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Identifying and characterising digital behaviour change interventions to improve fruit and vegetable intake in low-socioeconomic status primary school children: a systematic review

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Abstract

Background Digital behaviour change interventions aiming to improve dietary intakes; specifically fruit and vegetable intake, in low-socioeconomic children are being developed and tested. However there is currently no synthesis of the characteristics or reported effectiveness of these interventions**.** This systematic review aims to: (1) identify existing digital interventions targeting fruit and vegetable intake in low-socioeconomic status children, (2) identify and synthesise characteristics and reported effectiveness of these interventions using the Behaviour Change Intervention Ontology.

Method CINAHL, ERIC, PubMed, Cochrane Library, ACM Digital Library and Scopus were searched in December 2021 – February 2022 and in February–March 2024. Inclusion criteria for studies were: 1) children of low-SES families, aged between 5–11 years old; 2) Digital intervention to improve fruit and vegetable intake; 3) Comparison groups could be digital or non-digital; 4) Outcome measures were fruit and vegetable intake and antecedents to diet behaviours; 5) Randomised controlled trials (cluster and parallel designs). Characteristics of identified studies were coded using the Behaviour Change Techniques Taxonomy and Modes of Delivery, Setting and Source ontologies of the Behaviour Change Intervention Ontology.

Results Five studies met all inclusion criteria, with majority reporting significant effects of interventions on improving fruit and vegetable intake. Most common Behaviour Change Techniques found were Goal Setting (k = 4), Problem Solving (k = 3), Instruction on how to perform a Behaviour (k = 3), and Prompts and Cues (k = 3). Characteristics relating to intervention source were unclear.

Conclusions Digital interventions had positive outcomes in fruit and vegetable intake in children; particularly more for fruit than vegetable intake. Characteristics in digital interventions which have direct effects on child fruit

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and vegetable intake in low-socioeconomic families should be further investigated. Furthermore, clearer reporting on intervention characteristics is needed.

Keywords Diet, Fruit and vegetable intake, Digital interventions, Behaviour change interventions, Behaviour change techniques, Behaviour change intervention ontology, Digital interventions, Low-socioeconomic status, Children, Families

Background

A nutritious and healthy diet plays a critical role in maintaining health and well-being [1]. Nutrition in childhood specifically, is essential for growth, development, activity, and healthy eating habits [2]. Consumption of at least 5 portions of fruit and vegetables (FV) a day can have long-term positive effects on children's health, such as a decreasing risk of long-term chronic diseases including cardiovascular disease and cancer [3–6]. Conversely, evidence suggests that consuming < 1 portion daily of FV can result in increased risk in long-term chronic diseases [5, 7]. Despite this, Public Health England released a National Diet and Nutrition Survey (NDNS) which found both parents and children within the UK population consuming FV all below the current dietary recommendations of the EatWell Food Guide, with only 18% of children between 5 and 15 years of age meeting the recommendation fruit and vegetable intake daily [5, 8].

Barriers to FV consumption include child food preferences [9], lack of time for food preparation [10], family dynamics [11], and parental knowledge and food literacy [8]. Families in low-socioeconomic status (SES) communities are less likely to consume nutritious foods that are consistent with dietary guidelines compared to high-SES families [8, 12] due to these aforementioned barriers and increased cost of nutritious food such as FV [13, 14].

Behaviour Change Interventions have attempted to address these barriers by targeting interventions to a specific population and behaviour [15]. Digital Behaviour Change Interventions (DBCIs) specifically, are a popular method for addressing nutritional intake in children [16, 17]. DBCIs for improving child nutrition have targeted a wide range of outcomes, including antecedents of diet behaviour such as increasing nutritional knowledge [18] and self-efficacy [19, 20], as well as targeting behaviour itself in increasing FV [21], decreasing fat and sugar [22, 23], and decreasing sugar-sweetened beverages [21]. Despite the range of DBCIs aimed at a variety of nutrition outcomes, these interventions seemed to be most promising for improving FV intake compared with other nutrition outcomes, as existing reviews have found the significant impacts of DBCIs on adolescents and children [16, 24, 25]. However, DBCIs to increase FV intake in children within low-SES families have not yet been systematically reviewed for their characteristics of effectiveness.

Identifying the key characteristics of interventions; such as DCBIs, are essential to understand how an intervention is delivered, why an intervention may be effective, and to facilitate replication of intervention effectiveness [26]. Consistent classification of intervention characteristics are facilitated by standardised coding systems [27], such as the Behaviour Change Techniques Taxonomy (BCTTv1) [28] to code behaviour change techniques: the 'active ingredients' embedded within an intervention's content. More recently, the Behaviour Change Intervention Ontology (BCIO) has been developed to extend standardised classification of Behaviour Change Interventions [26, 29]. Ontologies are defined as a data structure of; (1) unique identifiers representing types of entity, (2) labels and definitions corresponding to these identifiers and (3) specified relationships between the entities [30, 31]. The BCIO specifically, aims to classify interventions beyond Behaviour Change Techniques (BCTs) alone, including Intervention Source; how an intervention is delivered [32], Mode of Delivery; how content is provided to a target population [33]; and Intervention Setting; where an intervention is delivered [34].

DBCIs are evidently being adopted to address healthy eating behaviours, such as FV consumption in children [16, 25, 35]. Previous reviews exist which have synthesized evidence on the effectiveness of digital interventions to improve children's diet [17, 25, 36]. However, these reviews focus solely on intervention effect sizes [36], intervention features, parent functionality and usability [25], and delivery methods and features such as health education, goal setting and self-monitoring towards adolescents [17]. To-date, no review has synthesised the evidence of DBCIs for FV consumption in low-SES children using an appropriate coding structure. Despite the BCIO being used to code intervention characteristics in two other previous studies, one of these interventions focused on digital tools targeting physical activity [37], and the second focused on smoking cessation interventions for those with physical disabilities [38]. Therefore, no review has identified common characteristics among effective and non-effective DBCIs for low-SES children's FV intake, including using the Behaviour

Change Intervention Ontology. Therefore, the aims of this systematic review were to: (1) identify existing digital interventions targeting fruit and vegetable intake in low-socioeconomic status children, (2) identify and synthesise characteristics or reported effectiveness of these interventions using the Behaviour Change Intervention Ontology.

Methods

The systematic review protocol was registered with PROSPERO (CRD42021291643). PRISMA 2020 Guidelines for reporting completed systematic reviews were followed [39] (see Additional file 1).

Search strategy

One search was conducted in February–March 2022 to capture studies published within the last 10 years (2011–2022) and a second conducted from February–March 2024, to capture all studies published between the years of 2022–2024. A systematic search was conducted using CINHAL, ERIC, PubMed, Cochrane Library, ACM Digital Library, and Scopus databases. The search strategy was supported by an information specialist librarian. Search terms included: 1) Digital Behaviour Change interventions, nutrition/dietary interventions, family-based interventions 2) Primary school children, low-SES communities, parental guidance 3) Dietary intakes, all combined with 'AND', with wildcards (*) also used. Search strategies used for each database can be seen in an additional file (see Additional file 2).

Inclusion criteria

Inclusion criteria were set in line with the PICOS framework (Population, Intervention, Comparison group, Outcome and Study Design) [40, 41]. Studies were included based on the following: 1) Participants were children of low-SES families, aged between 5–11 years old; 2) Featured a digital intervention to improve fruit and vegetable intake using any form of technology. Interventions could address fruit and vegetable consumption alone, or with additional diet behaviours such as consumption of sugar-sweetened beverages, and packing lunchboxes to include an increased range of nutritional foods, including fruits and vegetables; 3) Comparison groups could be digital or non-digital, address a diet behaviour other than fruit and vegetable consumption, or a placebo intervention group (e.g. a non-nutritional intervention focused on other curriculum, such as math or science); 4) Outcomes assessed included assessment of child fruit and vegetable intake as the primary outcome, whether subjective or objective. Assessment of antecedents to diet behaviours, such as nutrition knowledge and self-efficacy and other health behaviours, such as physical activity, were also included if reported; 5) Randomised controlled trial studies, including cluster and parallel designs were included. School, community, and home-based interventions were included. Studies were included if they were published in English, published in peer-reviewed journals, and published from 2011 onwards.

Study selection

Search results were imported into Zotero and duplicates removed. Titles, abstracts and full texts were screened by HF and EN and organised into a structured excel table. HF screened full texts for eligibility. If inconsistencies between two reviewers occurred, a third reviewer (KLC) was available to evaluate. No inconsistencies were apparent.

Data extraction

All data from included studies were extracted onto a standardised Excel form between February and March 2022 and February–March 2024. Data was extracted by the primary researcher (HF) and double-coded by a second reviewer (EN). Data extraction was informed by the Template for Intervention Description and Replication (TiDieR) checklist [42].

Overall study characteristics extracted included study design, length of intervention, participants, measurements of low-SES and direct parental involvement within the intervention. As child FV intake was the main outcome measure, parental behaviours were not assessed within the studies. Interventions that were considered multi-component; which included several approaches designed (2 or more) to improve behavioural outcomes, were also captured within this study [43].

Open science characteristics apparent within the paper were also coded: whether a study was pre-registration or had a protocol available, whether open data, open materials and open analysis scripts were available, whether the study was described as a replication of a previous intervention, whether a funding or conflict of interest statement was provided and whether the paper was open access [44].

Intervention characteristics of each study and each intervention group were extracted using the Behaviour Change Intervention Ontology [29], including the setting: where the intervention took place [34], modes of delivery: how the intervention was delivered [33], and source: who delivered the intervention [32]. Characteristics of the BCIO were coded onto the BCIO data extraction template v1 [45]. Intervention content of each study, in the form of BCTs, was extracted using the BCCTv1 [28]. Behaviour change theories reported as used within interventions were also extracted.

Outcome characteristics extracted included measures of dietary outcome assessment; such as 24-h dietary recall methods [46–48], dietitian assisted recalls [48], electronic food photos [23, 49]. Details of non-behavioural outcome measures were also extracted, including changes in attention, attitudes, acceptability towards healthy eating and digital interventions, barriers and facilitators to intervention implementation and participation (e.g., lack of sufficient resources, funding, time. lack of available facilities) and self-efficacy. Effectiveness characteristics extracted included statistical significance as reported within the papers, means and percentages of outcome change and changes to FV intake over time. Meta-analyses of intervention outcome data was not performed due to the heterogeneity of outcomes identified.

Quality appraisal

Risk of bias assessment was performed using the Cochrane Collaboration tool for assessing risk of bias in randomized trials [50, 51]. Assessment was performed for selection bias, study design, contamination, co-intervention, blinding, data collection and withdrawals and drop-outs. Studies were classified as high risk of potential bias if two or more of the categories are assessed as weak (high risk), moderate risk of potential bias if one category was assessed as weak (moderate) and low risk of potential bias if none of above categories were assessed as weak (low risk) [50, 52].

Results

After duplicate removal, 10,311 papers were identified in the first searches conducted in February–March 2022 for title and abstract screening, with 5 studies included in the final review. In February–March 2024, after duplicate removal, a total of 7,124 papers were identified for title and abstract screening. After assessing full-text, no new papers were identified. Therefore, a total of 5 studies were included in the final review. This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews Flow Diagram (PRISMA 2020) for identifying papers [39]. Details on the PRISMA 2020 Flow Diagram for updated systematic reviews can be seen in Fig. 1.

Overall study characteristics

Overall study characteristics are summarized in Table 1. All papers were randomized controlled trials, including two-group RCT (k = 3) [23, 46, 47], four-group RCT

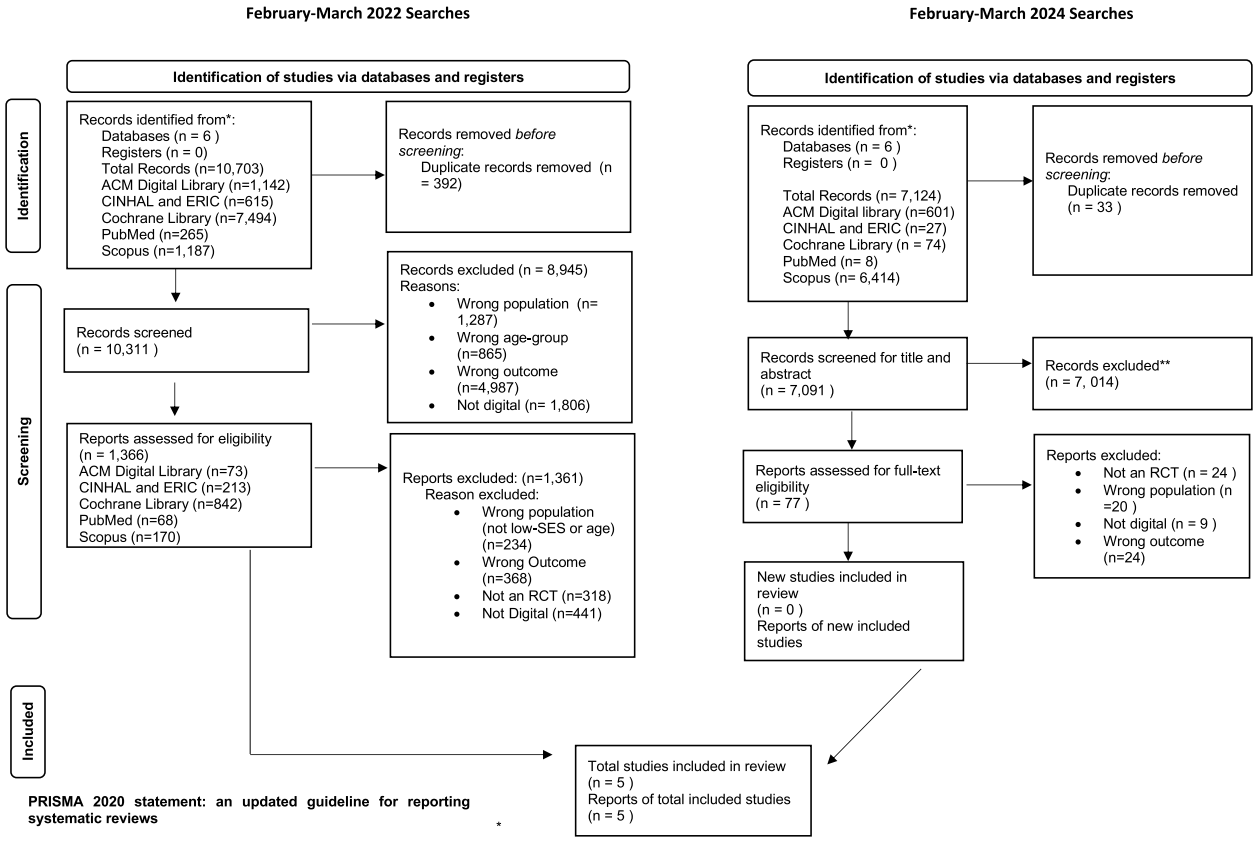

Fig. 1 The PRISMA 2020 diagram details the applied search and selection process

Table 1 Summary of overall study characteristics, outcomes and effectiveness

Author/Date/ Location/ Design	Age (years)	Measurements of low-SES	Intervention versus control	Parental involvement	Behaviour change theories	Primary outcomes and Results
Nollen (2014) [46], United States, 2-arm RCT	9–14	Median annual household. 2010 US Census obtained indicators of SES	**Intervention:** MyPal A626 handheld computer (similar to smartphone) **Length:** 12 weeks (FV intake only captured Baseline to Week 4) **Duration:** N/A **Follow-up:** For FV, Week 4 **Control:** Manuals composed of screenshots of the MyPal without some content	No behaviour/involvement mentioned	No theory mentioned	Fruit and Vegetable (FV) Intake (FVs: weeks 1–4); Sugar-sweetened beverages (SSBs: Weeks 5–8), and Screen time (Weeks 9—12) **Results:** Exhibited trends toward increased FVs from baseline to Week 4 follow-up (+0.88, $p=0.08$) and decreased SSBs (-0.33, $p=0.09$) from baseline to Week 4 FV follow-up. Increased FV from Baseline: $+2.53 \pm 1.45$ to Week 4: $+3.35 \pm 1.81$
Baranwoski (2011) [47], United Kingdom, 2-arm RCT	10–12	Highest household education	**Intervention:** Diab and Nano video game. 24-inch iMac computers with the games and Microsoft Windows XP operating system preinstalled **Length:** 9 sessions per game **Duration:** 40-min of gameplay per session (6 h total) **Follow-up:** 2-months **Control:** Diet and physical activity knowledge-based games on popular websites	No parental involvement. Post-game interviews with parents asking about children's playing time	Social Cognitive Self Determination, Persuasion theories	Servings of fruit, vegetable, and water; minutes of moderate to vigorous physical activity. **Results:** Baseline: $+1.88 \pm 0.13$ servings per day. Immediately after intervention: $+1.85 \pm 0.13$ servings per day. 2 months follow-up: $+2.15 \pm 0.13$ servings per day. Increased FV consumption by 0.67 servings per day (<0.018)

Table 1 (continued)

Author/Date/ Location/ Design	Age (years)	Measurements of low-SES	Intervention versus control	Parental involvement	Behaviour change theories	Primary outcomes and Results
Thompson (2015) [48], United States, 4-arm RCT	9–11 and one parent	Highest household education Average annual household income	**Intervention:** Squire's Quest I and II. School computers following a pre-set schedule **Length:** 10-episode video game for kids and 10 electronic newsletters to parents **Duration:** Episodes no longer than one hour to complete **Follow-up:** 3-months **Control:** Played the game, but only set a goal to eat FV and did not create an action or coping implementation intention	Parents taught how to help their child meet FV goals, ho to create a healthy home environment, and how to overcome barriers	Social cognitive theory Self-determination/determination Behavioral inoculation Maintenance Elaboration likelihood model	Fruit and vegetable intake **Results:** Baseline: children consumed average of 1.8 servings of FV. Post intervention: Action ($p > 0.0001$) and Coping ($p < 0.0001$) had significant increases in FV intake compared to baseline. Post 2 Intervention: Action group maintained these increases ($p > 0.0001$) and had almost a 50% increase in FV intake at Post 1 (0.72 servings), and maintained this increase at follow up (0.68 servings)
Bakirci-Taylor (2019) [23], United States, RCT	3–8	Family income	**Intervention:** Mobile Jump2Health website, Facebook, text messages, Facebook, posts, and text messages **Length:** 10 Weeks **Duration:** Website, 12-text messages and 177 Facebook posts **Follow-up:** Week 10 **Control:** No access to website or social media: only 12 text messages about physical activity	Parents encouraged to increase FV intake, variety of FV and accessibility of FV provided to child	Social Cognitive Theory	Improve fruit and vegetable consumption and accessibility in children and skin carotenoids **Results:** Intervention for total fruits was $n = 93$ and went to $n = 117$ at week 5 and then went back down to $n = 90$ post intervention week 10 ($p = 0.62$) compared with control who was at a total of $n = 87$ at week 10. Intervention for total vegetables was $n = 113$ then went up to $n = 128$ week 5, and then back down to $n = 97$ week 10 ($p = 0.90$). Significant week x treatment interactions in skin carotenoid levels from the Veggie Meter the intervention group compared with the control group ($p > 0.001$ and parents $p > 0.001$)

Table 1 (continued)

Author/Date/ Location/ Design	Age (years)	Measurements of low-SES	Intervention versus control	Parental involvement	Behaviour change theories	Primary outcomes and Results
Wengreen (2021) [49], United States, RCT	5–11	Qualifying for free/reduced lunch	**Intervention:** FIT Game. Comic-book formatted episodes projected onto a large screen in the school cafeteria daily in lunch **Length:** 8 weeks **Duration:** 3 min episodes, 32 episodes, Game played 44 days in a year **Follow-up:** 3-months **Control:** No intervention provided	No parental involvement stated	Not labelled	Fruit and vegetable intake and higher skin carotenoids **Results:** Children in intervention consumed more vegetables (10.66 g, $d = 0.41$, $p < 0.001$) compared with the control, (1.43 g, $d = 0.06$, $p = 0.458$), and more fruit (15.66 g, $d = 0.39$, $p < 0.001$). Gain did not last follow-up period (− 12.72 g, $d = -0.31$, $p < 0.001$). Fruit consumption returned to the pre-intervention level (2.95 g, $d = 0.07$, $p = 0.332$). Modest FV increase of + 26.45 g in the intervention phase. Maintained 3-months (d = 0.21). + 5.53 g of total fruits and vegetables

(k = 1) [25], and Cluster-RCT (k = 1) [49]. The length of the intervention including follow-up, ranged from 8 weeks [49] to 3 months [48, 49]. Participant ages ranged from 8–12 years, with participants most commonly being aged 9–11 (k = 4) [46–49]. Parents were directly involved in interventions within 2 of the 5 studies [23, 48].

Socio-economic status (SES) in participants were measured by identification of economically disadvantaged neighborhoods; demographic information collected to determine percentage of children living in poverty [46], highest household education and average annual household income [23, 47, 48], and children qualifying for free/reduced lunch [49].

One study pre-registered their research, using ClinicalTrials.gov [48]. One study had a study protocol available as a separate paper [48]. One study had their data, materials and analysis script fully open to the public where they provided the full code, data, and output available on the Open Science Framework [49]. No studies were replications of existing interventions. Majority of papers were Open Access [44, 46, 47] (Table 2).

Intervention characteristics

Theories described as used within these interventions included Social Cognitive Theory (k = 3) [23, 47, 48] and Self-determination Theory (k = 2) [47, 48]. No behaviour change theory was reported within two studies [46, 49]. Coding of intervention characteristics according to the Behaviour Change Intervention Ontology [29], include the intervention Setting [34], Modes of Delivery [33], and Source [32], are provided in an additional file (see Additional file 3). The Behaviour Change Intervention Data Extraction Coding Template [53] can be seen in an additional file (see Additional file 4). Coding of intervention content according to the Behaviour Change Techniques Taxonomy v1 [28], is provided in Table 3.

Intervention setting

All included studies took place in the United States and were considered low-income areas (k = 5) [23, 46–49]. In one study, while socioeconomic level of families were described as fairly high, average annual household income was < 61,000 [48], which is below the median household income [54]. One study is clearly described to take place in a primary school [49]. Due to unclear reporting, majority of these studies may take place within a household residential setting [23, 46–48], with two of these studies possibly being based in a primary school [46] and middle school [47]. Most studies were described to take place in urban areas [46–49], one in suburban [48] and one in a rural area [47].

Mode of delivery

All studies delivered their interventions using a form of electronic mode of delivery (k = 5) [23, 46–49]: conducive to them being DCBIs. Electronic modes of delivery used include mobile digital devices (k = 4) [23, 46, 55, 56]; including a handheld computer, mobile website and mobile communication app, computers (k = 3) [23, 47, 48], and electronic billboard and electronic environmental objects [49]. Digital content of interventions were delivered through text messaging (k = 1) [23], video game (k = 2) [47, 48], email (k = 1) [48], and website and mobile application such as a Facebook page [23, 46–48]. Information was described as delivered through audio- such as using a song-based reward system (k = 1) [46], visual- (k = 5), and textual information formats such as text messaging (k = 3) [23, 46, 48].

Some interventions were individual-based: aimed directly at either the child or parent (k = 3) [23, 46, 47], while other interventions were pair-based interventions; aimed at both child and parent (k = 1) [48], or group-based; involving participation within full school assemblies or classrooms (k = 1) [49]. Most studies featured asynchronous activities (k = 4) [23, 46–48]; different components of the intervention could be completed at different times. All interventions contained push components; notifications directly sent to participants to reinforce dietary intakes [23, 46–49]. For example, push components such as song-based reward systems [46], daily/weekly motivational text messages [23, 47], tips and feedback [48], and daily goals [49], all to be used as reminders, prompts and cues to complete daily goals and overcome barriers to FV intake [23, 46–49]. Some interventions contained pull messages, where participants needed to set their own goals and take electronic pictures of their foods (k = 3) [23, 46, 48]. Most interventions contained gamification features (k = 4) [46–49], including a song-based reward system [46], knowledge mini-games [47], goal setting and motivational messaging [47], problem solving and avatars or stories in order to encourage nutrition knowledge and FV intake [48, 49].

All interventions included used some form of Human Interactional mode of delivery (k = 5) [23, 46–49]. One study which included face-to-face human interactional mode of delivery, components of the intervention took place within a school environment, where teachers or research coordinators were directly involved delivering the nutrition content to the children [49]. As all interventions were digital, at-a-distance human interaction mode of delivery was more common among studies (k = 4), as the digital components of interventions took place in the home environment or with the participants themselves without the direct involvement of the researcher [23, 46–48]. Some studies found (k = 2) [23,

Table 2 Open science characteristics of included papers

	Study pre-registered	Protocol available	Open data	Open materials	Open Analysis script	Replication study	Funding statement	Conflicts of interest	Open access
Bakirci-Taylor (2019) [23]							√	√	
Baranowski (2011) [47]							√	√	√
Nollen (2014) [46]							√	√	
Thompson (2015) [48]	√	√					√	√	√
Wengreen (2021) [49]			√	√	√		√	√	√

√ Paper contains open science characteristic

Table 3 Behaviour change techniques within individual studies

Behaviour Change Techniques (BCTs) identified	Bakirci-Taylor, 2019 [23]	Baranowski, 2011 [47]	Nollen, 2014 [46]	Thompson, 2015 [48]	Wengreen, 2021 [49]
Goal Setting 1.1		√	√	√	√
Problem Solving 1.2	√		√	√	
Action Planning 1.4		√	√	√	
Review behavioural goals 1.5		√			
Feedback on behaviour 2.2			√	√	
Self-monitoring of behaviour 2.3			√	√	
Feedback on outcome of behaviour 2.7	√				
Social Support (unspecified) 3.1		√			
Instruction on how to perform behaviour 4.1	√	√		√	
Information about antecedents 4.2					
Information about health consequences 5.1		√	√		
Demonstration of the behaviour 6.1				√	
Prompts/Cues 7.1	√		√		√
Behavioural substitution 8.2					
Graded tasks 8.7	√	√		√	√
Credible source 9.1				√	√
Non-specific award 10.3			√	√	
Non-specific incentive 10.6					√
Adding objects to the environment 12.5					√
Valued self-identity 13.4					√
Remove reward 14.3					√
Situation-specific reward 14.6					√

√ Paper contains Behaviour Change Technique

48] contained more than 2 varying digital components of the interventions. One of the studies, which found a significant increase in child FV intake and was maintained at the 3-month follow up, used an online video game for the kids, and electronic newsletters to parents [48]. The second study, which found a significant effect of vegetable intake over time ($p < 0.001$) and maintained at the 10-week follow-up, the intervention used contained a web site, social media and text messages in order to improve FV intake in children [23].

Intervention source

All studies described using a researcher (k = 5) [23, 46–49] to deliver the intervention to participants, with one directly also involving a primary school teacher (k = 1) [49]. However, in some studies the source of the intervention were unclear [46]. The Intervention Source Ontology is designed to only characterise people involved in intervention delivery, not the collection of outcome measurements. Dietitians (k = 3) [47], undergraduate and graduate students (k = 1) [23] were reported as involved

in data collection, but were accordingly not coded as constituting an intervention's source. While few studies used professionals in a trained profession; such as dietitians to assess dietary recalls [47] and the digital story within the intervention being written by a professional writer [48], one study clearly stated that the first author was a registered dietitian and a graduate nutritional sciences students, so is therefore familiar with nutrition around fruits and vegetables [23].

Behaviour Change Techniques (BCTs)

A total of 22 individual BCTs were present across the five interventions. All studies featured at least one identifiable behaviour change technique (Table 3). The most frequently used BCTs were Goal setting (k = 4) [46–49], Instruction on how to perform a behaviour (k = 3) [23, 47, 48], Prompts and Cues (k = 3) [23, 46, 49] and Problem Solving (k = 3) [23, 46, 48]. No studies directly mentioned coding BCTs using the Behaviour Change Technique Taxonomy v1 [23, 46–49].

Outcome and effectiveness characteristics

Primary outcomes of all studies were fruit and vegetable intake (k = 5) [23, 46–49]. Primary outcome measurement tools include 24-h dietary recall methods [46–48], telephone recalls [48], dietitian assisted recalls [48], electronic food photos [23, 49]. Outcome follow-up lengths ranged from 4 weeks [46] to 3 months [48, 49].

Antecedents and secondary outcomes of behaviour

Secondary outcomes among studies included physical activity [47], sugar-sweetened beverage intake [46], water intake [47], fruit and vegetable intake separately [23, 48, 49], sedentary behaviour, skin carotenoid concentrations [23, 48], and BMI [23, 46] as secondary outcomes. While antecedents to diet behaviour were not reported as secondary outcomes, nutritional knowledge [23, 47, 48], parental skills [23, 48], and self-efficacy were captured within all interventions in order for the participants to achieve the behavioural outcome. Parents and guardians were directly involved within some studies (k = 2) [23, 48], with intervention content aiming to improve parental knowledge and skills to overcome barriers that impact dietary outcomes; such as FV intake, and how to increase FV accessibility for children [23, 48].

Changes in overall FV consumption

Statistically significantly improvements in FV intake were found in majority of studies (k = 4), with majority being maintained at follow-up [23, 47, 48]. For example, one study found an almost 50% increase in FV intake (+ 0.72 servings). This increase was maintained at a 3-month follow-up, reporting a 41% increase over baseline FV intake [48]. Another study found an increase in FV intake of + 0.67 servings per day at 2-month follow-up compared to baseline (< 0.018) [47]. One study found a non-significant change in FV consumption from baseline to Week 4 follow-up ($p = 008$), although nearly leading to an increased FV portion per day (+ 0.88) [46]. Only one study with significant improvements in FV intake were not maintained at follow-up of 3-months, however still had significant improvements for fruits alone ($p < 0.031$) [49].

Differences in fruit versus vegetable consumption

Differing effects were observed when comparing fruit versus vegetable intake at last follow-up. One study significantly improved FV consumption by + 0.68 servings per day at 3 month follow-up ($p < 0.001$), although there was no significant effects observed for vegetables alone [48]. Similarly, another study with a 3-month follow-up found significant improvements in both FV with only fruits having significant improvements at follow up ($p < 0.031$) [49]. Conversely, another study with a 10-week follow-up found significant increases in vegetable intake in the intervention group compared to the control group ($p > 0.0001$), but no significant effects for fruits alone ($p = 0.09$) [23]. Differences in longevity of effects on fruit versus vegetable consumption were also observed. For example, one study found a statistically significant time main effect for fruit intake increasing over time both immediately post-intervention ($p < 0.001$) and at 3-months follow-up ($p < 0.001$). However, no significant interaction or main effects were observed for vegetables [48].

Risk of bias

All five studies were assessed to be high risk of bias on at least one domain, with some studies (k = 3) [23, 46, 47] having an additional high risk of bias in at least one other domain (Table 4). One study was considered having an overall high risk of bias due to being a high risk of bias in four domains [46]. Majority of studies had a medium risk of bias (k = 4) as they had either one [48, 49] or two domains that had a high risk of bias [23, 47] but were not at critical risk of bias in any other domain. The most consistent domain in which studies had a high risk of bias included performance bias, where participants in all studies were either aware of the intervention (k = 5) [23, 46–49], blinding was not attempted (k = 2) [48, 49], or blinding status was not described (k = 3) [23, 46, 47]. Lastly, two studies had a high levels of detection bias, where nothing was stated in the study [46], or assessors were not blinded to the outcomes [23].

Due to the small number of studies identified, heterogeneity of the outcome variables within these studies,

Table 4 Risk of Bias among individual studies

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding participants & personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)
Bakirci-Taylor (2019) [23]	–	–	+	+	–	–
Baranowski et (2011) [47]	+	?	+	–	–	–
Nollen (2014) [46]	+	+	+	+	–	?
Thompson (2015) [48]	–	?	+	–	–	–
Wengreen (2021) [49]	–	?	+	–	?	–

+ High risk of bias

– Low risk of bias

? Unclear risk of bias

and majority of studies having a high risk of bias in more than one domain, a meta-analysis was not considered necessary to conduct as this may produce an inappropriate summary of the findings.

Discussion

This systematic review identified five papers which emphasized digital tools can achieve small to moderate changes in FV intake with lasting effects up to 3-months and therefore, are promising interventions for improving FV intake in children within low-SES families [16, 23, 48]. While improvements in child FV intake remain promising; vegetable intake was identified as harder to maintain overtime [48, 49]. Long term effects of interventions (≥ 12-months) are still unclear [16].

This review captured characteristics embedded in these interventions using the Behaviour Change Intervention Ontology. The Intervention Source Ontology identifies how behaviour change interventions are delivered, including by whom [32]. The Mode of Delivery Ontology specifies the way in which these interventions are delivered [33], and the Intervention Setting Ontology identifies the different contexts in which interventions may change behaviour [34]. These ontologies all form one individual part of the Behaviour Change Intervention ontology, which aims to cover all aspects of behaviour change interventions and is a key to understanding intervention effectiveness [32].

While the digital Mode of Delivery varied among websites, computers and apps, common digital content of the interventions found were delivered through text messaging [23], video games (k = 2) [47, 48], and website and mobile application such as a Facebook page [23, 46–48]. Some of the interventions identified were considered multi-component [23, 48] which include two or more digital components designed to improve behavioural outcomes [43]. These multi-component interventions maintained their positive effects on FV intake in their follow-up period of 10 weeks to 3 months [23, 48].

Most papers contained ≥ 6 + BCTs, with Goal setting, Problem Solving, Instruction on how to Perform a Behaviour, and Prompts and Cues being the most common BCTs among these papers [46–49]. The mode of delivery of DBCIs, such as using a mix of text messaging and communication through mobile apps may be an effective interactive method to use when delivering interventions, and using gamification features have been shown to maintain behavioural outcomes during follow-up periods [18, 35, 57].

The findings of this review align with previous reviews which show digital interventions can significantly improve FV intake compared with interventions not using digital technologies [17, 25, 36]. Studies which assessed FV intake separately [48, 49], found FV consumption to significantly improve at a 3-month follow-up, however no significant effects were observed for vegetables alone [48]. These findings have also been seen in prior interventions, which have assessed fruit and vegetable intake separately, and found minimal impact on vegetable intake overtime compared to fruit [58]. Therefore, vegetable intake in children may be harder to maintain overtime than fruit intake, however is possible to maintain if vegetables are further prompted and emphasized for their importance in health [59].

The importance of an intervention setting and has been described in previous literature, with one RCT reporting significant increases in child FV intake up to 12 months after completion with the intervention being based in the home environment due to the possibility of having more access to digital interventions [60]. However,

overall effects of dietary intervention settings have been unclear due to the lack of literature or mixed results [61]. Lastly, while this review did not directly show the impact that the intervention source may have on the reported effectiveness of interventions, majority of interventions reported in this review were delivered by the researcher. While impacts of parents as the source of the intervention were unclear, direct parental involvement were found in some studies (k = 2) [23, 47]. These studies aimed to teach parents how to assist their child in meeting goals and overcoming barriers to FV intake [47], and increasing accessibility to a variety of FV [23]. Both these studies found a significant effect in FV intake overtime. Therefore, more research is needed on understanding which setting and source; such as being delivered by a teacher or parent, should be further investigated.

As modes of delivery used within interventions are important to specify to facilitate replication [33], mobile digital devices and app-based interventions has been shown in current research to be accessible amongst all population groups [47, 49, 55, 56, 62–64]. For example, one existing digital intervention in this review which aimed to improve FV intake in children; and originally stated families were a mix of both high and low-SES, found significant increases in FV intake maintained for 3-months [65]. However, their long-term effects still remain mixed or unclear [17, 25, 36]. The significance of the mode of delivery have been supported within the literature, where a meta-analysis of RCTs found that text messages to deliver educational messages to families or parents were effective at promoting behaviour change, including children's dietary intakes [66, 67]. For children specifically, the literature has shown that mobile apps with the use of gamification features; such as rewards games, goals, avatars and stories, can improve FV intake [18, 35, 68, 69]. The interventions found within this review which had the longest maintained effects at 3-months on child FV intake included a mix of text messaging, computers, and communication through mobile apps, which were highly accepted by parents in this review [48].

Behaviour Change Techniques embedded within interventions are important to specify to facilitate replication and understanding of intervention content [28, 31]. Within the literature, 'Goal setting', 'Problem Solving', 'Instruction on how to Perform a Behaviour', and 'Prompts and Cues' are BCTs have been specified in other related diet interventions [70, 71]. The majority of the papers found in this current study contained more than 6 + BCTS, with Goal setting, Problem Solving, Instruction on how to Perform a Behaviour, and Prompts and Cues being the most common BCTs among these papers [46–49]. Interventions which had the longest follow-up period of 3 months, also contained these BCTs [48, 49]. To further support the effect these BCTs have on dietary outcomes, the results of another existing study; which identified BCTs for dietary and physical activity interventions, found the most effective BCTs resulting in long-term facilitators being 'goal setting', 'self-monitoring of behaviours', 'problem solving', 'feedback on outcome of behaviour', 'instruction on how to perform the behaviours' and 'adding objects to the environment' [70].

Lastly, the effectiveness of multi-component interventions on dietary intakes have been supported in the literature; such as interventions which include education, environment, mode of delivery or parental components, and can be more successful than single-component interventions [72, 73]. Two prior existing studies within the literature which aimed to have parents pack healthier lunchboxes, contained a multi-component intervention consisting of both parent and child involvement in the intervention, digital mobile applications, curriculum lessons, and paper pamphlets [55, 56]. The significant changes in this study were maintained for up to 6 months [56]. This review has shown that multi-component interventions may improve FV intakes significantly, compared to single-component interventions [56]. The two interventions identified contained more than one digital component and maintained their follow-up period of 10-weeks to 3 months [23, 48]. Identifying what embedded components and characteristics of an intervention exist may help in understanding how interventions can be tailored to the population when informing future interventions and implementation policies [74].

Strengths and limitations of identified studies

Studies were only included in this review if they were randomized controlled trials, which are considered the gold standard for health intervention effectiveness research [75]. However, all interventions were assessed via the Cochrane tool for risk of bias and were shown to have high risk of bias on at least one domain, with some studies (k = 3) having an additional high risk of bias in at least one other domain. All the RCTs in this present study had a high risk of performance bias, which could mean that participants may have been aware of the intervention and the behavioural outcomes may have been due to outside influences. Therefore, the intervention may not be as effective to dietary intakes as the RCT has claimed. Additionally, although all papers were Open Access, only one study only one study had open data, materials and code to facilitate replication and transparency [49].

Strengths and limitations of this study

Strengths of this systematic review include its inclusion of RCTs and its novel use of the Behaviour Change

Intervention Ontology to specify in-detail the characteristics of DCBIs to improve child fruit and vegetable intakes. This is one of the first systematic reviews to use the BCIO to code included papers, with one other review having coded DBCIs using the BCIO in the context of physical activity [37], and another scoping review which has used the BCIO in the context of smoking cessation [38]. Inclusion of the BCIO coding in future systematic reviews will facilitate greater clarity on the content, context and delivery of behaviour change interventions. This review is also one of the first to address the lack of digital tools aimed at low-SES families, and what characteristics may need to be implemented into digital interventions to result in outcome effectiveness for this population group. Understanding what characteristics benefit this population may help to limit digital intervention inequalities between populations.

Limitations of this systematic review include a lack of firm reported effectiveness conclusions based on a small number of eligible studies. Most included studies had relatively short follow-up periods (< 3 months), making it not possible to make firm conclusions on longer-term effectiveness. While this review covered an important topic around child FV intake in low-SES families, there were very limited studies that were found which focused directly on this behaviour and population. Additionally, majority of these studies were high risk studies, which may mean claims made about effectiveness are inaccurate. Only English language studies were included, which limits a wider range of studies globally. It is worth noting that all identified studies in this review took place within the United States (k = 5), which presents a significant limitation to understanding of the current findings. Additionally, as the population group is low-income families, issues related to digital interventions causing inequalities or a divide in the population need to be considered. While some studies exist which have found that low-SES families still have high access to smartphones [76], there is a lack of understanding in the current papers as to whether there were any limitations to accessing digital devices or whether developing digital interventions could result in widening inequality in relation to engagement within public health interventions [74].

Areas and implications for future research

Despite the evidence identified here that digital interventions have a significant impact on low-SES children's fruit and vegetable intake, the long-term effect that digital interventions have on child FV intakes have yet to be established. While digital interventions themselves are an individual level mechanism for improving FV consumption in children, future intervention development research in low-SES families also needs to be aware of how digital interventions may generate inequalities within the population at the public health level, and how to use these interventions to overcome other influential factors to FV consumption; such as food insecurity and poverty [74]. Therefore, it is important to consider other influences of fruit and vegetable intake, such as influences from the socioecological framework including, family-level and social-structural influences [77].

While this review identified digital dietary tools aimed at low-SES families, an existing digital divide may create a gap between low-SES and high-SES populations on accessing these tools, and can exclude people who could benefit the most from these interventions [78]. How to design and develop digital interventions to meet the needs of the low-SES families appropriately should be considered for future research.

This study is the first to use the Behaviour Change Intervention Ontology to provide detailed and consistent specification of DBCI characteristics in relation to children's diet. Future studies could provide further clarity on DBCI specification using the BCIO. Lastly, conducting further research using consistent outcome measurements would facilitate the ability to meta-analyse these interventions.

Conclusion

This systematic review has identified what characteristics are used in DBCIs for children in low-SES families to improve FV intake. The intervention found with the longest maintained effect of FV intake contained multicomponent digital tools (e.g. text messaging, computers and mobile apps), parental involvement, school and household setting, and 6 + BCTs [48] While the majority of studies identified reported significant improvements to FV intake [23, 47, 48], the quality of these studies were relatively low, and due to the limited evidence identified in this review, this makes providing firm conclusions on the effectiveness of digital interventions challenging.

This is the first review to report characteristics of diet DCBIs using the Behaviour Change Intervention Ontology. However, there is still limited knowledge on how digital tools can be disseminated and appropriately used for a specific population group without creating a greater digital divide. Therefore, further research on identifying what imbedded characteristics of an intervention; such as taking place outside the United States, using different modes of delivery, intervention settings and sources, may help to understand what characteristics work best for this type of intervention and population. Lastly, there is a need for clearer reporting of interventions. Improved intervention reporting using the BCIO would strengthen the evidence when reporting the effectiveness of DBCIs aimed at dietary intakes [26].

Abbreviations

FV	Fruit and Vegetables
DBCIs	Digital Behaviour Change Interventions
SES	Socioeconomic status
BCTTv1	Behaviour Change Techniques Taxonomy v1
BCIO	Behaviour Change Intervention Ontology
TiDieR	Template for Intervention Description and Replication
BCTs	Behaviour Change Techniques
BCW	Behaviour Change Wheel
MoD	Mode of Delivery

Supplementary Information

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Additional file 1: PRISMA 2020 checklist.

Additional file 2: Search strategy.

Additional file 3: Study intervention BCIO and BCT characteristics.

Additional file 4: BCIO data extraction template.

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Authors' contributions
HF conceived and designed the study. HF and EN contributed to Additional file 4. EN, KLC and HF contributed and data analysis. EN, KLC and WM played a supervisory role in the review and editing of the manuscript. All authors provided input into the final version of the manuscript.

Author's information
The research team are academics with a range of backgrounds in behavioural science, health psychology and sociology.

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