physical QOL, the sensitivity analyses showed non-significant positive effects of the intervention (SMD 0.05, 05% CI − 0.06 to 0.16; P = 0.37) with no heterogeneity ($Tau^2 = 0.00$, $I^2 = 0\%$, P = 0.41). For psychosocial QOL, there was also non-significant positive effects of the intervention compared to control (SMD 0.17, 95% CI − 0.18 to 0.52; P = 0.34) and there was substantial heterogeneity across studies ($Tau^2 = 0.06$, $I^2 = 59\%$, P = 0.09).

Self-efficacy

Five (5/17, 29.4%) studies measured self-efficacy (Chen et al., 2018; Cremers et al., 2015; Egilsson et al., 2021; Guo et al., 2014; Slootmaker et al., 2010). Self-efficacy was measured across different domains including physical activity (Chen et al., 2018; Slootmaker et al., 2010), nutrition (Chen et al., 2018), smoking cessation (Cremers et al., 2015; Guo et al., 2014) and general self-efficacy (Egilsson et al., 2021). Due to this variability, meta-analysis was not possible. Three studies used study-specific questionnaires (Cremers et al., 2015; Guo et al., 2014; Slootmaker et al., 2010), one study used the Health Behavior Questionnaire (Chen et al., 2018) and one used the General Self Efficacy Scale (GSE) (Egilsson et al., 2021). Both the Health Behavior Questionnaire and GSE have been validated in adolescent populations previously. No studies measured self-efficacy as a primary outcome. Significant effects of the intervention were seen across three studies measuring physical activity and nutrition self-efficacy (Chen et al., 2018), self-efficacy in smoking cessation (Guo et al., 2014) and self-efficacy in sports (significant among males only) (Slootmaker et al., 2010).

Depressive Symptoms

Six studies measured depressive symptoms (6/17, 35.3%) (Chan et al., 2022; Egilsson et al., 2021; Graham et al., 2021; Jones et al., 2008; Lopez et al., 2021; Richardson et al., 2021), with five having sufficient data for meta-analyses (Chan et al., 2022; Egilsson et al., 2021; Graham et al., 2021; Jones et al., 2008; Lopez et al., 2021). Depressive symptoms were measured using various validated measures including Hospital Anxiety and Depression Scale (HADS) (Chan et al., 2022), Children's Depression Inventory (CDI) (Egilsson et al., 2021), Patient Health Questionnaire-2 (PHQ-2) (Graham et al., 2021) and Center for Epidemiological Studies Depression Scale for Children (CES-DC) (Jones et al., 2008; Lopez et al., 2021). No studies measured depressive symptoms as the primary outcome. Overall, the results of the meta-analysis revealed that compared

with usual care controls, interventions decreased depressive symptoms but did not reach a significant level compared to control (SMD − 0.02, 95% CI − 0.09 to 0.05, P = 0.60) and results were homogenous across studies ($Tau^2 = 0.00$, $I^2 = 0\%$, P = 0.60). For depressive symptoms, three studies had a high RoB (Egilsson et al., 2021; Jones et al., 2008; Lopez et al., 2021) and sensitivity analysis was performed on the remaining two studies. Sensitivity analysis showed a non-significant decrease in depressive symptom levels comparing intervention to usual care controls (SMD − 0.05, 95% CI − 0.21 to 0.12; P = 0.59), and results had little heterogeneity ($Tau^2 = 0.01$, $I^2 = 23\%$, P = 0.26).

Anxiety

Four studies measured anxiety (4/17, 23.5%) all with sufficient data for meta-analyses (Chan et al., 2022; De Bruin et al., 2016; Egilsson et al., 2021; Graham et al., 2021). Anxiety was measured using the following questionnaires: Hospital Anxiety and Depression Scale (HADS) (Chan et al., 2022), Youth Self Report (De Bruin et al., 2016), Multidimensional Anxiety Scale (MASC) (Egilsson et al., 2021) and Generalized Anxiety Disorder (GAD-2) (Graham et al., 2021). No studies measured anxiety as the primary outcome. Overall, meta-analysis showed that compared with usual care controls, interventions decreased anxiety levels but did not reach a significant level with substantial heterogeneity amongst studies (SMD − 0.13, 95% CI − 0.45 to 0.19, P = 0.42; $Tau^2 = 0.07$, $I^2 = 69\%$; P = 0.02). Two of the studies measuring anxiety had a high RoB (De Bruin et al., 2016; Egilsson et al., 2021). The sensitivity analysis on two remaining studies (Chan et al., 2022; Graham et al., 2021), showed a non-significant decrease in anxiety levels comparing intervention to usual care controls in the sensitivity analysis (SMD − 0.04, 95% CI − 0.11 to 0.04) and results were homogenous across trials ($Tau^2 = 0.00$, $I^2 = 0\%$, P = 0.61).

Positive and Negative Affect

One study measured both positive and negative affect (Rodgers et al., 2018) and one study measured negative affect only (De Bruin et al., 2016). Although meta-analysis is recommended for 2 or more studies for better precision, significant heterogeneity existed between studies for negative affect and therefore results are summarised in a narrative synthesis. Affect was measured using Youth Self Report (De Bruin et al., 2016) and Positive and Negative Affect Schedule Children (PANAS-C) (Rodgers et al., 2018). No studies measured affect as the primary outcome. Rodgers and colleagues found no interaction effects for positive or negative affect and De Bruin and colleagues found no significant intervention effects on negative affect.

Self-esteem

One study measured self-esteem as a secondary outcome (Lubans et al., 2010, 2012) using the selective scales from Marsh's Physical Self-Description Questionnaire which is validated in an adolescent population. There were no significant effects of the intervention on self-esteem.

Intervention Satisfaction, Engagement and Adherence

Data on intervention satisfaction, engagement and adherence was poorly reported across studies. Four of 17 (23.5%) studies reported data on intervention satisfaction for participants, with over half of participants finding interventions acceptable (satisfaction 57–91%) (Egilsson et al., 2021; Lubans et al., 2012; Slootmaker et al., 2010; Thompson et al., 2016). Eight of 17 (47.1%) studies reported data on participant engagement or adherence with the intervention, assessed by the amount of the intervention received or accessed by participants which ranged from 22.5% to 83.1% across studies (Chan et al., 2022; Egilsson et al., 2021; Jones et al., 2008; Likhitweerawong et al., 2021; Lopez et al., 2021; Lubans et al., 2012; Slootmaker et al., 2010; Vargas-Martínez et al., 2019). Adherence to the intervention was reported to drop over time in five studies (Chan et al., 2022; Egilsson et al., 2021; Jones et al., 2008; Slootmaker et al., 2010; Vargas-Martínez et al., 2019). One study had a technical issue and therefore could not assess engagement or adherence (Rodgers et al., 2018).

Risk of Bias

Table 4 and 5 and Figs. 4 and 5 summarise the risk of bias assessment for RCTs and cRCTs. Nine of 17 studies (52.9%) had an overall RoB judged as high (Cremers et al., 2015; De Bruin et al., 2016; Egilsson et al., 2021; Guo et al., 2014; Jones et al., 2008; Köse & Yıldız, 2021; Lopez et al., 2021; Lubans et al., 2012; Rodgers et al., 2018). Twelve of 17 studies (76.5%) were judged as some concerns or high in the domain'risk of bias due to deviations from intended intervention', largely due to not blinding the participants and study personnel to intervention assignment, which is typically not possible in digital health interventions. Three of these studies also did not use appropriate analysis techniques for their data (Köse & Yıldız, 2021; Lopez et al., 2021; Rodgers et al., 2018). Across cRCTs, all were judged as some concerns for their randomization process as no information was provided. Of the four cRCTs, two had baseline differences between groups (Cremers et al., 2015; Vargas-Martínez et al., 2019). No significant publication bias was found from assessing funnel plots (Supplementary File 4).

Table 2 Study characteristics of included studies

Author, year, country	Study design	Total (n)	Intervention (n)	Control (n)	Risk factors targeted (n, type)	Duration of Intervention	Follow-up(s)	Attrition at follow-up(s) (from baseline)	Primary Outcome	Secondary Outcomes
Chan et al., 2022, Hong Kong	RCT	135	ESH: 45 GT: 45	45	1, Sleep	8 weeks	Post intervention, 1, 6 months	Post intervention: ESH: 18; GT: 2 WL: 15 1 month: ESH: 2; GT: 4 6 months: ESH: 1; GT: 4	Not relevant	Clinician rated depressive symptoms (HRSD) Self-reported mood symptoms (depression and anxiety): HADS
Chen et al, 2018, USA	RCT	40	23	17	3, Diet, PA, SB	3 months	3, 6 months	3 months: 0 6 months: I: 2, C: 2	Not relevant	Self-efficacy for healthy eating and PA: Health Behavior Questionnaire Paediatric QOL: PQOL-Adolescents
Cremers et al, 2015, Netherlands	Cluster RCT	3213	Prompt: 1207 No-Prompt: 1003	1003	1, Smoking	12 months	12 (T1), 25 (T2) months	T0–T1: 1067 T0–T2: 1730	Not relevant	Self-efficacy expectations for refusing cigarettes
De Bruin et al, 2016, Netherlands	RCT	116	IT: 39 GT: 38	WL: 39	1, Sleep	6 weeks	2, 6, 12 months	2 months: IT: 1, GT: 2, WL: 2 6 months: IT: 16, GT: 17 12 months: IT: 22, GT: 20	Not relevant	Anxiety problems, affective problems: YSR
Egilsson et al, 2021, Iceland	RCT	41	20	21	2, Diet, PA	6 weeks	Post intervention	Post intervention: I: 11, C: 8	Not relevant	General self-efficacy: GSE Depressive symptoms: CDI Anxiety: MASC
Graham et al, 2021, USA	RCT	2588	1304	1284	1, Smoking	9–12 weeks (depending on readiness to quit)	1, 7 months	1 month: I: 292, C: 239 7 months: I: 331, C: 290	Not relevant	Depressive symptoms: PHQ-2 Anxiety: GAD-2
Guo et al, 2014, Taiwan	Cluster RCT	143	79	65	1, Smoking	12 weeks	Post intervention, 1, 4 months	Post intervention: I: 12, C: 1 1 month: I: 16, C: 3 4 months: I: 25, C: 16	Not relevant	Self-efficacy in smoking cessation
Jones et al, 2008, USA	RCT	105	52	53	3, Diet, PA, SB	16 weeks	16 weeks, 9 months	16 weeks: I: 6, C: 5 9-months: I: 8, C: 8	Not relevant	Depressive symptoms: CES-D 20
Kose et al., 2020, Turkey	RCT	80	43	37	2, Diet, PA	6 months	6 months	I: 6, C: 10	Not relevant	QOL: PedsQL

Table 2 (continued)

Author, year, country	Study design	Total (n)	Intervention (n)	Control (n)	Risk factors targeted (n, type)	Duration of Intervention	Follow-up(s)	Attrition at follow-up(s) (from baseline)	Primary Outcome	Secondary Outcomes
Likhitweerawong et al, 2021, Thailand	RCT	70	35	35	1, Diet	6 months	6 months	6 months: I: 3; C: 4	Not relevant	QOL: PedsQL
Lopez et al, 2021, USA	RCT	113	AppCoach: 37 AppAlone: 38	38	2, Diet, PA	6 months	6 months	AppCoach:3 AppAlone: 11 C: 7	Not relevant	Depressive symptoms: CES-DC 10
Lubans et al, 2012, Australia	Cluster RCT	357	178	179	2, Diet, PA	12 months	12 months	I: 37, C: 26	Not relevant	Physical and global self-esteem: Marsh's Physical Self-description questionnaire
Richardson et al, 2021, USA	RCT	301	145	155	3, Diet, PA, Sleep	3 months	3, 6 months	3 months: I: 7, C: 10 6 months: I: 6, C: 10	Not relevant	Depressive symptoms: Risk Behavior Outcome
Rodgers et al, 2018, USA	RCT	274	129	130	3, Diet, PA, Sleep	6 weeks	6 (T2), 12 (T3) weeks	T2: 23, T3: 37	Not relevant	Positive and Negative Mood: Positive and Negatvie Affect Schedule 10-Children
Slootmaker et al, 2010, Netherlands	RCT	87	41	46	2, PA, SB	3 months	3, 8 months	3 months: I: 7, C: 12 8 months: I: 3, C: 5	Not relevant	Self-efficacy for sports participation, walking and biking and reducing screentime
Thompson et al, 2016, USA	RCT	160	P: 40 P + GP: 40 P + GP + T: 40	40	1, PA	12 weeks	12 weeks	C: 6, P: 4, P + GP: 9, P + GP + T: 3	Not relevant	Psychosocial variables: Basic Psychological Needs Satisfaction Questionnaire
Vargas-Martínez et al., 2019, Spain	Cluster RCT	1247	742	505	1, Alcohol	4 months	4 months	I: 393, C: 242	Health related QOL: EQ-5D-5L	Not relevant

C control, *CDI* Children's Depression Inventory, *CES-D* Center for Epidemiological Studies Depression Scale, *CES-DC* Center for Epidemiological Studies Depression Scale of Children, *EQ-5D-5L* EuroQol 5 Dimension 5 Level, *ESH* Email Self Help, *GAD-2* Generalized Anxiety Disorder 2-item, *GSE* General Self-Efficacy, *GT* Group Therapy, *HADS* Hospital Anxiety and Depression Scale, *HRSD* Hamilton Depression Rating Scale, *I* intervention, *IT* Internet Therapy, *MASC* Multidimensional Anxiety Scale for Children, *P + GT* Pedometer + Goal Prompt, *P + GT + T* Pedometer + Goal Prompt + Texts, *PA* physical activity, *PedsQL* Pediatric Quality of Life, *PHQ-2* Patient Health Questionnaire 2-item, *QOL* Quality of Life, *RCT* Randomised Controlled Trial, *SB* Sedentary Behavior, *SDT* self determination theory, *WL* waitlist, *YSR* Youth Self-Report

Table 3 Intervention characteristics of included studies

Intervention group	Theory for intervention	Digital health delivery method	Contact with research personnel	Intervention details and exposure	Comparator
Chan et al, 2022, Hong Kong					
ESH[a]	Cognitive behavioral therapy	Email	Weekly reminders to complete sleep diary	Weekly email with treatment materials for 8 weeks	Usual care
GT	Cognitive behavioral therapy	N/A	1 × week for 8 weeks	Group face-to-face CBT session once a week for 8 weeks	
Chen et al, 2018, USA					
iStart Smart for Teens	Social cognitive theory	Fitness tracker, website, mobile phone (app, program, text messaging)	In-person demonstration to access Fitbit data and iStart Smart for Teens program	Wearable sensor—Fitbit Flex (6-months) 8 online educational modules (months 1–3) Tailored, bi-weekly text messages (months 3–6)	Pedometer, blank food and activity diary, online program with 8 modules related to general adolescent health
Cremers et al, 2015, Netherlands					
Prompt[a]	I-Change Model	Website, text messaging	N/A	12-months access to 'Fun without Smokes' website: smoking and non-smoking information, animated videos with non-smoking content, games concerning non-smoking 3 × web-based computer-tailored feedback messages 6 × prompt messages via email and SMS every year to stimulate reuse of the website	Website access during three measurement sessions only, no access to non-smoking information or interactive elements, no computer-tailored feedback or prompt messages
No-Prompt	I-Change Model	Website only	N/A	As above without prompt messages	
De Bruin et al, 2016, Netherlands					
IT[a]	Cognitive behavioral therapy	Website	15 min chat (week 2)	'Sleeping Smart' Website with personalized advice and feedback, online material (90 min to complete, once a week for six weeks), and booster session after 2-months	Usual care
GT	Cognitive behavioral therapy	N/A	1 × week for 6 weeks	Group face-to-face 90-min CBT session once a week for six weeks, and a booster session after 2-months	

Table 3 (continued)

Intervention group	Theory for intervention	Digital health delivery method	Contact with research personnel	Intervention details and exposure	Comparator
Egilsson et al, 2021, Iceland					
SidekickHealth	Education and appetite awareness training (AAT)	Mobile phone application	5-min introduction to study specifications 10-min introduction to mobile app and its functions	6 weeks access to social health mobile application where the user sets goals and creates health-related missions (gamification) in physical activity, food and drink and mental health Completion of missions and competitions accumulates badges, moves to higher levels and aggregates points	Usual care
Graham et al, 2021, USA					
This is Quitting	Social cognitive theory	Text messaging	N/A	Tailored, interactive 8-week text message program (Additional 1–4 weeks of messages pre-quitting building skills and confidence)	Usual care
Guo et al, 2014, Taiwan					
Multicomponent smoking-cessation program	N/A	Text messaging	6 courses in classroom (2×45 min sessions) 6 telephone calls 10 text messages	Strength and skill building: classroom curriculum, self-study manual, Chinese acupressure video New modes of communication: telephone counselling and text messaging Coupon-based incentives	Educational flyers related to smoking cessation
Jones et al, 2008, USA					
StudentBodies2-BED	Cognitive behavioral principles, Healthy Habits (adolescent weight loss intervention)	Website	N/A	16 weeks access to internet facilitated program with interactive components: self-monitoring journals for dietary intake, PA, weight, personal thoughts and goals and discussion group	Usual care
Kose et al., 2020, Turkey					
Motivational support programme	Motivational interviewing	Text messaging	8×30-min MI	MI: 8×30 min sessions Text messages: 2/week for 6-months Parent education programme: 2 h face-to-face	Usual care

Table 3 (continued)

Intervention group	Theory for intervention	Digital health delivery method	Contact with research personnel	Intervention details and exposure	Comparator
Likhitweerawong et al, 2021, Thailand					
OBEST application	Self-awareness and self-monitoring	Mobile phone application	Two-hour workshop to learn application instructions, recommended diet, calories, portion sizes and nutritional facts	6-months app access 1. Goals and rewards: set goal for calorie intake and portion sizes per day, input weight every 2 weeks, adjustable photo display 2. Daily dietary record: record daily food intake 3. Tips and news: monthly updated information based on WHO recommendations to lose weight and maintain healthy eating habits 4. Messaging: every 2 weeks from healthcare provider as reminder and motivation	Usual care
Lopez et al, 2021, USA					
AppCoach[a]: interactive mHealth intervention with personalized health coaching	Founded on three addiction-based principles	Mobile phone (app, text messaging)	Text messages: 5 days/week Phone call: 15 min/week Face-to face visits: 2×1 h	6-months app access: targets three addictive eating behaviors: (1) staged withdrawal from problem foods; (2) staged withdrawal from daytime and nighttime snacking between meals; (3) withdrawal from consuming excessive amounts of food at meals Self-monitoring of weight and targeted behaviors Coaching: via text messages 5 days/week, 15 min weekly phone calls and 2×1 h face-to-face visits	Usual care
AppAlone: interactive mHealth intervention only	Founded on three addiction-based principles	Mobile phone application	N/A	As above without coaching	

Table 3 (continued)

Intervention group	Theory for intervention	Digital health delivery method	Contact with research personnel	Intervention details and exposure	Comparator
Lubans et al, 2012, Australia					
NEAT Girls	Social cognitive theory	Text messaging	3 × interactive seminars 3 × nutrition workshops Text messages: weekly during term 2/3, bi-weekly during term 4	Multicomponent program: enhanced school sport sessions (60–80 min) 3 × interactive seminars 3 × nutrition workshops lunch-time physical activity sessions handbooks and pedometers for self-monitoring 4 × parent newsletters over 12 months and text messaging for social support	Usual care
Richardson et al, 2021, USA					
Check Yourself tool (adapted)	N/A	Website/Application	Well-care visit with clinician counselling	Website/application electronic screening with integrated feedback – delivery of messages that increased motivation and self-efficacy for healthy behavior	Completed electronic screening but did not receive integrated feedback
Rodgers et al, 2018, USA					
BodiMojo	Self-compassion	Mobile phone application	Assistance downloading app and guided through registration, features, activities	6 weeks access to mobile app designed around three active components: 1: intervention messages delivered twice daily through the app with 5 content areas: mindfulness, self-kindness, common humanity, body image related content: media literacy, peer influences and appearance compassion, healthy lifestyle related content: healthy eating, sleep hygiene and PA 2: mood tracking and emotional regulation 3: gratitude journaling	Usual care

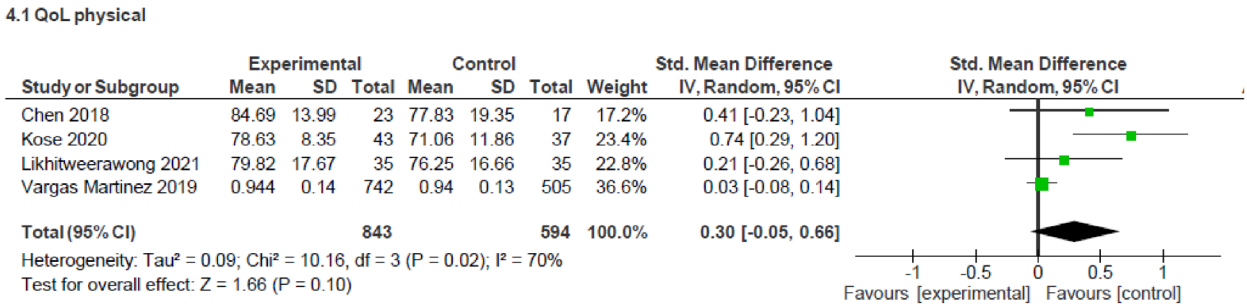
Table 3 (continued)

Intervention group	Theory for intervention	Digital health delivery method	Contact with research personnel	Intervention details and exposure	Comparator
Slootmaker et al, 2010, Netherlands					
PAM COACH	N/A	Website	Written and verbal instructions and practical demonstration on how to wear the accelerometer and use the website	PAM concept: objectively measured PA by an accelerometer with a web-based tailored PA advice (PAM COACH) accessible for 3-months	Received information brochure with brief PA recommendations
Thompson et al, 2016, USA					
Pedometer + goal prompts + SDT informed text messages[a]	Self determination theory (SDT)	Text messaging	N/A	Pedometer to track daily step count 12 Text messages to set a daily step goal for the week 72 SDT informed text messages promoting satisfaction of the basic psychological needs	Usual care
Pedometer + goal prompts	N/A	Text messaging	N/A	As above without 72 SDT informed messages	
Pedometer only	N/A	N/A	N/A	Pedometer only	
Vargas-Martínez et al., 2019, Spain					
ALERTA ALCOHOL	I-Change Model	Website	Research assistant attended session 1 to explain questionnaire	Web-based computer tailored intervention—6 sessions providing feedback through preventive messages and personalized information	Usual care

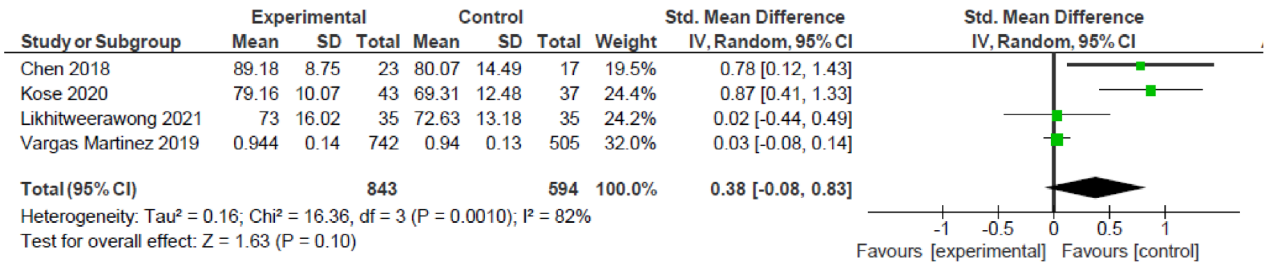
[a]'Most complex' intervention

CBT cognitive behavioral therapy, *ESH* Email Self Help, *GT* Group Therapy, *IT* Internet therapy, *MI* motivational therapy, *PA* physical activity, *SMS* Short Message Service

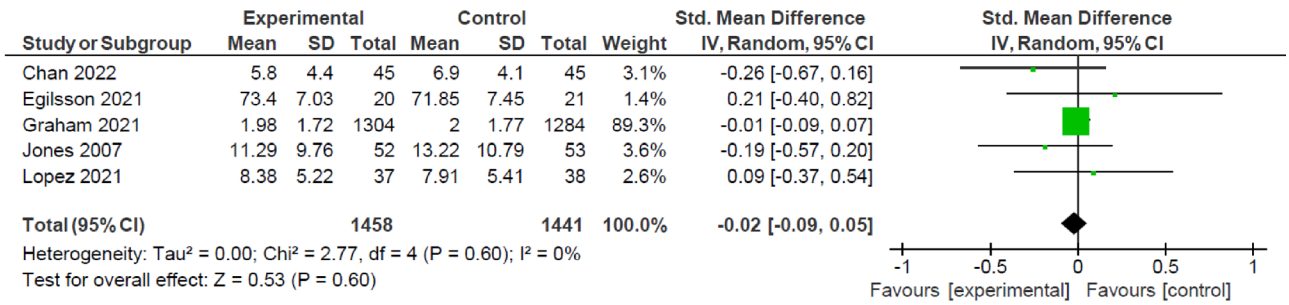
2.1 QOL physical



2.2 QOL psychosocial



2.3 Depressive symptoms



2.4 Anxiety

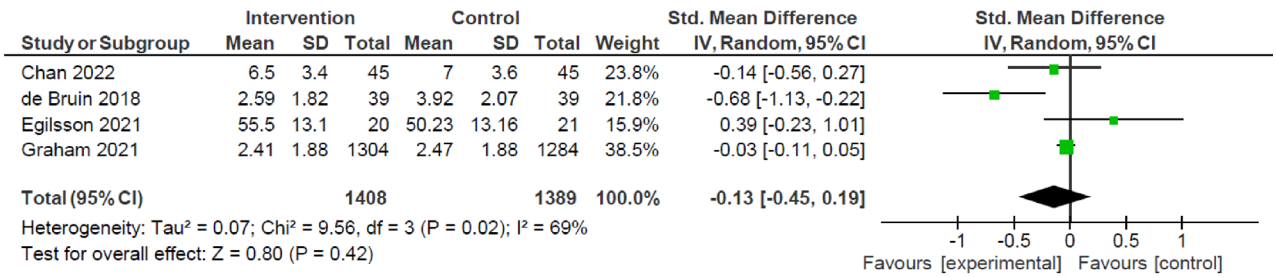
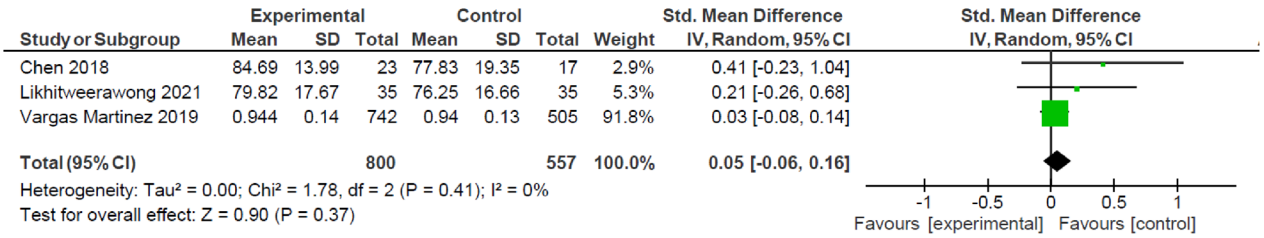
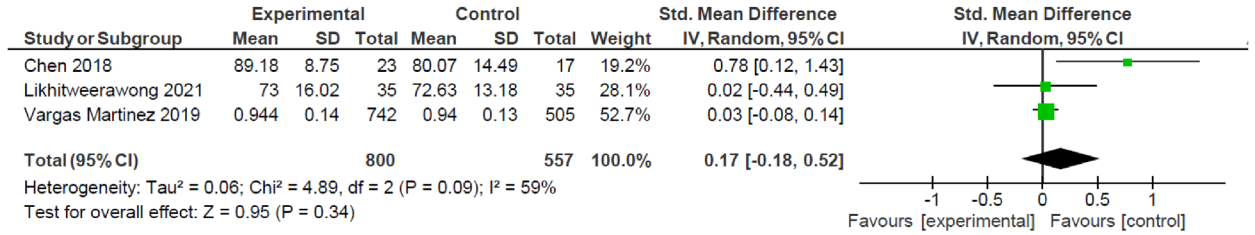


Fig. 2 Forest plots of meta-analyses. *CI* confidence interval, *IV* inverse variance, *QOL* quality of life, *SD* standard deviation

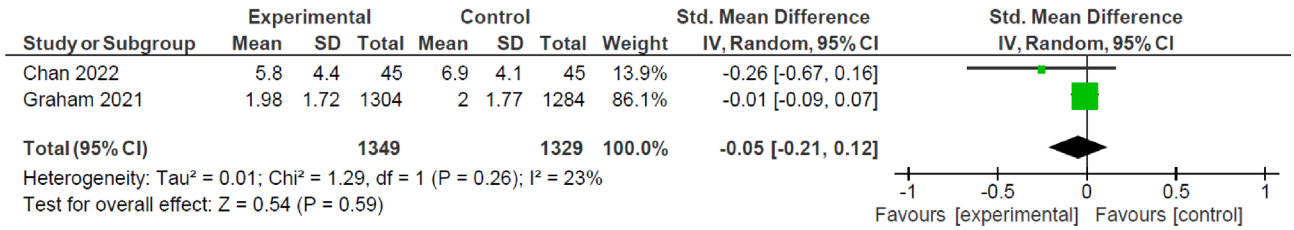
3.1 QOL physical



3.2 QOL psychosocial



3.3 Depressive symptoms



3.4 Anxiety

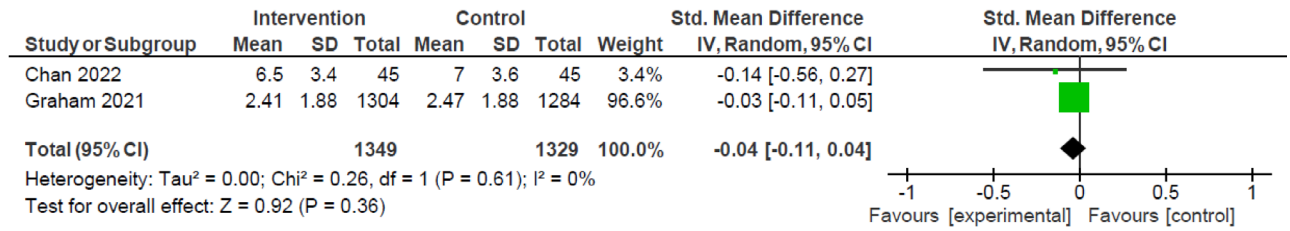


Fig. 3 Forest plots of sensitivity analyses. *CI* confidence interval, *IV* inverse variance, *QOL* quality of life, *SD* standard deviation

Discussion

Previous research has shown effectiveness of digital health interventions for improving diet and physical behaviors (Rose et al., 2017), supporting weight management (Kouvari et al., 2022) and prevention of mental health conditions among adolescents (Bantjes, 2022; Bergin et al., 2020; Werner-Seidler et al., 2020), yet no previous research informs us of the effectiveness of digital health interventions which target lifestyle risk behaviors on improving mental health or wellbeing among adolescents. This study found that digital health interventions targeting lifestyle risk behaviors among adolescents were associated with small, but non-significant improvements in quality of life, depressive

symptoms and anxiety. After excluding studies at high risk of bias, the sensitivity analyses did not change the effects. This review also showed that digital health interventions were wide-ranging in delivery method, duration and targeted risk behaviors. Co-design was rarely used in intervention development and data on intervention satisfaction, engagement and adherence were poorly reported across included studies, therefore it was unclear whether adolescents found the digital health interventions useful. Thus, mental health and wellbeing are measured outcomes in digital health interventions targeting lifestyle risk behaviors, but further work is needed to develop interventions for adolescents which have more of a holistic view, targeting the complex interplay of physical and mental health and measuring the transfer effect of one to the other.

This study identified several potential reasons for the small effects lifestyle digital health interventions can have on adolescent mental health and wellbeing. Firstly, many of the studies did not measure mental health or wellbeing as a primary outcome and so were possibly not powered to detect changes in these outcomes. Secondly, due to the sparsity of studies found in this review, results were pooled for conceptually related mental health and wellbeing outcomes (Johnston et al., 2022). Despite all being validated in an adolescent population, up to five different patient reported outcome measures were used. Furthermore, the small effect may be due to a floor effect. Incidences of mental health diagnosis for anxiety and depressive symptoms among adolescents range from 20–25% (Racine et al., 2021). As included studies only recruited otherwise healthy adolescents (i.e., no existing mental health diagnosis), participants baseline scores may have been within a healthy range and therefore only minimal improvements were seen. However, studies have shown that there are risks and considerations to both including or excluding people with a mental health diagnosis from digital mental health interventions, with consensus leaning toward ensuring that interventions are delivered to those who are in need (McCall et al., 2021). Previous research has suggested that small effects of digital health interventions targeting the prevention of mental health disorders still hold potential to have broad impact due to the increased number of adolescents able to access the intervention. Moreover, digital health interventions may be more acceptable because of the reduced stigma compared to targeted mental health interventions (Cuijpers, 2022; Montero-Marin et al., 2022). It must also be noted that five of the 17 studies only recruited adolescents who had overweight or obesity (Chen et al., 2018; Jones et al., 2008; Köse & Yıldız, 2021; Likhitweerawong et al., 2021; Lopez et al., 2021). As previous research shows, motivation is an important factor to sustain behavior change to promote weight loss in this population (Sundar et al., 2019; Woo & Park, 2020). However, this review did not choose to exclude these studies as per our protocol and due to the variation in weight categories of adolescents which exists naturally.

This review revealed that digital health interventions for lifestyle risk behaviors that assessed mental health or wellbeing outcomes were diverse, both in their content or focus and in the delivery method. Due to interest in six different lifestyle risk behaviors, the review found that nine of 17 (52.9%) interventions targeted more than one behavior, with physical activity and diet being the most prevalent. Further, only one of the 17 interventions assessed mental health or wellbeing as a primary outcome (Vargas-Martínez et al., 2019). Interventions targeting lifestyle risk behaviors that specifically look to improve mental health or wellbeing may look different in relation to the content and behavior change techniques used, compared to those which focus specifically on improving lifestyle risk behaviors (Hollis et al., 2017; Martin et al., 2013). Previous research has shown that there is a 'clustering effect', where adolescents who engage in multiple lifestyle risk behaviors have a higher prevalence of mental health symptoms (Champion et al., 2018; Gardner et al., 2023). Today's adolescents have reported that issues that affect their ability to maintain a healthy lifestyle are broad, but also interconnected and need to be considered in a multidimensional context (Valanju et al., 2022). Preventive interventions which target both the risk and protective factors for chronic diseases and mental health will also be cost-effective. Hence, there is likely to be considerable benefits when designing future digital health interventions by shifting the focus and aiming to improve lifestyle risk behaviors which are shared risk and protective factors for future development of chronic diseases and mental health (Carbone, 2020; Gardner et al., 2023).

There were vast differences in the digital health delivery method across the 17 included studies, with a combination of five different formats used. The differences in delivery methods for digital health interventions make it unclear which method is most effective. Adolescents are digital natives and use technology daily (Moreno et al., 2022), however, to effectively engage with digital health interventions they must have high digital health literacy skills. Previous research has shown that adolescents often rate their digital health literacy higher than demonstrated (Taba et al., 2022). Furthermore, it is essential that adolescents are engaged and satisfied with these interventions for them to be effective. Out of the 17 studies identified in this review, only five provided data on engagement with the intervention, which ranged broadly. Previous research has aimed to investigate adolescent engagement with digital health interventions across multiple areas (Aschbrenner et al., 2019; Thornton et al., 2022; Wong et al., 2020), however, all suggest that more rigorous RCTs are needed to understand engagement. Three strategies identified to increase adolescent engagement in digital health

Table 4 The Cochrane Collaboration for assessing risk of bias in included RCT's

Author, year, country	Domain 1: randomization		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Chan et al, 2022, Hong Kong	Low	Computer generated randomization table Allocation concealed Baseline differences between groups compatible with chance	Low	Participants aware of group assignment Assessors blinded to group assignment ITT analysis utilized	Some concerns	Participants aware of group assignment Assessors blinded to group assignment High level of dropout in one intervention arm	Low	Missing outcome data accounted for at each time point ITT analysis utilized	Low	Appropriate outcome measurement Comparable between groups Assessors blinded	Low	Pre-specified analysis plan All outcomes reported	Some concerns
Chen et al, 2018, USA	Low	Computer generated randomization table Allocation concealed No baseline differences between groups	Low	Participants unaware of group assignment Research team blinded to group assignment ITT analysis utilized	Low	Participants unaware of group assignment Research team blinded to group assignment	Low	Missing outcome data accounted for at each time point ITT analysis utilized	Low	Appropriate outcome measurement Comparable between groups Assessors blinded	Low	Pre-specified analysis plan All outcomes reported	Low

Table 4 (continued)

Author, year, country	Domain 1: randomization		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
De Bruin et al, 2016, Netherlands	Some concerns	Concealed simple randomization using random number table Baseline differences between groups incompatible with chance	Low	Participants aware of group assignment Authors stated how treatment integrity was ensured Multilevel regression analysis used	Some concerns	Participants aware of group assignment Authors stated how treatment integrity was ensured	Low	Missing outcome data accounted for at each time point Multilevel regression analysis used	Low	Appropriate outcome measurement Comparable between groups	Low	Pre-specified analysis plan All outcomes reported	High
Eglisson et al., 2021, Iceland	Some concerns	Randomization using coin toss method NI on allocation concealment NI on baseline differences	Some concerns	Participants aware of group assignment Research team blinded to group assignment Multiple regression analysis used	Some concerns	Participants aware of group assignment Research team blinded to group assignment High level of dropout in intervention arm	Low	Missing outcome data accounted for at each time point Multiple regression analysis used	Low	Appropriate outcome measurement Comparable between groups Assessors blinded	Low	Pre-specified analysis plan All outcomes reported	High

Table 4 (continued)

Author, year, country	Domain 1: randomization		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Graham et al, 2021, USA	Low	Computer generated randomization table No baseline differences between groups	Low	Participants concealed from group assignment Research team concealed from group assignment ITT analysis utilized	Low	Participants concealed from group assignment Research team concealed from group assignment	Low	Missing outcome data accounted for at each time point ITT analysis utilized	Low	Appropriate outcome measurement Comparable between groups Assessors blinded	Low	Pre-specified analysis plan All outcomes reported	Low
Jones et al, 2008, USA	Some concerns	Randomization sequence generated in SPSS NI on allocation concealment No baseline differences between groups	Low	Participants aware of group assignment Assessors blinded to group assignment ITT analysis utilized	Some concerns	Participants aware of group assignment Some non-adherences to intervention reported Assessors blinded to group assignment ITT analysis utilized	Low	ITT analysis utilized No differences between completers vs non completers	Low	Appropriate outcome measurement Comparable between groups Assessors blinded	Some concerns	Only results from completer analysis are included as no difference between ITT analyses	High

Table 4 (continued)

Author, year, country	Domain 1: randomization		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Kose et al., 2020, Turkey	Low	Computer generated randomization table No baseline differences between groups	High	Participants single-blindly assigned to groups Deviations to trial context No ITT analysis	High	Participants single-blindly assigned to groups No data provided on adherence to intervention Intervention group outnumbered control	High	Number lost to follow-up not accounted for/no appropriate analysis	Low	Appropriate outcome measurement Comparable between groups	Some concerns	No pre-specified analysis plan Various statistical analyses used, all eligible results reported	High
Likhitweerawong et al, 2021, Thailand	Low	Computer generated randomization table Allocation concealed Baseline differences between groups compatible with chance	Low	Participants aware of group assignment Assessors blinded to group ITT analysis utilized	Some concerns	Participants aware of group assignment Assessors blinded to group Adherence to intervention noted Participants in control unintentionally received intervention	Low	Missing outcome data accounted for at each time point ITT analysis utilized	Low	Appropriate outcome measurement Comparable between groups Assessors blinded	Low	Pre-specified analysis plan All outcomes reported	Some concerns

Table 4 (continued)

Author, year, country	Domain 1: randomization		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Lopez et al, 2021, USA	Low	Block randomization utilized Investigators blinded to block size No baseline differences between groups	High	Participants aware of group assignment Unlikely protocol deviations No ITT analysis	High	Participants aware of group assignment Poor engagement with intervention	High	Number lost to follow-up not accounted for/no appropriate analysis	Low	Appropriate outcome measurement Comparable between groups	Low	Pre-specified analysis plan All outcomes reported	High
Richardson et al, 2021, USA	Low	Computer generated randomization table No baseline differences between groups	Low	Participants potentially aware/ clinicians aware of group assignment Unlikely protocol deviations ITT analysis utilized	Some concerns	Participants potentially aware of group assignment Authors stated how treatment integrity was ensured	Low	Missing outcome data accounted for at each time point ITT analysis utilized	Low	Appropriate outcome measurement Comparable between groups	Low	Pre-specified analysis plan All outcomes reported	Some concerns
Rodgers et al, 2018, USA	Low	Randomization schedule used Allocation concealed until after baseline No baseline differences between groups	High	Participants and researchers aware of group assignment NI on protocol deviations No ITT analysis	High	Participants and researchers aware of group assignment No data provided on adherence to intervention	High	Total scores calculated using mean substitution for missing data	Low	Appropriate outcome measurement Comparable between groups	Low	Pre-specified analysis plan All outcomes reported	High

Table 4 (continued)

Author, year, country	Domain 1: randomization		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Slootmaker et al, 2010, Netherlands	Low	Sealed envelopes used for randomization Minimal baseline differences between groups	Low	Participants unaware of group assignment Unlikely protocol deviations ITT analysis utilized	Low	Participants unaware of group assignment Process measures reported	Low	Missing outcome data accounted for at each time point ITT analysis utilized	Low	Appropriate outcome measurement Comparable between groups	Low	Pre-specified analysis plan All outcomes reported	Low
Thompson et al, 2016, USA	Low	Computer generated randomization table No baseline differences between groups	Some concerns	Participants and researchers aware of group assignment Unlikely protocol deviations No ITT analysis	Low	Participants and researchers aware of group assignment Technical issues reported and adherence documented	Low	Missing outcome data accounted for at each time point	Low	Appropriate outcome measurement Comparable between groups	Low	Pre-specified analysis plan Some data not presented (though stated as not significant)	Some concerns

ITT intention-to-treat, *NI* no information

Table 5 The Cochrane Collaboration for assessing risk of bias in included cluster RCT's

Author, year, country	Domain 1a: randomization		Domain 1b: identification or Recruitment		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Cremers et al, 2015, Netherlands	Some concerns	Computer generated randomization table NI on allocation concealment Baseline differences between groups	Low	All participants recruited before randomization Baseline imbalances compatible with chance	Low	Participants unaware they are in trial NI on trial personnel Multiple imputation of missing data	Some concerns	Participants unaware they are in trial NI on trial personnel No data provided on adherence to intervention	Low	Data available for all clusters Outcome data accounted for at each time point	Low	Appropriate outcome measurement Comparable between groups No influence of outcome assessors	Some concerns	Pre-specified analysis plan Not all outcome reported	High
Guo et al, 2014, Taiwan	Some concerns	NI on randomization process No baseline differences between groups	Low	All participants recruited before randomization Baseline imbalances compatible with chance	Low	Participants unaware they are in trial Trial personnel aware of group assignment Linear mixed model analysis	Some concerns	Participants unaware they are in trial No data provided on adherence to intervention	Low	Data available for all clusters Outcome data accounted for at each time point	Low	Appropriate outcome measurement Comparable between groups No influence of outcome assessors	Low	Pre-specified analysis plan All outcomes reported	High

Table 5 (continued)

Author, year, country	Domain 1a: randomization		Domain 1b: identification or Recruitment		Domain 2: assignment to intervention		Domain 2: adhering to intervention		Domain 3: missing outcome data		Domain 4: outcome measurement		Domain 5: selective reporting		Overall risk of bias
	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	Judgement	Evidence	
Lubans et al, 2012, Australia	Some concerns	Randomized on geographical location No baseline differences between groups	Low	All participants recruited before randomization No baseline imbalances	Some concerns	Participants unaware they are in trial Trial personnel aware of assignment ITT analysis used	Some concerns	Participants unaware they are in trial Trial personnel aware of assignment Adherence data presented	Low	Data available for all clusters Outcome data accounted for at each time point	Low	Appropriate outcome measurement Comparable between groups No influence of outcome assessors	Low	Pre-specified analysis plan All outcomes reported	High
Vargas-Martínez et al., 2019, Spain	Some concerns	Randomized at school level Baseline differences between groups	Low	All participants recruited before randomization Baseline imbalances compatible with chance	Low	Participants unaware they are in trial NI on trial personnel Three regression models used for analysis	Low	Participants unaware they are in trial Adherence data presented	Low	Data available for all clusters Outcome data accounted for at each time point	Low	Appropriate outcome measurement Comparable between groups No influence of outcome assessors	Low	Pre-specified analysis plan All outcomes reported	Some concerns

ITT intention to treat, *NI* no information

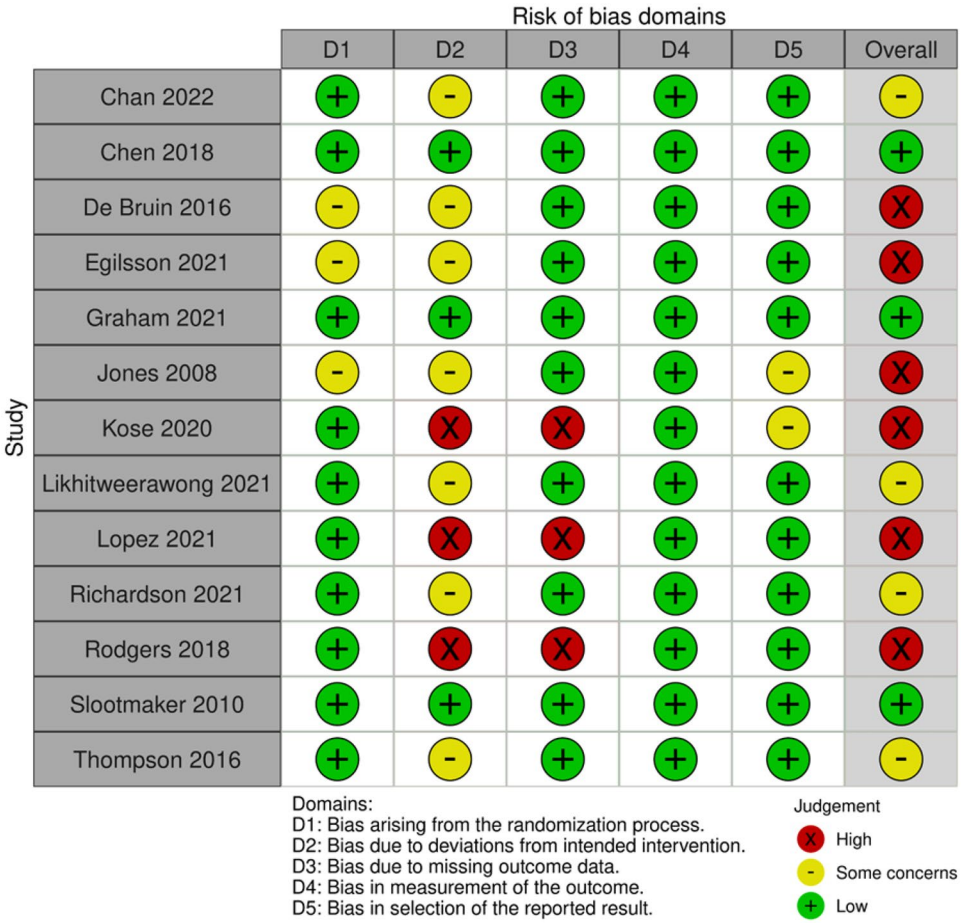


Fig. 4 RoB 2.0 quality assessment for randomized controlled trials

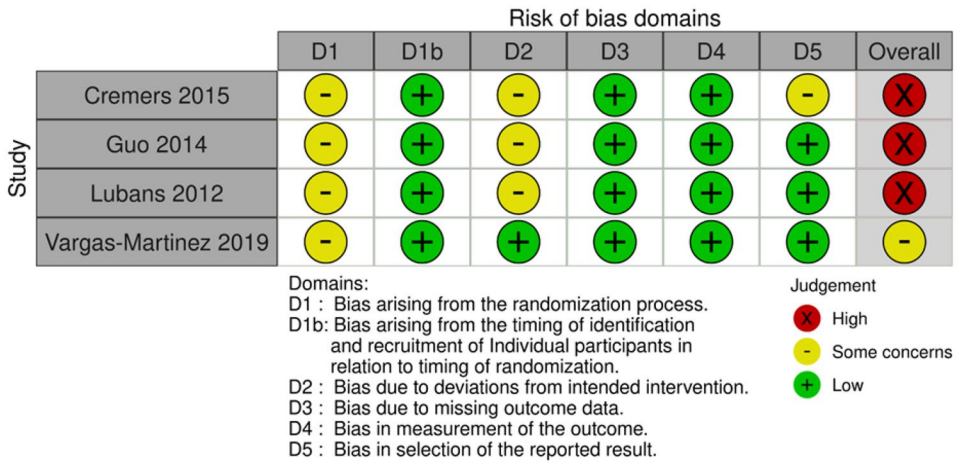


Fig. 5 RoB 2.0 quality assessment for cluster randomized controlled trials

interventions include personalization, just-in-time adaptation, and co-design with the end user (Partridge & Redfern, 2018). Only five of the 17 studies included in this review discussed the use of co-design of the intervention with adolescents. Engaging with adolescents throughout the entire research process is recognized in the WHO framework for developing and implementing digital health interventions for young people (World Health Organization, 2020). Lack of intervention co-design with adolescents potentially explains the broad range of engagement across studies and lack of significant results. Interestingly, three of the studies which reported co-designing the intervention with adolescents also reported data on satisfaction or retention, which was above 90% for two

studies (Richardson et al., 2021; Thompson et al., 2016). Future digital lifestyle interventions should ensure the use of co-design, with meaningful engagement of adolescents at every step, as well as determining the digital health literacy level of participants and tailoring the intervention to suit. This is critical to ensure that adolescent's knowledge and views are recognised and represented to enhance engagement, satisfaction, and intervention effectiveness.

This study is not without limitations. Firstly, due to the variety of studies and outcomes included, meta-analyses were based on a small number of studies and significant heterogeneity was present for most outcomes except depressive symptoms. Due to pooling of mental health and wellbeing outcomes, the variation in measurements should be considered when interpreting results. Further to this point, we were not able to adequately address our second aim due to variations in the data. We have provided a narrative synthesis of these variables where a quantitative analysis was inappropriate. Second, risk of bias was judged as high or had some concerns for many of the studies, which was mainly due to blinding of participants and outcome assessors. Third, the influence of publication bias must be considered. Grey literature was not searched in this review which may limit the number of included research studies, as negative study outcomes are less-likely to be published in peer-reviewed journals. Finally, very few studies reported a qualitative evaluation of the intervention to understand the barriers and enablers, which would enable a deeper understanding and interpretation of the usefulness of the interventions and allow planning for future research.

Conclusion

No previous research is available on the effectiveness of digital health interventions which target lifestyle risk behaviors on improving mental health or wellbeing among adolescents. This systematic review with meta-analyses revealed that digital health interventions targeting lifestyle risk behaviors amongst adolescents had small but non-significant positive effects on quality of life, anxiety and depressive symptoms at follow-up compared to usual care controls. Intervention satisfaction, engagement and adherence was poorly reported across included studies. Despite the shared nature of risk and protective factors for mental health and chronic diseases, this study highlights the scarcity of evaluation of mental health or wellbeing outcomes in digital health interventions targeting lifestyle risk behaviors among adolescents. It is recommended that future digital lifestyle health interventions consider a more holistic approach, focusing on the interplay between lifestyle risk behaviors and mental health and wellbeing.

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Author Contributions RR designed the study protocol, designed and implemented the search strategy, screened and coded articles and extracted data, led the meta-analysis, interpreted the findings and write-up of results, drafted the initial manuscript; SSJ provided input to the study protocol, screened and coded articles and extracted data and revised the manuscript; AT screened and coded articles and extracted data and revised the manuscript; KH provided input to the study protocol, assisted with interpretation of findings and revised the manuscript; AS provided input to the study protocol and revised the manuscript; LAG provided input to the study protocol and revised the manuscript; KEC provided input to the study protocol and revised the manuscript; JR provided input to the study protocol and revised the manuscript; SRP provided input to the study protocol, provided input to coding of articles and extracted data, assisted with interpretation of findings and revised the manuscript. All authors read and approved the final manuscript.

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Data availability All data generated or analyzed during this study are included in this published article. Search strategy for this study is available as Supplementary File 2. Data collection tables are available as Tables 1–3 and Supplementary File 3.

Declarations

Conflict of interest The authors report no conflict of interests.

Preregistration The review was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42021247738). https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=247738

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