Appetite 168 (2022) 105788

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

App-based food-specific inhibitory control training as an adjunct to treatment as usual in binge-type eating disorders: A feasibility trial

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ARTICLE INFO

Keywords:
Binge eating disorder
Bulimia nervosa
FoodT application
Inhibitory control training
mHealth intervention

ABSTRACT

Current treatments for binge eating disorder (BED) and bulimia nervosa (BN) only show moderate efficacy, warranting the need for novel interventions. Impairments in food-related inhibitory control contribute to BED/BN and could be targeted by food-specific inhibitory control training (ICT). The aim of this study was to establish the feasibility and acceptability of augmenting treatment for individuals with BN/BED with an ICT app (FoodT), which targets motor inhibition to food stimuli using a go/no-go paradigm. Eighty patients with BED/BN receiving psychological and/or pharmacological treatment were randomly allocated to a treatment-as-usual group (TAU; n = 40) or TAU augmented with the 5-min FoodT app daily (n = 40) for 4 weeks. This mixed-methods study assessed feasibility outcomes, effect sizes of clinical change, and acceptability using self-report measures. Pre-registered cut-offs for recruitment, retention, and adherence were met, with 100% of the targeted sample size (n = 80) recruited within 12 months, 85% of participants retained at 4 weeks, and 80% of the FoodT + TAU group completing ≤8 sessions. The reduction in binge eating did not differ between groups. However, moderate reductions in secondary outcomes (eating disorder psychopathology: SES = −0.57, 95% CI [-1.12, −0.03]; valuation of high energy-dense foods: SES = −0.61, 95% CI [-0.87, −0.05]) were found in the FoodT group compared to TAU. Furthermore, small greater reductions in food addiction (SES = −0.46, 95% CI [-1.14, 0.22]) and lack of premeditation (SES = −0.42, 95% CI [-0.77, −0.07]) were found in the FoodT group when compared to TAU. The focus groups revealed acceptability of FoodT. Participants discussed personal barriers (e.g. distractions) and suggested changes to the app (e.g. adding a meditation exercise). Augmenting treatment for BED/BN with a food-specific ICT app is feasible, acceptable, and may reduce clinical symptomatology with high reach and wide dissemination.

1. Introduction

Binge-eating disorder (BED) and bulimia nervosa (BN) are eating disorders (EDs) that are characterized by recurrent binge-eating episodes. During such episodes, individuals experience loss of control over eating and consume objectively large amounts of food (American Psychiatric Association, 2014). Cognitive Behavioural Therapy (CBT) is regarded as the treatment-of-choice for BN and BED (Costa & Melnik, 2016). However, the evidence-base for its efficacy reveals that remission rates are moderate (Brownley et al., 2016), with fewer than 50% of patients with BN, and approximately 50% of patients with BED achieving abstinence from binge eating at the end of treatment (Hay, 2013; Hilbert et al., 2019; Linardon & Wade, 2018). Over the last decade, it has been proposed that digital interventions targeting specific maintaining factors (e.g. heightened impulsivity, mood dysregulation, attentional biases) could be used to augment the efficacy of CBT (Aardoom, Dingemans, Spinhoven, & Van Furth, 2013; Dölemeyer, Tietjen, Kersting, & Wagner, 2013; Linardon, Shatte, Messer, Firth, &

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https://doi.org/10.1016/j.appet.2021.105788
Received 10 May 2021; Received in revised form 14 October 2021; Accepted 29 October 2021
Available online 30 October 2021

Fuller-Tyszkiewicz, 2020; Loucas et al., 2014; Schlegl, Bürger, Schmidt, Herbst, & Voderholzer, 2015).

Impulsivity is a trait that increases the vulnerability to binge-type eating disorders (Davis, 2013; Schag et al., 2013), and is characterized by heightened sensitivity to reward and disinhibited behaviour (Dawe & Loxton, 2004). Evidence from cross-sectional and neuroimaging studies indicate higher levels of self-reported impulsivity and atypical activation in impulse-control and reward-related brain regions in response to both food and non-food cues in patients with BN/BED (Balodis et al., 2013; Marsh et al., 2009; Mele, Alfano, Cotugno, & Longarzo, 2020, p. 104712; Skunde et al., 2016). Systematic reviews have shown confirmatory evidence of increased rash-spontaneous behaviour and reward sensitivity (Giel, Teufel, Junne, Zipfel, & Schag, 2017) and impairments in food-related inhibitory control in BED (Wu, Hartmann, Skunde, Herzog, & Friederich, 2013). Consequently, inhibitory control (the ability to inhibit a prepotent behavioural response to a cue in order to attain an overarching goal) is likely to be a promising target for interventions for binge-type eating disorders.

There has been interest in developing interventions that target inhibitory control (Chami et al., 2020; van Koningsbruggen, Veling, Stroebe, & Aarts, 2014). Food-specific inhibitory control training (ICT) requires users to consistently inhibit their motor responses to foods within the context of a speeded reaction time task (Lawrence et al., 2015). Meta-analyses of lab studies and real world trials in non-ED populations indicate that food-specific ICT, as opposed to general (non-food) ICT, is associated with reductions in high energy-dense food intake and liking (Allom, Mullan, & Hagger, 2016; Jones et al., 2016) and reductions in body fat and weight (Lawrence et al., 2015; Stice, Yokum, Veling, Kemps, & Lawrence, 2017; Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017). Previous studies have suggested that food-specific ICT is effective in reducing eating disorder psychopathology (Chami et al., 2020; Giel et al., 2017), weight (Preuss, Pinnow, Schnicker, & Legenbauer, 2017) and energy-dense food valuation (Chami et al., 2020) in patients with BN and BED. Additionally, there is preliminary evidence for improvements in binge eating frequency in patients with binge-type eating disorders who adhered to a 10-session inhibitory control intervention (Preuss et al., 2017).

The efficacy of ICT is suggested to be contingent on whether food-cues are paired with successful inhibition, making training formats using consistent mapping of foods with a "stop" response more successful (Allom et al., 2016; Aulbach, Knittle, & Haukkala, 2019; Jones et al., 2016). One example of this is the go/no-go (GNG) paradigm, designed to target the automatic approach response to highly palatable foods (Spierer, Chavan, & Manuel, 2013). While the mechanisms of change are yet to be uncovered, there is some suggestion that GNG training influences eating behaviour through the process of food-cue devaluation and potentially automatic (conditioned) inhibition (Veling et al., 2017). This makes it a promising intervention to target heightened food-cue valuation and the experience of 'loss of control over eating' (disinhibited eating) in BN and BED.

We recently conducted a feasibility study of a 28-day guided self-help intervention that targeted two aspects of inhibitory control: motor inhibition through computer-based GNG training and implementation intention formation in patients with BN and BED (Chami et al., 2020). Results indicated that the intervention was acceptable, feasible, and successful at reducing clinical symptomatology-including moderate-to-large within-group effect size reductions in binge eating frequency and eating disorder psychopathology and small within-group effect size reductions in high energy-dense food valuation (Chami et al., 2020). Feedback from focus groups with participants suggested improvements to the training, such as delivery via a mobile device instead of a computer, gamification, and greater personalisation of the food stimuli that appear in the training. In the current study, we built on this feedback and examined the effects of delivering food go/no-go training using a mobile app that includes some gamification (point scoring) and enables personalisation of "no-go" food stimuli.

The primary objective of the present study was to assess the feasibility (recruitment, adherence, and retention rates) and preliminary clinical efficacy of the app in augmenting TAU among individuals with BN or BED compared to TAU alone. Furthermore, we examined differences in binge eating frequency (primary outcome), eating disorder psychopathology, and food valuation (secondary outcomes). Exploratory outcomes included food approach, self-regulation of eating behaviour, food addiction, depression, anxiety, urgency, loss of premeditation, sensation seeking, loss of perseverance, and global health. Focus groups were used to explore participants' views of the helpfulness, possible harms, practicality, and potential improvements to the intervention methodology. The study was pre-registered on Clinicaltrials.gov (ID: NCT04364659).

2. Methods

2.1. Participants

Participants were recruited through UK-based eating disorder charity websites, social media, flyers, and the South London and Maudsley NHS Trust eating disorder services. Eligibility required that participants met full-threshold criteria for bulimia nervosa or binge eating disorder according to the *Structured Clinical Interview for DSM-5*, were currently receiving a form of treatment for their eating disorder (one or more of: psychotherapies such as CBT, nutritional support, and/or psychiatric medications such as anti-depressants), had a body mass index (BMI) of at least 18.5 kg/m^2, were between the ages of 18 and 60, and were fluent in written/spoken English. The mean ± SD age of the sample was 31.8 ± 11.2 and the mean ± SD BMI was 29.2 ± 10.5 kg/m^2. Most participants were female (n = 77; 96%). See Table 1 for a summary of the demographic characteristics of each group. Participants were excluded if they were currently pregnant, had a visual impairment that could not be repaired with eyewear, a neurological impairment, alcohol or drug dependence, or psychosis.

2.1.1. Sample size

Recommendations of sample sizes for feasibility studies indicate that it is appropriate to recruit between 24 and 50 participants per arm (Julious, 2005; Lancaster, Dodd, & Williamson, 2004; Sim & Lewis, 2012). Previous research using identical versions of food-specific and general ICT in overweight adults (Lawrence et al., 2015), detected group differences in weight loss with a sample size of 40 participants per intervention group. Thus, our target sample size was 40 participants per intervention group.

2.1.2. Trial design and randomization

Eighty participants with bulimia nervosa (N = 53) or binge eating disorder (N = 27) were recruited and randomly allocated to receive food-specific go/no-go training plus treatment as usual (TAU; N = 40) or TAU alone (N = 40). A random number generator (https://www.randomizer.org) was used to assign consecutive participants to the intervention arms. See the Consort Diagram below (Fig. 1) for further details on the flow of participation.

The flow-chart describes participants' recruitment and completion of the assessment measures at post-intervention and follow-up.

2.2. Intervention

2.2.1. Food-specific go/no-go training (FoodT)

The FoodT App is an inhibitory control training (ICT) game developed at the University of Exeter (Lawrence, Van Beurden, Javaid, & Mostazir, 2018). Each game consists of three blocks, for 5 min in total, in which 32 images are individually presented on the screen for 1500 ms, with an interstimulus interval of 500 ms. The training involves "go" and "no-go" trials, which are indicated by green and red cues in the form of circles around the images, respectively. These cues appear 100 ms after

Table 1
Baseline demographic and clinical factors.

Variable		TAU	FoodT + TAU	All
Age [Mdn (IQR)]		29 (23, 35)	30 (23, 40.75)	29 (23, 38)
Gender [n (%)]	Male	2 (5%)	1 (2%)	3 (4%)
	Female	38 (95%)	39 (98%)	77 (96%)
Diagnosis [n (%)]	BN	27 (68%)	26 (65%)	53 (66%)
	BED	13 (32%)	14 (35%)	27 (34%)
BMI [M (SD)]		27.5 (9.1)	29.6 (11.4)	28.6 (10.3)
Receiving Psychotherapy [n (%)]	Yes	23 (57.5%)	20 (50%)	43 (53.75%)
	No	17 (42.5%)	20 (50%)	37 (46.25%)
Receiving Counselling [n (%)]	Yes	4 (10%)	3 (7.5%)	7 (8.75%)
	No	36 (90%)	37 (92.5%)	73 (91.25%)
Receiving Group Therapy [n (%)]	Yes	4 (10%)	4 (10%)	8 (10%)
	No	36 (90%)	36 (90%)	72 (90%)
Psychiatric Medication Use [n (%)]	Yes	17 (47%)	22 (56%)	39 (52%)
	No	19 (53%)	17 (44%)	36 (48%)
Previous Hospital Admission for eating disorder [n (%)]	Yes	9 (23%)	6 (15%)	15 (19%)
	No	31 (77%)	34 (85%)	65 (81%)
Amenorrhea [n (%)]	Yes	10 (26%)	11 (28%)	21 (27%)
	No	28 (74%)	28 (72%)	56 (73%)
Ethnicity [n (%)]	White	34 (85%)	28 (70%)	62 (78%)
	Ethnic Minority	6 (15%)	12 (30%)	18 (22%)
Marital Status [n (%)]	Relationship	16 (40%)	15 (37.5%)	31 (38.75%)
	No Relationship	24 (60%)	25 (62.5%)	49 (61.25%)
Employment [n (%)]	Employed	24 (60%)	21 (52.5%)	45 (56.25%)
	Student	13 (32%)	12 (30%)	25 (31.25%)
	Unemployed	0 (0%)	3 (7.5%)	3 (3.75%)
	Other	3 (8%)	4 (10%)	7 (8.75%)
Years of Education [Mdn (IQR)]		16 (14, 18)	17 (14, 18.25)	17 (14, 18)
Family History of Psychiatric Disorder [n (%)]	Yes	20 (50%)	17 (43%)	37 (46%)
	No	20 (50%)	23 (57%)	43 (54%)

Notes: BMI = body mass index; IQR = interquartile range; mdn = median; n = number of participants; TAU = treatment as usual.

the presentation of the image, to ensure that participants' attention is directed to the images rather than the response signals (based on prior ICT trials; e.g. (Veling, van Koningsbruggen, Aarts, & Stroebe, 2014)). Participants are requested to tap the image on their touch device screen when a "go" cue appears (green circle) and inhibit a response when a "no-go" cue appears (red circle). Participants receive one point for a correct response to a 'go trial' and lose one point if they respond on a 'no-go trial' (commission error). They are given feedback regarding their mean accuracy and reaction time at the end of each block. Within each block, 8 images of low-energy dense foods (e.g. fruits, vegetables and rice cakes), 8 images of high energy-dense food pictures (e.g. chocolate, cake, crisps) and 16 filler images (e.g. stationery, clothing) are presented. Low-energy and high-energy dense food pictures are always paired with "go" and "no-go" cues, respectively. Meanwhile, filler pictures are paired with "go" or "no-go" cues 50% of the time. See Fig. 2 for a visualisation of the game. In order to personalise the training, participants were encouraged to select up to three categories of high energy-dense foods, which would later appear in their games (i.e. instead of the chocolate, biscuit, cake and crisp images that were presented by default). They were instructed to customise the game at the beginning of the training period and to keep the same categories for the full study duration (see Fig. 3 for food categories). Participants were instructed to attempt to play the game daily for 28 days, which both aligns with our previous trial (Chami et al., 2020) and with research suggesting a reduction in food intake is observed at this frequency (Aulbach, Knittle, van Beurden, Haukkala, & Lawrence, 2021).

2.3. Measures

2.3.1. Baseline assessment

Participants were initially screened over the phone using the *Structured Clinical Interview for DSM-5* (*SCID-5;* (First and Gibbon, 2004) to confirm a diagnosis of BN or BED. They also completed a *demographic questionnaire*, which included questions relating to age, gender, weight, height, ethnicity, marital status, years spent in education, employment status, current/previous mental health support received, and use of psychiatric medication.

2.3.2. Clinical outcomes

Primary, secondary, and exploratory outcomes were measured at each time-point: baseline, post-intervention (4 weeks) and follow-up (8 weeks).

2.3.2.1. Primary outcome. Binge eating frequency was measured using item 15 of the Eating Disorder Examination Questionnaire (EDE-Q; (Fairburn & Beglin, 2008) as a standalone outcome (*Over the last 28 days, on how many days have such episodes of overeating occurred (i.e. you have eaten an unusually large amount of food and have had a sense of loss of control at that time))?*

2.3.2.2. Secondary and exploratory outcomes

2.3.2.2.1. Eating disorder psychopathology. **The EDE-Q** (Fairburn & Beglin, 2008) is a 28-item self-report of eating behaviours in the previous 28 days. The questionnaire comprises four subscales: dietary restraint (DR), eating concern (EC), weight concern (WC), and shape concern (SC).

2.3.2.2.2. Food valuation. Participants' rating of the palatability of high energy-dense and low energy-dense foods was measured with a visual analogue scale ranging from 0 to 100 (numeric values not shown to participants). Participants rated 30 food items in a random order, which were different exemplars from the same food categories as those in the app (see https://osf.io/c8z6x/for the images, taken from (Blechert, Meule, Busch, & Ohla, 2014). An average rating was computed for the low energy-dense and high energy-dense foods.

2.3.2.2.3. Exploratory outcomes. Seven additional questionnaires were included to measure eating self-regulation (the ***Self-Regulation of Eating Behaviour Questionnaire***; SREBQ (Kliemann, Beeken, Wardle, & Johnson, 2016)), food approach/avoidance (the ***Adult Eating Behaviour Questionnaire;*** AEBQ (Hunot et al., 2016)), quality of life (the ***EQ-5D-3L*** (The EuroQol Group, 1990)), depressive symptoms (the ***Patient Health Questionnaire***; PHQ-9 (Kroenke, Spitzer, & Williams, 2001)), anxiety symptoms (the ***Generalised Anxiety Disorder Assessment***; GAD-7 (Spitzer, Kroenke, Williams, & Löwe, 2006)); impulsivity (the ***UPPS Impulsive Behaviour Scale*** (Whiteside & Lynam, 2001)) and

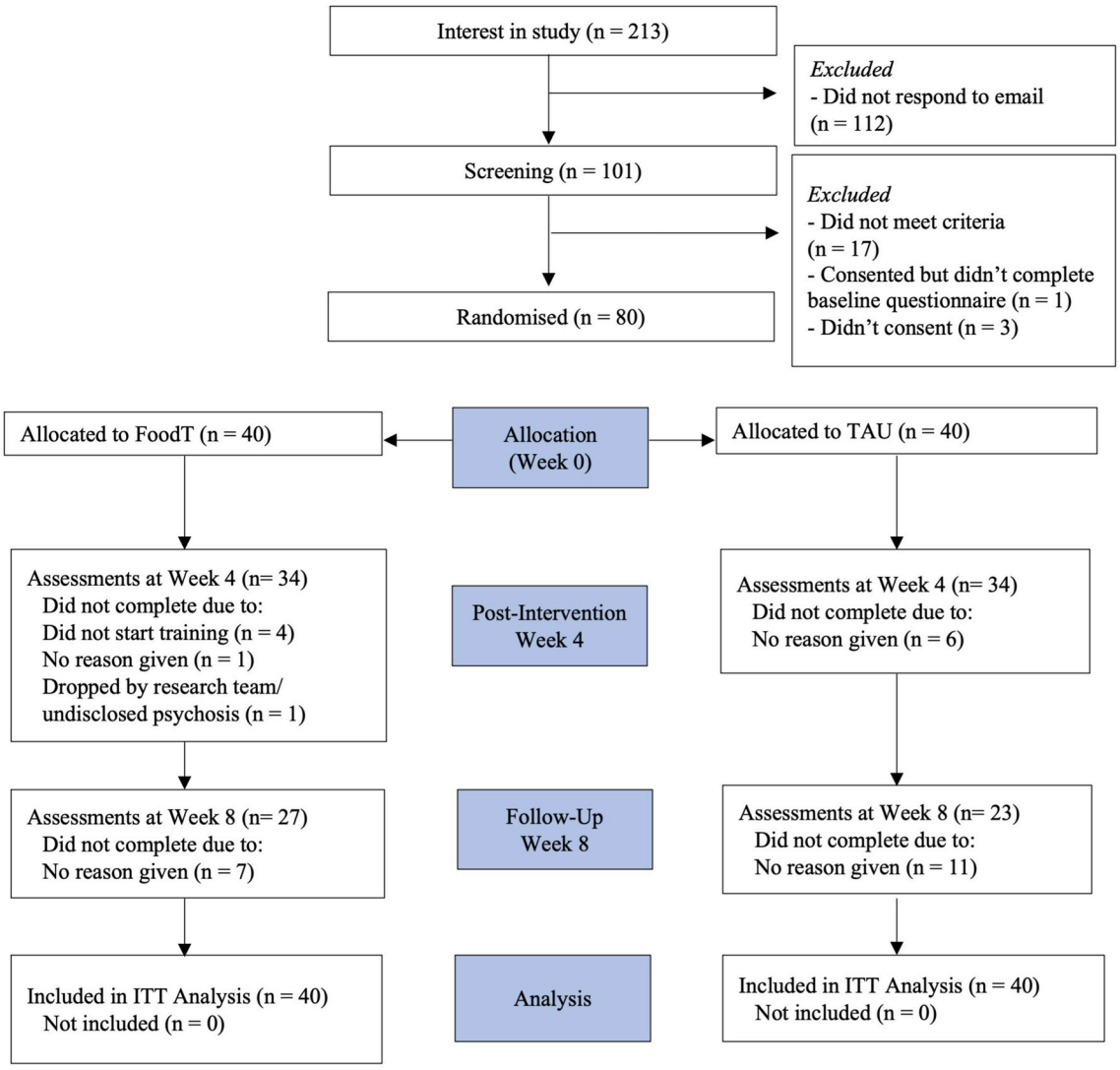

Fig. 1. Consort diagram of participation in the study.

food addiction (the ***Yale Food Addiction Scale***; YFAS (Gearhardt, Corbin, & Brownell, 2009)).

2.4. Procedure

After consent, participants were sent the baseline battery of questionnaires via Qualtrics (i.e. online platform). Once baseline measures were completed, participants were randomly allocated to the FoodT training + TAU or the TAU group. All participants received a personal email to inform them of their group allocation, and those who were allocated to the FoodT training group were introduced to another member of the research team (JK), who guided them through the process of downloading and using the FoodT App during a phone call.

Participants allocated to the FoodT training + TAU group were encouraged to complete one session of the training daily (~5 min) for 28 days and to use the app when stationary or seated with the mobile device placed on a surface. Moreover, they were guided through the customisation options (see Fig. 3) and asked to use the same customisation categories for the duration of the trial. A video guide and leaflet were also provided to participants, to ensure they had access to instructions throughout the trial. Participants allocated to the FoodT training group also completed a food diary daily, delivered via a survey. The purpose of the daily food diary was to assess mechanisms of change that may be implicated in treatment success or failure. The discussion of these findings is therefore beyond the scope of the current paper.

Participants were sent questionnaires to complete at post-intervention (four weeks from baseline) and follow-up (four weeks from post-intervention). These questionnaires were identical to those administered at baseline, with the exception of the demographic questionnaire. All participants received £15, in the form of a bank transfer, as compensation for their time and effort.

The methodology and hypotheses have been pre-registered on Clinicaltrials.gov (ID: NCT04364659) and approved by the London Dulwich Research Ethics Committee (Reference: 19/LO/10054).

2.5. Statistical analysis

Feasibility outcomes, % of recruitment target, adherence to app training and retention were estimated as proportions with 95% confidence intervals (CIs). Baseline demographic and clinical factors were summarized by mean, standard deviation, median and interquartile range or frequency and % of total by treatment group to check whether groups were balanced. The main focus of the analysis was effect sizes. Effect sizes were assessed against thresholds of 0.2 (small), 0.5 (moderate) and 0.8 (large). Estimates of mean group differences with 95% confidence intervals were produced and standardised effects sizes were calculated by dividing estimated mean differences from analysis models by the respective baseline standard deviation (SD). The main statistical

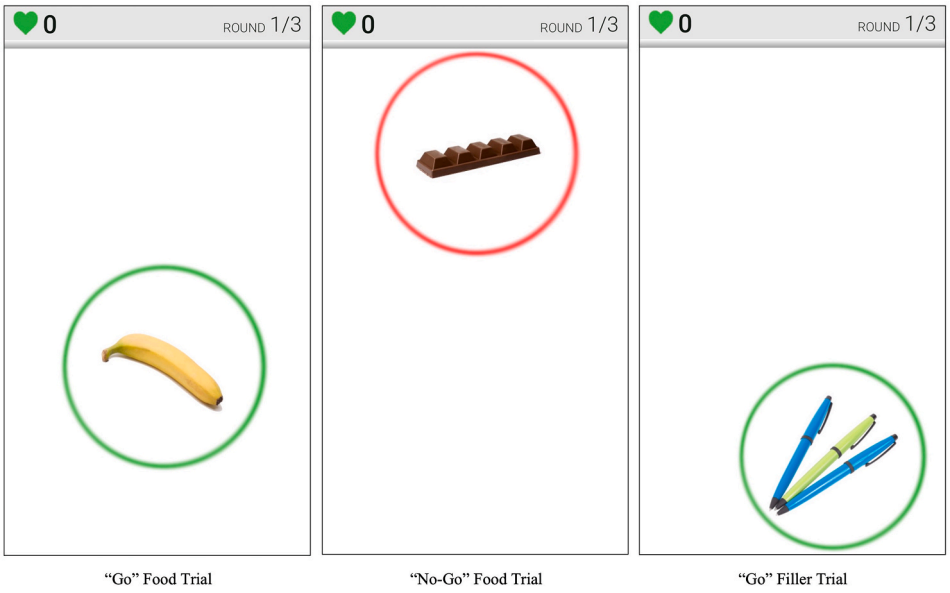

Fig. 2. Screenshots from the FoodT app. Participants respond to images within a green circle and inhibit responses to images within a red circle.

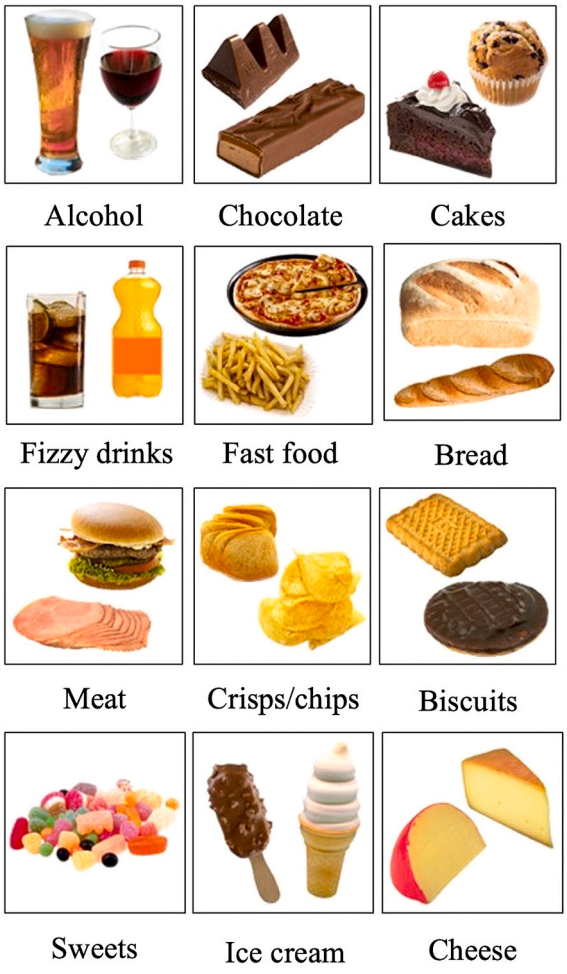

Fig. 3. Food categories in the FoodT app.

analysis consisted of a linear mixed model with maximum likelihood (ML) estimation, to adjust for the presence of missing data. Significance testing was carried out on an exploratory basis.

2.6. Focus groups

Following completion of the study, all participants from the FoodT training + TAU group were invited to a series of online focus groups with a single interviewer (R.C.). A total of eleven participants who were allocated to the FoodT Training + TAU group attended one of three 1.5 h focus groups that were conducted over three days; the first focus group had six attendees, the second group had three and the final group had two. The interview schedule included questions pertaining to the participants' experiences of using the app, including components that were particularly helpful or unhelpful, the usability of the app, and how it affected their daily lives. Qualitative data were independently coded and analysed using a thematic framework, by two researchers (P.M. and R.C.). Thematic analysis is a method of identifying, analyzing and reporting themes from qualitative data and the analysis followed the six phases outlined by Braun and Clarke (Braun & Clarke, 2006). During the coding procedure, the transcripts were read several times, after which initial codes were generated into meaningful clusters. An initial thematic framework was built using the computer software programme Nvivo 12 (QSR International Pty Ltd., 2020). The two researchers engaged in regular discussions to assess coding procedures and the emerging thematic framework. During these discussions, themes and sub-themes were either consolidated or merged into existing themes/sub-themes, and descriptive labels were altered or deleted if deemed irrelevant to the research question. Regular discussions continued until an agreement was reached between the researchers on the final thematic framework.

3. Results

3.1. Recruitment, retention, and adherence to intervention

The CONSORT diagram (Thabane et al., 2016) that describes participants' recruitment and completion of assessments is shown in Fig. 1. The pre-set recruitment target was met over a 12-month period (June

2019–May 2020), with a recruitment of 100% of the targeted sample size (N = 80). The pre-set retention rate of 80% at four weeks was met (85%). Of the 12 participants who did not complete the four-week assessment, four had not started the training, seven did not give a reason, and one was excluded by the research team due to an undisclosed diagnosis of psychosis. Thirty-two of 40 participants (80%) allocated to the FoodT training group completed our pre-registered adherence level of 8 training sessions or more; the median number of training sessions completed was 21 (IQR = 17, 26.25). The median number of sessions completed after the four-week time-point was 6.5 (IQR = 3.5, 7.8). An additional 7 FoodT and 11 participants from the TAU and the FoodT training groups, respectively, did not complete the follow-up assessment at 8 weeks. Please refer to Supplementary Materials 1 for information on missing data and visit windows.

3.2. Baseline demographic and clinical factors

The demographic and clinical features are shown in Table 1. The majority of participants were female, and there was a higher proportion of participants with a diagnosis of BN compared to BED. Psychiatric medications and psychological therapy were the most common forms of treatment. A fifth of the sample had a previous hospital admission for their eating disorder, potentially indicative of a more severe subset of individuals with BN/BED.

3.3. Clinical outcomes

Table 2 displays between-group differences in predicted means of primary, secondary, and exploratory outcomes at post-intervention and follow-up (based on the likelihood estimation model). Descriptive statistics for all outcome measurements from the raw data are available in Supplementary Materials 3.

3.3.1. Primary outcome

Both the TAU and FoodT groups showed a reduction in binge eating over time (see Fig. 4). However, there were no differences between the groups in binge eating frequency at post-intervention (SES = −0.01, 95% CI [−0.44, 0.41]) or at follow-up (SES = −0.12, 95% CI [−0.64, 0.41]).

3.3.2. Secondary outcomes

Both the TAU and FoodT groups showed a reduction in eating disorder psychopathology and high energy-dense food valuation (see Fig. 4).

At post-intervention (4 weeks), the FoodT group, compared to the TAU group, achieved moderate sized greater reductions in eating disorder psychopathology (SES = −0.57, 95% CI [−1.12, −0.03]) and high energy-dense food valuation (SES = −0.61, 95% CI [−0.99, −0.24]).

At follow-up (8 weeks), the FoodT group, compared to the TAU group, again achieved a small sized greater reduction in high energy-dense food valuation (SES = −0.46, 95% CI [−0.87, −0.05]). However, differences between groups in eating disorder psychopathology were not maintained at this timepoint (SES = −0.17, 95% CI [−0.78, 0.45]).

Low energy-dense food valuation was not significantly different between groups at any time-point (see Table 2).

3.3.3. Exploratory outcomes

At post-intervention (4 weeks), the FoodT group achieved a small-sized greater reduction in food approach (SES = −0.29, 95% CI [−0.65, 0.08]), a small-sized greater increase in self-regulation of eating behaviour (SES = 0.34, 95% CI [−0.08, 0.76]) and a small-sized greater reduction in food addiction (SES = −0.23, 95% CI [−0.81, 0.34]), albeit none of these differences were significant at the $p < 0.05$ threshold.

At follow-up (8 weeks), the FoodT group maintained a small-sized greater reduction in food approach (SES = −0.24, 95% CI [−0.67, 0.18]) and a small sized greater reduction in food addiction symptoms

Table 2
Standardised between-group effect sizes (SES) of primary, secondary and exploratory outcomes at post-intervention and follow-up, based on estimated mean difference and adjusted for baseline outcome data.

Variable	Estimated Mean Difference (95% CI)	SES (95% CI)	*t* (df)	*p*
Primary outcome				
Binge Eating Frequency				
4 weeks	−0.12 (−3.47, 3.24)	−0.01 (−0.44, 0.41)	−0.1 (94.9)	0.95
8 weeks	−0.9 (−4.99, 3.18)	−0.12 (−0.64, 0.41)	−0.4 (107.5)	0.67
Secondary outcomes				
EDE-Q				
4 weeks	−0.52 (−1.02, −0.02)	−0.57 (−1.12, −0.03)	−2.1 (78.3)	0.04
8 weeks	−0.15 (−0.72, 0.41)	−0.17 (−0.78, 0.45)	−0.5 (99.2)	0.59
HED food valuation				
4 weeks	−10.47 (−16.89, −4.04)	−0.61 (−0.99, −0.24)	−3.2 (72.8)	0.002
8 weeks	−7.89 (−14.95, −0.84)	−0.46 (−0.87, −0.05)	−2.2 (91.4)	0.031
LED food valuation				
4 weeks	0.29 (−5.1, 5.69)	0.01 (−0.25, 0.28)	0.1 (84.3)	0.915
8 weeks	−2.37 (−8.65, 3.9)	−0.12 (−0.42, 0.19)	−0.7 (102.7)	0.46
Exploratory outcomes				
AEBQ | Food Approach				
4 weeks	−0.66 (−1.51, 0.18)	−0.29 (−0.65, 0.08)	−1.5 (79)	0.128
8 weeks	−0.56 (−1.55, 0.42)	−0.24 (−0.67, 0.18)	−1.1 (99.8)	0.263
SREBQ				
4 weeks	0.23 (−0.06, 0.51)	0.34 (−0.08, 0.76)	1.6 (83.8)	0.119
8 weeks	0.07 (−0.26, 0.39)	0.1 (−0.39, 0.59)	0.4 (102)	0.692
GAD-7				
4 weeks	−0.92 (−3.14, 1.3)	−0.17 (−0.58, 0.24)	−0.8 (94.6)	0.42
8 weeks	0.75 (−1.96, 3.46)	0.14 (−0.37, 0.64)	0.5 (106)	0.59
PHQ-9				
4 weeks	0.03 (−2.2, 2.25)	0 (−0.35, 0.36)	0 (88.6)	0.98
8 weeks	1.41 (−1.28, 4.1)	0.22 (−0.2, 0.65)	1 (105)	0.306
YFAS				
4 weeks	−0.28 (−0.97, 0.41)	−0.23 (−0.81, 0.34)	−0.8 (91)	0.431
8 weeks	−0.56 (−1.37, 0.26)	−0.46 (−1.14, 0.22)	−1.3 (108.3)	0.185
UPPS | Urgency				
4 weeks	0.11 (−0.06, 0.27)	0.24 (−0.13, 0.6)	1.3 (73.2)	0.204
8 weeks	0.16 (−0.02, 0.34)	0.35 (−0.05, 0.75)	1.7 (93.1)	0.092
UPPS | Lack of Premeditation				
4 weeks	0 (−0.16, 0.15)	−0.01 (−0.31, 0.29)	−0.1 (79)	0.955
8 weeks	−0.22 (−0.4, −0.04)	−0.42 (−0.77, −0.07)	−2.3 (100.5)	0.021
UPPS | Sensation Seeking				
4 weeks	−0.08 (−0.25, 0.08)	−0.12 (−0.36, 0.12)	−1 (77.2)	0.332
8 weeks	0.04 (−0.14, 0.22)	0.06 (−0.21, 0.32)	0.4 (95.5)	0.68
UPPS | Lack of Perseverance				
4 weeks	−0.02 (−0.19, 0.15)	−0.04 (−0.42, 0.33)	−0.2 (77.1)	0.817
8 weeks	−0.09 (−0.28, 0.1)	−0.21 (−0.63, 0.21)	−1 (97.3)	0.334
EQ-5D | Index				
	0.04 (−0.04, 0.13)		0.9 (98.5)	0.349

(*continued on next page*)

Table 2 (*continued*)

Variable	Estimated Mean Difference (95% CI)	SES (95% CI)	*t* (df)	*p*
4 weeks		0.15 (−0.16, 0.47)		
8 weeks	0.01 (−0.09, 0.11)	0.04 (−0.35, 0.42)	0.2 (109.1)	0.852
EQ-5D | Visual Analogue Scale				
4 weeks	−7.5 (−14.99, −0.01)	−0.36 (−0.72, 0)	−2 (92.1)	0.053
8 weeks	−5 (−13.99, 3.99)	−0.24 (−0.68, 0.19)	−1.1 (106.8)	0.278

Notes: AEBQ = Adult Eating Behaviour Questionnaire; EDE-Q = Eating Disorder Examination Questionnaire; GAD-7 = Generalised Anxiety Disorder Assessment; HED = high energy-dense; LED = low energy-dense; PHQ-9 = Patient Health Questionnaire; SREBQ = Self-Regulation of Eating Behaviour Questionnaire; YFAS = Yale Food Addiction Scale.

(SES = −0.46, 95% CI [−1.14, 0.22]). At this timepoint, between-group differences in self-regulation of eating behaviour were lost (SES = 0.1, 95% CI [−0.39, 0.59]). However, a small sized greater reduction in lack of premeditation (SES = −0.42, 95% CI [−0.77, −0.07]), and a small-sized greater reduction in lack of perseverance was found (SES = −0.21, 95% CI [−0.63, 0.21]).

All other outcomes showed negligible differences between groups at post-intervention or follow-up (see Table 2).

3.4. Manipulation check

In order to examine the learning of GNG contingencies, we examined average "no-go" commission error rates for high energy-dense foods compared with "no-go" filler stimuli, as well as average 'go" RTs to low-energy foods compared with "go" filler stimuli. This allowed us to compare performance in response to stimuli (foods) that were 100% associated with a "go" or "no-go" signals to stimuli (fillers) that were 50% associated with a signal. A paired-samples *t*-test showed a significant difference in go trial RTs between stimulus types ($t(36) = -18.318$, $p = < .001$, 95% CI [−25.07, −18.32]), with faster go RTs to low-energy foods (M = 685.24, SD = 99.02) than filler items (M = 706.93, SD = 98.33), consistent with an associative learning effect. There was no significant difference in "no-go" error rates between stimulus types ($t(36) = -1.269$, $p = 0.213$, 95% CI [−0.02, 0.004]), although as expected, error rates to "no-go" food stimuli were lower (M = 0.008, SD = 0.008) than for filler no-go stimuli (M = 0.014, SD = 0.027).

3.5. Qualitative results

During the focus groups, participants reported finding the FoodT app simple and straightforward to use and the research team helpful and easy to communicate with. While participants reported positive impacts of participation, such as losing the craving for binge foods and becoming more inclined to seek social support, they also expressed personal barriers that got in the way of using the app and adverse reactions to using the app, such as experiencing an increase in hunger after usage or completing it whilst being distracted. Importantly, suggestions for intervention development were discussed, including suggestions to add a short meditation exercise, or to enable greater personalisation of the images that appear in the app. A comprehensive summary of themes and sub-themes can be found in Supplementary Materials 2.

4. Discussion

Our primary objective was to establish the feasibility and acceptability of augmenting treatment as usual for individuals with BN and BED with food-specific ICT delivered via a mobile app, FoodT (Lawrence et al., 2018). We were able to attain the pre-registered cut-off levels of feasibility, including recruitment, adherence, and retention. Qualitative results indicated that the delivery and use of the FoodT app was acceptable. While participants reported positive impacts of participation, they also expressed some negative aspects and personal barriers. Participants made suggestions for intervention development, such as adding a meditation practice and including statistics to track day-to-day progress, which should be considered in future trials within this population group (please refer to Supplementary Materials 2). Furthermore, we obtained preliminary evidence of clinical effectiveness, finding small-to-moderate between-group differences in secondary and exploratory outcomes that were in favour of the FoodT + TAU group compared to the TAU group. Those in the FoodT + TAU showed greater reductions in eating disorder psychopathology, as well as reductions in the valuation of high energy-dense foods. Negligible between-group differences were found for binge eating frequency after the intervention, our primary clinical outcome. Furthermore, reductions in food approach and food addiction symptomatology were obtained over the course of the

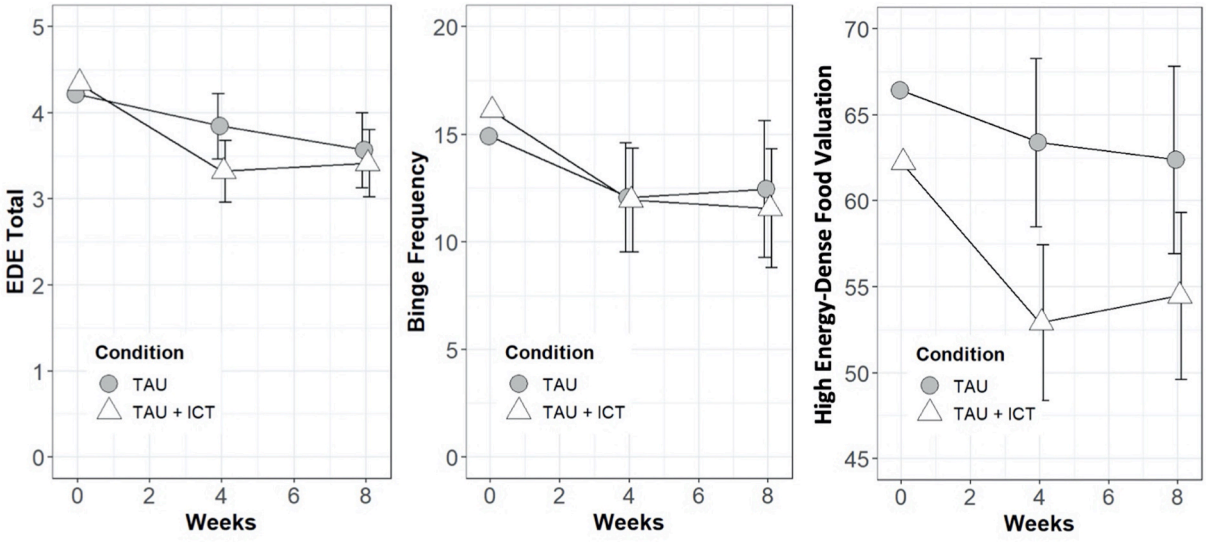

Fig. 4. Estimated means per group for eating disorder psychopathology (left), binge frequency (center) and high energy food valuation (right) at baseline, post-intervention and follow-up time-points. Notes: EDE = Eating Disorder Examination Questionnaire; TAU = treatment as usual; ICT = inhibitory control training. Error bars are indicative of 95% confidence intervals.

study, in favour of the FoodT + TAU group.

Both the present and previous studies (Chami et al., 2020) attest to the feasibility and acceptability of food ICT delivered via computer or mobile device. Adherence figures show improvements over our last trial: the average number of ICT sessions completed over the 28-day period has increased from 13 in the prior study using computer-based delivery (Chami et al., 2020) to 21 in the present study. However, it is important to note that computer-delivered ICT includes twice as many trials than the FoodT app, so the received "doses" were similar.

This study also supports our previous finding that food-specific ICT reduces eating disorder psychopathology in the short-term. However, we did not find between-group differences in binge eating frequency in the present study as within our previous study (Chami et al., 2020). In the present study, both the FoodT + TAU and TAU groups showed reductions in binge frequency that were of a similar magnitude to those reported in the intervention group in Chami et al. (2020). Therefore, it is possible that the conjunctive TAU may have been beneficial to both groups in reducing binge eating episodes, separately from the FoodT intervention. However, the discrepancies between studies could also be due to a number of differences. First, the intervention was different (computer-delivered ICT combined with implementation intentions previously vs. app-delivered ICT here). Second, participants in the present trial were required to be receiving treatment and are likely to constitute a more treatment-resistant and complex clinical sample than in Chami et al. (2020). A larger proportion had bulimia nervosa and of these, some fulfilled the criteria of the atypical anorexia nervosa binge-purge subtype, who are more resistant to treatment. These clinical differences may have influenced which specific ED symptoms were most sensitive to specific intervention effects here (EDE-Q total score) vs. in our previous study (binge frequency).

As predicted, we found a larger reduction in energy-dense food valuation in the intervention group, corroborating consistent evidence of cue devaluation following ICT (Chen, Veling, Dijksterhuis, & Holland, 2016). As expected, this devaluation did not extend to the low energy-dense foods that were paired with go responses in the training task. The fact that the intervention group only showed greater devaluation of (no-go) high energy-dense foods is consistent with evidence that devaluation is driven by inhibition in the training task, rather than by stimulus exposure or habituation effects, which would have affected both high and low energy-dense foods. The moderate between-group difference in food devaluation here shows a slight improvement from our previous study (Chami et al., 2020), where small-to-moderate effects were reported. The food cue devaluation observed here was greater than the reduction in eating disorder psychopathology, consistent with a more proximal effect of the training on the former and a more distal ("far-transfer") effect on the latter. However, post-hoc correlations indicated that the change in eating disorder psychopathology in the training group was only weakly correlated with food cue devaluation at the post-intervention time point ($r(34) = 0.226$, $p = 0.185$), suggesting that other mechanisms may have contributed to the effects of ICT on eating disorder psychopathology. For example, feedback from participants suggested increases in self-regulation, self awareness and seeking of support (see Supplementary Materials 2). Nevertheless, food ICT may help to reduce the reward value of high energy-dense foods, which may be particularly helpful in people with BN or BED who find binge foods highly rewarding (Schienle, Schäfer, Hermann, & Vaitl, 2009). Tailoring the intervention to individuals' specific binge foods in further research (as recommended by some participants in the focus groups) may yield greater benefits.

Generic measures of quality of life (QoL) have been shown not to be responsive to change in patients with ED (for a summary of the literature, see (Adair et al., 2010), and it has been shown that specific measures generally perform better in detecting change than generic instruments (Wiebe, Guyatt, Weaver, Matijevic, & Sidwell, 2003). An ED-specific measure of QoL is available (EDQLS; (Adair et al., 2007)), but this consists of 40 items in 12 domains and does not allow for the calculation of quality-adjusted life years. Our study is in line with previous research in finding that, despite some change on clinical outcomes, no significant change in QoL was seen. For a future full trial, we therefore recommend using the primary and secondary outcome measures (EDE-Q, binge frequency and HED food valuation) in any cost-effectiveness analysis.

4.1. Strengths and limitations

There are several limitations to this study. One limitation was the relatively poor retention of participants at 8 weeks. Whilst statistical analysis attempted to control for missing data, our exploratory findings at this timepoint should be interpreted with caution. As such, questions remain regarding the long-term effects of food-specific ICT in this population. Secondly, the participant's explicit knowledge of group allocation mean that the findings may be biased; it may be that the act of just receiving an additional intervention was beneficial. However, the fact that between-group effects were restricted to some outcomes argues against general demand characteristics. Nevertheless, the use of an active control (e.g. using another game-style app or a generalised non-food ICT task as in the previous study (Chami et al., 2020)) would elucidate whether the therapeutic effects of the current trial were due to the food ICT intervention alone. Proportionally, there were fewer men recruited into this study, which reflects the relatively higher number of women recruited into studies of eating disorders. Whilst more women receive a BN/BED diagnosis than men (Galmiche, Déchelotte, Lambert, & Tavolacci, 2019), the proportion recruited into this study does not represent the overall proportion in eating disordered populations. Moreover, it is possible that there are gender differences in behavioural inhibitory control (Yuan, He, Qinglin, Chen, & Li, 2008). Thus, this may have affected our results, which can be generalised only to women with BN/BED, and future studies should endeavour to recruit a more diverse population. Finally, including the Yale Food Addiction Scale and UPPS-Impulsivity scale as outcomes in a 4-week trial is a limitation, as the questions are directed towards examining trait-like features of food addiction and impulsivity. As such, future studies should avoid using these measures at short follow-up points, unless the questionnaires are modified to cover shorter periods of time.

Future research would benefit from including a longer follow-up period (e.g. 6 months) in order to investigate how food-specific ICT impacts relapse and remission rates. Moreover, whilst there was heterogeneity in the treatment received by participants in this study, the proportions were balanced between groups. A potentially interesting avenue for a future large RCT would be to investigate how food-specific ICT interacts with different treatments (e.g. psychological and psychopharmacological treatments). Such research would aid the optimisation of this intervention in the context of pre-existing therapies.

Furthermore, there are still improvements to be made in order to optimise the trial methodology. Feedback from participants suggests that the battery of questionnaires was too lengthy, which is likely due to extensive exploratory questionnaires. This may contribute to attrition at follow-up. On this basis, we suggest that the SREBQ and AEBQ are omitted in similar future trials and that trait-like measures such as the UPPS-Impulsivity scale and YFAS scale are either used only as baseline variables, or are adjusted to reflect a finite time period. Additionally, participants in the FoodT group were given an additional daily survey-based food diary to complete, which was intended to measure thoughts and feelings around food and eating across the 28-day training period. It is possible that the inclusion of this had additive therapeutic value, and thus the findings should be interpreted with caution.

4.2. Clinical implications

This study suggests that app-based ICT can confer benefits above those achieved by TAU in reducing eating disorder psychopathology. Current treatments for binge-type EDs result in less than 50% abstinence

(Brownley et al., 2016; Hay, 2013), warranting the need for novel approaches to improve outcomes in this population. The next step would be to examine where in the care pathway the current food inhibition training could be applied. It is possible that it might be a useful augmentation to guided self-help interventions in primary care. There has been great progress in digital interventions with apps that deliver many therapeutic methods such as components of CBT, monitoring and feedback, psychoeducation, emotion regulation and behaviour change techniques (e.g. Brighter Bite; (Linardon et al., 2020). FoodT is likely to be a useful additive intervention, particularly for individuals who find food highly rewarding or struggle with impulse control. One participant commented that additional impulse control components, such as mindfulness, would be beneficial (see Supplementary Materials 2). It would be valuable to test the effects of multi-component digital interventions such as ImpulsePal, which incorporates GNG training, along with visuospatial loading, meditation support and if-then planning (van Beurden, Smith, Lawrence, Abraham, & Greaves, 2019).

4.3. Conclusion

The FoodT app is able to reduce the value of high energy-dense food and reduce some elements of the psychopathology of people with binge-type eating disorders. Augmenting treatment for binge eating with an app which uses a food Go/No-Go paradigm has potential to improve elements of food-related impulsivity in this population. Since FoodT was made freely available to the public in 2017, it has been used by over 80,000 people. As such, this augmentation has the potential for high reach and wide dissemination.

Data availability

The dataset is available from the Open Science Framework (URL: https://osf.io/c8z6x/).

Declaration of competing interest

None.

Acknowledgements

Rayane Chami received funding from the Psychiatry Research Trust (PRT). Dr Valentina Cardi, Dr John Hodsoll, and Professor Janet Treasure are funded by the National Institute for Health Research (NIHR) Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and King's College London. A special thank you to the eating disorders charity Beat for their support in advertising this research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2021.105788.

Author contributions

VC, NL and JT contributed to the conception and design of the study. JK and RC contributed to the acquisition of data. JH conducted the statistical analysis of the data. JK, RC, NL, VC, JT, EB and JH have made substantial contributions to the interpretation of the data. JK, RC, NL, VC and JT drafted the manuscript, which was reviewed by all authors prior to publication.

Funding

This paper presents independent research funded by the NIHR under its Research for Patient Benefit (RfPB) Programme (PB-PG-1216-20044). The views expressed are those of the author(s) and not necessarily those of the NIHR or the Department of Health and Social Care.

Ethical statement

All procedures contributing to this study complied with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975. The London Dulwich Research Ethics Committee provided ethical approval for this study (reference: 19/LO/10054). The study was pre-registered on Clinicaltrials.gov (ID: NCT04364659). The study was conducted and the data were analyses aligned with the preregistration.

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