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Construal beliefs moderate the usability and effectiveness of a novel healthy eating mobile app

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ABSTRACT

Reduced self-control is a strong predictor of overeating and obesity. Priming a high construal level mind-set has been shown to enhance self-control and reduce snack consumption in the lab but the long-term and real-world effects are not known. The use of digital technology is an efficient way to deliver priming cues in real-world settings. Many mobile apps claim to support healthy eating but few are grounded in psychological theories of self-control. The aim of this study was to test the feasibility and effectiveness of a novel, construal-theory-based mobile app to promote self-control and healthy eating. In an exploratory analysis, the moderating influence of user characteristics was also examined. Using an iterative process involving users at every stage of the process, a prototype mobile app was developed. The final version included a high construal, self-control priming task, sent personalised reminder cues before each eating occasion, provided a just-in time 'crave-buster' for unanticipated eating opportunities and an optional food log. In a longitudinal trial the app was used over an eight-week period ($N = 71$; 51 females; M (SD) Age = 33.34 (11.68) years; M (SD) BMI = 26.22 (4.94)) with pre-post measures of weight, percent body fat and dietary intake. The app received high usability ratings on the System Usability Scale ($M = 76.55$; $SD = 11.35$), however food intake, per cent body fat and weight pre- and post- app use showed no significant change ($p > .05$). Exploratory analyses showed that baseline construal belief moderated the extent to which engagement with the app predicted dietary changes ($p < .05$). These findings indicate that this novel app was user-friendly and effective but that this was dependent on the user's characteristics. Future development in this area should consider tailoring apps to the specific characteristics of the user for improved support and effectiveness.

1. Introduction

The consumption of high calorie diets remains popular across cultures and is a contributing factor to obesity [15]. Obesity increases the risk of individuals developing serious health problems including Type 2 Diabetes, cardiovascular diseases and cancer [9] and innovative solutions are now needed to address dietary intake and rising obesity levels. Everyday decision making about what to eat can involve a self-control dilemma, for example, "Should I eat a tasty chocolate bar now? Or resist in order to obtain the long-term rewards of a healthy diet?" and people vary widely in their response to this dilemma. Healthy eating interventions would therefore benefit from developing practical techniques for enhancing self-control during such decision making.

Construal level theory (Trope and Liberman, 2003) maintains that we may construe a tempting situation using either higher or lower construal level thinking. Individuals with a lower construal level of thinking focus attention on concrete aspects of a situation (e.g. the rewarding taste of indulgent foods) whereas those with a higher construal level direct their attention to broader overarching goals (e.g. the benefits of eating nutritional foods for health). As such, a high construal level has been shown to reduce the attractiveness of indulgent foods and promote self-control [[6], [7], [30]]. Encouraging a high (versus low) construal level can be achieved using the 'How/Why?' task [5] that presents participants with a common goal-statement (e.g. 'Achieve

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at work/study') and a series of blank boxes connected by arrows. For the 'Why' (high construal level) condition participants are required to think about why this goal is important in four successive steps, each one encompassing a broader reason and encouraging access to higher order values (e.g. 'to get a good/better job'). For those in the 'How' (low construal level) condition the task is identical, except that the participants are required to think about how they would achieve the goal in the first box, focusing on practical details and lower order concerns (e.g. 'go to the library'). MacGregor, Carnevale, Dusthimer and Fujita [19] found that the extent to which people believe in the benefits of a high (why) or low (how) level construal for achieving a desired goal, can have consequences for self-control behaviours. In a series of studies they provide evidence that individuals who believe that low level construal thinking (knowing 'How' to do something) is helpful in reaching a desired goal show less success in the dieting domain, compared with those who believe that a high level construal is helpful. Furthermore, individual differences in this belief predicts body mass index among those who are motivated by dieting goals. Specifically, individuals who believed that knowing 'How' to do something (e.g. How many calories to eat per day) was more beneficial, had a higher BMI than individuals who believed that knowing 'Why' we do something (e.g. To be healthy and have more energy) is more beneficial to reaching a dieting goal.

Therefore, a viable target for a healthy eating intervention is to promote a higher construal level. Indeed, priming a high (versus low) level construal using the 'How/Why?' task has been shown to promote self-control in a number of non-eating behaviour domains [37] and to reduce snack intake in the presence of a visual cue-reminder [25] - when participants completed the 'Why?' task presented alongside a visual symbol, they went on to eat less than those in the 'How?' condition, but only when the same symbol was later presented next to the available snacks. These lab based findings indicate that the use of construal primes can enhance self-control and reduce overeating, and that visual cue reminders are important for maintaining the effect, but are yet to be tested in real-life settings over the longer term. One viable method for investigating construal priming in real-world settings is to make use of mobile technology.

The use of digital technology is an efficient way to deliver a population level health intervention when compared with delivery by health care professionals. Mobile health (mHealth) solutions to support healthier decisions are commonplace and scalable, for example, mHealth interventions that use text messaging to send reminders and advice to users have successfully supported individuals to quit smoking and manage conditions such as diabetes and asthma [3]. However, healthy eating and weight loss mHealth apps often rely on information provision and goal reminders and have been shown to be no more effective than typical weight loss strategies [[14], [18]]. Although mobile apps based on psychological theories are relatively scarce [27] interventions informed by psychological theory have the potential to increase self-control in an environment that promotes unhealthy eating and support people to resist the temptation of high calorie foods and manage bodyweight [11]. Theory -based mHealth apps to date have varied in user acceptability, engagement and effectiveness (Jake-[13], [17], [22], [28], [34], [36]]).

One reason for this limited success could be the failure to consider the users personality characteristics and subjective experiences [32]. This fits with established norms in the fields of software development and computer science where this is referred to as the User Experience (UX) paradigm or UX Design. Tailoring an app to the specific health goals of the user in order to meet their individual needs may go some way to increasing the effectiveness of mHealth interventions. However, the design of mHealth apps is not systematic and a wide range of design choices, beyond the selection of a specific theory, such as whether an app generates reminders, how the user-interface is laid out, how reliable it is and whether it depends on some form of mobile data connectivity to function will impact upon the usability, user experience and reliability of an mHealth intervention.

Attempts to tailor healthy eating and weight loss apps to the user have been made and Ryan, Dockray, and Linehan [29] conducted a systematic review of tailored mHealth weight loss interventions. Across eight studies (N = 4356; Mean BMI = 30.06) various methods of tailoring were implemented, for instance, objectives (e.g. desired weight), health-related behaviours (e.g. physical activity), psychosocial factors (e.g. social support) and theoretical determinants (e.g. desire to change habits). This makes it difficult to directly compare them but overall, four studies showed significant reductions in weight when compared with control groups but two studies did not find any significant differences between intervention and control groups in weight loss. Mandracchia and colleagues [20] conducted a systematic review of tailored apps aimed at enhancement of daily fruit and vegetable consumption. Again the tailoring features varied, examples including motivational and informative messages, and regular personal dietary and personal goal reminders. Six out of eight studies found a significant increase in fruit and vegetable intake, but the greatest effects were found when self-monitoring and dietary feedback were included in the app. As self-monitoring has been shown to improve weight and diet outcomes by itself (see [2] for a review) it is possible that the feature may have confounded previous findings that implemented it alongside tailored and/or theory-based intervention (e.g. [[23], [28]]). Therefore, it would be useful now to consider the potential moderating effects of self-monitoring on mHealth use and effectiveness.

Overall, research to date suggests that mHealth apps based on psychological evidence and theory are feasible, but retention rates, engagement with the apps over the longer term and health outcomes are variable. Furthermore, users have expressed a desire for more tailored support. Although tailored apps have been tested, they are mostly tailored to specific health goals and fail to consider the user characteristics. Recent research indicating that consideration of the users' characteristics [38] is a key factor missing from existing mHealth diet and weight loss interventions and should be included on future app development. Furthermore, no mHealth intervention to date is based on Construal Level Theory, which has been shown to be an effective intervention for improving self-control and healthy food choices in the lab.

We therefore designed a mobile health intervention that encourages a high construal level mind-set, using personalised information tailored to the individual in order to promote healthy eating and allow consumers to better manage their body weight in day-to-day life and over the longer term.

Specifically, the app presented the users with a 'Why' construal task, as described earlier from Price et al. [25], but this time the task was specifically related to why the user wanted to "Eat more healthily?" This was intended to prime a high construal level mind set related to eating behaviour, but also to provide the basis for personalised timely cues that the app sends to the users before each meal time (see the method section for a detailed description of the app). For example, if the user answered "I want more energy to play with my children", then this cue was presented to them in the form of a timely chat head push notification before each meal time, acting as a high construal level cue tailored to the individual user.

We also considered that the effectiveness of the app may be moderated by user characteristics. In particular, given the app is based on construal level theory, the users baseline construal beliefs may influence the effectiveness of the app. For example, people who have a tendency to believe that that knowing why we do something is beneficial to achieving a goal (high construal baseline belief) might find the app more useful than people who have a tendency to believe that knowing how to do something is beneficial to achieving a goal (low construal baseline belief). Therefore, the aims of this study were to 1) test the usability (acceptability and engagement) of a novel, personalised app based on construal level theory, 2) examine the moderating influence of self-monitoring, and 3) examine changes in diet and weight before and after an eight week app user trial. A fourth exploratory aim was also planned to investigate if user construal beliefs moderate app usability and changes in diet and weight.

2. Method

2.1. Participants

The inclusion criteria were: an interest in healthy eating; a willingness to trial the app daily for eight weeks; the use of an android smart phone; and the ability to use the English language fluently. Participants were excluded if they were pregnant, on any commercial dieting programme, taking medication/had a condition that affected appetite, or had been diagnosed with an eating disorder, anxiety or depression in the last 12 months. The software program G*Power [4] was used to establish the sample size needed to detect a small/medium effect. This was based on previous research examining pre-post intervention changes in health outcome measures such as weight and diet (e.g. [[21], [28], [31]]). To detect a small/medium effect (f = .2), with a power level of 0.8 and the alpha level set to p = < .05, a sample size of N = 35 was indicated. In addition to this, the aim of the study was to examine these effects in food log versus non-food log users. This is because a food log is a form of self-monitoring, which has been shown to improve weight and diet outcomes by itself (see [2] for a review). As around half of the users were expected to engage with the food log (based on previous pilot work), the number of participants was doubled for a sample size of N = 70 (N = 35 food log user, N = 35 non-food log users). To allow for attrition, we aimed to recruit up to a further 30 users to increase the chances of a fully powered sample at the end of the user period. This study was pre-registered on the OSF (https://osf.io/wscyz/).

By the end of the recruitment period, a total of N = 82 participants from Swansea University and surrounding areas had signed up for the 8 week trial. N = 11 participants were excluded for failing to meet the inclusion criteria (e.g. did not have use of an android smart phone), experiencing technical difficulties preventing use of the app or failing to use the app for longer than one week. Therefore, the final sample consisted of 71 participants (51 females; M (SD) Age = 33.34 (11.68) years; M (SD) BMI = 26.22 (4.94) kg/m^2). All interactions with the app over the eight week period were recorded on a secure remote server in real-time. This allowed us to see which functions were being used and when for each user. Ethics approval was granted by the Department of Psychology Research Ethics Committee and participants were compensated with a £50 shopping voucher (or for university staff, the equivalent payment via their staff salary) for taking part in the study, whether or not they completed the trial.

2.2. Materials

2.2.1. Healthy Eating Mobile Application

The mobile application was developed over an eighteen-month period of user and expert engagement. The expert user group was made up of computer scientists, psychologists and software developers at Swansea University. The app was then piloted over a week-long period by N = 20 individuals before the final design was agreed upon. The final version of the mobile app was compatible with Android smart phones version 4.4 and above. The app used construal level cues to promote healthier eating with four main specifications:

Construal level mind-set task: Once the users entered their unique user ID (so that their app engagement data could be anonymously identified and matched with survey and anthropometric data), the app guided them to the high construal level mind-set task (see Figure 1 a). The users typed in their answer for each successive step and the information was used to send personalised reminders to the users i.e. selecting one of the multiple reasons they gave for wanting to improve their eating habits and presenting it back to them just before they would eat. Users were instructed that they could update this at any time should they feel that their answers have changed.

Meal times and cue reminders: Predicted meal times were entered in the morning of each day (see Figure 1 b). The app then sent a personalised cue reminder at appropriate times 10-15 minutes before the scheduled commencement of each meal to remind the user of their healthy eating mind-set and support healthier choices. The timing of the reminders was based on user focus group feedback during the development of the app and emerged from the general feeling that if the reminders were sent any sooner, they may lose their potency. The answers given in the construal level mind-set task were randomly selected to vary the content of the reminders but the visual cue remained constant. This was a chain link symbol developed and trademarked specifically for this app (see Figure 1). The presentation of both the visual cue and one of the users' mind-set reminders was used to maximise the potential impact of the reminder and enhance its personalised nature.

Crave-buster: As individuals do not always stick to an eating routine or may experience a craving for something unhealthy at unexpected times, then the app had a just-in-time 'crave-buster' function. Accessing the app and selecting the crave-buster in times of need automatically gave the users access to one of their healthy eating mind-set cues, selected randomly by the app (see Figure 1 d).

Food Log (Optional): After consuming each meal or snack, users were given the option of recording what they had eaten in the food log to create a detailed record of what had been eaten each day (see Figure 1 c). Because a food log is a form of self-monitoring, which has been shown to improve weight and diet outcomes by itself (see [2] for a review) then it was important to include this in the app. However, it was left as an optional feature as feedback during the development stages of the app indicated that not all users felt that they would use it/want to use it because it seemed onerous to them.

2.2.2. Health outcome measures

Pre- and post-trial Food Diary: Participants completed a daily online food diary using the dietary assessment tool 'myfood24' (www.myfood24.org). Entries were provided for three days before using the app and for three days at the end of the trial to calculate participants' pre- and post-intervention mean daily fat, sugar, fruit, vegetable and salt intake (g) as well as mean daily calorie intake. Both weekdays and weekends were included in entries where feasible to account for possible habitual differences.

Anthropometric Measures: Weight (Kg) and Percent Body Fat were recorded in the lab using a TANITA BF-350 body composition analyser (Tanita Europe, Amsterdam, The Netherlands). Height was recorded using a standard stadiometer.

2.2.3. User Characteristic Measures

Tacit construal knowledge [19]*:* In order to assess the baseline tacit construal beliefs of the participants they were asked the following questions: 1) How much would thinking about why you are eating help you eat more healthily? (*Why Construal Belief*) and 2) How much would thinking about how you eat help you eat more healthily? (*How Construal Belief*). Participants responded using a Likert scale between 1-7 (1-Not at all helpful 7-Extremely helpful).

Behaviour Identification Form (BIF; [33]*):* This is a 25-item questionnaire that measures an individuals' trait cognitive-construal. The questionnaire requires participants to describe an action (e.g., reading) by choosing one of two options corresponding to either a high-level (e.g., gaining knowledge) or low-level representation of that action (e.g., following lines of print). Answers are coded as one if participants choose the high-level construal or as zero if participants choose the low-level construal. The total score is then summed for each participant with higher BIF scores indicating a higher cognitive-construal [12].

Intervention Efficacy Beliefs: In order to assess intervention efficacy beliefs about the app before use the participants were asked "How confident are you that the app and information provided to you will

Figure 1. Example screen shots from the mobile app: a) The high construal level mind-set task screen; b) The meal time setting screen; c) The optional food-log screen; d) The personalised cue reminder screen that is sent via chat head push notifications and crave-buster selection.

help you eat more healthily?" and responded using a 100mm Visual Analogue Scale (VAS) from 'not at all confident' to 'extremely confident'. In order to assess the intervention efficacy beliefs about the app after use the participants were asked "How confident are you that the app and information provided to you helped you to eat more healthily?" and again responded using a 100mm Visual Analogue Scale (VAS) from 'not at all confident' to 'extremely confident'

Dutch Eating Behaviour Questionnaire [35]: In order to describe the sample for comparison with related eating behaviour research we also measured dietary restraint and disinhibited eating, which have previously been associated with overeating and overweight/obesity (e.g. [24]). The DEBQ measure has 33 items and is comprised of three sub-scales. The dietary restraint sub-scale has ten items relating to restrained eating (e.g. "When you have put on weight, do you eat less than you usually do?"). The external eating sub-scale has ten items relating to the presence of food cues in the environment (e.g. "If you see others eat do you have the desire to eat?"). The emotional eating sub-scale has thirteen items and relates to the tendency to eat in response to negative emotions (e.g. "Do you have the desire to eat when someone lets you down?"). A score is obtained for each sub-scale by obtaining an average from the sum-scores, with higher scores indicating greater tendencies to restrain, eat in response to external cues or when in a negative mood respectively.

Zimbardo Time Perspective Inventory (ZTPI; [16]*):* Again, in order to describe the sample for comparison with related eating behaviour research we also measured time perspective, which has previously been associated with overeating and overweight/obesity (e.g. [26]). Data was collected using the future and present-hedonistic sub-scales of the ZTPI, as described by Keough, Zimbardo, and Boyd [16]. The future sub-scale contains 13 items measured on a 5-point scale ranging from 1 (very untrue of me) to 5 (very true of me). Example items include 'I believe that a person's day should be planned ahead each morning' and 'When I want to achieve something, I set goals and consider specific means of reaching those goals'. The present-hedonistic sub-scale contains 9 items also measured on a 5 point scale (as above). Example items include 'I try to live one day at a time' and 'I believe getting together with friends to party is one of life's important pleasures'.

System Usability Scale (SUS; [1]*):* The SUS is a simple, ten-item scale giving a global view of subjective assessments of usability. Answers are given on a Likert scale between 1 (Strongly Agree) and 5 (Strongly Disagree). Scores range between 0 and 100, with a score of 68 or over being considered "Above Average". SUS has proved to be a valuable evaluation tool, being robust and reliable and is generally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. Respondents should be asked to record their immediate response to each item, rather than thinking about items for a long time. Items include "I think that I would like to use this system frequently", "I found the system unnecessarily complex" and "I thought the system was easy to use".

2.3. Procedure

Participants submitted their first set of food diaries prior to beginning the trial. Participants then attended their first session in the

Table 1
Mean (SD) scores on user characteristics pre-app use

User Characteristic	Mean (SD)
How Construal Belief (1-7)	5.77 (.94)
Why Construal Belief (1-7)	5.86 (.91)
Behavior Identification Form (0-25)	13.45 (3.88)
Efficacy Beliefs (0-100)	59.87 (23.17)
Dietary Restraint (1-5)	2.72 (.61)
External Eating (1-5)	3.29 (.59)
Emotional Eating (1-5)	2.79 (.84)
Future Time Perspective (1-5)	3.66 (.44)
Present Time Perspective (1-5)	3.02 (.48)

Note: How/Why Construal Belief – Tacit Construal Knowledge scale that measures the extent to which an individual believes that knowing How/Why to do something will help them to reach a goal; Behavior Identification Form is a measure of trait cognitive construal, with higher scores indicating a higher construal; Efficacy Beliefs – A scale that measures the extent to which an individual believes that the app helps them to reach their goal; Dietary Restraint, External Eating and Emotional Eating are sub-scales of the Dutch Eating Behaviour Questionnaire and measure restrained eating, eating in response to food in the environment and eating as a consequence of negative emotions respectively; Future and Present Time Perspective are sub-sales of the Zimbardo Time Perspective Inventory and measures the extent to which an individual has a bias toward future thinking or present-minded thinking.

laboratory which lasted approximately one hour. The app was downloaded onto the participants' phone and then the nature of each feature of the app was explained. The participants then completed the questionnaire measures (Tacit construal knowledge for How and Why; Behavior Identification Form; Intervention Efficacy Beliefs; Dietary restraint; Emotional Eating; External Eating; Future and Present Time Perspective; see Table 1 for Mean (SD) scores) using the online software 'Qualtrics' and anthropometric measurements were then recorded. After using the app for eight weeks (with an email reminder at four weeks), participants completed another set of food diaries online and attended a 30- minute appointment in the laboratory to complete the follow-up questionnaires (as in session one but with the addition of the System Usability Scale) and record anthropometric measurements for a second time. All participants then completed the SUS and were debriefed at the end of the session.

3. Analysis Plan

3.1. Confirmatory Analysis

In line with the pre-registered analysis plan, in order to describe app usability, mean (SD) scores were calculated for the SUS usability questionnaire, frequency of use for each app specification over the eight week user period (mind-set task entries, chat head notification responses, crave-buster use, food log use and total engagement) and post-app efficacy ratings. To explore how these all relate to the user characteristics, two-tailed bivariate correlations were carried out between the usability outcomes (SUS scores, frequency of use indices and app efficacy ratings) and age, gender, construal beliefs (why and how) and BIF scores. A Bonferroni correction was applied to control for multiple comparisons.

To examine the health outcomes related to app use over the eight week user period, two separate mixed model MANOVAs were used. One was conducted for changes in dietary intake before and after using the app (mean Fruit, Vegetable, Fat, Sugar and Caloric Intake) and another for changes in Weight and Percent body fat. Pre-post values were the within subjects factor and food log use (yes or no) was the between subjects variable. Two MANOVAs were selected over eight separate ANOVAs as the dietary outcome measures were expected to correlate and anthropometric outcome variables were expected to correlate. Any significant differences were explored using post-hoc t-tests.

Note: All groups of food Intake were significantly skewed and so corrected using Log Transformations and removal of scores >3SDs from the mean ($N=4$). Weight was also significantly skewed but corrected with log transformation. Any missing data resulted in removal of the case from analysis.

3.2. Planned Exploratory analysis

To explore the moderating influence of the user characteristics on app engagement in predicting changes in dietary intake, weight and per cent body fat, moderation analyses in PROCESS were conducted [10]. Any baseline characteristic identified in the confirmatory correlations as being associated with app user ratings or health outcomes were examined as a potential moderator of the relationship between app engagement and changes in dietary intake, weight and per cent body fat. All analyses were conducted using IBM SPSS 22.0.

4. Results

The sample characteristics ($N=71$) are presented in Table 1.

4.1. Confirmatory Analysis

Mean (SD) scores for app usability (SUS) and efficacy ratings are presented in Table 2 along with frequency of use of each of the four app specifications and total engagement frequency over the eight week period.

Correlational analysis showed a significant positive correlation between age and chat head notification responses ($r=.36$; $p=.003$; $\rho=.41$) indicating that older users responded to the chat head push notifications more often. How Construal Belief and SUS scores were significantly and negatively correlated ($r=-.36$; $p=.002$; $\rho=.42$), low belief in the usefulness of knowing how to achieve a goal at baseline was related to higher acceptability ratings on the SUS after app use. Lastly, SUS scores and app efficacy ratings were positively correlated ($r=.38$; $p=.001$; $\rho=.44$), higher SUS scores were associated with higher app efficacy ratings.

To examine changes in dietary intake for food-log users ($N= 11$) versus non-food log users ($N= 60$), a mixed model MANOVA was conducted (see Table 3 for mean (SD) dietary intake pre and post app use). Mean pre-post intake of calories, fat, sugar, fruit and vegetables

Table 2
Mean (SD) scores for app usability and total number of interactions with the app features over the app user period.

Measure	Mean (SD)
SUS (0-100)	76.55 (11.35)
Mind-set task entries	1.97 (2.0)
Chat head notification responses	32.10 (37.55)
Crave-buster Use	53.30 (124.93)
Food Log Use	25.27 (55.20)
Total Engagement	109.80 (156.94)
App Efficacy Ratings (0-100)	45.89 (24.52)

Note: SUS (System Usability scale - scores over 60 indicate an acceptable system score); Mind-set task entries (the total number of times the responses on the Why task were inputted – participants were asked to do this at least once at the beginning but were told they could change these answers at any point); Chat head notification responses (the total number of times the cue reminder notification was responded to); Crave-buster use (the total number of times the crave buster function was accessed); Food log use (the total number of times a food log entry was made); Total engagement (the total number of times the app was engaged with across all of the above functions); Efficacy beliefs (A scale that measures the extent to which an individual believed that the app helped them to reach their goal).

Table 3
Mean (SD) scores for dietary intake and anthropometric measures pre and post app use.

Measure	Mean (SD) pre-app use	Mean (SD) post app use
Caloric intake (kcal)	1766.69 (642.36)	1660.18 (539.53
Fat intake (g)	68.32 (28.85)	66.16 (25.91)
Sugar intake (g)	76.99 (35.15)	70.82 (28.01)
Sodium intake (g)	2.49 (1.19)	2.28 (.91)
Fruit intake (g)	98.96 (88.06)	89.49 (96.25)
Vegetable intake (g)	182.21 (123.81)	137.08 (109.16)
Weight (Kg)	74.11 (16.58)	72.97 (15.16)
Percent Body Fat (%)	29.70 (8.94)	28.89 (8.29)

were the within subject variables and food log versus non-food log use was the between subject variable. The model was not significant for pre-post differences in intake of any of the foods (F (1,33) = .58; p = .45; f = .11), there was no two-way interaction between pre-post food intake with food log use (F (1,33) = .56; p = .46; f = .11), and no three way interaction between food type, pre-post app use and food log use (F (4,30) = .10; p = .98; f = 0).

To examine changes in weight and percent body fat for food log users versus non-food log users, a mixed model MANOVA was conducted. Pre-post measures were the within subject variables (see Table 3 for mean (SD) anthropometric measures pre and post app use) and food log use was the between subject variable. The model was not significant for pre-post differences in anthropometric measures (F (1, 59) = 2.83; p = .10; f = .23) but there was a significant interaction between pre-post measures and food log use (F (1, 59) = 6.26; p = .02; f = .30), and a significant three-way interaction between anthropometric measures, pre-post app use and food log use (F (1, 59) = 6.24; p = .02; f = .30). Follow up T-tests were conducted to probe the three way interaction, however no significant differences were found (p > .10). Trends indicated that the only comparison that appeared to demonstrate any change over time was for food log users, who showed a reduction in percent body fat from pre (M (SD) = 26.72 (9.35)) to post app use (M (SD) = 24.87 (7.74); p = .19; d = .21). No change in weight was detected from pre (M (SD) = 77.93 (17.98)) to post (M (SD) = 77.01 (16.67); p = .21; d = .20) app use. Similarly, for non-food-log users no pre-post changes in either percent body fat (pre-app use M (SD) = 29.23 (8.37); post-app use M (SD) = 29.59 (8.32); p = .23; d = .20) or weight (pre-app use M (SD) = 72.40 (15.28); post-app use M (SD) = 72.18 (14.88); p = .32; d = .20) were evident.

4.2. Planned Exploratory Analysis

4.2.1. Moderation

How Construal Belief was the only user characteristic to correlate significantly with any user acceptability outcomes (SUS scores). Therefore it was tested as a moderator of total app engagement in predicting changes in health outcomes (dietary intake, weight and percent body fat).

Neither How Construal Belief nor total app engagement directly predicted change in any dietary intake measures, weight or percent body fat (p > .05). How Construal Belief did not significantly moderate total app engagement for changes in weight (t = .13, p = .18; f^2 = .04), percent body fat (t = -.06, p = .95; f^2 = 0), salt (t = .95, p = .35; f^2 = .02), sugar (t = 1.14, p = .26; f^2 = .03), fruit (t = 1.27, p = .21; f^2 = .04) and vegetable (t = .77, p = .44; f^2 = .01) intake. However, How Construal Belief did significantly moderate total app engagement in predicting changes in caloric (t = 2.53, p = .02; f^2 = .12; 95% CIs = .40 -3 .59) and fat intake (t = 3.87, p = .0004; f^2 = .30; 95% CIs = .06 - .20). See Figures 2 and 3 respectively.

Individuals who showed high engagement with the app and who have low (versus high) How Construal Beliefs showed a significant decrease in caloric and fat intake. In contrast to this, high (versus low)

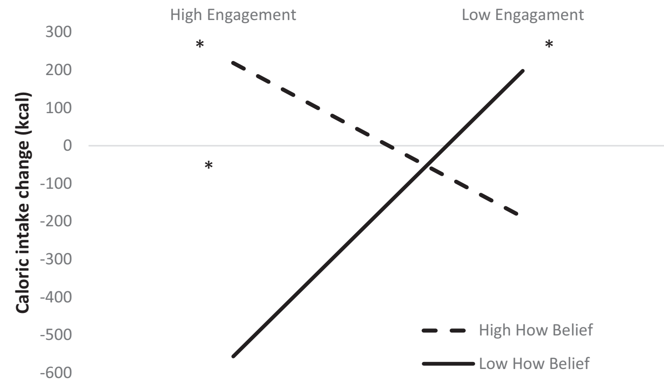

Figure 2. Change in caloric intake (kcals) after app use. High and Low Engagement and How Beliefs indicate slopes +/- 1 SD from the mean. *p < .05.

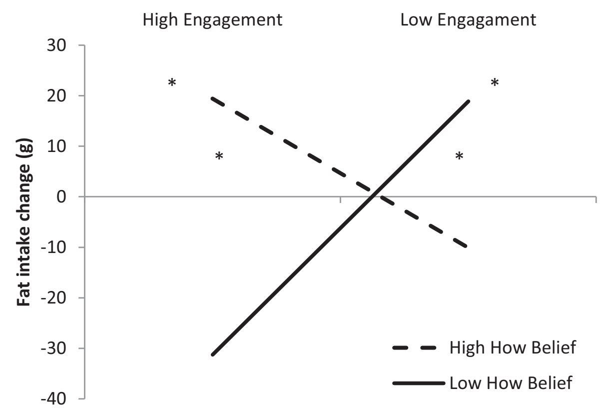

Figure 3. Change in fat intake (g) after app use. High and Low Engagement and How Beliefs indicate slopes +/- 1 SD from the mean. *p < .005.

engagement with the app predicted a significant increase in intake for those who have high How Construal Beliefs. For individuals who were low in How Construal Beliefs, low (versus high) engagement with the app also resulted in significant increases in intake.

5. Discussion

The aims of this study were to test the usability and effectiveness of a novel healthy eating app, personalised to the user and based on Construal Level Theory. The moderating influence of optional self-monitoring of food intake was also examined. Finally, the moderating influence of the user characteristics on app engagement and effectiveness were explored. Findings showed that the app received favourable user ratings overall, but that user engagement with the app and efficacy ratings varied greatly across the sample. While we did not find any pre-post differences in health outcomes (weight, percent body fat and food intake) over the eight week trial, we did find that low baseline construal beliefs in 'How' to achieve a goal was related to higher post-app user and efficacy ratings, which was in turn related to weight loss. Moreover, we also showed that reductions in mean caloric and fat intake were predicted by increased app engagement frequency, but only in those who had low baseline construal beliefs in 'How' to achieve a goal. Notably, for individuals with a high baseline construal belief in 'How to achieve a goal', high app engagement frequency actually led to increases in fat and caloric intake.

The high user ratings indicated on the System Usability Scale suggest that the app was considered both usable and acceptable. This is in line with recent studies showing the feasibility of theory-based mHealth apps [[13], [28], [31], [36]] and adds weight to the continued development of mHealth approaches to healthy eating and weight loss.

However, these kinds of apps have previously received only satisfactory usability scores (e.g. [34]) and can had low retentions rates (e.g. [22]), indicating low engagement. The user rating scores and app engagement varied widely across our current sample. Such variation across previous studies may have been the result of the failure to personalise the app to the user. Kliemann et al [17] reported that the users in their study felt that a more personalised approach would have been beneficial in encouraging engagement with their app. Lending weight to this argument, the app used in our study provided personalised decision support (in the form of the individuals specific reasons for why they want to eat more healthily) and we demonstrated high retention rates (87%).

Although our app provided personalised decision support we still found variation in user ratings. It was recently suggested that current mHealth apps are limited by their failure to consider the characteristics of the users [8]. We explored if user characteristics were related to the user experience of the app and found a significant correlation between baseline 'How' construal beliefs and the user rating scores in our sample, where low baseline belief in the value of being told 'how' to eat more healthily was related to higher user ratings for this app. Given that our app did not implement any features that helped users to know how they may achieve their healthy eating goals, this stands to reason - if the user felt that knowing how to achieve a goal is useful then the app (not having this feature) was rated less favourably. On the other hand, if the user had a low belief in the usefulness of knowing how to achieve their healthy eating goal, then the absence of this in our app resulted in higher user ratings. This supports the suggestion that the characteristics of the user, in this case their construal beliefs, can explain some of the variation in their subjective experience of an app.

We did not find any pre-post differences in any of the health outcomes (weight, percent body fat and food intake) over the eight week trial. This is contrary to recent research which has shown changes in weight and/or diet using theory led mHealth apps [[13], [22], [34]]. However it is worth noting that these trials were conducted over a twelve week period and so the effects may be more likely to emerge over this longer time period. On the other hand, inconsistent findings are reported for diet and weight change by two systematic reviews of more tailored apps [[20], [29]].

We also did not find that self-monitoring (via the use of the food-log) moderated the effectiveness of the app. But it is important to point out that only a very low number of our app users opted to engage with the food log (N = 11) and so it merits further investigation in a fully randomised controlled trial. This would allow for the assessment of the independent contribution and added value of a self-monitoring component to apps designed to enhance self-control. It would also be of benefit to assess the participants motivation to engage with the app at the outset to determine if self-monitoring is key or if it is engaged with because of individual differences in motivation.

We also examined whether total app engagement (number of interactions with the app over the trial period) predicted changes in weight, percent body fat and dietary intake and whether this was moderated by baseline construal belief in 'How'. We found app engagement predicted changes in mean caloric and fat intake but that this was moderated by baseline construal beliefs. The tendency to have low confidence in knowing 'how' to achieve a goal is an influential characteristic for the effectiveness of this app. In this case, a low 'How' construal belief, when combined with increased engagement with the app resulted in significant reduction in mean calorie and fat intake. This suggests that for these individuals, high engagement with the app was beneficial. Contrary to this and perhaps even more interesting is the finding that for individuals who had stronger construal beliefs in the usefulness of knowing 'How' to achieve their healthy eating goals, increased engagement with the app actually led to significant increases in caloric and fat intake. This suggests that engagement with this app may not just be ineffective for these individuals, but may actually have adverse consequences for their healthy eating goals. This has important implications for mHealth design and future research in this area. These findings are again in line with the evidence that construal beliefs predict the success (or not) in dieting and that individual differences in these beliefs predict body mass index among those who are motivated by dieting goals [19]. Individuals who have a tendency to believe in the usefulness of knowing 'How' to achieve their goals appear to be more vulnerable to weight gain and less successful overall in implementing dietary changes. They therefore represent a vulnerable group for whom higher construal support cues, as delivered by our app, are not helpful and may in fact be detrimental to diet goals. We observed high retention rates with 71 of the original 82 participants who attended the first session, also completing the final session after eight weeks, thus indicating high levels of engagement with the app. Although the participants were paid to take part in the trial, it is important to note that the payment was made regardless of completion and is therefore not likely to be a reason for high retention. It is also worth noting that as part of the inclusion criteria the participants had to be willing to trial the app for eight weeks. This may have resulted in a sense of obligation to the trial that may not replicate in the real-world and highlights the importance of the next step being a full randomised controlled trial of the app. The sample itself is a notable strength for this study, with a wide BMI and age range and being composed of both males and females. Furthermore, the participants were not a student sample and were recruited from the community and university staff. A further strength to this study was that the app was developed using an informed iterative process, involving users and experts at every stage of development, which was likely to have contributed to high user and acceptability scores. Although our app targeted the pre-meal period 10-15 minutes before the specific meal times of each individual, making it a tailored approach, this relatively short time period may not allow for meals that require more planning or for grocery shopping. Although our app includes a 'cravebuster' that could be used during such times, we did not include a specific function for sending reminders during grocery shopping. This would be a useful addition to future development of this app.

The low return-rate and self-report nature of the online food diaries, as well as the low number of participants selecting to use the food log in the app limit the reliability and power of the analysis to detect the small to medium main effects expected. A fully randomised controlled trial with individuals being assigned to food log/non-food log groups with a large enough sample to allow for self-report error and high attrition rates in online food diaries would be advisable. Furthermore, an exploration of which user characteristics differ between those who choose to use the food log and those who do not would be of benefit in future research to inform more tailored interventions. The sample size for the exploratory moderation analysis is also small for these types of analyses, but the promising results suggest the need for confirmatory research in a larger sample.

The novel consideration of the users' characteristics and the application of Construal Level Theory to a mHealth app for the first time make this study a significant advancement in knowledge. The exploratory findings that engagement with the app was either helpful or harmful depending on the users baseline construal beliefs also represents a potentially significant advancement for mHealth development. We recognise that a limitation to this study is the lack of a control group and conclusions made here now need to be confirmed in follow-up randomised controlled trials. The ethical considerations of potentially poor outcomes for some users will need to be carefully considered and the development of alternative mHealth interventions that target those users who did not benefit from our app in its current form is recommended.

In conclusion, our data show that a novel mHealth app rooted in psychological theory shows promise for assisting dietary change and weight loss, but future development should consider the characteristics of the user for optimal support and effectiveness.

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