Review

Evaluation of the Aspects of Digital Interventions That Successfully Support Weight Loss: Systematic Review With Component Network Meta-Analysis

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Abstract

Background: Obesity is a chronic complex disease associated with increased risks of developing several serious and potentially life-threatening conditions. It is a growing global health issue. Pharmacological treatment is an option for patients living with overweight or obesity. Digital technology may be leveraged to support patients with weight loss in the community, but it is unclear which of the multiple digital options are important for success.

Objective: This systematic review and component network meta-analysis aimed to identify components of digital support for weight loss interventions that are most likely to be effective in supporting patients to achieve weight loss goals.

Methods: We searched MEDLINE, Embase, APA PsycInfo, and Cochrane Central Register of Controlled Trials from inception to November 2023 for randomized controlled trials using any weight loss intervention with digital components and assessing weight loss outcomes in adults with BMI ≥25 kg/m^2 (≥23 kg/m^2 for Asian populations). Eligible trials were prioritized for synthesis based on intervention relevance and duration, and the target population. Trial arms with substantial face-to-face elements were deprioritized. Prioritized trials were assessed for quality using the Cochrane Risk of Bias Tool v1. We conducted intervention component analysis to identify key digital intervention features and a coding framework. All prioritized trial arms were coded using this framework and were included in component network meta-analysis.

Results: Searches identified 6528 reports, of which 119 were included. After prioritization, 151 trial arms from 68 trials were included in the synthesis. Nine common digital components were identified from the 151 trial arms: provision of information or education, goal setting, provision of feedback, peer support, reminders, challenges or competitions, contact with a specialist, self-monitoring, and incentives or rewards. Of these, 3 components were identified as “best bets” because they were consistently and numerically, but not usually significantly, most likely to be associated with weight loss at 6 and 12 months. These were patient information, contact with a specialist, and incentives or rewards. An exploratory model combining these 3 components was significantly associated with successful weight loss at 6 months (–2.52 kg, 95% CI –4.15 to –0.88) and 12 months (–2.11 kg, 95% CI –4.25 to 0.01). No trial arms used this specific combination of components.

Conclusions: Our findings indicate that the design of digital interventions to support weight loss should be carefully crafted around core components. On their own, no single digital component could be considered essential for success, but a combination of information, specialist contact, and incentives warrants further examination.

Trial Registration: PROSPERO CRD42023493254; https://tinyurl.com/ysyj8j8s

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KEYWORDS

systematic review; component network meta-analysis; obesity; digital interventions; digital technology; weight loss; PRISMA

Introduction

Background

Obesity is a complex chronic disease associated with increased risks of developing life-limiting and life-threatening conditions, including cardiovascular disease, stroke, and type 2 diabetes [1]. It is a growing global health problem, with the number of obese adults across the world more than doubling since 1990 [2]. This is reflected in the rising prevalence of obesity in the United Kingdom, with 27% of adults in England considered obese in 2017 [3], and this proportion is expected to rise to 35% by 2030 [4].

Weight loss interventions center on lifestyle and behavioral approaches to reduce calorie intake or increase physical activity, pharmacological treatment, and bariatric surgery [5]. Digital technology may be leveraged to support patients with weight loss by providing key motivational features to improve adherence to interventions and sustain weight loss. Digital interventions may offer more coverage, flexibility, and sustainability in service provision and require less resources than face-to-face services.

There is an abundance of literature on the use of digital technology to support weight loss interventions, with several systematic reviews evaluating the effectiveness of interventions using mobile phones (or "mHealth") or other electronic (or "eHealth") and digital technologies to lose weight (eg, [6-13]).

This abundant and varied evidence, with equivocal findings, provides both a challenge and an opportunity. The challenge is to make sense of such a heterogeneous body of evidence and identify consistencies between digital approaches and successful outcomes. The volume and variability of trials in this field provide the opportunity for a dataset with which one can establish patterns between intervention components and trial outcomes. In turn, this can inform the development of more effective and efficient digital tools to support weight loss in the community.

Overall Aim and Objective

The main aim is to identify components of digital support for weight loss interventions that are most likely to be effective in supporting patients to achieve weight loss goals.

The research questions are as follows:

1. What is the breadth and scope of evidence for the effectiveness of weight loss interventions that include digital components?
2. How do we categorize the nature and content of digital components of included interventions?
3. What is the relative effectiveness of different digital intervention components for digitally led weight loss interventions?

Methods

Protocol

The protocol for this review was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO; ID: CRD42023493254).

Search Methods

The search strategy was developed by 2 information specialists (JB and AB) in MEDLINE and translated to other databases. The searches used a combination of relevant controlled vocabulary terms (eg, Medical Subject Headings) and free-text terms. Validated search filters for randomized controlled trials (RCTs) were used for searching MEDLINE [14] and Embase [15]. The search strategies for all databases are shown in Multimedia Appendix 1.

Information Sources

Four bibliographic databases were searched on November 20, 2023: MEDLINE (1946 to current), Embase (1974 to current), APA PsycInfo (1806 to current) via OvidSP, and Cochrane Central Register of Controlled Trials (CENTRAL) (2003 to current) via Wiley Cochrane Library. The databases were searched from inception with no date or language restrictions. Search results were downloaded into EndNote (Version 20; Clarivate Analytics) and deduplicated. Forward and backward citation chasing of prioritized reports was conducted in Scopus (1788 to present) and Citationchaser [16]. The results of citation searching were deduplicated using Systematic Review Accelerator [17], downloaded into EndNote, and deduplicated against the database search results. Finally, a simple search of the terms "trial" and "random" in the title and abstract fields was carried out to identify relevant papers for full-text screening.

Inclusion and Exclusion Criteria

The below inclusion and exclusion criteria according to the PICO (population, intervention, comparator, and outcome) framework were applied to the identified records.

Participants or Population

All participants were required to be adults (18 years or older) with a BMI of ≥25 kg/m^2 (or ≥23 kg/m^2 for Asian populations). We excluded trials where participants were recruited from specialist or tertiary settings (eg, hospital or inpatient clinics) or where individuals with specific comorbidities (eg, hypertension and diabetes) were targeted for recruitment.

Intervention

Any type of weight loss intervention was eligible, so long as there was a digital component associated with its delivery and it was not delivered as part of secondary or tertiary care weight loss management. Following the definition adopted by Chan et al [18], we defined "digital" intervention components as follows: interventions that are delivered (either in part or full) via an

online platform (eg, website, web application, and online forum), a computer or smartphone ‐ based platform (eg, mobile app, SMS text message–based intervention, and game), or an electronic device of any type. Interventions were required to explicitly target people with obesity or those who were overweight.

Comparator or Control

Any comparator was eligible.

Outcome

A measure of weight loss, such as absolute or percentage change in body mass or BMI from baseline, was required for inclusion. Outcomes must have been collected at least 6 months (approximately 24 weeks) after baseline assessment.

Study Design

Only RCTs and cluster RCTs were eligible for inclusion.

Date Limit

There were no restrictions.

Process for Applying Inclusion Criteria

The title and abstract of each record retrieved by the search were screened by 2 independent reviewers (MN, SF, GJMT, JTC, KB, AB, RA, RW, or LS) to identify records that were clearly irrelevant. The full text of each remaining record was then sought and screened by 2 independent reviewers (MN, SF, GJMT, JTC, KB, AB, RA, RW, LS, or JB) to determine inclusion. Disagreements at each title and abstract stage were not discussed, and instead, full texts were sought. At full-text screening, disagreements were resolved through discussion and group consensus. Articles excluded at the full-text screening stage were coded to indicate the first reason for exclusion.

Critical Appraisal

Risk of bias was assessed with the Cochrane Risk of Bias Tool v1 [19]. Appraisal was conducted by one reviewer (RA) and checked by a second reviewer (RW), with disagreements resolved through discussion. The results of critical appraisal informed the discussion of evidence.

Data Extraction

Key information was extracted from included trials by one reviewer and checked by a second reviewer (MN, SF, JB, RA, or GJMT). Discrepancies in extracted data were highlighted and resolved to ensure accuracy. Data were extracted in relation to the following variables to provide an overview of the studies included in the synthesis: study details (author names, title, and date of publication), study aims (stated aim and intervention focus), funding and conflict of interest information, sample characteristics (sample size, age, female percentage, BMI, ethnicity, relevant comorbidities, etc), and outcomes (all categories of outcomes reported).

Sample characteristics relating to age, ethnicity or race, socioeconomic status, and gender or sex were discussed in the context of PROGRESS Plus, a framework used to help draw out the consideration of equity characteristics within research design and analysis [20]. PROGRESS stands for place of residence, race/ethnicity/culture/language, occupation, gender or sex, religion, education, socioeconomic status, and social capital. “Plus” represents other factors associated with discrimination, exclusion, marginalization, or vulnerability, such as personal characteristics, relationships that limit opportunities for health, and environmental situations that provide limited control of opportunities for health. Additional information was extracted to allow description and categorization of the trial arms, as detailed in the synthesis section.

Outcome data were extracted by one reviewer (GJMT) and checked by another (RA). We sought effect sizes (or data to allow their calculation) for weight loss at time points around 6, 12, and 24 months (or longer) from the start of the trial, where available. When multiple estimates of the same effect were provided, we preferred the most complete set of estimates available, extracting imputed estimates over completer-only analyses. We preferred multiple imputation-based estimates over simpler methods but treated multiple imputations using missing not at random models as sensitivity analyses, where these were presented. We preferred model-based estimates of mean differences over simple differences computed from means and SDs, and we preferred model-based estimates of SEs. Where necessary, we estimated SEs of mean differences using the exact *P* values provided. Failing this, we constructed SEs using available data on means, group-specific SEs or SDs, and sample sizes. The only exception to this was in cluster trials with incomplete presentation of outcome data, where we used approximate *P* values to construct SEs for mean differences (eg, [21]).

Synthesis

The synthesis involved a narrative description of studies, intervention component analysis (ICA), and component network meta-analysis (NMA).

Prioritization

To optimize the validity of the synthesis, we focused on interventions that were predominantly digital, thereby reducing the number of unknown nondigital variables that would not be coded.

ICA Process

ICA was conducted to identify key features of interventions that would be carried forward to the component NMA. ICA is an inductive approach that facilitates the identification of critical features of an intervention [22]. ICA is appropriate when dealing with heterogeneous and potentially poorly described interventions, attributing significance to common features without the constraint of “fitting” components to established behavior change taxonomies [22,23].

The ICA process involved the following key stages:

- Two reviewers (MN and SF) selected 10 diverse but well-described interventions from the included papers and independently extracted and categorized key components, using “open coding.”
- The reviewers compared and combined component lists, identifying a tentative set of codes.

- Using axial coding (ie, considering relationships between identified components), the reviewers independently coded the remaining interventions.
- The reviewers met at regular intervals to compare categories, adding or collapsing them as necessary. Further meetings with the review team and members of PERSPEX took place to sense check axial coding and overall categories.
- A final list of intervention component descriptors was produced, using findings from axial coding to organize codes hierarchically (eg, peer support, with axial codes relating to Facebook, chat function, etc).
- All trial arms in the included studies were coded using the intervention component descriptors, with coding checked by a second reviewer (MN or SF).

Intervention component descriptors were tabulated and described with examples. The coded trial arms were taken forward to the component NMA.

Component NMA

We considered effectiveness on weight loss outcomes using random effects component NMA in a frequentist paradigm, which was implemented using the package *netmeta* in R [24]. We used the component codes (R codes can be found in Multimedia Appendix 2) developed through ICA in an additive model and estimated meta-analyses based on the quality and sufficiency of evidence, focusing on 6-month and 12-month outcomes. We considered heterogeneity over each evidence network but were unable to compare model fit to a standard NMA model due to the complexity of the component scheme. To identify "best bet" components, we examined components that within a given outcome had numerically positive effects at both time points and that had similar patterns of benefits over all included outcomes. Because of the nature of component NMA, we were unable to test for the presence of publication bias.

Patient and Public Involvement and Engagement

This review benefited from several interactions with PERSPEX, a group of 17 public collaborators who bring their carer, patient, or public perspective to the work of Isca Evidence. PERSPEX members meet monthly online, and membership is culturally, geographically, and demographically diverse [25].

PERSPEX contributed substantially to this review throughout the process. The review topic was first discussed at the August 2023 PERSPEX meeting. Members shared their knowledge of digital support and highlighted digital exclusion and health inequality as areas of concern. Feedback was then sought on the protocol; members could choose to either view a video summary of the draft protocol or read a text-based, plain English version. This led to changes to increase clarity and improve readability. In addition to the protocol summaries, PERSPEX reviewed the search strategy by reading an initial version and making suggestions for additional search terms. PERSPEX provided further input in the early synthesis by reviewing the initial categories identified as part of the ICA (allocated by the review team) to describe the different ways that digital technologies were used within the included studies.

Ethical Considerations

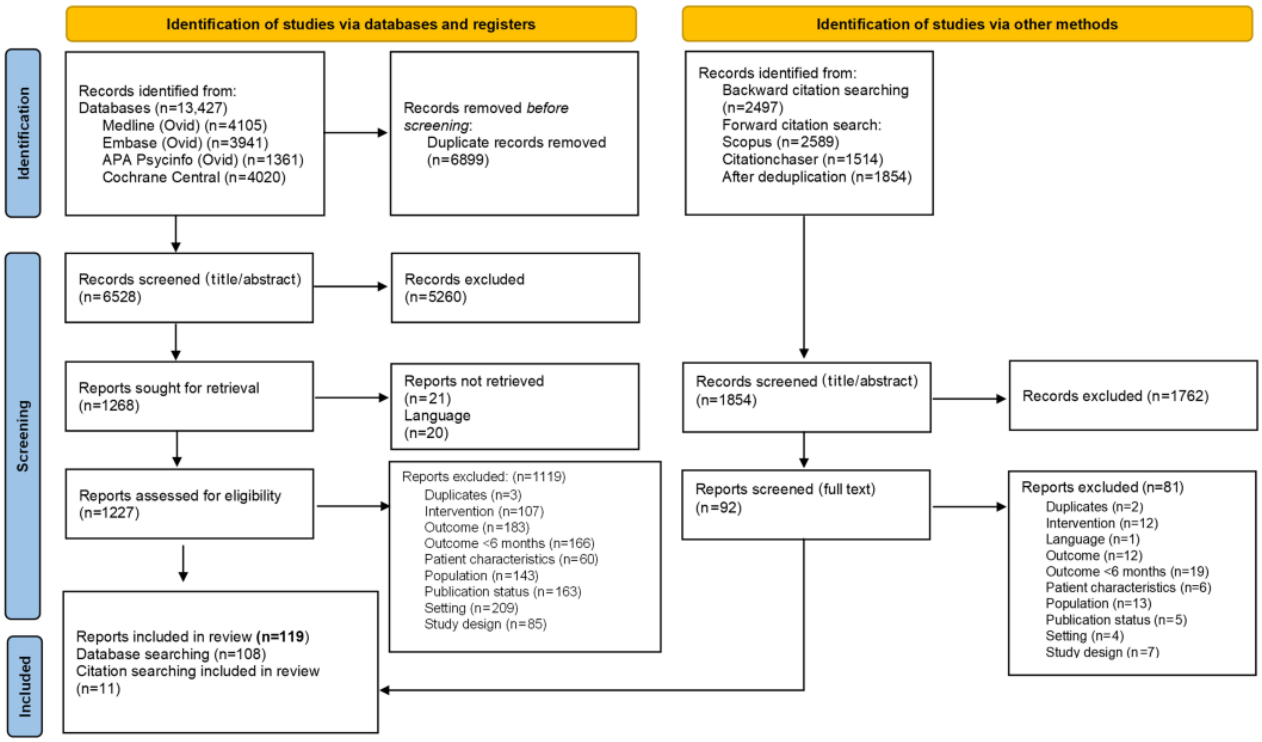
No ethical approval was required for this project, which exclusively involved secondary analysis of data. To incorporate a diverse range of experiences and views into this work, the research team drew upon the knowledge and expertise of the PERSPEX team throughout the conduct of this review. The PERSPEX team represents individuals living with a range of health conditions, who have different communication preferences. Hence, the research team used a variety of modes of communication to engage with the group, including face-to-face verbal updates and plain-language protocols. During this review, we were not required to handle any personal information.

Results

Study Selection

Figure 1 depicts the study selection process and summarizes reasons for exclusion at full-text screening. Bibliographic searches identified 6528 records after deduplication. After title and abstract screening, 1268 (19.4%) references were taken forward and screened at the full-text stage. This led to the exclusion of 1147 reports, with setting (209 reports, 18.2%), outcome (183 reports, 15.9%), no measurements at 24 weeks or beyond (166 reports, 14.4%), and publication status (163 reports, 14.2%) being the most common reasons for ineligibility. Citation chasing identified a further 1854 records after deduplication, of which 92 (4.9%) records were taken forward to full-text screening, and 11 (0.6%) were included in the review. In total, 119 reports from 99 studies were eligible for inclusion. Further prioritization of studies, based on trial arm characteristics, was performed (ICA), and 68 trials were prioritized for full synthesis.

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart summarizing the results of the literature search and screening for eligibility.



Sample Characteristics

Multimedia Appendix 3 provides information about the 68 prioritized studies. Of the 68 studies, 36 (53%) were conducted in the United States [21,26-66], 8 (12%) in Australia [67-77], 7 (10%) in the United Kingdom [78-88], 5 (7%) in Germany [89-93], 3 (4%) in Finland [94-96], 2 (3%) in the Netherlands [97-100], and 1 (1%) each in Denmark [101-103], Brazil [104], Switzerland [105], Spain [106], Canada [107], Republic of Korea [108], and Latvia [109].

The interventions evaluated were predominantly aimed at weight loss (52/68, 76%), with others aiming to promote weight maintenance (7/68, 10%) [27,28,36,48,68,77,88,97] or physical activity (1/68, 1%) [107]. Moreover, 8 (12%) studies reported multiple aims, including weight loss and increased physical activity (1/68, 1%) [105], weight loss and disease risk reduction (5/68, 7%) [39,71,72,92,96,109], increased physical activity and disease risk reduction (1/68, 1%) [42], and cost-effectiveness outcomes alongside weight loss (1/68, 1%) [83]. The number of randomized participants per study ranged from 28 [29] to 1386 [98-100]. The mean age of participants ranged from 21.8 years [108] to 58.0 years [61], and the female percentage ranged from 0% (n=7) [38,52,73-77,79,80,107] to 100% (n=10) [26-29,41,42,57,65,66,70,108]. Mean BMI ranged from 28.0 kg/m^2 [97] to 46.6 kg/m^2 [29].

Of the 68 studies, 25 (37%) reported no conflicts of interest to disclose [27-32,34,35,37,38,42,45,54,57,59,62,68-76,81-83,96,105-107,109,110], 8 (12%) did not report this information [26,58,64-66,77,97-100], and 35 (51%) reported some conflicts of interest. Moreover, 67 (99%) studies reported funding sources, with 10 (15%) being funded by an organization directly linked to the diet industry [32-35,59,60,89,108], pharmaceutical industry [56], or other business or commercial sectors [53,56,67,68]. Conversely, 3 (4%) studies did not receive external funding [71,72,101-103,106].

PROGRESS-Plus Data

All 68 prioritized studies reported the age and gender or sex of their study populations, 38 (56%) reported race or ethnicity [21,26-28,30-38,40-65,78-80,83-87], 49 (72%) reported education attainment [21,26-28,30-35,37,38,40-52,55-65,67-70,73-81,84-89,93-95,97-102,107], 19 (28%) reported employment [21,27,28,30-35,37,38,42,43,51,57,63,69,77-80,86-89,101,102,105], 4 (6%) reported occupation [37,63,73,74,78], 18 (26%) reported income [27,28,30,31,38,41,42,44-46,48,51,57,67,68,70,75-77,88,107], 5 (7%) reported a deprivation or poverty score [27,28,79-81,86,87], 2 (3%) reported a socioeconomic status score [75-77], and 1 (1%) reported the rural residency of the study population [41]. Of the 68 studies, 16 (24%) specifically targeted a particular gender for recruitment, with 7 (10%) [38,52,73-77,79,80,107] including only men and 9 (13%) [26-29,41,42,57,65,66,70] including only women. Moreover, 1 (1%) had a complete female population, although this was not specified in the inclusion criteria [108]. The inclusion criteria of 3 (4%) studies targeted Black and minority ethnic populations, all of which also targeted women. Furthermore, 1 (1%) study described the intervention as culturally tailored toward African American women [42]. Bennett et al [27] recruited women from health centers with populations that were predominantly racial or ethnic minorities and socially disadvantaged with a low household income [28]. In the study by Steinberg et al [57], recruitment was targeted toward racial or ethnic minority women, and 82% of the recruited population represented non-Hispanic Black women [57]. Additionally, 1 (1%) study recruited women from low-income communities

[26]. In the study by Hageman et al [41], recruitment was targeted toward women from rural communities. Of the 7 (10%) studies that targeted men only, 1 specifically recruited men from a rural community [38]. There were no studies targeting older populations specifically. Some studies had an inclusion age of 18 years or older [40,45,64,65,79-82,84,85,88,98-100], while others had an upper age limit restriction, with the oldest limit being 75 years [105] and the youngest limit being 35 years [46].

Critical Appraisal

The outcome of critical appraisal of prioritized studies is summarized in Figure 2 [21,26-81,83-92,94-102,104-109]. All studies could not blind participants to their allocation due to the nature of the intervention. Taking this into account, 20 of the 68 (29%) studies were considered to be at relatively low risk of bias (1 area of high risk due to blinding of participants with or without 1 area of unclear reporting) [21,31,41,44,46-48,52,54,60,63,70,73-77,81,82, 86-88,91,95]. Some concern for risk of bias (multiple areas of unclear reporting with or without 1 area of high risk due to blinding of participants) was identified in 25 (37%) studies [29,32-35,37,40,45,49,50,53,56-59,61,64-66,71,72,89,90,94,96-100,104,105,109]. Areas that were commonly unclearly reported were allocation concealment (23/68, 34%), blinding of outcome assessment (25/68, 37%), other sources of bias (34/68, 50%), and incomplete outcome data (18/68, 26%). Moreover, 7 (10%) studies did not report their random sequence allocation clearly, and 23 (34%) studies were considered at high risk (more than one area of high risk, including due to blinding). The other areas of high risk identified were blinding of outcome assessment [26-28,36,38,39,42,43,51,55,62,79,80,83-85,92,93,101,102,106,108], incomplete outcome data [69,78,84,85,101,102,107], and other forms of bias [67,68].

Figure 2. Results of risk of bias appraisal of prioritized studies.

ICA Process

Development of the Coding Structure

Categorizing Interventions

The 99 included trials were highly heterogeneous in terms of the trial arms being compared. Our broad approach to the definition of "digital intervention" meant that interventions that were notionally digital and largely delivered face to face could be included in the ICA, but the nondigital components would not be captured. An example of a notionally digital intervention is the in-person group exercise intervention with email feedback or the "Football Fans In Training" intervention evaluated by Wyke et al [111], which is almost exclusively delivered face to face, with a pedometer used to facilitate activity self-monitoring. The main active ingredients of this intervention would not be captured by our ICA. By contrast, many interventions were fully or primarily digital in their delivery. As our focus was on the effect of digital components of interventions on overall effectiveness, we opted to filter out trial arms that heavily involved face-to-face interactions. We coded trial arms as digital only, digitally led, notionally digital, face-to-face, treatment as usual (TAU), TAU+, or waitlist control, as follows:

- Digital only: Trial arm received content wholly via digital means. This could refer to a single digital component or a combination of digital approaches. No face-to-face delivery of content occurred, but this definition allows for a baseline in-person contact to set-up digital components or in-person assessment visits.
- Digitally led: Trial arm received content primarily via digital means. Nondigital elements, such as an occasional peer-group meeting and face-to-face advice visit, were eligible for inclusion, but these additional nondigital components were supplementary to the main delivery mode of the intervention.
- Notionally digital: Trial arm received content primarily through in-person contact. Digital components might have been involved in content delivery, but these were supplementary to the main approach.
- Face-to-face: Trial arm received only in-person content, either as a group or as individuals.

- TAU (sometimes called usual care): Trial arm may or may not have received limited, often freely available, printed diet, physical activity, or lifestyle information.
- TAU+: Trial arm received nondigital "intervention" information (eg, printed intervention manual). No face-to-face counseling or advice was provided, but the information provided was beyond usual care.
- Waitlist control: Trial arm received nothing other than what it would have normally received.

For inclusion in ICA, studies were required to have trial arms comparing any of the following categories: digital only, digitally led, TAU, TAU+, and waitlist. This approach removed comparisons where our focus on digital component coding would fail to recognize the presence of significant nondigital intervention components. Coding identified 39 of 233 (16.7%) arms as notionally digital and 23 (9.9%) as face-to-face, leaving 68 trials (from 84 papers) and 151 (64.8%) arms for inclusion in the ICA (down from 99 studies and 233 trial arms). Multimedia Appendix 4 lists the trials or arms that were not carried forward because they were notionally digital or primarily face-to-face.

Describing Intervention Components

During the multiple rereading of interventions to determine their approach, key characteristics emerged that would form the basis of the ICA coding framework. Despite using an array of digital technologies, all interventions targeted behavior change using similar categories of approaches: provision of information or education, goal setting, provision of feedback, peer support, reminders, challenges or competitions, contact with a specialist, self-monitoring, and incentives or rewards.

These categories were identified from the included trials after initial discussion among reviewers (MN and SF) and subsequent discussion with the wider research team. Categories were discussed with PERSPEX to check sense and to identify categories that might be missing or that could be collapsed. These discussions led to the addition of the "incentives or rewards" category and consideration of whether the intervention was tailored or customized in any way for participants. We also coded whether the intervention more broadly targeted diet, exercise, or both, and whether any face-to-face components were delivered individually or in groups. Table 1 provides a description of digital components, with examples and the frequency of each component among the 151 trial arms.

Table 1. Descriptions, examples, and frequencies of digital components of interventions.

Component	Description	Examples	Frequency (N=151), n (%)
Self-monitoring	Participants tracked their own physical activity, dietary intake, or anthropometric measurements (usually weight). This was typically performed using smartphone apps linked to a fitness tracker or by logging in to web-based platforms, but could also be completed using emails or via online consultation.	• Self-monitoring smartphone app (Eisenhauer et al [38]; page 3): "received a premium version of a commercially available weight loss app (Lose-It!, FitNow Inc., Boston, MA) that allowed for real-time self-monitoring of eating and activity" • Provision of digital tools to facilitate self-monitoring (LaRose et al [46]; page 4): "Participants received digital tools (self-monitoring app and wireless scale) to facilitate self-monitoring" • Self-monitoring using a website (Womble et al [66]; page 1013): "[it was recommended to] log on daily to eDiets.com and to record food intake daily during the first 16 weeks"	103 (68.2)
Information or education	Participants received educational information in relation to diet, exercise, weight loss, or general well-being. Most commonly, this was provided via websites, email newsletters, or videos. Participants may receive access to a source of information to sample at their leisure (eg, website or smartphone app) or receive more structured sessions (eg, podcasts, text messages, and webinars).	• Website providing educational content (Hutchesson et al [70]; Table number 1, page 3): "Resources provide advice on weight loss, general healthy eating and physical activity, and the 10 Steps to Success" • Information delivered by text message (Eisenhauer et al [38]; page 3): "The [intervention] group also received one-way text messages containing content on healthy eating and physical activity" • Information provided by a podcast (Dunn et al [37]; page 1527): "Podcasts included behavioral weight-loss techniques based on Social Cognitive Theory and the Diabetes Prevention Program"	99 (65.6)
Feedback	Participants received feedback on any aspect of the intervention or progress toward goals. This could be delivered using a variety of media, with email and text messaging being the most common, and smartphone and web-platform messages were also widely used. Message content was usually in relation to self-monitoring data and could be automated or bespoke.	• Feedback via email (Hutchesson et al [70]; Table number 1, page 3): "Participants received automated personalized email feedback from their accredited practising dietitian…focusing on: setting a realistic weight loss goal, their energy requirements for weight loss, and their current eating behaviours and physical activity levels compared to the 10 Steps to Success" • Use of email for feedback (LaRose et al [46]; page 4): "Participants received…weekly tailored, written feedback via email on goal progress" • Multimodal feedback in response to self-monitoring (Gemesi et al [89]; page 119): "According to the data entered by the users, automated feedback was generated in form of weight trajectory curves, reminders (e.g. to enter the current weight at least once a week), motivating notifications, and interpretations (e.g. which food categories are under- or over-represented in the diet)"	74 (49.0)
Goal setting	Participants set goals for any intervention component or outcome, such as weight loss, physical activity, or diet, over any time period. This was most commonly performed via smartphone apps and web-based platforms. Initial goals were usually set at the beginning of the intervention but could relate to daily, weekly, monthly, or longer time points and require revisiting as necessary.	• Goal setting using a web-based platform (Thomas et al [61]; page 589): "The [Weight Watchers] programme focused on the use of a points system to track dietary intake relative to a daily goal in order to produce an energy deficit and increase dietary quality. The daily points goal was personalized based on sex, age, starting weight and activity level" • Goal setting using a smartphone app (Gemesi et al [89]; page 119): "participants could set their daily/weekly goals by choosing ones suggested by the app or by choosing self-appointed ones" • Website and app providing support for goal setting (Simpson et al [86]; Fig 3, page 13): "Encourage and provide support for goal-setting, action-planning and problem-solving"	72 (47.7)
Reminders	Participants received reminders to complete tasks related to the intervention, such as to log or submit data (self-monitoring), perform exercise, or attend sessions. These may typically be sent through emails, text messages, and notifications from a smartphone app or website.	• Use of HTML newsletters sent via email to act as a reminder (Hutchesson et al [70]; Table number 1, page 3): "…reminded participants to complete other program tasks (e.g., quiz, self-monitoring, and goal setting)" • Use of a smartphone app to provide reminders (Patel et al [51]; Table number 1, page 3): "In-app automated reminders to track diet and/or weight sent daily" • Use of text messaging to provide reminders (Joseph et al [42]; page 5): "Text messages included inspirational quotes, reminders, and tips for how to increase daily [physical activity]"	54 (35.8)

Component	Description	Examples	Frequency (N=151), n (%)
Peer support	Peer support involved contact with other participants, intervention deliverers, and nominated partners or "buddies" and usually occurred via messaging services, such as WhatsApp or SMS text messaging, email, or social media groups like Facebook.	• Use of social media to provide peer support (Hutchesson et al [70]; Table number 1, page 3): "Participants joined a private Facebook group and followed a private Instagram account using their personal account" • Discussion forum hosted on a website (Hageman et al [41]; Table number 1, page 4): "Discussion board: Peer-led asynchronous discussion with weekly primers posted by peer" • Buddy system facilitated by email (Tate et al [59]; page 1621): "A weight loss e-buddy network system that enabled users to match themselves with other persons in the United States with similar characteristics and act as peer support for weight loss via e-mail"	50 (33.1)
Specialist contact	Participants had contact with a trained expert, for example, a dietitian, nutritionist, or psychiatrist. This may have been to discuss progress, revise goals, or provide education. Typically, contact was via email, chat functions, or online meeting platforms such as Zoom.	• Email contact from a specialist (Leahey et al [48]; page 4): "Each week participants…emailed the self-monitoring data to their professional coach (a registered dietitian with training in behavioral weight control), they received an email from their coach providing social reinforcement (support, encouragement)" • Specialist contact facilitated by chat or video-based digital methods (West et al [65]; page 515): "Groups met online for 1 hour each week in a text - based or video - based synchronous chat session facilitated by an experienced behavioural weight control counsellor" • Specialist contact via email (Hutchesson et al [70]; Table number 1, page 3): "Participants received automated personalized email feedback from their accredited practising dietitian (APD) focusing on: setting a realistic weight loss goal, their energy requirements for weight loss, and their current eating behaviours and physical activity levels" • Semiautomated email contact with primary care physicians (Tate et al [21]; page 5): "In the portal, [primary care providers] could view and edit the default messages for 6 days, after which messages were sent to the patient"	27 (17.9)
Competition or challenge	Competitions, challenges, or games were used within the intervention as extra games or to set short-term goals. Examples include step-based challenges within a smartphone app (eg, Fitbit), hypothetical scenarios, or challenges involving logging food intake for 7 days in a row. Participants may compete with others or by themselves.	• Challenge within a web-based system (Thomas et al [61]; page 591): "The first mini-game asked participants to plan ahead and problem solve to stay under a calorie goal while ordering food from a takeout menu or cooking at home" • Challenge provided through an app (Kim et al [108]; page 5): "Weekly group missions were provided to the digital CBT group based on the expectation that social supports (eg, communicating needs and building positive support) would intensify the motivation"	15 (10.0)
Incentive or reward	Digital incentives or rewards were offered either as an explicit component of the intervention or in relation to progress toward goals (eg, virtual "badges" for achievements). Incentives could be facilitated using digital means, for example, a digital "bank," or could be linked to peer support and challenges (social incentives).	• Virtual reward (Tate et al [21]; page 17): "Progress page where participants could view graphs of their weight, diet, and exercise, view progress toward their goals, and receive virtual badges for achieving weight loss milestones" • Virtual reward (Simpson et al [86]; Table number 46, page 137): "In-app reward of medals/trophies for regular login and progress" • Virtual bank (Leahey et al [47]; page 4): "If participants completed all reporting, they earned a maximum of $45 during the entire program. The SII website included a "bank" which displayed the participant's previous week's earnings and total earnings" • Social incentive (Kurtzman et al [44]; page 1670): "every Monday, the team was endowed with 70 points… Each day, the team was informed of the one member who was selected at random to represent their team. If that member weighed in on the prior day… the team kept its points; otherwise, 10 points were lost" • Social reward (Leahey et al [48]; page 4): "Each week participants self-monitored their weight and the prescribed diet or activity behavior for at least 5 days, and emailed the self-monitoring data to their professional coach…they received an email from their coach providing social reinforcement"	10 (6.6)

ICA Findings

Multimedia Appendix 5 shows how the 151 trial arms were coded. Of the 151 trial arms, 90 (59.6%) were digital only, 28 (18.5%) were digitally led, 12 (7.9%) were TAU+, 10 (6.6%) were TAU, and 11 (7.3%) were waitlist. Most arms (130/151, 86.1%) targeted diet and exercise, with 7 (4.6%) targeting diet alone [37,39,81,82,108] and 5 (3.3%) focusing on physical activity alone [42,105,107]. In 3 (1.9%) trial arms from the same study, the intervention targets were unclear [79,80], and in 1 (0.6%), the focus was on general health and well-being [42]. While all prioritized studies included a weight loss outcome at 6 months or beyond, intervention durations ranged from 14 days [105] to 24 months [32,34-36,104,110]. The median intervention duration was 6 months (mean 8.4, SD 5.4 months). There were 8 (12%) trials with more than two included arms [41,48,51,71,72,78-80,90,96].

A tenet of all interventions was to achieve a certain amount of weight loss, reduce calories by a certain amount, or increase activity to a certain level, and as such, all included goal setting to some extent, whether as a social process or an intervention activity, and it was made explicit or facilitated with digital technologies. We coded digitally facilitated goal setting as an intervention exercise. Websites and web-based platforms were the most common approaches for this, featuring in 31 of 151 (20.5%) trial arms. Applications, predominantly for use with a smartphone, were adopted in 24 (15.9%) trial arms. Goal setting was often conducted during initial consultation and orientation, where this occurred, and therefore, it could have been completed in-person. Goal setting and revision, and checking against progress could be completed quickly and easily using a digital platform. For example, in the study by Kurtzman et al [44], baseline weight was entered and a target based on 6% or 8% weight loss was provided. Smartphone apps offer similar and arguably more convenient functionality, with Eisenhauer et al [38] demonstrating that they facilitated the engagement of men from rural communities in a weight loss program owing to their ease of use with respect to goal setting (and provision of real-time feedback).

The use of other technologies was often linked with achieving goals. For example, reminders were often in relation to meeting targets for diet or exercise, or to completing self-monitoring, which itself was usually conducted to measure progress against goals. Incentives were provided, and competitions or challenges were designed with goals in mind. Feedback frequently focused on progress in relation to goals. Only the provision of broader information and educational content was less explicitly about achieving goals, although it was still linked to the overall goal of achieving weight loss.

The linked nature of components was emphasized by the fact that only 7 of 151 (4.6%) intervention arms (not counting trial arms designated as comparators by study authors) from 5 (7%) studies [71,78,90,91,109] were coded as having a single digital component. This was unsurprising because of the abundant literature highlighting the importance of multiple behavior change techniques in weight loss interventions. Furthermore, in many cases, a single digital device or technology was able to provide multiple components of the intervention. For example, smartphone apps facilitated three or more components in 18 (26%) trials [37-39,42,44,45,51,60,61,69,72,78,86,87,89,92,93,95,101,102,108], and this was the case in 17 (25%) trials using websites [21,41,47,49,50,52,59-61,64,65,70,73,79,80,83,96,97,101,102,112] and in 7 (10%) trials using web-based platforms [36,40,61,66-68,104].

Component NMA

We estimated component NMA models for absolute weight loss, absolute change in BMI, weight loss expressed as a percentage of baseline weight, and responders (defined as the proportion achieving more than 5% weight loss from baseline). Model diagnostics are presented in Multimedia Appendix 6. Meta-analyses varied in size from 43 trials for absolute weight loss at 6 months to 14 trials for absolute change in BMI at 12 months. Across the main analyses, heterogeneity was as expected, ranging from an I^2 of 30.1% for change in BMI at 12 months to 61.1% for absolute weight loss at 6 months. Analyses for weight loss expressed as a percentage of baseline weight are presented as exploratory given the high levels of heterogeneity relative to the richness of the data structure. All extracted effect sizes can be found in Multimedia Appendix 7.

Because of the data structures of each evidence network, we were unable to compare model fit to standard combination-based NMA models, meaning we were unable to formally assess for the presence of inconsistency. However, heterogeneity estimates in every case were lower than those from pairwise meta-analyses of interventions against TAU, indicating that inconsistency would be unlikely to threaten the validity of our analyses. Goal setting could only be evaluated as a component at 12 months for the absolute weight loss outcome given its co-occurrence with other components in our meta-analyses.

Findings from meta-analyses are presented in Figures 3-5 (see Multimedia Appendix 8 for meta-analyses of weight loss as a percentage of baseline weight). In analyses for absolute weight loss (Figure 3), the only component linked to a statistically significant effect was specialist contact, which was associated with weight loss of 1.08 kg (95% CI 0.17-1.99) at 6 months. A similar effect was in the evidence for this component in weight loss as a percentage of baseline weight (–2.21%, 95% CI –3.64 to –0.78; Multimedia Appendix 8). In analyses for BMI (Figure 4), the only component linked to a statistically significant effect was information, which was linked to a BMI loss of 0.59 (95% CI 0.06-1.12) at 6 months. Feedback was the only component linked to a significant increase in the odds of achieving at least 5% weight loss (odds ratio 1.68, 95% CI 1.09-2.59) at 6 months (Figure 5), but the estimate of the effect at 12 months suggested some numerical, but not statistical, evidence of harm.

Figure 3. Component network meta-analysis of digital components of interventions for absolute weight loss at 6 and 12 months. ES: effect size.

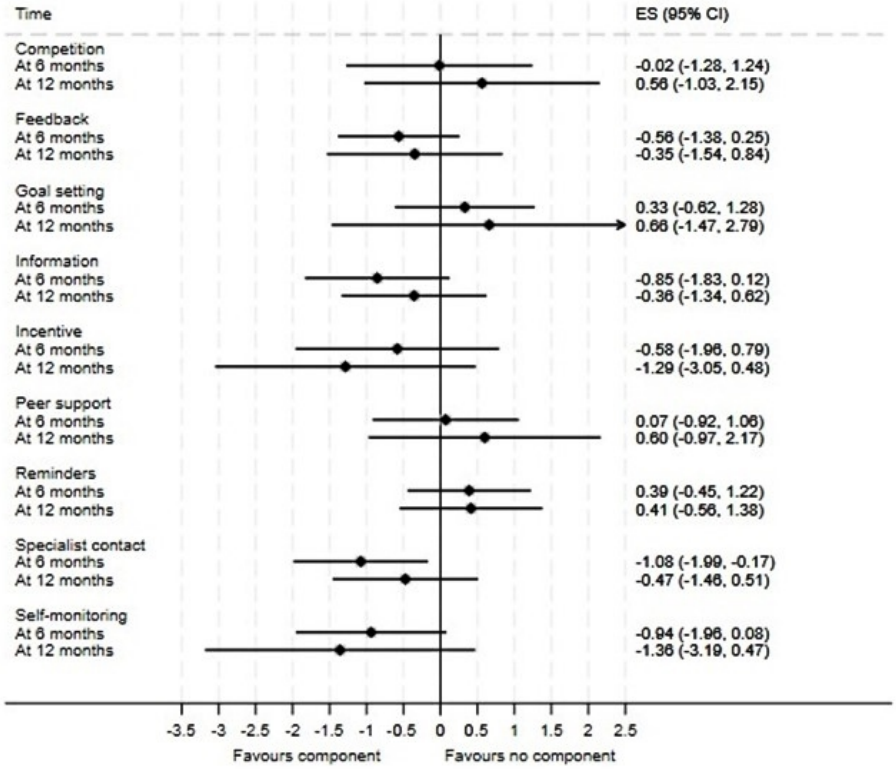


Figure 4. Component network meta-analysis of digital components of interventions for change in BMI at 6 and 12 months. ES: effect size.

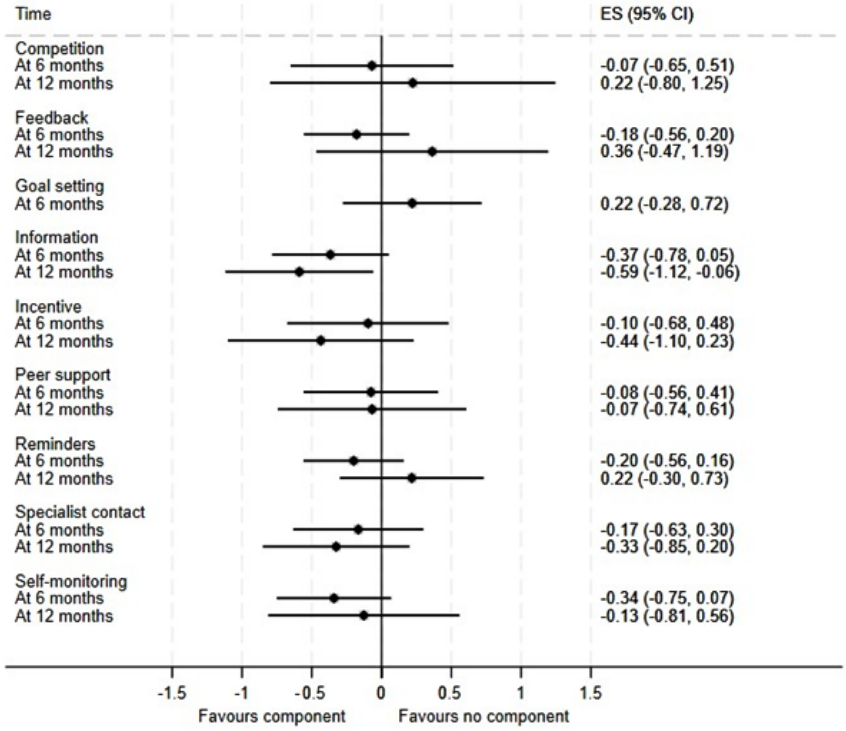
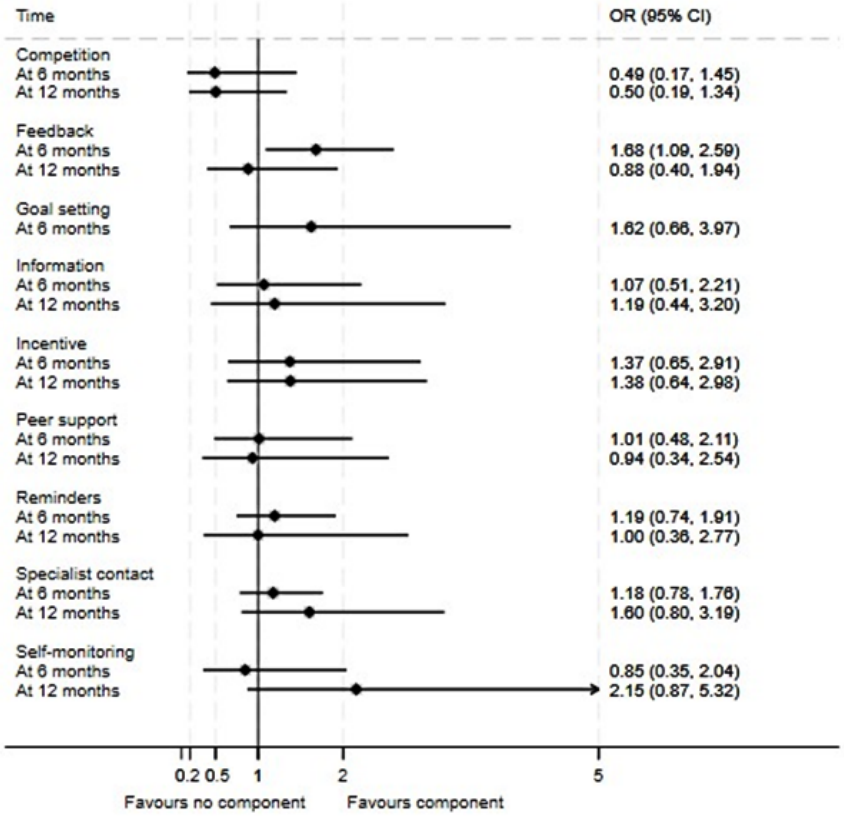


Figure 5. Component network meta-analysis of digital components of interventions for participants achieving 5% weight loss at 6 and 12 months. OR: odds ratio.



Reading across outcomes, 3 components emerged as the best bets: information, incentives or rewards, and specialist contact. Each of these components had numerically beneficial effect estimates in every meta-analysis model. An exploratory random effects meta-analysis modeling the potential effectiveness of an intervention comprising these 3 components alone suggested significant short-term impacts on absolute weight loss (–2.52 kg, 95% CI –4.15 to –0.88), indicative long-term impacts on this outcome (–2.11 kg, 95% CI –4.25 to 0.01), and significant effects for BMI loss at 12 months (–1.35, 95% CI –2.40 to –0.30) but not 6 months (–0.63, 95% CI –1.38 to 0.11). However, no trial arms used this specific combination of components.

Discussion

Principal Findings

This review is the first to investigate which digital components of weight loss interventions are associated with successful weight loss. After deprioritizing trials not evaluating predominantly digital interventions, we focused on 68 trials, roughly equally categorized as those that had low risk of bias, those that had some concern over risk of bias, and those that had high risk of bias. We performed ICA on 151 trial arms from the 68 studies with data from over 14,500 participants to identify the key digital components of interventions. We then conducted component NMA to ascertain which of the components were associated with successful outcomes.

The ICA identified 9 components facilitated by digital technology: goal setting, self-monitoring, peer support, reminders, feedback, specialist contact, information or education, competitions or challenges, and incentives or rewards. These components were delivered or facilitated by a range of digital technologies, with websites, web-based platforms, apps (ie, for smartphones), SMS text messages, and emails being the most common.

The component NMA showed that no single digital component stood out as being singularly linked to effectiveness at 6-month or 12-month time points, but there were 3 “best bet” components that were consistently associated with favorable, but not usually statistically significant, point estimates across outcomes. These were provision of information or education, specialist contact, and incentives or rewards. An exploratory analysis modeling the potential effectiveness of an intervention comprising these 3 components alone suggested significant 6-month impacts and indicative 12-month impacts on absolute weight loss, with a significant reduction in BMI at 12 months.

It is unsurprising that a single digital component did not stand out as being crucial for weight loss interventions. All 9 components have appropriate underpinnings from behavioral science that would suggest their effectiveness, but there are also reasons why they (or their digital versions) may have limited impacts. Goal setting is likely a valuable approach for weight loss. For example, Melendez-Torres et al [113] identified directive, provider-led goal setting as an important component of interventions. However, our null findings suggest that a more self-directed approach inherent with digital approaches does not mimic this, but perhaps an approach involving goal setting by or in consultation with a specialist might mimic this. A mix

of complementary components is likely to be the most successful approach.

Our exploratory analysis suggests that a combined approach involving digitally facilitated information, specialist contact, and incentives or rewards may be linked with successful weight loss, though we note that none of our included trial arms used this specific 3-component approach, and thus, we are unable to further validate this proposal with direct evidence.

Websites and web-based platforms, smartphone apps, newsletters, and emails were the most common sources of information provision, and it is logical to conclude that provision of high-quality, on-demand information is beneficial for patients.

Components that employ regular or repetitive participant interaction, such as reminders, automated feedback, and self-monitoring, are likely to fade in effectiveness over time, even when habit formation has occurred. The median intervention duration in this review was comfortably beyond the proposed 66 days suggested to be linked with habit formation [114]. However, motivation and behavior change habits are typically short-lived [115]. Perhaps relatedly, weight loss interventions targeting behavior change frequently see a peak in effectiveness around 6 months, followed by a tendency for weight regain [116].

Our review suggests that interventions combining the 3 digital components of information, specialist contact, and incentives or rewards may lead to weight loss benefits, but trials are needed. We provide examples of these elements from included trials. The nature (eg, intensity, mode of delivery, timing, etc) of digital interventions combining key components should be investigated. In general, there is a need for more trials of digital interventions to capture longer-term outcome data (beyond 24 months).

Limitations

Although we refined the evidence to include interventions that were wholly or predominantly digitally delivered, we were unable to account for other factors that may have influenced outcomes, such as nondigital intervention versions of the 9 coded components and patient characteristics like age and comorbidities. Our refined approach also led to the elimination of 82 trial arms that were only notionally digital or compared with face-to-face comparators, reducing the data available for synthesis.

The component NMA used coding that captured the presence of a component but not its nature (ie, frequency, intensity, etc). The examples we highlight for each “best bet” component demonstrate variations in delivery, and it can be expected that different modes of delivery will yield variations in effectiveness. As such, further investigation is required to determine the optimal components of future interventions, which may vary between individuals.

Many of the included trials imposed an upper BMI limit of 39.9 kg/m^2 for inclusion into the study (upper range for “obese” patients). Therefore, the needs of patients with severe obesity are not well represented in this review.

We focused on weight loss outcomes, and it was beyond our scope to consider other important health-related or process-relevant outcomes, such as effects on well-being and mental health, or consider the implementation of, engagement with, or adherence to interventions. As such, it must be acknowledged that this work addresses a small part of the weight loss conundrum.

Comparison With Prior Work

Digital self-monitoring, which is one of the intervention components where leveraging technology has the most obvious advantage over analog approaches, was shown in a systematic review to be associated with weight loss [117], but it can have greater benefits when part of a broader weight loss intervention involving specialist contact [118]. Contact with a specialist has previously been shown to complement and enhance the power of other intervention components, such as self-monitoring and goal setting [113,118]. While the provision of contact with specialists has resource implications for weight loss interventions, our findings suggest that digital technology can be leveraged to help facilitate contact between patients and specialists. Examples from trials in this analysis include contact through videoconferencing, removing the need for travel (eg, [26,29]), implementing an embedded forum with contact initiated from either side [104], and using the electronic health record portal to allow primary care practitioners to review progress and provide feedback [36].

Weight regain is a complex and multifaceted phenomenon, influenced in part by behavioral factors (eg, noncompliance, lack of motivation, and waning of newly formed habits) and by the interaction of hormonal and metabolic factors [119]. As such, behavior change interventions may be expected to have limited long-term effectiveness. Weight loss that is maintained for 2 years or longer is likely to be sustained for several years [120,121], but we did not have enough data at 24 months or beyond to be able to explore digital intervention components associated with weight loss at this time point.

Conclusions

Overall, this is the first systematic review exploring which digital components of weight loss interventions are associated with successful weight loss outcomes, using a novel approach combining ICA and component NMA based on 68 trials. Our findings suggest that there are 9 widely used digital approaches in weight loss interventions: goal setting, feedback, self-monitoring, information or education, reminders, contact with a specialist, peer support, competitions or challenges, and incentives or rewards. No single component stands alone as being crucial to intervention success, but there are 3 “best bets” that have effect estimates numerically, but not statistically, linked with successful outcomes. These are information or education, specialist contact, and incentives or rewards. Exploratory modeling suggests that a digital intervention combining these 3 components may be associated with successful weight loss or BMI reduction at 6 and 12 months.

Our findings, drawn from a sizeable body of weight loss RCTs, indicate no consistent association between components of digital support and weight loss outcomes. This report provides

directions for future research in an effort to establish more reliable support. We suggest that further evidence is needed to develop simplified digital interventions to support people with weight loss. These should provide high-quality digital information, should facilitate contact with a specialist (eg, a dietitian), and may include incentives or rewards for progress and intervention compliance. There is a need for such trials to have longer-term follow-up that extends beyond 2 years.

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Authors' Contributions

MN contributed to development of the protocol, engaged in all stages of the review, and led write-up of the manuscript. SF contributed to development of the protocol, engaged in all stages of the review, and wrote sections of the manuscript. RA contributed to development of the protocol, engaged in all stages of the review, and wrote sections of the manuscript. JB contributed to development of the protocol, conducted searches and document retrieval, assisted with data extraction and study selection, managed referencing, and wrote sections of the manuscript. RW contributed to development of the protocol, contributed to study selection and critical appraisal, wrote sections of the report, and critically reviewed the manuscript. LS contributed to development of the protocol, wrote sections of the report, and critically reviewed the manuscript. AB contributed to development of the protocol, oversaw the conduct of searches and reference management, and critically reviewed the manuscript. KB managed engagement with PERSPEX and wrote and critically reviewed relevant sections of the report. JTC contributed to development of the protocol, contributed to study selection, and critically reviewed the manuscript. GJMT oversaw all stages of the project, contributed to development of the protocol, contributed to study selection and data extraction, conducted the component network meta-analysis, critically reviewed the manuscript, and wrote sections of the manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Search strategies for all databases.
[DOCX File , 40 KB-Multimedia Appendix 1]

Multimedia Appendix 2

R Codes for component network meta-analysis.
[TXT File , 3 KB-Multimedia Appendix 2]

Multimedia Appendix 3

Sample characteristics.
[DOCX File , 225 KB-Multimedia Appendix 3]

Multimedia Appendix 4

Trials or trial arms not carried forward to full synthesis.
[DOCX File , 148 KB-Multimedia Appendix 4]

Multimedia Appendix 5

Intervention coding table.
[DOCX File , 327 KB-Multimedia Appendix 5]

Multimedia Appendix 6

Component network meta-analysis model diagnostics.
[DOCX File , 33 KB-Multimedia Appendix 6]

Multimedia Appendix 7

Extracted effect sizes for all trial arms included in the component network meta-analysis.
[DOCX File , 383 KB-Multimedia Appendix 7]

Multimedia Appendix 8

Results of component network meta-analysis for percentage weight loss.
[DOCX File , 92 KB-Multimedia Appendix 8]

Multimedia Appendix 9

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist.
[PDF File (Adobe PDF File), 462 KB-Multimedia Appendix 9]

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Abbreviations

ICA: intervention component analysis
NMA: network meta-analysis
RCT: randomized controlled trial
TAU: treatment as usual

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