Effectiveness of school-based eHealth interventions to prevent multiple lifestyle risk behaviours among adolescents: a systematic review and meta-analysis

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Summary
Background Lifestyle risk behaviours typically emerge during adolescence, track into adulthood, and commonly co-occur. Interventions targeting multiple risk behaviours in adolescents have the potential to efficiently improve health outcomes, yet further evidence is required to determine their effect. We reviewed the effectiveness of eHealth school-based interventions targeting multiple lifestyle risk behaviours.

Methods In this systematic review and meta-analysis, we searched Ovid MEDLINE, Embase, PsycINFO, and the Cochrane Library databases between Jan 1, 2000, and March 14, 2019, with no language restrictions, for publications on school-based eHealth multiple health behaviour interventions in humans. We also screened the grey literature for unpublished data. Eligible studies were randomised controlled trials of eHealth (internet, computers, tablets, mobile technology, or tele-health) interventions targeting two or more of six behaviours of interest: alcohol use, smoking, diet, physical activity, sedentary behaviour, and sleep. Primary outcomes of interest were the prevention or reduction of unhealthy behaviours, or improvement in healthy behaviours of the six behaviours. Outcomes were summarised in a narrative synthesis and combined using random-effects meta-analysis. This systematic review is registered with PROSPERO, identifier CRD42017072163.

Findings Of 10 571 identified records, 22 publications assessing 16 interventions were included, comprising 18 873 students, of whom on average 56–2% were female, with a mean age of 13·41 years (SD 1·52). eHealth school-based multiple health behaviour change interventions significantly increased fruit and vegetable intake (standard mean difference 0·11, 95% CI 0·03 to 0·19; p=0·007) and both accelerometer-measured (0·33, 0·05 to 0·61; p=0·02) and self-reported (0·14, 0·05 to 0·23; p=0·003) physical activity, and reduced screen time (−0·09, −0·17 to −0·01; p=0·03) immediately after the intervention; however, these effects were not sustained at follow-up when data were available. No effect was seen for alcohol or smoking, fat or sugar-sweetened beverage or snack consumption. No studies examined sleep or used mobile health interventions. The risk of bias in masking of final outcome assessors and selective outcome reporting was high or unclear across studies and overall we deemed the quality of evidence to be low to very low.

Interpretation eHealth school-based interventions addressing multiple lifestyle risk behaviours can be effective in improving physical activity, screen time, and fruit and vegetable intake. However, effects were small and only evident immediately after the intervention. Further high quality, adolescent-informed research is needed to develop eHealth interventions that can modify multiple behaviours and sustain long-term effects.

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Introduction Chronic diseases are the leading cause of death globally.1 Up to an estimated 80% of cases of heart disease, stroke, and type 2 diabetes, and more than 30% of cancers worldwide, could be prevented by reducing smoking and harmful alcohol use and improving diet and physical activity.2 Sedentary behaviour (ie, sitting and screen time) and poor sleep have been associated with poor health outcomes.3 Collectively, these six risk factors have been linked to poor health outcomes. For example, among young people (aged 2–20 years’ and 9–16 years’), short sleep duration, poor quality sleep, and sleep–wake timing are associated with obesity,4 and screen time (eg, watching television, gaming, and computer and smartphone use) has been linked with increased obesity and adiposity, poor diet, depression, and reduced quality of life.5 In Australia and Canada, national health guidelines now integrate recommendations about physical activity, sleep, and sedentary time because of the clear links between these behaviours and poor quality of life.6,7,8 Risk behaviours typically emerge during adolescence, track into adulthood, and commonly co-occur.9 Engaging in multiple risk behaviours increases the risk of chronic disease and all-cause mortality, more so than the additive...
effects of single behaviours. Moreover, young people who engage in multiple risk behaviours have a higher prevalence of mental health problems than their peers. Early adolescence is a crucial time to intervene and interrupt trajectory towards poor adult health. Multiple health behaviour change interventions target risk factors in combination and are a promising method to improve lifelong health. This approach capitalises on evidence that changing one lifestyle behaviour could increase self-efficacy to improve others. Given that teaching time is often restricted, interventions that simultaneously address multiple risk behaviours are particularly advantageous in school settings. eHealth interventions (delivered via the internet, computers, tablets, mobile technology, or tele-health) offer increased student engagement, fidelity, and scalability, and internet technology is becoming increasingly embedded in school education. Previous reviews have shown eHealth school-based interventions for single health behaviours to be effective; however, less is known about interventions targeting multiple behaviours.

Methods
Search strategy and selection criteria
In this systematic review and meta-analysis, written in accordance with the published review protocol and the Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines, a research librarian (QEW) searched Ovid MEDLINE, Embase, PsycINFO, and the Cochrane Library, with no language restrictions, for publications since Jan 1, 2000, on Oct 6, 2017, of research on school-based eHealth multiple health behaviour changeshould find school-based interventions targeting change in multiple health behaviours to be effective in preventing substance use and increasing physical activity; however, this review did not include sleep in its inclusion criteria and did not focus on eHealth interventions. To our knowledge, no existing review has specifically examined preventive eHealth school-based multiple health behaviour change interventions.

We aimed to systematically review eHealth school-based interventions targeting two or more of the following: alcohol use, smoking, diet, physical activity, sedentary behaviour (sitting and screen time), and sleep. We also aimed to identify intervention characteristics associated with effectiveness. The growing recognition of the co-dependence of sleep, sedentary behaviour and screen time, and physical activity;8 the increasing prevalence of obesity;9 mental health problems among adolescents;8 and early onset of cardiovascular disease;8 highlights the timely nature of this Article.

Research in context
Evidence before this study
We searched MEDLINE and the Cochrane Database of Systematic Reviews to identify any existing systematic reviews and meta-analyses published between Jan 1, 2000, and Sept 1, 2017, on school-based eHealth interventions targeting multiple lifestyle risk behaviours. We identified several reviews of multiple health behaviour change interventions for adolescents focusing on various combinations of lifestyle risk factors. Together, these reviews suggest that although universal multiple health behaviour change interventions for young people might be more efficient and cost-effective, whether they are effective is uncertain and further research is needed. Few of the identified reviews examined emerging risk behaviours, such as sleep and screen time, and no review examined all six chronic disease risk factors of interest: alcohol use, smoking, poor diet, physical inactivity, sedentary behaviour (sitting and screen time), and sleep.

Added value of this study
To our knowledge, this is the first systematic review and meta-analysis to assess the effectiveness of eHealth school-based multiple health behaviour change interventions to prevent traditional (alcohol use, smoking, poor diet, and physical inactivity) and emerging (sedentary behaviour [including screen time] and sleep) chronic disease risk factors.

We did a comprehensive and systematic review of published studies and grey literature from 2000 to 2019. We found that eHealth school-based interventions are effective in improving physical activity, screen time, and fruit and vegetable intake. However, effects were small and only evident immediately after the intervention and the quality of evidence was generally low. We found no evidence of an effect on alcohol and smoking, or the consumption of fat or sugary drinks and snacks, and no study targeted sleep.

Implications of all the available evidence
This systematic review and meta-analysis highlights the need for further high quality research informed by adolescents to develop and assess eHealth interventions that can modify multiple behaviours and sustain effects in the long term. Further work is needed to better understand the mechanism of change in relation to multiple health behaviour change among adolescents. Our findings support the development of future eHealth multiple health behaviour change interventions targeting substance use and emerging risk behaviours, such as sleep and sedentary time.
interventions in humans. This search was repeated on March 14, 2019. These date restrictions were chosen because of the substantial increase in eHealth interventions during this period. An example search for Ovid MEDLINE is in the appendix (pp 1–2). Studies were eligible if they assessed a school-based prevention programme that was universal (ie, delivered to all students regardless of their level of risk) and that targeted two or more of the following behaviours: alcohol use, smoking, diet, physical activity, sedentary behaviour (screen time and sitting), or sleep; targeted students aged 11–18 years; and were primarily delivered via eHealth methods (eg, the internet, computers, tablets, mobile technology, or tele-health). Eligible study designs were randomised controlled trials (including randomisation at the school grade or class level) and comparison groups included no intervention, education as usual, or an alternate evidence-based intervention not delivered via eHealth (eg, face to face). We did manual searches of the reference lists of eligible papers to check for additional studies. Before starting this review, we did a search to identify existing systematic reviews and meta-analyses published previously on this topic. We did manual searches of the reference lists of systematic reviews, using the same screening process.

All identified papers were exported into Endnote for removal of duplicates. Records were uploaded to Covidence Systematic Review software (Veritas Health Innovation; Melbourne, VIC, Australia) for screening. We also searched the grey literature, including dissertations and clinical trial registries, and conference proceedings for unpublished studies. We did not have limitations on the level of data that were eligible.

Titles and abstracts of identified studies were independently screened by one author (KEC), with a random sample (25%) double screened by a second author (CM). Full-text copies of papers were assessed for eligibility by two authors (CM, KEC) with any disagreements resolved by a third author (LAG). Data for each included study were extracted by one author (CM) and cleaned and checked by another (KEC). The two reviewers (CM and KEC) extracted data using a standardised extraction form, to ensure that it adequately captured trial data. The corresponding authors of included studies were contacted to request any missing data. Further details of data extraction are included in the published protocol.

**Data analysis**
Our primary outcome of interest was the prevention or reduction (for unhealthy behaviours), or improvement (for healthy behaviours) in any of the six behaviours of interest: alcohol use, smoking, diet, physical activity, sedentary behaviour (screen time and sitting), or sleep. Secondary outcomes of interest included change in knowledge, attitudes, intentions, mental health, and obesity.

For our meta-analysis, our outcomes were prevalence of alcohol and tobacco use (% yes and no); intake of fruit and vegetables (mean servings per day), sugary drinks or snacks (mean glasses or servings per day), and fat (g per day); physical activity (accelerometer and self-report, min per day); screen time (h per day spent using screens—eg, television, tablets, computers, or smartphones), sedentary behaviour (h per day spent sitting or lying down, excluding sleep), and body-mass index (BMI; weight/height²). Where possible, units were converted so that related outcomes were on consistent scales (eg, min per day converted to h per day).

We did a qualitative synthesis of intervention and sample characteristics. We then entered the data into review manager (RevMan) software for meta-analysis. Where appropriate (ie, two or more studies measuring the same outcome), we combined studies measuring the same outcome, by doing an inverse variance-weighted random-effects analysis on each primary and secondary continuous outcome. For dichotomous outcomes (alcohol use and smoking), we did a fixed effect, Mantel-Haenszsel meta-analysis. We report continuous outcomes using standard mean difference (SMD) and dichotomous outcomes using odds ratios (ORs). If SDs, CIs, or within-group p values were not present, we calculated the difference between the means.
| Study design and key sample demographics | Targeted risk behaviours | Primary outcomes | Secondary outcomes | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|------------------------------------------|-------------------------|------------------|-------------------|---------------|------------------|------------------------|-------------------------------|----------------|----------------|----------|
| Bannink et al (2014)17 | Three-arm cluster design; Netherlands; 12 schools; n=1256; 15.9 years (SD 0.67); 54.7% male; 76.2% Dutch | Alcohol use, smoking | Frequency of drinking to excess; frequency of being drunk; frequency of smoking | Emotional and behavioural difficulties; health-related quality of life | INT1: web based; INT2: web based and nurse consult | Online self-report survey (Strength and Difficulties Questionnaire, Child Health Questionnaire-Child Form) | Web-based tailored messages generated on the basis of baseline questionnaire data; normative feedback relative to Dutch norms; links to websites and Facebook page for further information; email reminders sent 1 month after intervention, with same tailored messages; optional self-referral to nurse or mandatory referral based on risk profile. Additional components: face-to-face nurse consultation, including motivational interviewing | One 45-min lesson on a single day | NR | Education as usual | 4 months |
| Brick et al (2015); Brick et al (2017); Velicer et al (2013)28 | Two-arm cluster design; USA; 20 schools; n=4158; 11.4 years (SD 0.7); 52.2% male; 65% white | Alcohol use, smoking, physical activity, diet, screen time | Physical activity (days per week of at least 60 min); fruit and vegetable consumption (servings per day); television viewing (h per day); smoking (yes or no); alcohol use (yes or no); alcohol use (yes or no); stage of change | NA | INT1: web, energy balance content; INT2: web, substance use content | Online self-report survey | Computerised assessment with tailored feedback; multimedia components; INT1 and INT2 differ in content areas | Five 30-min lessons over 3 years | Transtheoretical model | INT1 compared with INT2 | 12, 24, and 36 months |
| Casaza et al (2007)31 | Three-arm cluster design; USA; three schools; n=311; 15.8 years (SD NR); 42% male; 52% non-Hispanic Black | Physical activity, diet | Moderate-to-vigorous physical activity; intake of fat (g per day); saturated fat (g/day); fruit and vegetable (servings per day); and fibre (g per day) | BMI, self-efficacy, nutrition knowledge | INT1: CD-ROM based; INT2: lecture format delivered offline | 24-h recall, food frequency questionnaire, online self-report (PAQ-a) survey, objective height and weight | INT1: computer-based education delivered via CD-ROM, self-guided; optional study guide and answer key provided to reinforce material; INT2: same content as INT1 but in an offline, face-to-face lecture format | Five 45-min lessons over 4 months | NR | Assessment only | 4 months |

(Table continues on next page)
### Study design and key sample demographics

#### Exendam et al (2012)²²
Two-arm cluster design; Netherlands; 20 schools; n=883; 12·7 years (SD 0·7); 54·9% male; 63·5% Western (both parents born in Europe, North America, Oceania, Indonesia, or Japan)

| Targeted risk behaviours | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|--------------------------|---------------|------------------|-------------------------|-----------------------------------|------------------|-----------------|----------|
| Physical activity, diet, sedentary behaviour | Moderate-to-vigorous physical activity (days per week for at least 60 min); transport to school (min walking) in past week; sports outside of school (steps per week); intake of sugar-sweetened beverages, high-energy snacks, fruit and vegetables, and whole wheat bread (servings per day); television and computer viewing (h per day) | BMI | 24-h recall, food frequency questionnaire, online self-report survey (Flemish validated questionnaire), objective height and weight | Computer-tailored intervention; individually tailored feedback on behaviours and theory of planned behaviour determinants; normative and comparative feedback | Eight 15-min modules over 10 weeks | Theory of planned behaviour; precaution adoption process model, and implementation intentions | Assessment only | 4 and 24 months |

#### Frenn et al (2003)²³
Quasi-experimental design; USA; two schools; n=341; 12–15 years (SD NR); 43·1% male; 53·5% African American

| Targeted risk behaviours | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|--------------------------|---------------|------------------|-------------------------|-----------------------------------|------------------|-----------------|----------|
| Physical activity, diet | Percentage dietary fat, moderate-to-vigorous physical activity (past 17 days) | NA | Web based self-report survey (Food Habits Questionnaire and Child and Adolescent Activity log) | Web-based and video sessions; web-based feedback and messaging based on stage of change; web-based food log with feedback; peer models* used in supplemental online videos; additional components healthy snack and exercise laboratories (face to face) led by peer models* | Four 50-min lessons over 1 school year | Transtheoretical model, health promotion model | Education as usual | Immediately after intervention |

#### Frenn et al (2005)²⁴
Quasi-experimental design; USA; one school; n=103; 12–14 years (SD NR); sex NR, ethnicity NR

| Targeted risk behaviours | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|--------------------------|---------------|------------------|-------------------------|-----------------------------------|------------------|-----------------|----------|
| Physical activity, diet | Percentage dietary fat, moderate-to-vigorous physical activity (past 17 days) | NR | Online or web based, videos, email | Website with four 2–3 min videos; computer-generated tailored feedback based on stage of change; online discussion boards; individualised feedback for 1-day food recall via email | Eight 40-min lessons over 1 month | Transtheoretical model, health promotion model | Education as usual | 1 month |

*(Table continues on next page)*
| Study design and key sample demographics | Targeted risk behaviours | Primary outcomes | Secondary outcomes | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|------------------------------------------|-------------------------|-----------------|-------------------|---------------|-----------------|----------------------|-------------------------------|-----------------|----------------|----------|
| (Continued from previous page)           |                         |                 |                   |               |                 |                      |                               |                 |                |          |
| Harens et al (2006)                      | Physical activity, diet | Leisure time moderate-to-vigorous physical activity, sport outside of school, school physical activity, active transport, total physical activity, light physical activity (min per day), moderate-to-vigorous physical activity, sedentary activity (min per day), fat (g per day), fruit (servings per day), soft drinks (glasses per day); percentage energy from fat | BMI | INT1: web based, environmental aspects; INT2: web based, environmental aspects, and parental support | Online self-report survey (Flemish physical activity questionnaire), accelerometer, objective height and weight | One diet and one physical activity lesson per school year; computerised (CD-ROM) assessment with tailored feedback about intentions, attitudes, self-efficacy, knowledge, and barriers to physical activity; normative feedback; transtheoretical model used to match feedback to stages of change; online factsheet with stage-matched advice; short quiz. Additional components: environmental changes including additional sports equipment, reduced fruit prices, and additional water fountains at school; information on healthy food and physical activity published in school newsletters for parents three times per year; for INT2 only, CD-ROM for parents | Four 60-min lessons over 2 school years | Theory of planned behaviour; transtheoretical model | Assessment only | 12 and 24 months |          |
| Harens et al (2007)                       |                         |                 |                   |               |                 |                      |                               |                 |                |          |
| Lana et al (2014)                        | Alcohol use, smoking, physical activity, diet, sedentary behaviour | Smoking (prevalence); intake of fruit and vegetables (% not enough fruit and vegetables); percentage dietary fat; alcohol use (prevalence); sedentary time (% sedentarism) | BMI | INT1: online or web based; INT2: online or web and text messaging | Online self-report survey | Website with information about risk behaviours; problem solving challenges; expert dietary advice based on 24-h food recall; peer-starred educational videos; forums and chat lines; websites and online educational games; weekly text messages to encourage compliance with healthy behaviours | One lesson per week over 3 months | Attitude, social influence and self-efficacy model; transtheoretical model | Assessment only | 9 months |          |
| (Table continues on next page)            |                         |                 |                   |               |                 |                      |                               |                 |                |          |
### Study Design and Key Sample Demographics

| Study design and key sample demographics | Targeted risk behaviours | Primary outcomes | Secondary outcomes | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|-----------------------------------------|-------------------------|------------------|-------------------|---------------|------------------|-----------------------|----------------------------------|-----------------|-----------------|----------|
| (Continued from previous page)          |                         |                  |                   |               |                  |                       |                                  |                 |                 |          |
| Lord et al (2007)                       | Three-arm design; USA; seven schools; n=295; 12.5 years (SD NR); 48% male; 48% ethnic minority (20% African American, 18% Latino or Latina) | Alcohol use, smoking | Alcohol use (yes or no), smoking (yes or no) | Knowledge, intentions | INT1: online or web based; INT2: video only | Self-guided online modules and activities; self-assessments with tailored feedback; point reward system (users earn points while completing activities); topic-specific quiz at the end of the module; multimedia components including animation features, video peer stories, and interactive gaming | Five 30-min modules over 3 weeks | Social learning theory; competence enhancement | Assessment only | 3 and 6 months |
| Malmberg et al (2014), Malmberg et al (2015) | Three-arm cluster design; Netherlands; 23 schools; n=3784; 13.0 years (SD 0.5); 51% male; 96.7% Dutch | Alcohol use, smoking | Lifetime alcohol use; past month alcohol use; lifetime smoking, past month smoking | Lifetime marijuana use | INT1: web based; INT2: web based and parental participation, regulation, and monitoring and counselling | E-learning modules about alcohol, tobacco, and marijuana; films, animations, chatroom forms, and other interactive tasks; additional components: for INT2, parent information session, rule setting at school, and a monitoring and counselling training session for school personnel | Ten lessons over 3 years | Attitude, social influence and self-efficacy model; theory of reasoned action, Social cognitive therapy | Education as usual | 8, 20, and 32 months |
| Marsch et al (2007)                      | Two-arm cluster design; USA; four schools; n=272; age, sex, and ethnicity NR | Alcohol use, smoking | NR | NR | Web based | Online self-report survey | Delivered via CD-ROM or the internet; interactive, simulated scenarios that require students to engage in substance-related decision making; ten topics related to substance use; skills cards earned for mastering each topic (students use skill cards to engage in an electronic card game designed to reinforce the knowledge learned) | 5 $30–45 min lessons | Social learning theory | Life skills training prevention programme | 12 months |
| Mauriello et al (2010)                   | Two-arm cluster design; USA; eight schools; n=1800; 9th-11th graders (age NR); 49% male; 71.5% white | Physical activity, diet, sedentary behaviour | Moderate-to-vigorous physical activity (days per week for 60 min of physical activity); fruit and vegetable consumption (servings per day); television viewing (h per day) | NR | Web based | Online self-report survey | Self-directed online modules; computer-based assessments with normative feedback based on stage of change; multimedia components including audio, video, and animations | Three 30-min lessons over 5 months | Transtheoretical model | Assessment only | 14 months |

(Table continues on next page)
| Study design and key sample demographics | Targeted risk behaviours | Primary outcomes | Secondary outcomes | Interventions | Measurement tools | Intervention components | Intervention frequency and duration | Theoretical basis | Comparison group | Follow-up |
|------------------------------------------|-------------------------|------------------|-------------------|---------------|------------------|-----------------------|-----------------------------------|-----------------|-----------------|----------|
| Muzaffar et al (2014)†²                    | Two-arm cluster design; USA; two schools; n=216; 6th–8th graders (age NR); sex and ethnicity NR | Physical activity, diet | NA * | Knowledge, beliefs, attitudes, intentions | INT1: web based, active online learning; INT2: web based, passive online learning with minimal interactivity | Online self-report survey | INT1: Active Online Learning website with interactive elements such as videos, narrated text or voiceovers, and knowledge-based and skill-based games; INT2: passive online learning website containing only text and images with minimal interactivity | Five 30–40 min modules over 1–2 weeks | Theory of planned behaviour; Social Cognitive Theory | INT1 compared with INT2 | 1–2 weeks |
| Panchal et al (2004)³                    | Three-arm design; USA; one school; n=136; 12·1 years (SD 0·9); 34·8% male; 27% non-Hispanic white | Physical activity, diet | Moderate-to-vigorous physical activity (min per day); fruit and vegetable consumption (servings per day) | BMI | INT1: web based, physical activity and nutrition content; INT2: web based, physical activity alone | 3-day food records, accelerometer | Tailored feedback based on responses to computerised survey; individualised behaviour change or relapse prevention plans as appropriate | One 30-min lesson | NR | Assessment only | 3 months |
| Schinke et al (2005)²                    | Two-arm cluster design; USA; two schools; n=93; 7th graders (age NR); 100% female; ethnicity NR | Alcohol use, smoking | NA * | Intentions to use alcohol and smoke cigarettes | CD-ROM self-report survey | Sex-specific intervention delivered via CD-ROM; participants self-select content of interest; rotoscoped video footage of girls sharing perceptions and experiences with stress and coping strategies; audio, video, and graphics | One 20–30 min lesson | NR | Conventional drug prevention programme | 2 weeks |
| Whittemore et al (2013)³                  | Two-arm cluster design; USA; three schools; n=384; 15·3 years (SD 0·7); 58% male; 65% non-white | Physical activity, diet, sedentary behaviour | Television, computer, and video game use (h per day); moderate-to-vigorous physical activity (days/week); muscle strengthening (days/week); intake of fruit and vegetables, sugar-sweetened beverages, fast food, and junk food (servings per week) | BMI | INT1: web based, INT2: web based, intervention and coping skills training | Online self-report survey (adapted Sedentary Behavior Questionnaire; items from Youth Risk Behavior Survey; adapted After School Student Questionnaire); objective height and weight | Interactive online lessons; individualised feedback via self-assessments; self-monitoring; goal setting; blog by a health coach; opportunity to interact with health coach and forum to interact with other students; additional components: INT2 only, online coping skills training | INT1: eight lessons; INT2: 12 lessons (eight web-based and four online coping skills training) | Principles of interactive technology, social learning theory | INT1 compared with INT2 | 3 and 6 months |

All studies are randomised controlled trials. INT=intervention. NR=not reported. NA=not applicable. BMI=body mass index. PAQ-a: Physical Activity Questionnaire for adolescents. *Primary outcomes of interest for our study not reported.

Table: Intervention characteristics for studies of eHealth school-based interventions included in narrative synthesis
using Coe’s Effect Size Calculator and calculated the corresponding τ and p values using the Cochrane Handbook Finding SDs calculator. Our calculations are based on the assumption that the SDs of outcome measurements are the same in both the intervention and control groups, so we then entered the one SD derived into RevMan for both study groups. If studies did not report the number of participants in each trial group, we derived the sample sizes by dividing the total sample equally between groups. We present these results using forest plots for each outcome of interest, with the weight (in %) indicating the influence of an individual study on the pooled result. We quantified inconsistency between groups using the $I^2$ statistic, which is the total variation that is attributed to the true difference between the studies, with values greater than 50% indicating substantial heterogeneity. We examined the significance of any heterogeneity identified using the Cochrane’s Q ($\chi^2$) test ($p<0.05$). If significant heterogeneity was present, we did subanalyses on outcomes by sample characteristics to identify sources of heterogeneity. A priori variables identified for subanalysis were age, sex, and intensity of actual physical activity (as reported by the study authors). If more than ten studies were included in an outcome analysis, we intended to use funnel plot symmetry to detect publication bias; however, since we did not have any analyses with more than two studies, we do not include any funnel plots here.

Two authors (LAG and LT) independently assessed the risk of bias at the study level using the Cochrane Collaboration’s tool for assessing risk of bias. Any discrepancies between the raters were resolved by a third author (KEC). We used the Grading of Recommendations, Assessment, Development and Evaluation framework to assess the quality of the body of evidence.

We used RevMan (version 5.3, Cochrane, London, UK) for all statistical analyses. This systematic review and meta-analysis is registered with PROSPERO, identifier CRD42017072163.

Role of the funding source
The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results
Of 10,571 records identified, 155 full-text articles were screened, of which 22 publications of 16 unique interventions were deemed eligible and included in the narrative synthesis. Of these studies, 11 provided sufficient data for inclusion in the meta-analysis (Figure I). Some inter-rater reliability was present at the full-text screening stage (Cohen’s K 0·29; 69% agreement). An overview of the characteristics of each study included in the qualitative synthesis is in the table. The 16 trials comprised 18,873 students, of whom an average of 56·2% were female (some studies did not report sex), with a mean age of 13·41 years (SD 1·52). Most studies were undertaken in the USA (n=11; 69%), sample sizes ranged from 91 to 4,158 students, and length of follow-up varied from 2 weeks to 36 months. Comparison groups included assessment only (n=7; 44%), education as usual (n=4; 25%), a face-to-face evidence-based intervention (n=3; 19%), another eHealth intervention (n=1; 6%), or the same eHealth intervention with additional components (n=1; 6%). Five of six risk behaviours were targeted in at least one study, with no studies addressing sleep. Studies targeted between two and five risk factors (mean 2·56 risk factors [SD 1·03]). The most common combinations were physical activity and diet (n=6)$^{25,33–36}$ and alcohol and smoking (n=5).$^{27–29,40–42,47}$ 14 interventions were web based (ie, internet based or online programmes)$^{27–31,32–44}$ and two were delivered via CD-ROM.$^{35,47}$ No studies of mobile health (mHealth) interventions were identified. Intervention length ranged from one to 15 lessons, with durations of 15–60 min, delivered over 1 day to 36 months. 12 interventions were underpinned by behavioural theory, most commonly the transtheoretical model (n=6) and the theory of planned behaviour (n=3). Most of the interventions used computer-tailored feedback in the eHealth intervention (n=10). Thirteen interventions$^{26–31,33–47}$ used multimedia components, such as audio or animations, nine included offline or face-to-face components,$^{15–18,41–46}$ two included goal setting,$^{12,48}$ and one prompted self-monitoring of behaviours.$^{15}$

Primary dietary outcomes included consumption of fat, fruit and vegetables, and sugar-sweetened beverages or snacks. Nine studies assessed fruit and vegetable consumption.$^{30–32,37,39,44,46}$ of which six provided sufficient data for inclusion in the meta-analysis.$^{30–32,37,39,44,46}$ Overall, eHealth school-based multiple health behaviour change interventions led to a small but significant increase in fruit and vegetable intake (mean servings per day) immediately after the intervention (SMD 0·11, 95% CI 0·03 to 0·19; p=0·007; figure 2A). We found moderate non-significant heterogeneity across the trials ($I^2=42$%; p=0·08). Effect on fruit and vegetable intake were not sustained at follow-up (SMD 0·07, –0·01 to 0·15; p=0·07), with substantial heterogeneity between trials ($I^2=52$%; p=0·06; figure 2B).

Three trials$^{31,35,48}$ had mean fat consumption (g per day) data suitable for meta-analysis. Compared with an assessment-only control, the interventions did not significantly reduce fat consumption (SMD –0·06, 95% CI –0·15 to 0·03; p=0·16), with substantial heterogeneity present between studies ($I^2=52$%; p=0·08; figure 2C). Four trials$^{13,15,18,44}$ assessed intake of sugar-sweetened beverages or high-energy snacks and three were combined in the meta-analysis. When compared with assessment-only controls, no change in intake was seen immediately

For Coe’s Effect Size Calculator see http://davidmlane.com/hyperstat/effect_size.html
For Finding SD calculator see https://training.cochrane.org/resource/revman-calculator
after the intervention (SMD −0.02, −0.10 to 0.06; p=0.58; I²=54%; p=0.07) or at follow-up (−0.06, −0.15 to 0.03; p=0.21; I²=17%; p=0.30; appendix p 6).

Three trials reported screen-time outcomes and all had sufficient data for meta-analysis. A significant reduction was seen in screen time immediately after intervention (SMD −0.09, −0.17 to −0.01; p=0.03), with moderate non-significant heterogeneity (I²=43%; p=0.18; figure 3A). This effect did not remain significant at follow-up at 6 and 12 months (−0.21, −0.52 to 0.09; p=0.16).

| A | Intervention | Control | Weight (%) | Standard mean difference |
|---|-------------|---------|------------|--------------------------|
| Fruit only intake, after intervention | Haerens et al (2006a; boys) | −0.30 (7.13) 966 −0.60 (7.95) 227 | 14.8 | 0.04 (−0.10 to 0.19) |
| | Ezendam et al (2012) | 0.07 (1.77) 421 −0.05 (1.77) 374 | 15.4 | 0.07 (−0.07 to 0.21) |
| | Haerens et al (2006a; girls) | 0.30 (7.10) 421 −0.50 (7.76) 330 | 14.9 | 0.11 (−0.04 to 0.25) |
| Subtotal (95% CI) | 1808 | 931 | 45.1 |

Heterogeneity: χ²=1.72; df=2; p=0.41; I²=0%
Test for overall effect: Z=1.72 (p=0.09)

| Fruit and vegetable intake, after intervention | Prochaska et al (2004; boys, physical activity and nutrition) | −0.38 (1.06) 18 | 0.71 (0.90) 13 | 1.0 | −1.06 (−1.8) to −0.30 |
|-----|---------------------------------|----------------|----------------|-----|-----------------|
| | Prochaska et al (2004; boys, physical activity only) | 0.18 (1.64) 17 | 0.71 (0.90) 13 | 1.1 | −0.38 (−1.0 to 0.35) |
| | Casazza et al (2007) | 0.30 (1.81) 92 | 0.10 (1.63) 92 | 5.9 | 0.12 (0.07 to 0.27) |
| | Velicer et al (2013) | 0.06 (2.84) 1579 | −0.34 (2.67) 1404 | 24.0 | 0.14 (0.07 to 0.22) |
| | Mauriello et al (2010) | 1.61 (5.44) 837 | −0.57 (5.44) 403 | 18.4 | 0.19 (0.08 to 0.30) |
| | Prochaska et al (2004; girls, physical activity only) | 0.09 (2.14) 29 | −0.43 (1.84) 33 | 2.2 | 0.26 (0.24 to 0.28) |
| | Prochaska et al (2004; girls, physical activity and nutrition) | −0.33 (1.32) 28 | −0.43 (1.84) 33 | 2.2 | 0.34 (0.17 to 0.51) |
| Subtotal | 2600 | 2051 | 54.9 |

Heterogeneity: χ²=2.12; df=6; p=0.64; I²=54%
Test for overall effect: Z=1.74 (p=0.08)

| Total | 4408 | 2982 | 100.0 |

Heterogeneity: χ²=0.91; df=9; p=0.64; I²=42%
Test for overall effect: Z=2.12 (p=0.01)

Test for subgroup differences (fruit only vs fruit and vegetables): χ²=0.23; df=1; p=0.63; I²=0%

| B | Fruit and vegetable intake at follow-up | Haerens et al (2006a, boys) | −0.20 (7.29) 966 | 0.00 (8.03) 227 | 15.4 | −0.03 (−0.17 to 0.12) |
|---|---------------------------------|----------------|----------------|-----|-----------------|
| | Ezendam et al (2012, fruit only) | −0.19 (1.76) 371 | −0.17 (1.77) 372 | 15.5 | −0.01 (−0.06 to 0.03) |
| | vegetables only | −1.00 (205.28) 375 | −1.00 (103.57) 330 | 15.0 | 0.00 (0.15 to 0.55) |
| | Haerens et al (2006a, girls) | 0.40 (7.52) 421 | −0.10 (8.13) 330 | 15.4 | 0.06 (0.08 to 0.21) |
| | Mauriello et al (2010) | 1.42 (5.53) 775 | 0.56 (4.47) 457 | 18.7 | 0.17 (0.05 to 0.29) |
| | 12-month follow-up | 0.30 (5.53) 906 | 0.30 (5.53) 524 | 20.0 | 0.18 (0.07 to 0.29) |
| | Mauriello et al (2010) | 6-month follow-up | 0.07 (0.03 to 0.19) |
| Total | 3764 | 2240 | 100.0 |

Heterogeneity: χ²=0.00; df=5; p=0.06; I²=52%
Test for overall effect: Z=1.81 (p=0.07)

| C | Fat intake after intervention | Casazza et al (2007) | −3.50 (98.15) 92 | −7.40 (58.92) 92 | 7.6 | −0.32 (−0.61 to 0.09) |
|---|---------------------------------|----------------|----------------|-----|-----------------|
| | Ezendam et al (2012) | −1.40 (67.34) 447 | −4.20 (51.09) 340 | 20.1 | −0.17 (−0.32 to 0.03) |
| | Haerens et al (2007a) | −6.00 (66.05) 1055 | −4.00 (62.04) 655 | 27.4 | −0.03 (−0.13 to 0.07) |
| | Haerens et al (2006a, boys) | −2.90 (78.35) 1005 | −3.10 (70.80) 214 | 19.2 | 0.00 (0.04 to 0.15) |
| | Haerens et al (2007a) | −3.00 (71.05) 685 | −4.00 (62.04) 655 | 25.6 | 0.01 (−0.09 to 0.12) |
| Total | 3284 | 1956 | 100.0 |

Heterogeneity: χ²=0.01; df=3; p=0.88; I²=52%
Test for overall effect: Z=1.40 (p=0.16)

Figure 2: Effect of eHealth school-based interventions on dietary outcomes

Fruit and vegetable consumption (servings per day) immediately after intervention (A) and at follow-up (B) and fat intake (g per day) immediately after intervention (C). Data are mean (SD) consumption and standard mean difference (95% CI) between groups by inverse variance-weighted random-effect meta-analysis. df=degrees of freedom.
Articles

www.thelancet.com/digital-health Vol 1 September 2019 e216

p=0·16); however, considerable heterogeneity was seen across studies (I²=94%; p<0·0001; figure 3A). Three studies assessed sedentary time,35,37,46 but only one had sufficient data for inclusion in the meta-analysis.35 None of the studies reported significant reductions in sedentary time (data not shown).

Two studies, analysing three interventions, assessed physical activity using accelerometers35,37,46 and were pooled in our meta-analysis. Overall, compared with assessment-only controls, the interventions significantly increased objectively measured moderate-to-vigorous physical activity immediately after the intervention (SMD 0·33, 95% CI 0·05 to 0·61; p=0·02), and little heterogeneity was seen (I²=94%; p<0·0001; figure 3A). When explored via subanalysis, boys had a greater increase in moderate-to-vigorous physical activity (SMD 0·33, 95% CI 0·05 to 0·61; p=0·02), and little heterogeneity (SMD 0·67, 0·21 to 1·13; p=0·004) than girls (0·14, −0·14 to 0·42; p=0·33), with little heterogeneity (figure 3B). Only one study35 reported accelerometer data beyond immediately after the intervention, precluding a meta-analysis of such data. In this study,35 intervention effects were not maintained over time for moderate-to-vigorous physical activity, but increases in the amount of light physical activity were sustained for up to 2 years among boys.

Nine studies assessed self-reported physical activity,35–37,44,46 and seven had sufficient data for inclusion in the meta-analysis.35–37,44 Overall, compared with assessment-only controls, interventions significantly increased total physical activity levels immediately after intervention (SMD 0·14, 0·05 to 0·23; p=0·003), but heterogeneity between studies was significant (I²=75%, p<0·0001; figure 3C). Subgroup analysis showed a significant effect in trials with adolescents aged 13 years and older (SMD 0·23, 0·10 to 0·36; p=0·0007; figure 3C); however, significant heterogeneity remained (I²=76%; p=0·0001). No effect was seen in trials with children younger than 13 years (SMD 0·03, −0·03 to 0·09; p=0·30) and results

| A | Intervention | Control | Weight (%) | Standard mean difference |
|---|-------------|---------|------------|-------------------------|
| | Mean (SD) | Participants | Mean (SD) | Participants |
| Screen time after intervention | | | | |
| Ezendam et al (2012)32 | −0·21 (3·30) | 404 | −0·30 (3·60) | 358 |
| Velicer et al (2013)35 | −0·52 (2·80) | 1579 | −0·15 (3·10) | 1404 |
| Mauriello et al (2010)35 | −1·18 (4·70) | 837 | −0·64 (4·70) | 461 |
| Subtotal | 2820 | 2225 | 100·0 | |
| Heterogeneity: t²=0·00; χ²=0·62; df=2 (p=0·43); r²=43% |
| Test for overall effect: Z=2·27 (p=0·02) |
| Screen time at follow-up | | | | |
| Mauriello et al (2010) | −1·32 (0·60) | 725 | −1·01 (0·60) | 457 |
| 12-month follow-up | | | | |
| Mauriello et al (2010) | −1·12 (0·70) | 906 | −1·05 (0·70) | 524 |
| Ezendam et al (2012) | 0·22 (3·60) | 355 | 0·30 (3·60) | 316 |
| 12-month follow-up | | | | |
| Subtotal | 1986 | 1297 | 100·0 | |
| Heterogeneity: t²=0·07; χ²=35·10; df=2 (p<0·0001); r²=94% |
| Test for overall effect: Z=2·17 (p=0·03) |
| Test for subgroup differences (after intervention vs at follow-up): χ²=0·00; df=2 (p=0·98); r²=0% |

| B | Objectively measured moderate-to-vigorous physical activity after intervention in girls | | | |
|---|---------------------------------|----------|----------|------------------|
| | Physical activity only35 | Physical activity and nutrition46 | Physical activity only35 | Physical activity and nutrition46 |
| Prochaska et al (2004; girls) | −15·00 (28·00) | −15·00 (28·00) | 33 | 20·3 |
| Haerens et al (2006a; girls)35 | 5·00 (26·74) | 0·40 (19·83) | 36 | 23·1 |
| Prochaska et al (2004; girls, physical activity and nutrition)46 | 9·00 (26·00) | −15·00 (28·00) | 33 | 20·0 |
| Subtotal | 98 | 102 | 63·4 | |
| Heterogeneity: t²=0·00; χ²=0·42; df=2 (p=0·81); r²=0% |
| Test for overall effect: Z=0·96 (p=0·33) |

| Objectively measured moderate-to-vigorous physical activity after intervention in boys | | | |
|---|---------------------------------|----------|----------|------------------|
| | Physical activity and nutrition46 | Physical activity only35 | Physical activity and nutrition46 | Physical activity only35 |
| Haerens et al (2006a; boys)35 | −1·80 (33·31) | −1·10 (45·38) | 12 | 14·7 |
| Prochaska et al (2004; boys) | 2·00 (25·00) | −3·00 (50·00) | 13 | 11·1 |
| Subtotal | 86 | 38 | 36·6 | |
| Heterogeneity: t²=0·03; χ²=2·50; df=2 (p=0·29); r²=20% |
| Test for overall effect: Z=2·85 (p=0·004) |
| Total | 184 | 140 | 100·0 | |
| Heterogeneity: t²=0·04; χ²=1·71; df=5 (p=0·21); r²=30% |
| Test for overall effect: Z=2·31 (p=0·02) |
| Test for subgroup differences (boys vs girls): χ²=3·74; df=1 (p=0·05); r²=73% |

(Figure 3 continues on next page)
Articles

...were homogeneous across trials ($I^2=0\%$; p=0.70; figure 3C). When assessed at follow-up, other forms of self-reported physical activity (eg, school-based activity or leisure time) did not improve (SMD 0.07, −0.06 to 0.19; p=0.29), with substantial heterogeneity across trials ($I^2=59\%$; p=0.06; appendix p 7).

Six studies reported smoking outcomes,27,38,39,40–42 with data from three studies being sufficient for inclusion in the meta-analysis.22,39,42 Pooled results indicate that interventions did not reduce the prevalence of smoking immediately after the intervention (OR 1·23, 95% CI 0·95 to 1·59; p=0.12; figure 4A) and heterogeneity was substantial ($I^2=65\%$; p=0·01). Six studies reported alcohol use outcomes27,38,39,40 and two studies, with four intervention groups, were combined in the meta-analysis.41,42 Overall, interventions had no effect on the prevalence of alcohol use (OR 1·13, 0·95 to 1·36; p=0·17), with little heterogeneity ($I^2=9\%$; p=0·35; figure 4B).

BMI was the only secondary outcome of interest with sufficient data to be pooled. Two studies, with three interventions, were combined in the meta-analysis.19,20 Overall, interventions did not significantly reduce BMI immediately after the intervention (SMD −0.13, 95% CI −0.43 to 0.16; p=0.38), with some non-significant heterogeneity ($I^2=30\%$; p=0·38; appendix p 8). Although the pooled effect was non-significant, one study40 of a five-lesson programme reported a significant decrease in BMI after the intervention.

Figure 5 is a summary of the overall risk of bias assessment for all included papers and study-specific judgments are provided in the appendix (p 9). 19 publications were at high risk of bias for not blinding participants and study personnel to intervention assignment; however, such blinding is typically not possible in school-based interventions. For most publications, the risk associated with blinding of assessors of the final outcome was high (n=5) or unclear (n=15). 16 studies did not provide sufficient detail to determine whether they were free of selective outcome reporting, and so risk was rated as unclear. Of the outcomes listed in the summary of findings table in the appendix (pp 3–5), we deemed the quality of the evidence to be low to very low. We judged that much of the evidence related to alcohol use, BMI, and intake of fat, fruit, and vegetables, and discretionary food items to be of low quality, primarily because of high risk of bias and imprecise measurement. Furthermore, much of the evidence related to smoking, screen time, and objectively measured self-reported physical activity was found to be of very low quality because of high risk of bias, inconsistency in findings between studies, and imprecise measurement. The quality of evidence for screen time and fruit and vegetable outcomes immediately after the intervention was deemed to be moderate.

| C | Intervention | Control | Weight (%) | Standard mean difference |
|---|-------------|---------|-----------|-------------------------|
|   | Mean (SD)   | Participants | Mean (SD) | Participants |

Self-reported physical activity in adolescents <13 years

| Study | Mean (SD) | Participants |
|---|---|---|
| Haerens et al (2006a; boys, school related) | 2·00 (28·32) | 943 |
| Haerens et al (2006a; boys, school related) | 5·00 (64·27) | 214 |
| Haerens et al (2006a; girls, school related) | 0·70 (8·56) | 92 |
| Haerens et al (2006a; girls, school related) | 0·32 (4·29) | 837 |
| Freren et al (2003) | 2·00 (8·27) | 92 |
| Freren et al (2005) | 0·20 (21·89) | 214 |
| Velicer et al (2013) | 4·00 (162·90) | 378 |
| Total | 4·00 (189·90) | 444 |

Heterogeneity: $I^2=30\%$; $p=0·01$; appendix p 7)

Test for overall effect: Z=2·94 (p=0·003)
Figure 4: Effect of eHealth school-based interventions on smoking and alcohol use outcomes
Prevalence of smoking (A) and prevalence of alcohol use (B). Data are number of participants and events and odds ratio (95% CI), calculated by fixed effect, Mantel–Haenszel meta-analysis. df=degrees of freedom. *Website-based intervention with parents and school components.

Discussion
We systematically reviewed the effectiveness of eHealth school-based preventive interventions targeting two or more of the following behaviours: diet, smoking, alcohol use, physical activity, sleep, and sedentary behaviour (screen and sitting time). Most studies assessed interventions for preventing alcohol use and smoking or improving diet and physical activity. Few studies targeted screen or sitting time, and none addressed sleep. Overall, eHealth school-based multiple health behaviour change interventions significantly reduced screen time immediately after the intervention, and significantly increased accelerometer-measured and self-reported physical activity immediately after the intervention. However, only short-term effects were found, and all trials were judged to be of very low to moderate quality. Of three studies that used screen time interventions, the length of the intervention varied from three to eight lessons, but all three studies included computer-tailored feedback. We found several eHealth multiple health behaviour change interventions were only effective in increasing self-reported physical activity in trials with students aged 13 years or older. The physical activity tools used in these studies might not have been designed for assessing behavioural change in intervention settings and self-report of moderate-to-vigorous physical activity might have been cognitively challenging for young adolescents.

Additionally, our subanalysis of objectively measured moderate-to-vigorous physical activity indicated that boys had a greater increase in moderate-to-vigorous physical activity than girls did. This result is consistent with previous research that found consistent sex differences in physical activity levels in adolescents. These observations suggest that current eHealth multiple behaviour change interventions might not adequately engage girls or young teenagers (<13 years), and formative research is required to better understand the beliefs, attitudes, and motivations of these groups in relation to moderate-to-vigorous physical activity.

In eHealth school-based interventions included in our meta-analysis, we found increased fruit and vegetable intake immediately after the intervention only. Studies
with larger improvements \cite{24,44} were guided by the transtheoretical model and provided computer-tailored feedback to students. Conversely, we found no evidence for reducing intake of fat or sugar-sweetened beverages or snacks. Although other research has shown that consumption of sugar-sweetened beverages can be reduced among children,\cite{39} reducing unhealthy dietary behaviours is generally considered more difficult than initiating new healthy behaviours.\cite{40,41} Further research is needed to examine mechanisms of change in relation to these dietary outcomes to increase the size and sustainability of the effects of multiple health behaviour change interventions, especially in school settings.

Overall, eHealth school-based multiple health behaviour change interventions were not effective in preventing or reducing alcohol use or smoking, which is in contrast with the findings of some reviews\cite{39,46} that reported such interventions to be beneficial in preventing or reducing tobacco and alcohol use. However, these reviews did not specifically focus on eHealth interventions and the primary studies did not overlap with those in the present meta-analyses. Furthermore, previous research\cite{41} has shown eHealth school-based interventions can be effective in preventing alcohol and drug use among school students when substance use is the sole focus of the intervention. A Cochrane review\cite{42} of universal school-based substance use prevention programmes reported that those based on principles of social influence and competence, such as normative education and life skills training, had the greatest effects. Longer-term follow-up of students is particularly important for substance use prevention because the full intervention effects are likely to be most evident in late adolescence once exposure to alcohol use and smoking has increased. However, follow-up length in two of the three studies of smoking outcomes included in the meta-analysis was short (4 months\cite{27} and 9 months\cite{39}). Generally, we found that ineffective interventions for alcohol use and smoking were brief,\cite{27} not grounded in social influence theory, primarily used the transtheoretical model,\cite{28,29,39} or did not provide sufficient opportunities for skill building.\cite{40} Future interventions targeting alcohol and tobacco or smoking alongside other risk behaviours should be guided by principles of effective substance use prevention (eg, normative education and life skills training), while incorporating key behaviour change principles relevant to the other risk behaviours in their conceptual models.

Multiple health behaviour change interventions are hypothesised to have a synergistic or transfer effect,\cite{41} whereby the lessons, skills, and knowledge learned in relation to one behaviour are applied to another, resulting in improvements across multiple behaviours. This effect was observed in one study,\cite{27} in which a dietary and physical activity intervention improved physical activity, diet, and screen time, but also increased smoking and drinking abstinence despite not targeting substance use behaviours. This effect suggests that by improving diet and physical activity, the intervention might have increased healthy behaviours overall. Future research should seek to explore this effect in trials of multiple health behaviour change interventions.

Strengths of this study include the focus on a wide array of lifestyle risk behaviours associated with poor health outcomes, and our rigorous methodology. Nonetheless, our study had several limitations. First, our meta-analyses were typically based on a small number of studies and significant heterogeneity was present between these studies for many outcomes. Second, high or unclear risk of bias existed regarding masking of final outcome assessors and selective outcome reporting, and, overall, we deemed the quality of the evidence to be low to very low. Particularly, much of the evidence related to smoking, screen time, and objectively measured and self-reported physical activity was found to be of very low quality. Studies also varied in the secondary outcomes assessed, with BMI being the only prespecified secondary outcome with sufficient data to be pooled. Finally, we found little evidence of sustained effects beyond immediately after the intervention. Longer-term follow-up is needed, and future studies should explore how effects can be maintained throughout adolescence, especially for tobacco smoking and alcohol use, for which we expect to observe a natural increase in use.

This Article highlights important directions for future research. First, none of the eligible interventions addressed sleep, despite the fact that many young people report insufficient sleep or sleep problems\cite{47} and growing recognition that movement behaviours, such as physical activity, sedentary behaviour, and sleep are co-dependent.\cite{48} Second, all interventions included in this systematic review were computer or website based, with no mHealth interventions identified. This lack of mHealth interventions might be due to school policies that prohibit use of mobile phones in the classroom or our eligibility criteria, which required interventions to be primarily delivered via eHealth methods. Given the high proportion of adolescents who own a smartphone (95% in 2018\cite{49}), the full potential of mHealth applications to supplement website-based programmes for school students has not been fulfilled. Future research should also explore the feasibility and efficacy of mHealth interventions for lifestyle risk behaviours when implemented in other contexts, such as home or peer environments. Reporting of intervention components is vital for understanding which behavioural change techniques are effective and which to employ when developing future eHealth interventions for adolescents, targeting single or multiple health behaviours. However, few studies described specific behaviour change techniques and none referred to an established taxonomy,\cite{50} so we could not draw conclusions about the effectiveness of specific techniques or intervention components. Finally, most of the studies were from the USA and high-income countries
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Queensland, Brisbane, QLD); L Mewton (Centre for Healthy Brain and Movement and Nutrition Sciences, The University of Queensland, Australia); C Chapman, T Slade, M Sunderland, L Birrell, L Stapinski (The Matilda Centre for Research in Mental Health and Substance Use, The University of Queensland, Brisbane, QLD); S Allsop (National Drug Research Institute, Curtin University, Perth, WA); L Hides (School of Psychology, The University of Queensland, Brisbane, QLD); and only evident immediately after the intervention, including substance use and sleep outcomes, and that can sustain effects over time. Future interventions should apply effective prevention principles and behaviour change techniques from single behaviour eHealth interventions to multiple health behaviour change interventions, be developed in close consultation with adolescents and teachers, and make use of emerging technology. Effective school-based multiple behaviour change interventions targeting modifiable lifestyle risk factors have the potential to not only improve current adolescent health and wellbeing, but also to reduce the risk of chronic disease in later life.

Contributors
KEC designed the study protocol with input from NCN, BS, QEW, BP, and MT. QEW designed and implemented the search strategy, KEC and CM screened and coded articles and extracted data, with assistance from LAG and LT. BP led the meta-analysis and write-up of results, with LAG and LT. BP led the meta-analysis and write-up of results, with assistance from KEC and CM. KEC, BP, and CM drafted the initial manuscript. KEC, BP, CM, BS, MT, LAG, LT, NM, and ELB interpreted the findings and assisted in revising the manuscript. All authors reviewed and approved the final manuscript.

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Declaration of interests
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