Behaviour Change Techniques within Digital Interventions for the Treatment of Eating Disorders: A Systematic Review and Meta-Analysis

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Abstract

Background: Previous systematic reviews of digital eating disorder interventions have demonstrated effectiveness at improving symptoms of eating disorders, however our understanding of how these interventions work and what contributes to their effectiveness is limited. Understanding the behaviour change techniques which are most commonly included within effective interventions may provide valuable information for researchers and developers. Establishing whether these techniques have been informed by theory will identify whether they target those mechanisms of action which have been identified as core to changing eating disorder behaviours. It will also evaluate the importance of a theoretical approach to digital intervention design.

Objective: The aim of this study was to define the behaviour change techniques (BCTs) within digital self-management interventions or minimally guided self-help interventions for adults with eating disorders which have been evaluated within randomised controlled trials (RCTs). It also assessed which of the digital interventions were grounded in theory and the range of modes of delivery included.

Methods: A literature search identified RCTs of digital intervention for the treatment of adults with eating disorders with minimal therapist support. Each digital intervention was coded for behaviour change techniques using the established Behaviour Change Technique Taxonomy (v1); the application of theory using an adapted version of the Theory Coding Scheme and for modes of delivery using the Mode of Delivery Ontology. A meta-analysis evaluated the evidence that any individual BCT moderated effect-size, or that other potential factors such as the application of theory or number of modes of delivery had an effect on eating disorder outcomes.

Results: Digital interventions included an average of 14 BCTs (range 9-18). “Self-monitoring of behaviour” was included in all effective interventions, with “Problem-solving”, “Information about antecedents”, “Feedback on behaviour”, “Self-monitoring of outcomes of behaviour” and “Action Planning” identified in over 75% of effective interventions. “Social support” and “Information about health consequences” were more evident in effective interventions at follow-up compared with post-intervention. The mean number of modes of delivery was 5 (n=12), with the majority of interventions being web-based. Digital interventions which had a higher score on the Theory Coding Scheme (TCS) had a greater effect size than those with a lower TCS score (subgroup differences: Chi2 = 9.68 , P=.002, I^2 = 89.7%) within the meta-analysis. No other subgroup analyses had significant results.

Conclusions: There was a high level of consistency in terms of the most common BCTs within effective interventions, although no evidence that any specific BCT contributed to intervention efficacy. Those interventions which were more strongly informed

by theory demonstrated greater improvements in eating disorder outcomes compared to waitlist/treatment-as-usual controls. These results can be used to inform the development of future digital eating disorder interventions.

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A Systematic Review and Meta-Analysis of Behaviour Change Techniques within Digital Interventions for the Treatment of Eating Disorders

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Abstract

Background

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A literature search identified RCTs of digital intervention for the treatment of adults with eating

disorders with minimal therapist support. Each digital intervention was coded for behaviour change techniques using the established Behaviour Change Technique Taxonomy (v1); the application of theory using an adapted version of the Theory Coding Scheme and for modes of delivery using the Mode of Delivery Ontology. A meta-analysis evaluated the evidence that any individual BCT moderated effect-size, or that other potential factors such as the application of theory or number of modes of delivery had an effect on eating disorder outcomes.

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Conclusions

There was a high level of consistency in terms of the most common BCTs within effective interventions, although no evidence that any specific BCT contributed to intervention efficacy. Those interventions which were more strongly informed by theory demonstrated greater improvements in eating disorder outcomes compared to waitlist/treatment-as-usual controls. These results can be used to inform the development of future digital eating disorder interventions.

KEYWORDS

digital health; eHealth; mHealth; mobile applications; smartphone; behaviour change; behaviour change technique; systematic review; eating disorders; disordered eating; binge eating; bulimia nervosa.

Introduction

Background

The current eating disorder (ED) treatment model is falling short for patients [1], with a significant majority of people with EDs failing to get help [2]. This may be due to limited access to services [3] and the stigma and shame associated with their condition [4]. Eating disorders have the highest mortality of any psychiatric disorder [5], may be long-lasting and cause physical, emotional and neurobiological damage if left untreated [6]. The Covid-19 pandemic has further compounded the problem, with a surge in urgent referrals and increased waiting time in an already under-resourced system [7]. Action is urgently required to address this treatment gap [8]. One promising strategy that can improve access to evidence-based treatments is the development and implementation of digital interventions. Digital interventions refer to the use of digital technologies, such as mobile apps, websites or virtual reality to deliver healthcare or behavioural interventions.

Advantages of digital interventions include the ability to reach many people at minimal or no additional cost per person and they can be used at an individual’s convenience, at home, anonymously, and at a self-suited pace [9]. Shame and stigma may make people with EDs more likely to engage in digital interventions to achieve improvements in their symptoms [10,11] and

evidence demonstrates the demand for self-guided digital interventions is growing among people with eating disorders [11]. While digital self-management interventions are not the only solution to address the existing service gap, they can broaden the dissemination of evidence-based treatments and help more people get support for their condition [12].

Digital interventions for EDs have shown promising evidence in treating eating disorder symptoms [13,14,15] with results sustained, even improving, at follow-up [16]. However, our understanding of how these interventions work and what contributes to their effectiveness is limited [17], restricting the potential effectiveness and impact of digital ED interventions. It is widely recognised that digital health interventions should incorporate evidence-based methods and behaviour change theory into their development [18]. Theory represents the accumulated knowledge of the mechanisms of action (mediators) and moderators of change as well as the a priori assumptions about what human behaviour is, and what the influences on it are [19]. Using behaviour change theory in designing digital health interventions may help pinpoint the factors influencing the target behaviour, referred to as 'mechanisms of action' (MOA) in behavioural science. These mechanisms of action, such as knowledge and beliefs, are pathways through which interventions can impact behaviours. Designers can then connect these MOAs to practical elements called 'behaviour change techniques' (BCTs), which play a crucial role in transforming disordered behaviours into healthier target behaviours. While there are some dissenters regarding such systematisation of practice, arguing for the importance of variability, there is general agreement of the value of better descriptions of interventions for clarity and replication [20]. This systematic approach has been applied in the development of effective digital health interventions in areas such as the treatment of addictive disorders, physical activity and weight loss [21,22], as well as in more clinically oriented interventions such as in diabetes management [23,24,25]. Specific BCTs have been linked to improved clinical outcomes [26,27,28] and are a useful means of describing active components within complex digital interventions [29]. The integration of specific behaviour change techniques may optimise digital ED treatment interventions helping achieve significant symptom improvement by addressing those factors (e.g. food avoidance, dietary restriction, body image concerns) which influence common eating disorder behaviours (e.g. bingeing, purging).

Objectives

This review aimed to gain insights from previous RCTs as to which behaviour change techniques may contribute to the effectiveness of digital eating disorder interventions [30]. It focused on RCTs as they have the highest possible level of evidence compared to other study designs and can be used to make causal inferences [31]. It also assessed whether the interventions were grounded in theory, given theory is a “necessary precursor to the development of effective interventions” [32].

We hypothesized that interventions which specifically targeted the behavioural and psychological aspects of ED via the use of relevant behaviour change techniques would be more likely to improve ED outcomes. We also hypothesized that those interventions informed by theory were more likely to be effective. Having multiple modes of delivery (e.g. apps, video, audio), may be associated with enhanced treatment outcomes [15] based on the idea that the diversity offered by multimedia formats might facilitate effectiveness through an enhanced and more engaging user experience [33].

Our specific research questions were:

- Which behaviour change techniques are most frequently included in digital interventions for the treatment of eating disorders which have been evaluated in RCTs? Which BCTs are most frequently associated with effective interventions?
- Are included BCTs informed by theory?
- Which modes of delivery have been adopted to deliver the behaviour change techniques?
- Was there evidence to suggest that specific BCTs, or related factors, moderated the intervention effect size?

Methods

Search Strategy

The searches were completed across the following databases between 1st April and 30th June 2023: MEDLINE (Ovid), EMBASE, PsycINFO, CINAHL, EMCARE (Ovid), Cochrane CENTRAL Register of Controlled Trials, Web of Science and Scopus. The protocol was registered in the PROSPERO database (CRD42023410060). These findings are reported in accordance with the PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies [34]. The search strategy was developed based upon previous similar systematic reviews of digital interventions and eating disorders [15,35] and in consultation with a specialist librarian at UCL. The search strategy included two main concepts based on eating disorders and types of digital intervention (web-based or smartphone). It included a combination of medical subject headings (MeSH terms) and free text terms. The search was adapted for each database. A Cochrane Randomised Controlled Trial (RCT) filter was applied to the search results within relevant databases [36]. Full details of the search strategy can be found in Multimedia Appendix 1.

The first reviewer (PT) initially screened all titles and/or abstracts for the first phase of the review and a second reviewer (PB) screened a random 10% of the results (within Covidence). Both reviewers independently screened 100% of articles in the final full-text screening stage. Results were compared, and any discrepancy resolved by discussion. There was a good to excellent degree of inter-rater agreement (initial screening κ=0.92; final screening κ=0.720).

Study Selection

Eligible studies were selected by applying the inclusion/exclusion criteria (Figure 1).

Figure 1. Inclusion/Exclusion Criteria

Inclusion	Exclusion
- Adults in general population - Self-management interventions and Guided Self-help interventions for individuals - Included study participants who meet sub-threshold and/or threshold criteria for an ED. - Standalone digital intervention with minimal or some therapist support[a] - Outcome measure using the EDE-Q - Randomised controlled trials.	- Interventions aimed at < 16 years old - Intervention aimed at healthcare professionals - Intervention specific to relapse prevention, aftercare - Intervention specific to eating disorder prevention - Intervention aimed at obesity, weight management - Telemedicine / teleconferencing - Augmentation therapy (app as an 'add-on') - Digital intervention with intensive levels of supplementary therapist support - Group-CBT; group-therapy - Technologies which have been superseded (i.e. CD-ROM, vodcast, SMS/text messaging)

	- Interventions that used mobile phones, but did not involve apps (e.g. were based solely on SMS messaging or emails) - No clear description of the intervention design (not possible to code for BCTs) - Qualitative studies - Feasibility and acceptability studies, pilot studies - No clear outcome measures (using the EDE-Q).

[a]Only studies with digital interventions with relatively minimal levels of therapist support (in one treatment arm) were included. A basic level of guided support (e.g. weekly emails) was defined as 'minimal', with any extra level of support or feedback defined as 'some'. This was defined as up to 25 mins per week and allowed for extra sessions at the beginning and end of treatment. If the level of support was greater than this, the study was excluded.

Data Extraction

The primary researcher (PT) extracted/coded the data for included studies including author, year, country of origin, study and participant characteristics (no. of participants, age, gender, ethnicity, diagnosis, inclusion/exclusion criteria, dropout rates) and intervention characteristics (intervention description, therapist involvement, behaviour change techniques, modes of delivery, duration of treatment, follow-up, key outcomes). Outcomes data for all the studies was independently extracted by two reviewers (PT and TR). Results were compared and any disagreements were resolved by discussion. Where key data was missing, study authors were contacted for the missing information. A cut-off period of 4 weeks was provided.

Outcome Measures

The Eating Disorder Examination Questionnaire (EDE-Q) [37] was used as the primary outcome measure of interest, given it is the NICE ED "gold standard" measure of ED psychopathology and was used as the primary outcome measure in the majority of included RCTs. It includes frequency data on key behavioural features of eating disorders in terms of number of episodes of the behaviour (including bingeing, purging etc.) making it a suitable outcome measure for this review [38]. Where reported, changes in number of objective binge episodes (OBEs) post-treatment were examined for consistency, providing complementary data on intervention effectiveness.

BCT Coding, Modes of Delivery and Theory Coding Scheme

Each study was assessed for the presence of each of the 93 behaviour change techniques using the Behaviour Change Taxonomy v1 [30], assessing the number of BCTs in each digital intervention and the frequency of each BCT in the sample overall. The BCT Taxonomy is a hierarchically organised, common language tool for the classification of the 'active ingredients' [30] required to bring about change in an intervention. The validity of this approach has been well established and its reliability and value demonstrated consistently across multiple areas since its inception [39,40,41].

The modes of delivery used within each of the interventions to deliver the BCTs was assessed using relevant components from the Model of Delivery Ontology v2 [42]. If the modes of delivery were changed during the course of the study, the modes of delivery included within the initial study design were coded, as these were appropriate for the outcome measures used.

An adapted version of the Theory Coding Scheme [43] was used to evaluate the theoretical basis of the included studies. These adaptations were made in consultation with an experienced behaviour change scientist (KC), on the basis that the coding scheme was originally developed for use in a different context and some of the criteria were not relevant. Hobbis and Sutton (2005) [44] justified the case for Cognitive Behavioural Therapy (CBT) as an addition to the Theory of Planned Behaviour-based interventions, hence it was considered a valid theoretical basis when used to inform intervention design. All studies were independently coded against these frameworks by two reviewers (PT and RC), with any discrepancies resolved by discussion, involving a third reviewer (KC). This meant the BCTs were double-blind coded by two reviewers across all studies. These results were compared, with a third reviewer involved where necessary to resolve any discrepancies. A briefing document was provided to the second reviewer in advance of coding, which included definitions and examples of BCTs, to ensure reliability. The coding was completed in two stages, with the second reviewer coding approx. 25% (5 papers) first. This coding was compared across the two reviewers to identify any inconsistencies in terms of how the BCT framework was being applied, to aim to maximise consistency when reviewing the remaining 75% (12 papers).
For interventions to be included at follow-up, this had to be least 8 weeks after post-intervention, to allow for a reasonable evaluation of sustained treatment effects, and to avoid post-treatment and follow-up evaluations coinciding at 8 weeks across different studies.

Data Synthesis

Associations between BCTs and intervention effectiveness was completed. A brief narrative synthesis was used to organise and present the data within the text, with a summary of the information extracted from each study, including outcomes reported, BCTs and other items provided in tabular form.
Frequency counts of the most commonly used BCTs were completed across “all interventions” and only “effective interventions” and the results compared. The effectiveness of an intervention was determined by a statistically significant effect ($P<.05$) on eating disorder behaviour change (as measured by the EQE-Q 6.0). Where the study was against an active comparator, the pre-post outcome data for the intervention arm was examined independently to assess for efficacy and considered in the context of the study design and alongside similar waiting list (WL) control studies. BCTs were considered effective if they were identified in at least 75% of effective interventions [18]. A further division of effective interventions was completed based on whether they were effective at post-intervention or follow-up.

Meta-Analytic Procedure

The purpose of this meta-analysis was to pool data across RCT studies regarding the effectiveness of digital interventions compared to waitlist control/treatment-as-usual controls at post-intervention and follow-up to explore what might be contributing to the overall effect sizes, primarily the contribution of any particular BCT. Studies with an active control group such as face-to-face therapy, bibliotherapy, another digital intervention, or day patient programs were excluded from the meta-analysis, as well as studies with missing (EDE-Q total) outcome data.
As a first stage, the meta-analysis procedure calculated pooled estimates of effect sizes (differences in EDE-Q total scores) at post-intervention and follow-up for waitlist/treatment-as-usual RCTs and presented these results as forest plots (using RevMan 5). Effects were based on means, standard deviations and sample sizes reported within the studies. The primary outcome was EDE-Q behaviours (dietary restraint, weight concern, shape concern and eating concern). As the included studies were RCTs, baseline values were not adjusted for across studies, as they would be expected to be similar across treatment and control groups. As studies possessed substantial heterogeneity based on differences in study designs (duration of treatment; level of therapist involvement etc.), a

random-effects model was used to estimate the weighted pooled effect for each outcome, to account for the distribution of the true effect across individual studies [45]. The I2 statistic was used as a measure of heterogeneity, describing the percentage of variation across studies that was due to heterogeneity rather than chance [46]. Heterogeneity above 60% was considered substantial [47] and suitable for subgroup analyses. Given the EDE-Q primary outcome measure was continuous, the mean difference was used to describe the pooled outcome effects as well as the overall effect size (z-statistic) alongside it's P value. Sensitivity analysis was completed to check for consistency of the effect size and publication bias was explored using funnel plots (see Multimedia Appendix 2).
It was then possible to complete subgroup analyses to identify whether there was evidence for any BCTs, acting as moderators of effect size. A shortlist of BCTs were identified upfront, according to Fairburn's transdiagnostic theory of eating disorders [48,49]. This was to avoid post-hoc analysis of multiple BCTs, which would increase the likelihood of finding significant results through chance. If any of these pre-specified BCTS were identified in >75% of effective interventions, they were included in the subgroup analyses: "2.2. Feedback on behaviour"; "2.3 Self-monitoring of behaviour"; "2.4 Self-monitoring of outcome(s) of behaviour"; "4.2 Information about antecedents"; "7.7 Exposure" and "11.2 Reduce negative emotions". The additional related concepts of Mode of Delivery (<5/12; 5 or more/12), Theory Coding Scheme (High / Low) were also explored, as well as Degree of Therapist Support (None-Minimal/Some) and Duration of Therapy (<8 weeks / 8 weeks or longer) given these additional sources of heterogeneity could also have an impact on effect size.

Risk of Bias Assessment

The revised Cochrane Risk-of-Bias tool for randomized trials (RoB2) was used for assessing risk of bias in randomised controlled trials with studies assessed against six domains [50] (see Multimedia Appendix 3). Risk of bias analysis was completed for all articles by researcher PT with 20% of the articles also being independently assessed by a second reviewer (TR). Disagreements were resolved via discussion. There was a high level of inter-rater agreement (IRR=0.9).

Results

A PRISMA flow diagram (Figure 2) represents the literature search. 17 RCT studies were identified for inclusion within this review.

Figure 2. PRISMA Flow Diagram

Of the 17 identified, 12 included a waiting list comparator (or treatment as usual) with 5 having ‘active’ controls.

General Study Characteristics

The studies included 12 parallel arm trials, 4 multiple arm studies [13,51,52,53], and one cluster RCT [54]. Of these, 12 studies included active treatment against a waiting list control / informational control / treatment as usual (TAU) whilst 5 studies were against active comparators, including face-to-face treatment [16], day patient care [55] and other digital treatment interventions [56,57,58].
Nine studies included all/nearly all females (>95%); 5 studies included 5-10% males and 2 studies included >10% males. Ethnicity was not mentioned in 12 of the 17 studies (70.6%), with 2 mentioning nationality but not ethnicity, and only 3 providing any ethnic breakdown. Mean age ranged from 22.1 years [54] to 43.2 years [16] across studies, with participants from 17.3 to 55.5 years old. The total number of participants overall was 5254 with 1956 included in the meta-analysis (WL/TAU studies only). Inclusion/Exclusion criteria were highly variable, with some studies having clear diagnostic criteria which had to be met, excluding participants with comorbidities, or with previous experience of I-CBT whilst others permitted individuals to participate without meeting any diagnostic criteria provided, they were over 16 years old and had access to the internet. One study allowed participants to receive other forms of psychological, medical or other treatment for their eating disorder, whether in the digital intervention treatment arm or control condition [59].
The studies took place in North America (n=2) [54,56], Europe (n=11) Switzerland, Germany, Sweden, Austria and Netherlands) [13,15,16,52,53,59,60,61,62 63,64] and Australia/New Zealand (n=4) [14,51,57,58]. The included studies are listed in Multimedia Appendix 4.

Summary of Intervention Types and Outcomes

The ED diagnoses included 6 studies focusing on binge eating disorder / binge eating symptoms [15,16,51,57,58,59], 3 on bulimia / Eating Disorder Not Otherwise Specified (EDNOS) [13,61,62] and 8 concerned individuals with any ED symptoms [14,52,53,54,56,60,63,64]. The studies included a number of different interventions (see Multimedia Appendix 5), with the most common being SALUT-BED/SALUT-BN (n=5) [13,15,16,61,62] Break Binge Eating/Break the Diet Cycle (n=4) [14,51,57,58] and Featback (n=2) [52,53].
Studies included internet and mobile-based digital interventions, frequently including messaging and/or email feedback or prompts. Two studies focused specifically on an app [14,56], four included blended internet and smartphone interventions [51,54,57,58] and 11 were internet-only interventions. Interventions lasted between 4 weeks and 12 months, with 11 interventions less than or equal to 8 weeks, and 6 interventions over 8 weeks [13,15,52,53,54,60]. Interventions had between 4 and 11 modules, so differed in terms of the amount of content provided and permitted different timescales to complete these modules.
Only studies with digital interventions with no or relatively minimal levels of therapist support were included (e.g. weekly emails) as well as interventions with ‘some’ therapist support. This resulted in 4 studies with no therapist involvement [14,52,53,56], 7 with ‘minimal’ therapist involvement [13,15,51,57,58,59,63] and 6 studies with ‘some’ therapist involvement [16,54,55,61,60,64].
Outcome measures were most commonly the Eating Disorders Examination Questionnaire, although other measures such as the number of objective binge episodes (OBEs) were frequently also reported. Dropout rates at post-intervention were between 6.7%-58% for the digital intervention. They tended to be higher in those interventions with minimal or no support conducted in a community setting such as those in which participants signed-up and participated via an internet service [14,14,52,53,56,58], although design characteristics such as feedback on behaviour or feedback on outcomes of behaviour also seemed important [58].
The details of the digital interventions within the 17 studies, including their constituent BCTs, are described in Multimedia Appendix 5.

Study Outcomes at Post-Intervention and Follow-Up

All 11 of the 12 RCTs which compared a digital intervention to a WL/TAU control demonstrated a significant improvement in ED outcomes (as measured by the EDE-Q) for the digital intervention over the control condition at post-intervention, except for Aardoom et al (2016) [52]. Those WL/TAU control studies which reported the number of binge eating episodes at post-intervention (n=11) [13,14,13-15,51-53,58,60,63,64] also reported a significant reduction in objective binge episodes (OBEs) compared to the WL/TAU control condition. For those WL/TAU studies which reported follow-up data (n=9), all of these reported a significant reduction in ED outcomes (EDE-Q total and OBEs) compared to the control condition, including Aardoom et al (2016) [52].
When the control condition was an active comparator, of traditional face-to-face (F2F) treatment [16] or a Day Patient Programme (DPP) [55], participants in the active comparator arm performed considerably better than the digital intervention at post-intervention, but results were comparable at follow-up in both studies. Where the active comparator was a similar digital health intervention, either broader in terms of functionality [58] or consisting of interactive vs. static content [56,57], there were no significant differences observed in EDE-Q total outcomes, or secondary outcome measures, at post-intervention (and no follow-up data).

Behaviour Change Techniques in Effective Interventions

A total of 38 out of 93 behaviour change techniques were identified across the clinical content of the interventions. The mean number of BCTs per intervention was 14 (range 9-18). The following BCTs were reported in over 75% of effective interventions: “2.3 Self-monitoring of behaviour”, “1.2 Problem-solving”, “4.2 Information about antecedents”, “2.2 Feedback on behaviour” and “2.4 Self-monitoring of outcomes of behaviour” and “1.4 Action Planning”. “7.7 Exposure” and “11.2 Reduce negative emotions”, which had been predicted to be important, were identified 56.3% and 37.5% of effective interventions respectively. “5.2 Behavioural practice/rehearsal”, “13.2 Framing/Reframing” and “7.1 Prompts/Cues” were present in over 50% of effective interventions, suggesting they may also be important in supporting ED behaviour change. The inter-rater reliability was high (IRR=0.84).

Figure 3. BCTs Included in Treatment Interventions (by Study)

Evaluation of ED Studies	Carrard (2011)	Ruwaard (2013)	de Zwaan et al (2017)	Strandskov et al (2017)	Wyssen et al (2021)	Tregarthen et al (2019)	Linardon et al (2022a)	Linardon et al (2022b)	Linardon et al (2021b)	Linardon et al (2020)	Mellisse et al (2023)	Rohrbach et al (2022)	Fitzsimmons-Crat et al (2020)	Aardoom et al (2016)	Jacobi et al (2012)	Hogdahl et al (2023)	Wagner et al (2013)	ALL INTERVENTIONS / STUDIES		EFFECTIVE INTERVENTIONS (at post-intervention)	
	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I		*Eff P/I	*Eff P/I	*Eff P/I	Counts	%	Counts	%
2.3 Self-monitoring of behaviour	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	17	100.0%	16	100.0%
1.2 Problem solving	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	16	94.1%	15	93.8%
4.2 Information about antecedents	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	16	94.1%	15	93.8%
2.2 Feedback on behaviour	X	X	X	X	X			X	X	X	X	X	X	X	X		X	14	82.4%	13	81.3%
2.4 Self-monitoring of outcomes of	X				X	X	X	X	X	X	X	X	X	X	X	X	X	14	82.4%	13	81.3%
1.4 Action planning	X	X			X	X	X	X	X	X	X		X			X	X	12	70.6%	12	75.0%
8.1 Behavioural practice / rehearsal	X		X			X	X	X		X			X		X	X	X	10	58.8%	10	62.5%
13.2 Framing / reframing	X	X				X	X	X	X	X			X		X	X		10	58.8%	10	62.5%
7.1 Prompts / cues				X		X	X	X	X	X	X	X		X				9	52.9%	9	56.3%
7.7 Exposure	X	X	X	X			X		X				X		X		X	9	52.9%	9	56.3%
3.2 Social support (practical)	X		X	X	X							X		X	X		X	8	47.1%	7	43.8%
4.1 Instructions on how to perform the				X	X		X	X	X	X			X	X				8	47.1%	7	43.8%
5.1 Information about health consequences					X		X		X		X	X		X	X	X		8	47.1%	7	43.8%
2.7 Feedback on outcomes of behaviour									X		X	X	X	X	X		X	7	41.2%	6	37.5%
3.1 Social support (unspecified)	X		X									X	X	X		X	X	7	41.2%	6	37.5%
8.2 Behaviour substitution				X				X		X	X				X	X		6	35.3%	6	37.5%
11.2 Reduce negative emotions				X				X		X			X		X		X	6	35.3%	6	37.5%
8.4 Habit reversal				X		X		X		X			X					5	29.4%	5	31.3%
5.6 Information about emotional					X				X			X	X	X				5	29.4%	4	25.0%
8.3 Habit formation				X			X						X			X		4	23.5%	4	25.0%
9.3 Comparison of future outcomes	X		X			X			X									4	23.5%	4	25.0%
1.1 Goal setting (behaviour)				X	X	X												3	17.6%	3	18.8%
1.3 Goal setting (outcome)				X	X	X												3	17.6%	3	18.8%
9.2 Pros and cons	X		X			X												3	17.6%	3	18.8%
12.4 Distraction							X		X				X					3	17.6%	3	18.8%
15.4 Self-talk	X	X											X					3	17.6%	3	18.8%
3.3 Social support (emotional)				X								X		X				3	17.6%	2	12.5%
5.3 Information about social and												X		X	X			3	17.6%	2	12.5%
10.4 Social reward						X						X		X				3	17.6%	2	12.5%
5.4 Monitoring of emotional consequences	X		X															2	11.8%	2	12.5%
15.3 Focus on past success				X		X												2	11.8%	2	12.5%
15.1 Verbal persuasion about capability												X		X				2	11.8%	1	6.3%
1.5 Review behavioural goal						X												1	5.9%	1	6.3%
1.7 Review outcome (goal)						X												1	5.9%	1	6.3%
1.9 Commitment				X														1	5.9%	1	6.3%
2.1 Monitoring of behaviour by others											X							1	5.9%	1	6.3%
4.4 Behavioural experiments		X																1	5.9%	1	6.3%
13.4 Valued self-identity				X														1	5.9%	1	6.3%

BCTs were not identified from the following BCT categories in the taxonomy: “6. Comparison of the behaviour”; “14. Schedules consequences” or “16. Covert learning”. Only 3 studies included a component from the “10. Reward and Threat” category, the “10.4 Social Reward” component.

Follow-up data (> 8 weeks after post-intervention) was available for 9 out of the 17 studies. In 2 of the studies, there was no data for the control condition (as they were given the intervention), but outcome effects at post-intervention were sustained at follow-up so they were included [13,59]. Two studies included an active comparator [16,55], with improvements on the EDE-Q for the digital intervention arm at post-intervention sustained/improving at follow-up so they were included. This analysis resulted in the following BCTs being identified in those interventions which were effective

at follow-up (in >75% of interventions): “2.2 Feedback on behaviour, “2.3 Self-monitoring of behaviour”, “2.4 Self-monitoring of outcomes of behaviour”. “4.2 Information about antecedents”, “1.2 Problem-solving”,” (all these were the same as at post-intervention) but also “3.2 Social support (practical)” / “3.1 Social support (unspecified)” and “5.1 Information about health consequences” were more evident in those interventions effective at follow-up compared with post-intervention. These may be important in sustaining positive outcome effects; however these findings are based on a small number of studies.

Figure 4. BCTs Included in Effective Treatment Interventions at Follow-Up (by Study)

Evaluation of ED Studies	Carrard (2011)	Ruwaard (2013)	de Zwaan et al (2017)	Wyssen et al (2021)	Rohrbach et al (2022)	Fitzsimmons-Crat et al (2020)	Aardoom et al (2016)	Jacobi et al (2012)	Hogdahl et al (2023)	EFFECTIVE (at follow-up) 9 studies had F/U data*	
	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	Counts	%
2.3 Self-monitoring of behaviour	X	X	X	X	X	X	X	X	X	9	100.0%
1.2 Problem solving	X	X	X	X	X	X	X		X	8	88.9%
2.2 Feedback on behaviour	X	X	X	X	X	X	X	X		8	88.9%
4.2 Information about antecedents	X	X	X	X	X	X	X		X	8	88.9%
2.4 Self-monitoring of outcomes of behaviour	X			X	X	X	X	X	X	7	77.8%
3.1 Social support (unspecified)	X		X		X	X	X		X	6	66.7%
3.2 Social support (practical)	X		X	X	X		X	X		6	66.7%
1.4 Action planning	X	X		X		X			X	5	55.6%
5.1 Information about health consequences				X	X		X	X	X	5	55.6%
7.7 Exposure	X	X	X			X		X		5	55.6%
8.1 Behavioural practice / rehearsal	X		X			X		X	X	5	55.6%
13.2 Framing / reframing	X	X				X		X	X	5	55.6%

(*to be considered follow-up, data had to be at least 3-months after start of treatment)

Definitions of the most common BCTs (included in >50% of interventions) with examples of how they were implemented within the interventions is included in Appendix 6.

Theoretical Basis

Nearly all studies (16/17) reported some level of theoretical basis to their intervention design (see Multimedia Appendix 3). Of those that did mention a theoretical basis, Cognitive Behavioural Therapy (CBT) and the transdiagnostic theory of eating disorders were most frequently reported [31,48], sometimes in combination with other theoretical approaches including Acceptance Commitment Therapy (ACT) and Dialectical Behaviour therapy (DBT) [58,59]. The description of this theoretical basis was often minimal within the studies, however these approaches are generally well understood and accepted within eating disorder treatment, and further literature was often referenced [48] to support their use.

13/17 studies (76.5%) mentioned a target construct as a predictor of behaviour (e.g. emotional regulation, body image concerns), and designed interventions which targeted these constructs to change ED behaviours. 13/17 studies (76.5%) reported how theory/predictors were used to select/develop behaviour change techniques, though this was not often done explicitly, but rather by association listing intervention features alongside their theoretical constructs (e.g. emotional

regulation - access to an emotions tracker; body image concerns – an exercise to break avoidance patterns). Only 4 studies used theory/predictors to tailor interventions to participants [56,57,60,64] based on their specific eating-related concerns.

Modes of Delivery

The mean number of modes of delivery per intervention was 5 (range: 4-8) out of 12 possible modes (see Multimedia Appendix 3). All interventions included textual information, after which the most common mode of delivery was website, (15/17; 88.2% of studies). Mobile applications ("apps") were included in just 6/17 (35.3%) studies, of which 4 studies included both website and app modes of delivery [51,54,57,58] and 2 were app only [14,56].

Video and audio modes of delivery were identified in only 3/17 (17.6%) and 5/17 (29.4%) of the apps respectively, suggesting rather limited use of multimedia functionality within the interventions, with a greater reliance upon textual information. At-a-distance mode of delivery (human interaction) was included in 8/17 studies (47.1%) typically involving therapists providing weekly feedback on behaviours and/or assignments and delivering this via messaging (58.5%) and/or email (52.9%) mode of delivery. Email was also used to 'check-in' with participants to ensure engagement with the intervention. Although phone was used in 4/17 (23.5%) interventions, this was usually only if the user was not engaging in the service at risk of dropout, rather than being part of the service.

Note: Fitzsimmons-Craft changed their study design after 1-year, based on performance in the first year, from a web-based intervention to an app. Given the outcomes at 1-year were used in the analysis, the app mode of delivery was not coded.

Risk of Bias

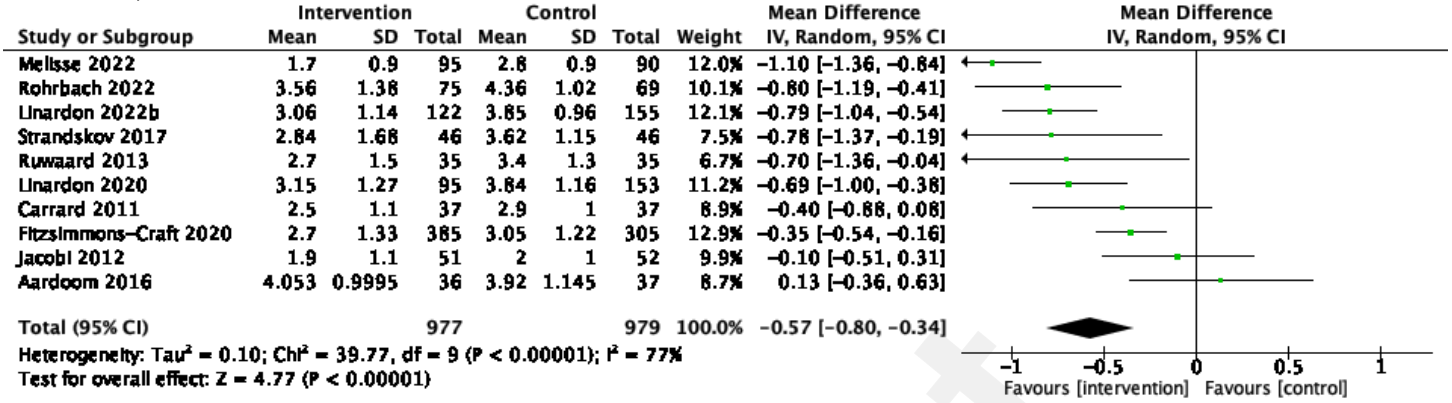
Most studies reported an adequate method of randomisation, frequently including computer-generated randomisation sequence although assessors were not always blind to treatment allocation. Most studies reported adequate blinding of outcome assessment, either through use of self-report outcome assessments administered online or through F2F/phone assessments in which assessors were blind to treatment allocation. No studies reported blinding of participants to the digital intervention, given this would have been difficult to achieve, but neither discussed how this might have biased the self-reported outcomes.

The domain where studies scored lowest was in terms of missing outcome data (10/17 studies), due to the relatively high attrition rates across studies. Some studies deviated from their analysis plan, including alternative statistical methods in their analysis [53]. Although these may have been justified, they introduced "some concerns" in how those studies had been analysed and the data which was reported. There was also selective reporting of the results in 5 of the studies, which put them at a higher risk of bias (see Multimedia Appendix 3). When a subgroup analysis between low/some concerns studies and those at high risk of bias was completed, no significant differences in outcomes was observed (see Multimedia Appendix 2).

Results from Meta-Analysis

We used the Mean Difference (MD) of EDE-Q total scores as the primary estimate of effect size for each intervention. 10 studies were included with WL/TAU control with EDE-Q outcome data at post-intervention. Although 12 studies had a WL/TAU control, one was excluded due to missing outcome data on the dietary restraint subscale [51] and another was excluded as the control group was given the intervention at 4 weeks, so the study comparison at post-intervention was against 8-weeks vs. 4-weeks active treatment [59]. The pooled effect sizes for the comparison between digital eating disorder interventions and WL/TAU control groups was moderate, and statistically significant in favour of the treatment group for ED psychopathology (MD =-0.57; 95% CI [-.080, -0.39]; Z=4.77 (P<.00001). Heterogeneity was high (I2 = 77%), making it sensible to conduct subgroup analyses.

Figure 5. Mean Difference in Outcomes (EDE-Q) for Digital ED Interventions vs. WL/TAU controls (at post-intervention)



Sensitivity analysis was completed by removing studies one at a time to consider the impact on effect size, but this did not change the results significantly. There was no clear evidence of publication bias based on a relatively even distribution of studies around the summary estimate line (see Multimedia Appendix 2).

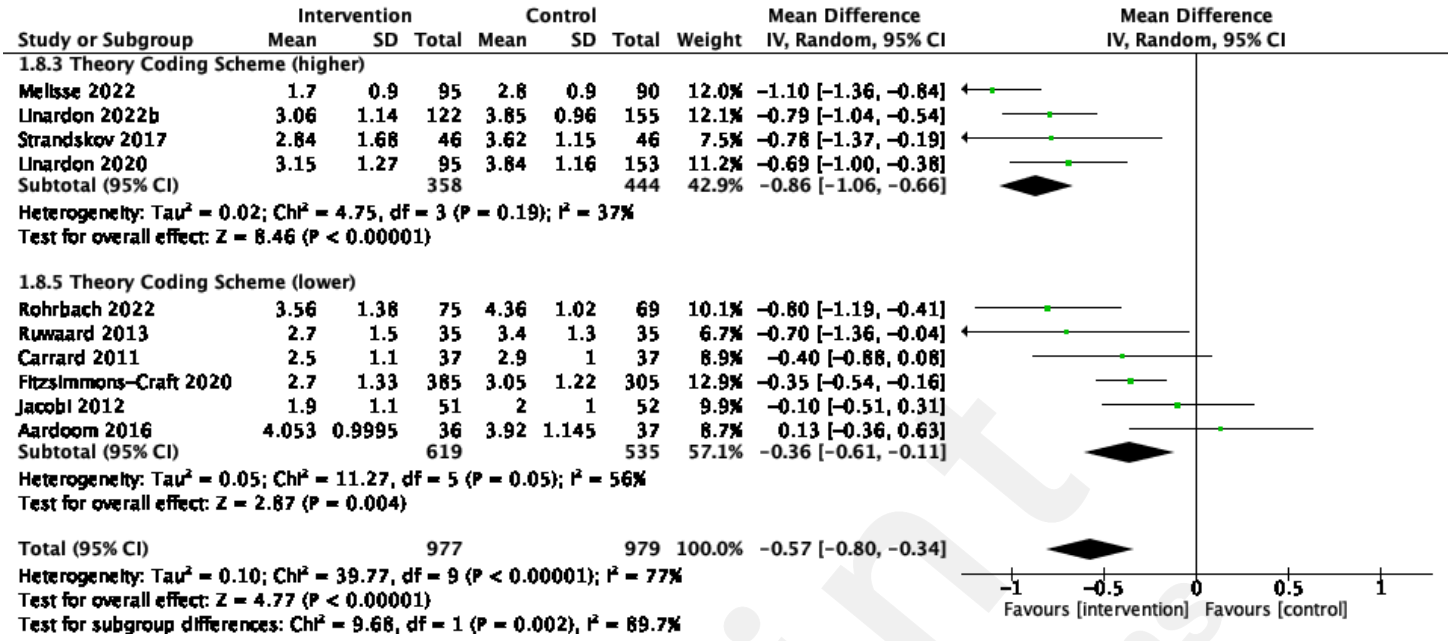
Note: Whilst data used for this meta-analysis did not demonstrate significance for Jacobi (2012) or Carrard (2011), when baseline values were adjusted for (as in the original papers) outcomes significantly favoured the interventions compared to the control at post-intervention in both studies (P<.0001). The interventions were therefore considered to be effective at post-intervention. Baseline values were not adjusted for within the meta-analysis based on the assumption that randomised controlled studies should not have baselines differences.

Moderator/Subgroup Analyses

Six moderator analyses were conducted to investigate differences in EDE-Q total pooled effect size according to the presence or absence of BCTs in digital interventions. None of the subgroup analyses of BCTs explained any of the heterogeneity of effect sizes across the studies, suggesting there were other factors which explained this heterogeneity (see example in Multimedia Appendix 1: Figure 2). Heterogeneity within BCT subgroups was also moderate, confirming that there were likely to be other factors explaining this variability.

Digital ED interventions which had a higher score on the Theory Coding Scheme (TCS) had a greater effect size than those with a lower TCS score. Subgroup analyses showed that interventions which were more highly grounded in theory (high TCS M=-0.86, [95% CI -1.06, -0.66], I2 = 37%) were significantly more effective than those which had a low theoretical basis (low TCS M=-0.36 [95% CI -0.61, -0.11], I2 = 56%); Subgroup differences: Chi2 = 9.68 , P=.002, I^2 = 89.7%) (see Multimedia Appendix 2). This was the only statistically significant moderation effect which emerged from the subgroup analyses.

Figure 6. Results of meta-analysis from theory coding scheme subgroup analysis

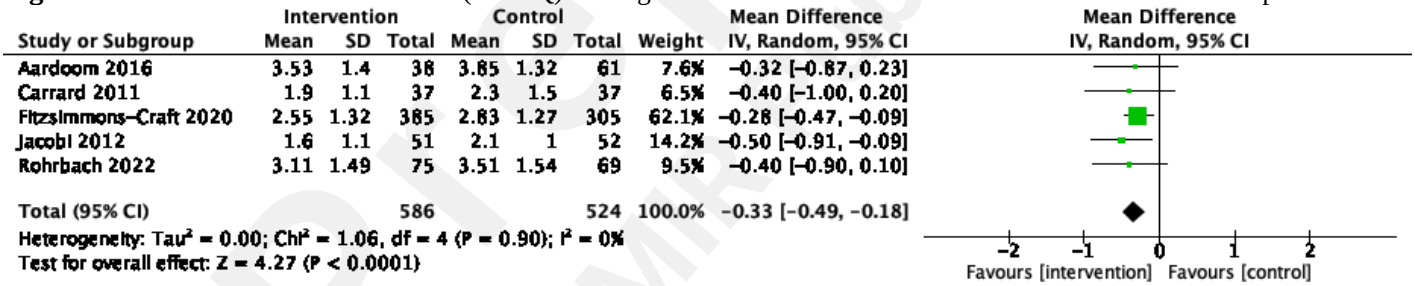


There were no significant differences across other subgroup analyses. All subgroup analyses are presented in Multimedia Appendix 2.

Follow-Up

Only 5 studies with WL/TAU control included EDE-Q outcome data at follow-up (> 8 weeks) [15,52,54,63]. The results were significant, with reduction in ED psychopathology favouring the treatment arm (MD =-0.33; 95% CI [-.049, -0.18] and an overall effect size of Z = 4.27 (P< .0001). There was no heterogeneity (I2 = 0%).

Figure 7. Mean Difference in Outcomes (EDE-Q) for Digital ED Interventions vs. WL/TAU controls at Follow-up



2 studies were considered high risk of bias and the remaining 3 had ‘some concerns’, due to missing data and selective reporting of the study data, so this data should be interpreted cautiously. Given the limited number of studies with outcome data at follow-up (and lack of heterogeneity) subgroup analyses were not completed.

Discussion

Principal Results

There is good evidence to support the efficacy of digital interventions (mainly websites) for people with mild to moderate eating disorders, with 16/17 studies demonstrating efficacy at post-intervention, strengthening findings from previous reviews [15,35,65,66]. Effects appear to be maintained at follow-up, with some studies demonstrating continuous reduction in bingeing and purging symptoms with effect sizes similar to those observed in face-to-face treatment [16,55]. There were few studies on smartphone-based interventions (“apps”), so data on their effectiveness as self-management tools, or as guided interventions, remains limited and further research is required.

Interventions included an average 14 BCTs (range: 9-18), which compares favourably with other

reviews of digital behaviour change interventions [67,68], demonstrating that existing interventions already incorporate behaviour change techniques to help change eating disorder behaviours. Across the various interventions reviewed, there was a high level of agreement regarding behaviour change techniques which were included, which were self-monitoring of behaviour, self-monitoring of outcomes of behaviour, information about antecedents, problem-solving skills and feedback on behaviour. These are in line with the principles of CBT-ED and Fairburn's transdiagnostic theory of eating disorders [48]. Other CBT-ED related BCTs of exposure, cognitive restructuring and reducing negative emotions also ranked moderately highly, although there may be an opportunity to integrate these techniques further within digital interventions based on their relevance in treating patients with eating disorders. While prompts/cues were present in just 56.3% of interventions, these techniques may be important to facilitate user engagement within digital interventions [69], which is important if these interventions are to be effective for a greater number of people by reducing dropout rates.

Some interventions included additional techniques which are often used in therapy, such as distraction and pros and cons, however there was insufficient evidence to evaluate if these helped contribute to intervention effects. There were no BCTs in the categories of "Comparison of the behaviour", "Scheduled consequences", or "Covert learning" across the digital eating disorder interventions and "Reward or Threat" techniques were rarely used. There is an opportunity to explore how these could be utilised, potentially learning from other areas of digital health behaviour change and testing some of these techniques with potential users. At follow-up, it seemed that social support may be important in supporting a sustained outcome effect [15,52,54] achieved through achieved through personalised feedback, encouragement and practical advice provided within the intervention. This enabled users to achieve greater self-awareness, improved coping skills, greater accountability and the development of a more supportive social network to assist them in their recovery.

There was no indication that individual BCTs were responsible for differences in outcome effects. This may have been due to the limited number of studies, small numbers of participants, other factors accounting for the heterogeneity and possibly due to similarity of digital intervention characteristics. It is also because of the study designs, which did not facilitate direct comparison of intervention components across studies. A different approach to design involves employing a Factorial Randomised Controlled Trial (RCT) guided by the Multiphase Optimization Strategy (MOST)[70], which enables the simultaneous evaluation of multiple variables (e.g. BCTs, modes of delivery) and their interactions, without the need for a large sample size. Most studies used CBT-based internet interventions (and some used the same/similar interventions e.g. SALUTBN/SALUTBED; Break Binge Eating), hence it could be that there was insufficient variability in the BCTs across studies, making it difficult to detect an association between the most commonly reported BCTs and treatment outcomes. It is also most likely a combination of BCT inclusion, dose, mode of delivery and theoretical basis may be important for intervention effectiveness, alongside other key design characteristics. Further studies are required to better understand how these factors interact to achieve their effects.

Nearly all studies (16/17) referred to a theoretical basis for their intervention design, however they differed to the extent to which theory had been rigorously applied. The majority of interventions were based on Cognitive Behavioural Therapy, informed by Fairburn's transdiagnostic theory of eating disorders [31,48] though Acceptance Commitment Therapy and Dialectical Behaviour Therapy techniques were incorporated into some interventions [58,64]. Interventions which were informed by theory, seemed to have a greater effect size within the meta-analysis, consistent with what was hypothesized. They were designed to target those specific mechanisms of action (e.g. dietary restraint, body image concerns, emotional dysregulation) which have been identified as important in changing ED behaviours. However, this result should be interpreted with caution due to the small number of studies, other factors which could explain this result, and the remaining heterogeneity within these subgroups requiring further explanation.

The mean number of modes of delivery per intervention was 5 (range: 4-8) out of 12 possible modes,

with a heavy reliance upon textual information and a limited use of audio and video to deliver the BCTs. Nearly half of the interventions included some degree of human interaction, delivered "at a distance", however there was no evidence that therapist involvement moderated effect size. There was also no evidence that an increased number of modes of delivery moderated any outcome effect. A key finding was that 2 of the 17 interventions were app only, suggesting that we require more evidence on app only approaches with no or minimal therapist support. At the time of this review, the technology used across interventions was relatively homogeneous, so we focused on modes of delivery to capture differences in how the interventions were delivered. As technology evolves it may be important to consider type of technology used, such as AI, as an additional moderating factor.

Comparison with Prior Work

These results strengthen findings from previous meta-analyses, which provide initial evidence for the effectiveness of digital interventions for reducing eating disorder symptoms [15,71,35,72]. Loucas et al (2014) [66] found small effects in their review of internet-based treatments for eating disorders (n=20), but with the inclusion of more recent studies, small to moderate effects have consistently been demonstrated, with some participants showing significant improvement in eating disorder behaviours at post-intervention [60] and at follow-up [15].

Results are consistent with a previous systematic review of mHealth interventions for EDs [73] that concluded that mHealth interventions, either as a self-management tool or complementary to F2F therapy, had limited support. Previous qualitative research has highlighted the promise of such interventions, with high levels of interest in mobile apps and level of acceptability [74,75], though the number of RCTs which demonstrate efficacy remains limited [14,56]. Specific advantages have been identified by patients and clinicians such as better supporting the real-time logging (food and mood), tracking and feedback to users, reminders to increase adherence to the intervention [17] and the opportunity for just-in-time interventions when an individual may be an elevated risk of engaging in an 'unhealthy' behaviour (e.g. purging) [76]. Research to translate these ideas into effective ED apps that have a place in treatment is still ongoing.

Although this study found that increased levels of multimedia within the digital interventions did not mediate intervention effects, previous research [15] did find that studies with increased use of multimedia channels (audio, video etc.) were associated with greater improvement in ED symptoms. Barakat's (2019) study performed a more robust analysis of multimedia channels, analysing data from surveys returned by the study authors, and incorporating additional components such as quizzes and homework, which provided a more detailed and accurate reflection of multimedia inclusion although they did include a range of study designs. Their findings need to be replicated including more recent RCTs, especially given they included older studies some of which were based on now obsolete technologies (i.e. CD-ROM, vodcasts). Interactivity alone is unlikely to meaningfully affect key outcomes in Internet-based interventions, instead it will likely be a combination of interactivity and other design characteristics such as the quality of intervention content, personalisation, persuasive design or therapeutic alliance principles [7] which are important determinants of outcomes. It could also be that certain populations, such as those with neurodiversity such as autism spectrum disorder [77], benefit more from increased levels of multimedia within digital interventions.

Strengths

We only included studies using an RCT design, which has not been the case in previous reviews [15,35]. This is the first study to systematically review the behaviour change techniques within digital eating disorder interventions, providing greater insights and a more comprehensive picture to inform intervention design and evaluation. Studies which included blended interventions, or high levels of therapist support were excluded to allow for a thorough analysis of the BCTs within digital

interventions and how these specifically may be contributing towards symptom improvement. This study evaluated the effect of BCTs, modes of delivery and theoretical underpinning on intervention outcomes quantitatively as well as narratively, to enable a rigorous evaluation of the data. A large number of databases were searched to ensure that all relevant studies should be included in this review, and we found 9 studies which were not included in previous similar reviews. This study has furthered our understanding of how to develop effective digital interventions, providing an opportunity to develop new/improved mHealth interventions for eating disorders which have the potential to be effective.

The majority of participants in these studies were recruited from within a community setting, so should be reflective of those with ED in the population who may not currently be getting help from clinical services. This is especially important given the significant increase in demand for eating disorder services since the pandemic [7], and a sustained move to the use of more digital services.

Limitations

Only 10 studies were suitable for inclusion in the meta-analysis, restricting the power required to detect significant moderating effects of BCTs. Some studies included a small number of participants so might be underpowered to demonstrate significant differences compared to control groups, or significantly affect the meta-analytic findings due to low weight. Confidence intervals in several of the studies were relatively large, limiting the ability to find significant results across the pooled studies.

Given the meta-analysis only examined differences in effect sizes between the digital interventions and control at post-intervention and follow-up without including baseline values, it did not assess whether the observed differences were clinically meaningful. Also, use of the EDE-Q may not have provided a clear picture of all changes in eating disorder behaviours, as not all compensatory behaviours are adequately covered by the EDE-Q [78]. For example, it is possible that some participants replaced purging with non-purging compensatory behaviour, such as excessive physical exercise, dieting and fasting. Most studies used self-reported measures of outcomes, which may not have accurately reflected actual outcomes being subject to self-reporting bias.

Dropout rates in some of the studies was high, varying from 6.7-58%. Although most studies assessed for differences in baseline characteristics between those who completed and those who dropped out, and typically found minor or no differences, the proportion of participants across who did not complete treatment and provide post-intervention assessments is a significant limitation.

We did not have access to the interventions, so the BCT coding was based on descriptions of interventions which were available in the public domain (i.e. journal publications, supporting info etc.) and some discussion with authors. Studies often did not go into much detail about the theoretical basis upon which the interventions were developed, so we were limited in terms of the information which could be coded. While there was a high level of inter-rater reliability (IRR=0.83), there was an element of subjectivity in how the BCT taxonomy was interpreted and applied. The theoretical coding scheme used was abbreviated for the purposes of this review and has not been externally validated. There was limited follow-up data, so it was not possible to evaluate the effectiveness of the interventions over the longer-term (nor complete subgroup analyses). Some BCTs may have helped specific user populations, but studies did not report on outcomes for specific populations, limiting our understanding of what worked for whom. While it is helpful to categorise interventions based on their BCTs, the BCT v1. Taxonomy may be inadequate for identifying all active ingredients which might be contributing to the effectiveness of an intervention, such as those included within Acceptance Commitment Therapy.

Further Work

Further research is required to evaluate the effects of specific BCTs, and combinations of BCTs, to

identify those that are most crucial to improving outcomes in digital eating disorder interventions, for whom and using which modes of delivery. A factorial experiment would allow different combinations of BCTs to be tested to see which combinations are the most effective, as well as the effect of different modes of delivery [79]. Greater consistency in RCT design would be helpful, to maximise the learnings which can be gained as to what is effective, as there continues to be considerable heterogeneity across study designs. Existing digital programs for eating disorders typically involve numerous strategies, techniques, or modules designed to target a range of behaviour change mechanisms, such as restrictive eating, mood dysregulation, body image concerns, and low self-esteem deficits [16,54] so further research is required into how to tailor interventions to better meet the needs of individual patients or user 'clusters' [80]. Receiving intervention content that is not relevant to a user's symptom profile may lead to issues with motivation, engagement and dropout [81]. One way in which this could be explored is via bandit trials, which are a type of adaptive intervention design that allow for personalised treatment allocation based on individual responses. Treatment outcomes across the different intervention options could be evaluated, with a further analysis to determine which treatment options are most effective for which individuals.

The BCT v1. Taxonomy has since evolved into an ontology [82] which could be applied to help identify any additional techniques, such as in Acceptance Commitment Therapy (ACT), which may not have been accounted for in this review. We did not consider dose of BCTs, by coding the number of times an individual BCT was coded in each intervention, to avoid introducing an additional level of complexity in this review. Further research could be completed to explore whether there is an optimal dose for BCTs.

There is some evidence to suggest that some specific BCTs may improve the user experience and adherence to treatment, which could be explored via further qualitative research including the way in which BCTs are translated in an intervention. It also may be worthwhile to get user feedback on those BCTs which have rarely been incorporated into digital ED interventions to establish if they may be beneficial to users. This should include those which are commonly used within therapy but are not widely implemented within digital interventions. Further work is required to understand how to leverage the benefits of mobile apps such as enabling real-time data capture and the opportunity for just-in-time intervention [76] at the point of need.

These studies included minimal or no therapist support. Aardoom's (2016) [52] study suggests that self-guided interventions can be effective with automated feedback, while some therapist involvement improves user satisfaction. In depression and anxiety, studies show that treatment programs with some level of guidance are more effective than without [83,84]. More work is required to understand what level of support is optimal, how it benefits users, and the cost-effectiveness of additional support [85]. Research into what level and type of therapist interactions are sufficient to develop any therapeutic alliance within digital ED interventions requires further study, given therapeutic alliance has been shown to be positively associated with treatment outcome in both F2F treatment [86] and internet-based treatment [87]. This includes research into the use of AI chatbots and how they might support the establishment of an alliance [88].

There remains a lack of studies of digital eating disorder interventions involving older people, men, and sexual and ethnic minorities [17]. There is evidence to suggest ethnicities may have differing requirements from an eating disorder intervention, and these populations may also be less likely to access treatment [72]. It is important that these groups are represented in future research on digital health interventions in eating disorders from the outset [35] to support the design and development of more accessible and inclusive digital interventions.

Further research is required to understand exactly where these interventions should fit in the treatment pathway to complement the work of eating disorder therapists and healthcare professionals in this field. It is then crucial that this research is translated into 'real-world' interventions to offer more evidence-based apps to people with mild to moderate eating disorders [89,90] while recognising that they may not be suitable for all and that healthcare professional support may still be

necessary at some stage.

Conclusions

There is increasing evidence for the effectiveness of digital interventions for the treatment of people with mild to moderate eating disorders, with improved outcomes at post-intervention and sustained at follow-up. Effective digital eating disorder interventions mostly used the same specific behaviour change techniques, informed by theory, however there was no evidence that any one behaviour change technique contributed to improvements in eating disorder behaviours. However, the presence of self-monitoring in 100% of effective intervention suggests it may be important for enabling eating disorder behaviour change. There seems to be the opportunity for further refinement of BCTs within digital interventions to improve intervention effectiveness by applying learnings from what works in therapy and conducting factorial experiments.

Those interventions which were informed by theory, and where theory had been applied to identify mechanisms of change and select specific behaviour change techniques within the intervention, had better outcomes. There was no evidence that increasing the number of modes of delivery had an impact on effect size. There were few studies which evaluated digital apps, suggesting there may be the potential for the development of improved quality evidence-based apps, to improve access to treatment. Future interventions should be grounded in theory targeting those specific mechanisms of change which are important for improving individuals' eating disorder behaviours.

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Conflicts of Interest

Pamela Thomas is an Honorary Eating Disorder Researcher at Thrive Mental Wellbeing. Pamela has received no funding for this project.

Multimedia Appendices

“Multimedia Appendix 1: Search strategy”
“Multimedia Appendix 2: Supplementary sub-group analyses from the meta-analysis”
“Multimedia Appendix 3: Results of theory coding scheme, modes of delivery and risk-of-bias analyses”
“Multimedia Appendix 4: Summary of study characteristics”
“Multimedia Appendix 5: Summary of interventions including behaviour change techniques and modes of delivery”
“Multimedia Appendix 6: Most common BCTs, definitions and implementation examples”

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Abbreviations

ACT: Acceptance Commitment Therapy
AN: Anorexia Nervosa
BCT: Behaviour Change Technique
BED: Binge Eating Disorder
BN: Bulimia Nervosa
CBT: Cognitive Behavioural Therapy
CBT-ED: Cognitive Behavioural Therapy for Eating Disorders
DBT: Dialectical Behaviour Therapy
DPP: Day Patient Programme
ED: Eating Disorder
EDE-Q: Eating Disorder Examination Questionnaire
MD: Mean Difference
MOA: Mechanism of Action
OBE: Objective Binge Episode
RCT: Randomised Controlled Trial
ROB: Risk-of-Bias
TAU: Treatment-as-usual
TCS: Theory Coding Scheme
WL: Waiting list.

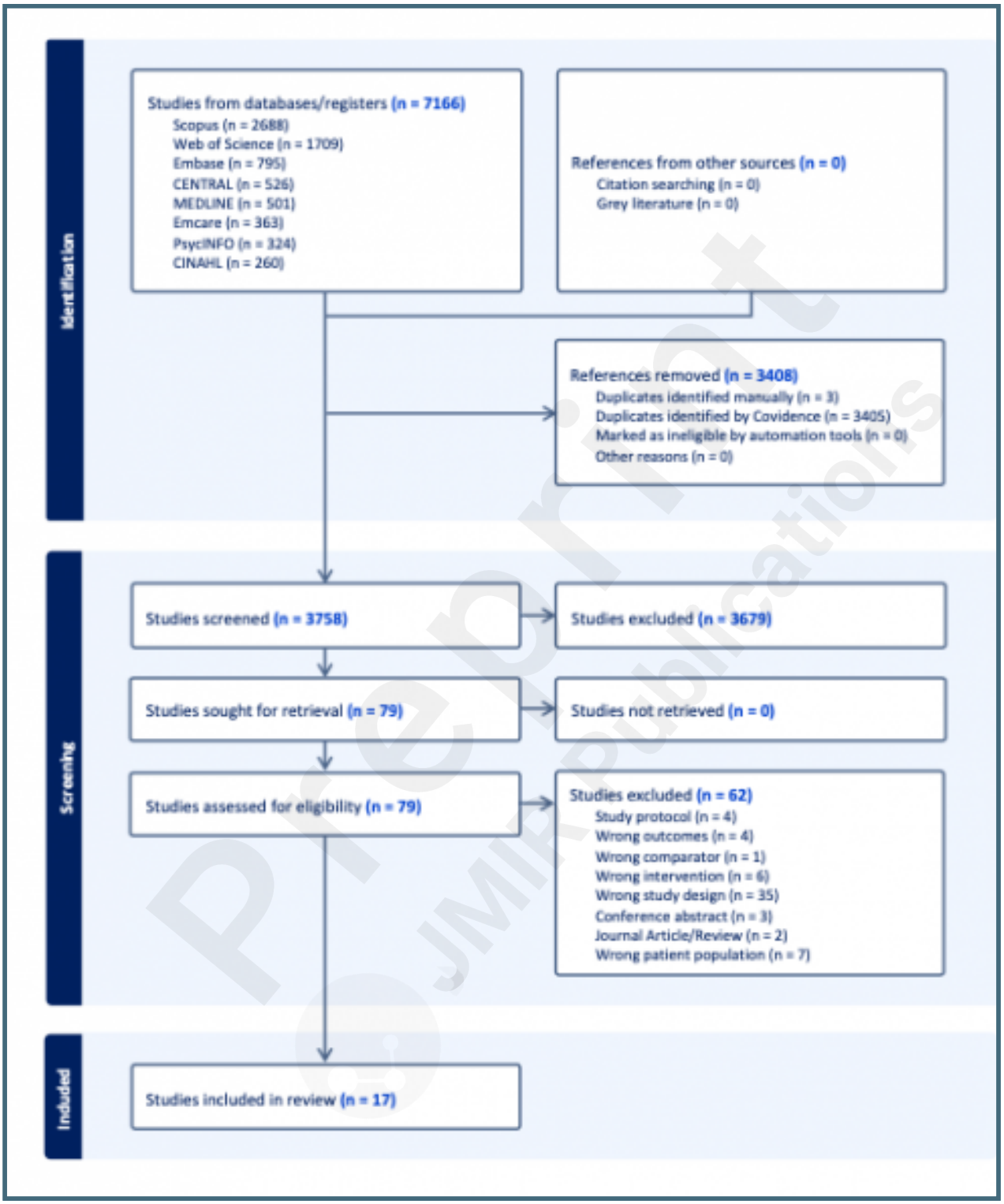
Supplementary Files

Figures

Inclusion/Exclusion Criteria.

Inclusion	Exclusion
- Adults in general population - Self-management interventions and Guided Self-help interventions for individuals - Included study participants who meet sub-threshold and/or threshold criteria for an ED. - Standalone digital intervention with minimal or some therapist support* - Outcome measure using the EDE-Q - Randomised controlled trials.	- Interventions aimed at < 16 years old - Intervention aimed at healthcare professionals - Intervention specific to relapse prevention, aftercare - Intervention specific to eating disorder prevention - Intervention aimed at obesity, weight management - Telemedicine / teleconferencing - Augmentation therapy (app as an 'add-on') - Digital intervention with intensive levels of supplementary therapist support - Group-CBT; group-therapy - Technologies which have been superseded (i.e. CD-ROM, vodcast, SMS/text messaging) - Interventions that used mobile phones, but did not involve apps (e.g. were based solely on SMS messaging or emails) - No clear description of the intervention design (not possible to code for BCTs) - Qualitative studies - Feasibility and acceptability studies, pilot studies - No clear outcome measures (using the EDE-Q).

PRISMA Flow Diagram.



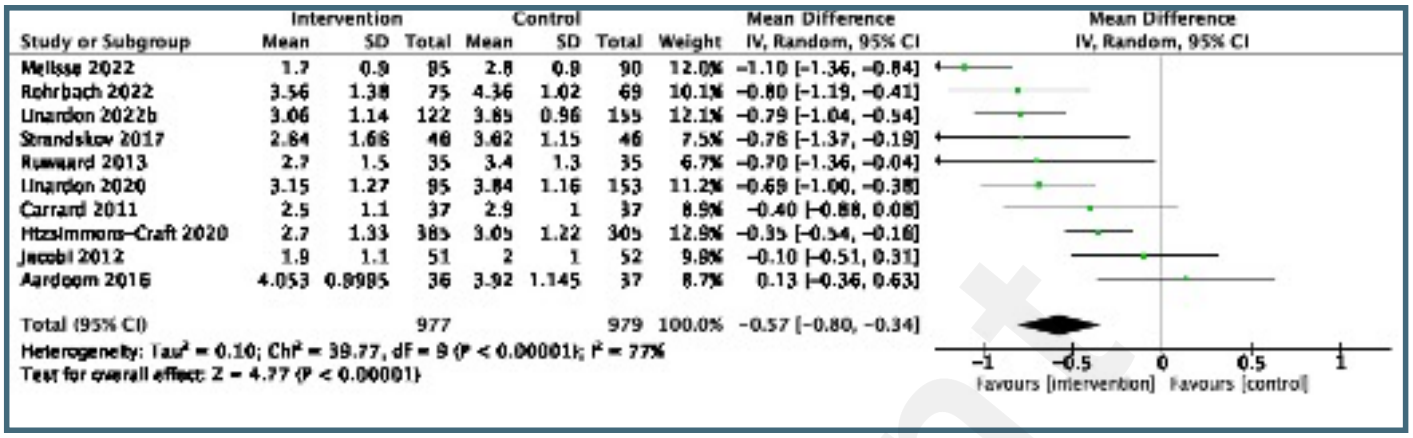
BCTs Included in Treatment Interventions (by Study).

Evaluation of ED Studies	Carrard (2011)	Ruwaard (2015)	de Zwaan et al (2017)	Strandskov et al (2017)	Wgaan et al (2021)	Trigorthee et al (2019)	Linardon et al (2022a)	Linardon et al (2022b)	Linardon et al (2021b)	Linardon et al (2020)	Melisse et al (2020)	Rohrbach et al (2022)	Fitzsimmons-Cra et al (2020)	Aardoen et al (2016)	Iacobi et al (2012)	Hoglöhl et al (2020)	Wagner et al (2015)	ALL INTERVENTIONS / STUDIES		EFFECTIVE INTERVENTIONS (at post-intervention)	
	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I	*Eff P/I		*Eff P/I	*Eff P/I	*Eff P/I	Counts	%	Counts	%
2.3 Self-monitoring of behaviour	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	17	100.0%	16	100.0%
1.2 Problem solving	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	16	94.1%	15	93.8%
4.2 Information about antecedents	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	16	94.1%	15	93.8%
2.2 Feedback on behaviour	X	X	X	X	X			X	X	X	X	X	X	X	X		X	14	82.4%	13	81.3%
2.4 Self-monitoring of outcomes of	X				X	X	X	X	X	X	X	X	X	X	X	X	X	14	82.4%	13	81.3%
1.4 Action planning	X	X			X	X	X	X	X	X	X		X			X	X	12	70.6%	12	75.0%
8.1 Behavioural practice / rehearsal	X		X			X	X	X		X			X		X	X	X	10	58.8%	10	62.5%
13.2 Framing / reframing	X	X				X	X	X	X	X			X		X	X		10	58.8%	10	62.5%
7.1 Prompts / cues				X		X	X	X	X	X	X	X		X				9	52.9%	9	56.3%
7.7 Exposure	X	X	X	X			X		X				X		X		X	9	52.9%	9	56.3%
3.2 Social support (practical)	X		X	X	X							X		X	X		X	8	47.1%	7	43.8%
4.1 Instructions on how to perform the				X	X		X	X	X	X			X	X				8	47.1%	7	43.8%
5.1 Information about health consequences					X		X		X		X	X		X	X	X		8	47.1%	7	43.8%
2.7 Feedback on outcomes of behaviour									X		X	X	X	X	X		X	7	41.2%	6	37.5%
3.1 Social support (unspecified)	X		X									X	X	X		X	X	7	41.2%	6	37.5%
8.2 Behaviour substitution				X				X		X	X				X	X		6	35.3%	6	37.5%
11.2 Reduce negative emotions				X				X		X			X		X		X	6	35.3%	6	37.5%
8.4 Habit reversal				X		X		X		X			X					5	29.4%	5	31.3%
5.6 Information about emotional					X				X			X	X	X				5	29.4%	4	25.0%
8.3 Habit formation				X			X						X			X		4	23.5%	4	25.0%
9.3 Comparison of future outcomes	X		X			X			X									4	23.5%	4	25.0%
1.1 Goal setting (behaviour)				X	X	X												3	17.6%	3	18.8%
1.3 Goal setting (outcome)				X	X	X												3	17.6%	3	18.8%
9.2 Pros and cons	X		X			X												3	17.6%	3	18.8%
12.4 Distraction								X		X			X					3	17.6%	3	18.8%
15.4 Self-talk	X	X											X					3	17.6%	3	18.8%
3.3 Social support (emotional)				X								X		X				3	17.6%	2	12.5%
5.3 Information about social and												X		X	X			3	17.6%	2	12.5%
10.4 Social reward						X						X		X				3	17.6%	2	12.5%
5.4 Monitoring of emotional consequences	X		X															2	11.8%	2	12.5%
15.3 Focus on past success				X		X												2	11.8%	2	12.5%
15.1 Verbal persuasion about capability												X		X				2	11.8%	1	6.3%
1.5 Review behavioural goal						X												1	5.9%	1	6.3%
1.7 Review outcome (goal)						X												1	5.9%	1	6.3%
1.9 Commitment				X														1	5.9%	1	6.3%
2.1 Monitoring of behaviour by others											X							1	5.9%	1	6.3%
4.4 Behavioural experiments		X																1	5.9%	1	6.3%
13.4 Valued self-identity				X														1	5.9%	1	6.3%

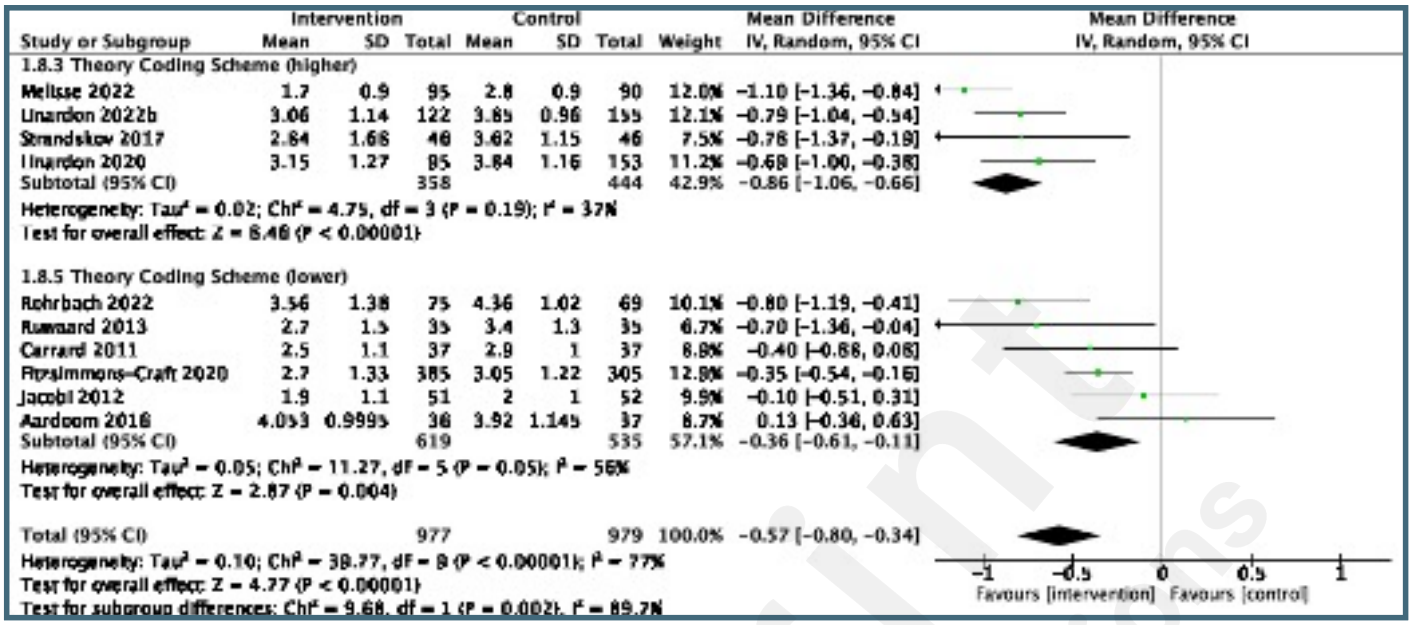
BCTs Included in Effective Treatment Interventions at Follow-Up (by Study).

Evaluation of ED Studies	Gerard (2011)	Ruwaard (2013)	de Zwaan et al (2017)	Wyssen et al (2021)	Röhrbach et al (2022)	Fitzsimmons-Craft et al (2020)	Aardoom et al (2016)	Jacobi et al (2012)	Hogdahl et al (2023)	EFFECTIVE (at follow-up) 9 studies had F/U data*	
	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	*F/U	Counts	%
2.3 Self-monitoring of behaviour	X	X	X	X	X	X	X	X	X	9	100.0%
1.2 Problem solving	X	X	X	X	X	X	X		X	8	88.9%
2.2 Feedback on behaviour	X	X	X	X	X	X	X	X		8	88.9%
4.2 Information about antecedents	X	X	X	X	X	X	X		X	8	88.9%
2.4 Self-monitoring of outcomes of behaviour	X			X	X	X	X	X	X	7	77.8%
3.1 Social support (unspecified)	X		X		X	X	X		X	6	66.7%
3.2 Social support (practical)	X		X	X	X		X	X		6	66.7%
1.4 Action planning	X	X		X		X			X	5	55.6%
5.1 Information about health consequences				X	X		X	X	X	5	55.6%
7.7 Exposure	X	X	X			X		X		5	55.6%
8.1 Behavioural practice / rehearsal	X		X			X		X	X	5	55.6%
13.2 Framing / reframing	X	X				X		X	X	5	55.6%

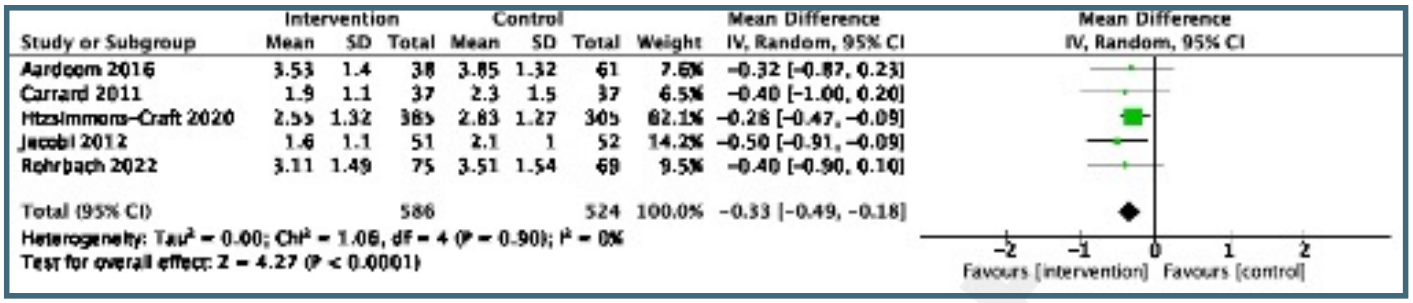
Mean Difference in Outcomes (EDE-Q) for Digital ED Interventions vs. WL/TAU controls (at post-intervention).



Results of meta-analysis from theory coding scheme subgroup analysis.



Mean Difference in Outcomes (EDE-Q) for Digital ED Interventions vs. WL/TAU controls at Follow-up.



Multimedia Appendixes

Search strategy.
URL: http://asset.jmir.pub/assets/5453946398c52ccea211ac3eb0c6904e.docx

Supplementary sub-group analyses from the meta-analysis.
URL: http://asset.jmir.pub/assets/7b240864c284557d0b3358c9f1668899.docx

Results of theory coding scheme, modes of delivery and risk-of-bias analyses.
URL: http://asset.jmir.pub/assets/684ba74ca4285566c6039ebd4c0456ad.docx

Summary of study characteristics.
URL: http://asset.jmir.pub/assets/0813ad288c74d1be323c80d492f720b3.docx

Summary of interventions including behaviour change techniques and modes of delivery.
URL: http://asset.jmir.pub/assets/936e17aedcd97bafed0f516806d1d71c.docx

Most common BCTs, definitions and implementation examples.
URL: http://asset.jmir.pub/assets/ff1e099c6b9ea8ed1b679cc645a9084c.docx

CONSORT (or other) checklists

PRISMA checklist.
URL: http://asset.jmir.pub/assets/494d67c1911c33e977a83dc96ed39e8c.pdf