

1 **Title:** Construal beliefs moderate the usability and effectiveness of a novel healthy eating mobile app

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21 **Abstract:**

22 Reduced self-control is a strong predictor of overeating and obesity. Priming a high construal level
23 mind-set has been shown to enhance self-control and reduce snack consumption in the lab but the
24 long-term and real-world effects are not known. The use of digital technology is an efficient way to
25 deliver priming cues in real-world settings. Many mobile apps claim to support healthy eating but
26 few are grounded in psychological theories of self-control. The aim of this study was to test the
27 feasibility and effectiveness of a novel, construal-theory-based mobile app to promote self-control
28 and healthy eating. In an exploratory analysis, the moderating influence of user characteristics was
29 also examined. Using an iterative process involving users at every stage of the process, a prototype
30 mobile app was developed. The final version included a high construal, self-control priming task,
31 sent personalised reminder cues before each eating occasion, provided a just-in time 'crave-buster'
32 for unanticipated eating opportunities and an optional food log. In a longitudinal trial the app was
33 used over an eight-week period (N=71; 51 females; M (SD) Age = 33.34 (11.68) years; M (SD) BMI =
34 26.22 (4.94)) with pre-post measures of weight, percent body fat and dietary intake. The app
35 received high usability ratings on the System Usability Scale (M=76.55; SD=11.35), however food
36 intake, per cent body fat and weight pre- and post- app use showed no significant change ($p>.05$).
37 Exploratory analyses showed that baseline construal belief moderated the extent to which
38 engagement with the app predicted dietary changes ($p<.05$). These findings indicate that this novel
39 app was user-friendly and effective but that this was dependent on the user's characteristics. Future
40 development in this area should consider tailoring apps to the specific characteristics of the user for
41 improved support and effectiveness.

42 Key words: mHealth; Construal Level Theory; User Experience; Tailoring; Weight Change; Healthy
43 Eating

44

45 **Introduction:**

46 The consumption of high calorie diets remains popular across cultures and is a contributing factor to
47 obesity (Kearney, 2010). Obesity increases the risk of individuals developing serious health problems
48 including Type 2 Diabetes, cardiovascular diseases and cancer (Guh, Zhang, Bansback, et al., 2009)
49 and innovative solutions are now needed to address dietary intake and rising obesity levels.

50 Everyday decision making about what to eat can involve a self-control dilemma, for example,
51 “Should I eat a tasty chocolate bar now? Or resist in order to obtain the long-term rewards of a
52 healthy diet?” and people vary widely in their response to this dilemma. Healthy eating
53 interventions would therefore benefit from developing practical techniques for enhancing self-
54 control during such decision making.

55 Construal level theory (Trope and Liberman, 2003) maintains that we may construe a tempting
56 situation using either higher or lower construal level thinking. Individuals with a lower construal level
57 of thinking focus attention on concrete aspects of a situation (e.g. the rewarding taste of indulgent
58 foods) whereas those with a higher construal level direct their attention to broader overarching
59 goals (e.g. the benefits of eating nutritional foods for health). As such, a high construal level has
60 been shown to reduce the attractiveness of indulgent foods and promote self-control (Fujita, 2008;
61 Fujita & Han, 2009; Sullivan, Hutcherson, Harris, & Rangel, 2015). Encouraging a high (versus low)
62 construal level can be achieved using the ‘How/Why?’ task (Freitas, Gollwitzer, & Trope, 2004) that
63 presents participants with a common goal-statement (e.g. ‘Achieve at work/study’) and a series of
64 blank boxes connected by arrows. For the ‘Why’ (high construal level) condition participants are
65 required to think about why this goal is important in four successive steps, each one encompassing a
66 broader reason and encouraging access to higher order values (e.g. ‘to get a good/better job’). For
67 those in the ‘How’ (low construal level) condition the task is identical, except that the participants
68 are required to think about how they would achieve the goal in the first box, focusing on practical
69 details and lower order concerns (e.g. ‘go to the library’). MacGregor, Carnevale, Dusthimer and
70 Fujita (2017) found that the extent to which people believe in the benefits of a high (why) or low

71 (how) level construal for achieving a desired goal, can have consequences for self-control
72 behaviours. In a series of studies they provide evidence that individuals who believe that low level
73 construal thinking (knowing 'How' to do something) is helpful in reaching a desired goal show less
74 success in the dieting domain, compared with those who believe that a high level construal is
75 helpful. Furthermore, individual differences in this belief predicts body mass index among those who
76 are motivated by dieting goals. Specifically, individuals who believed that knowing 'How' to do
77 something (e.g. How many calories to eat per day) was more beneficial, had a higher BMI than
78 individuals who believed that knowing 'Why' we do something (e.g. To be healthy and have more
79 energy) is more beneficial to reaching a dieting goal.

80 Therefore, a viable target for a healthy eating intervention is to promote a higher construal level.
81 Indeed, priming a high (versus low) level construal using the 'How/Why?' task has been shown to
82 promote self-control in a number of non-eating behaviour domains (Fujita et al, 2006) and to reduce
83 snack intake in the presence of a visual cue-reminder (Price, Higgs, & Lee, 2016) - when participants
84 completed the 'Why?' task presented alongside a visual symbol, they went on to eat less than those
85 in the 'How?' condition, but only when the same symbol was later presented next to the available
86 snacks. These lab based findings indicate that the use of construal primes can enhance self-control
87 and reduce overeating, and that visual cue reminders are important for maintaining the effect, but
88 are yet to be tested in real-life settings over the longer term. One viable method for investigating
89 construal priming in real-world settings is to make use of mobile technology.

90 The use of digital technology is an efficient way to deliver a population level health intervention
91 when compared with delivery by health care professionals. Mobile health (mHealth) solutions to
92 support healthier decisions are commonplace and scalable, for example, mHealth interventions that
93 use text messaging to send reminders and advice to users have successfully supported individuals to
94 quit smoking and manage conditions such as diabetes and asthma (Cole-Lewis & Kershaw, 2010).
95 However, healthy eating and weight loss mHealth apps often rely on information provision and goal
96 reminders and have been shown to be no more effective than typical weight loss strategies (Jakicic

97 et al., 2016; Laing, Mangione, & Tseng, 2015). Although mobile apps based on psychological
98 theories are relatively scarce (Rivera et al., 2016) interventions informed by psychological theory
99 have the potential to increase self-control in an environment that promotes unhealthy eating and
100 support people to resist the temptation of high calorie foods and manage bodyweight (Higgs,
101 Robinson & Lee, 2012). Theory -based mHealth apps to date have varied in user acceptability,
102 engagement and effectiveness (Jake-Schoffman et al ., 2018; Ogden, Maxwell, and Wong, 2019; Van
103 Beurden et al., 2019; Kliemann et al., 2019; Robinson et al., 2013; Whitlock et al., 2019).

104 One reason for this limited success could be the failure to consider the users personality
105 characteristics and subjective experiences (Triberti & Barello, 2016). This fits with established norms
106 in the fields of software development and computer science where this is referred to as the User
107 Experience (UX) paradigm or UX Design. Tailoring an app to the specific health goals of the user in
108 order to meet their individual needs may go some way to increasing the effectiveness of mHealth
109 interventions. However, the design of mHealth apps is not systematic and a wide range of design
110 choices, beyond the selection of a specific theory, such as whether an app generates reminders, how
111 the user-interface is laid out, how reliable it is and whether it depends on some form of mobile data
112 connectivity to function will impact upon the usability, user experience and reliability of an mHealth
113 intervention.

114 Attempts to tailor healthy eating and weight loss apps to the user have been made and Ryan,
115 Dockray, and Linehan (2019) conducted a systematic review of tailored mHealth weight loss
116 interventions. Across eight studies (N=4356; Mean BMI=30.06) various methods of tailoring were
117 implemented, for instance, objectives (e.g. desired weight), health-related behaviours (e.g. physical
118 activity), psychosocial factors (e.g. social support) and theoretical determinants (e.g. desire to
119 change habits). This makes it difficult to directly compare them but overall, four studies showed
120 significant reductions in weight when compared with control groups but two studies did not find any
121 significant differences between intervention and control groups in weight loss. Mandracchia and
122 colleagues (2019) conducted a systematic review of tailored apps aimed at enhancement of daily

123 fruit and vegetable consumption. Again the tailoring features varied, examples including
124 motivational and informative messages, and regular personal dietary and personal goal reminders.
125 Six out of eight studies found a significant increase in fruit and vegetable intake, but the greatest
126 effects were found when self-monitoring and dietary feedback were included in the app. As self-
127 monitoring has been shown to improve weight and diet outcomes by itself (see Burke, Wang and
128 Sevick, 2011 for a review) it is possible that the feature may have confounded previous findings that
129 implemented it alongside tailored and/or theory-based intervention (e.g. Robinson et al., 2013;
130 Pelligrini et al., 2018). Therefore, it would be useful now to consider the potential moderating effects
131 of self-monitoring on mHealth use and effectiveness.

132 Overall, research to date suggests that mHealth apps based on psychological evidence and theory
133 are feasible, but retention rates, engagement with the apps over the longer term and health
134 outcomes are variable. Furthermore, users have expressed a desire for more tailored support.
135 Although tailored apps have been tested, they are mostly tailored to specific health goals and fail to
136 consider the user characteristics. Recent research indicating that consideration of the users'
137 characteristics (Gorini *et al.*, 2019) is a key factor missing from existing mHealth diet and weight loss
138 interventions and should be included on future app development. Furthermore, no mHealth
139 intervention to date is based on Construal Level Theory, which has been shown to be an effective
140 intervention for improving self-control and healthy food choices in the lab.

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

144 Specifically, the app presented the users with a 'Why' construal task, as described earlier from Price
145 et al. (2016), but this time the task was specifically related to why the user wanted to "Eat more
146 healthily?" This was intended to prime a high construal level mind set related to eating behaviour,
147 but also to provide the basis for personalised timely cues that the app sends to the users before
148 each meal time (see the method section for a detailed description of the app). For example, if the

149 user answered “I want more energy to play with my children”, then this cue was presented to them
150 in the form of a timely chat head push notification before each meal time, acting as a high construal
151 level cue tailored to the individual user.

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

163 **Method:**

164 **Participants:**

165 The inclusion criteria were: an interest in healthy eating; a willingness to trial the app daily for eight
166 weeks; the use of an android smart phone; and the ability to use the English language fluently.

167 Participants were excluded if they were pregnant, on any commercial dieting programme, taking
168 medication/had a condition that affected appetite, or had been diagnosed with an eating disorder,
169 anxiety or depression in the last 12 months. The software program G*Power (Faul et al., 2009) was
170 used to establish the sample size needed to detect a small/medium effect. This was based on
171 previous research examining pre-post intervention changes in health outcome measures such as
172 weight and diet (e.g. Norman et al., 2007; Sze et al., 2015; Robinson et al., 2013). To detect a
173 small/medium effect ($f=.2$), with a power level of 0.8 and the alpha level set to $p<.05$, a sample size

174 of N=35 was indicated. In addition to this, the aim of the study was to examine these effects in food
175 log versus non-food log users. This is because a food log is a form of self-monitoring, which has been
176 shown to improve weight and diet outcomes by itself (see Burke, Wang and Sevick, 2011 for a
177 review). As around half of the users were expected to engage with the food log (based on previous
178 pilot work), the number of participants was doubled for a sample size of N=70 (N=35 food log user,
179 N=35 non-food log users). To allow for attrition, we aimed to recruit up to a further 30 users to
180 increase the chances of a fully powered sample at the end of the user period. This study was pre-
181 registered on the OSF (<https://osf.io/wscyz/>).

182 By the end of the recruitment period, a total of N=82 participants from Swansea University and
183 surrounding areas had signed up for the 8 week trial. N=11 participants were excluded for failing to
184 meet the inclusion criteria (e.g. did not have use of an android smart phone), experiencing technical
185 difficulties preventing use of the app or failing to use the app for longer than one week. Therefore,
186 the final sample consisted of 71 participants (51 females; M (SD) Age = 33.34 (11.68) years; M (SD)
187 BMI = 26.22 (4.94) kg/m²). All interactions with the app over the eight week period were recorded
188 on a secure remote server in real-time. This allowed us to see which functions were being used and
189 when for each user. Ethics approval was granted by the Department of Psychology Research Ethics
190 Committee and participants were compensated with a £50 shopping voucher (or for university staff,
191 the equivalent payment via their staff salary) for taking part in the study, whether or not they
192 completed the trial.

193 Materials:

194 *Healthy Eating Mobile Application:*

195 The mobile application was developed over an eighteen-month period of user and expert
196 engagement. The expert user group was made up of computer scientists, psychologists and software
197 developers at Swansea University. The app was then piloted over a week-long period by N=20
198 individuals before the final design was agreed upon. The final version of the mobile app was

199 compatible with Android smart phones version 4.4 and above. The app used construal level cues to
200 promote healthier eating with four main specifications:

201



202

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

206 *Construal level mind-set task:* Once the users entered their unique user ID (so that their app
207 engagement data could be anonymously identified and matched with survey and anthropometric
208 data), the app guided them to the high construal level mind-set task (see Figure 1 a). The users typed
209 in their answer for each successive step and the information was used to send personalised
210 reminders to the users i.e. selecting one of the multiple reasons they gave for wanting to improve

211 their eating habits and presenting it back to them just before they would eat. Users were instructed
212 that they could update this at any time should they feel that their answers have changed.

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

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

227 *Food Log (Optional):* After consuming each meal or snack, users were given the option of recording
228 what they had eaten in the food log to create a detailed record of what had been eaten each day
229 (see Figure 1 c). Because a food log is a form of self-monitoring, which has been shown to improve
230 weight and diet outcomes by itself (see Burke, Wang and Sevick, 2011 for a review) then it was
231 important to include this in the app. However, it was left as an optional feature as feedback during
232 the development stages of the app indicated that not all users felt that they would use it/want to
233 use it because it seemed onerous to them.

234 *Health outcome measures:*

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

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

244 *User Characteristic Measures:*

245 *Tacit construal knowledge (McGregor et al, 2017):* In order to assess the baseline tacit construal
246 beliefs of the participants they were asked the following questions: 1) How much would thinking
247 about why you are eating help you eat more healthily? (*Why Construal Belief*) and 2) How much
248 would thinking about how you eat help you eat more healthily? (*How Construal Belief*). Participants
249 responded using a Likert scale between 1-7 (1-Not at all helpful 7-Extremely helpful).

250 *Behaviour Identification Form (BIF; Vallacher & Wegner, 1989):* This is a 25-item questionnaire that
251 measures an individuals' trait cognitive-construal. The questionnaire requires participants to
252 describe an action (e.g., reading) by choosing one of two options corresponding to either a high-level
253 (e.g., gaining knowledge) or low-level representation of that action (e.g., following lines of print).
254 Answers are coded as one if participants choose the high-level construal or as zero if participants
255 choose the low-level construal. The total score is then summed for each participant with higher BIF
256 scores indicating a higher cognitive-construal (Hong & Lee, 2010).

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

259 will help you eat more healthily?” and responded using a 100mm Visual Analogue Scale (VAS) from
260 ‘not at all confident’ to ‘extremely confident’. In order to assess the intervention efficacy beliefs
261 about the app after use the participants were asked “How confident are you that the app and
262 information provided to you helped you to eat more healthily?” and again responded using a
263 100mm Visual Analogue Scale (VAS) from ‘not at all confident’ to ‘extremely confident’

264 *Dutch Eating Behaviour Questionnaire_(DEBQ; Van Strein, Frijter, Bergers, & Defares, 1986):* In order
265 to describe the sample for comparison with related eating behaviour research we also measured
266 dietary restraint and disinhibited eating, which have previously been associated with overeating and
267 overweight/obesity (e.g. Price, Higgs & Lee, 2015). The DEBQ measure has 33 items and is comprised
268 of three sub-scales. The dietary restraint sub-scale has ten items relating to restrained eating (e.g.
269 “When you have put on weight, do you eat less than you usually do?”). The external eating sub-scale
270 has ten items relating to the presence of food cues in the environment (e.g. “If you see others eat do
271 you have the desire to eat?”). The emotional eating sub-scale has thirteen items and relates to the
272 tendency to eat in response to negative emotions (e.g. “Do you have the desire to eat when
273 someone lets you down?”). A score is obtained for each sub-scale by obtaining an average from the
274 sum-scores, with higher scores indicating greater tendencies to restrain, eat in response to external
275 cues or when in a negative mood respectively.

276 *Zimbardo Time Perspective Inventory_(ZTPI; Keough, Zimbardo & Boyd, 1999):* Again, in order to
277 describe the sample for comparison with related eating behaviour research we also measured time
278 perspective, which has previously been associated with overeating and overweight/obesity (e.g.
279 Price, Higgs & Lee, 2017). Data was collected using the future and present-hedonistic sub-scales of
280 the ZTPI, as described by Keough, Zimbardo, and Boyd (1999). The future sub-scale contains 13 items
281 measured on a 5-point scale ranging from 1 (very untrue of me) to 5 (very true of me). Example
282 items include ‘I believe that a person’s day should be planned ahead each morning’ and ‘When I
283 want to achieve something, I set goals and consider specific means of reaching those goals’. The

284 present-hedonistic sub-scale contains 9 items also measured on a 5 point scale (as above). Example
285 items include 'I try to live one day at a time' and 'I believe getting together with friends to party is
286 one of life's important pleasures'.

287 System Usability Scale (SUS; Brooke, 1996): The SUS is a simple, ten-item scale giving a global view of
288 subjective assessments of usability. Answers are given on a Likert scale between 1 (Strongly Agree)
289 and 5 (Strongly Disagree). Scores range between 0 and 100, with a score of 68 or over being
290 considered "Above Average". SUS has proved to be a valuable evaluation tool, being robust and
291 reliable and is generally used after the respondent has had an opportunity to use the system being
292 evaluated, but before any debriefing or discussion takes place. Respondents should be asked to
293 record their immediate response to each item, rather than thinking about items for a long time.
294 Items include "I think that I would like to use this system frequently", "I found the system
295 unnecessarily complex" and "I thought the system was easy to use".

296

297 Procedure:

298 Participants submitted their first set of food diaries prior to beginning the trial. Participants then
299 attended their first session in the laboratory which lasted approximately one hour. The app was
300 downloaded onto the participants' phone and then the nature of each feature of the app was
301 explained. The participants then completed the questionnaire measures (Tacit construal knowledge
302 for How and Why; Behavior Identification Form; Intervention Efficacy Beliefs; Dietary restraint;
303 Emotional Eating; External Eating; Future and Present Time Perspective; see Table 1 for Mean (SD)
304 scores) using the online software 'Qualtrics' and anthropometric measurements were then
305 recorded. After using the app for eight weeks (with an email reminder at four weeks), participants
306 completed another set of food diaries online and attended a 30- minute appointment in the
307 laboratory to complete the follow-up questionnaires (as in session one but with the addition of the

308 System Usability Scale) and record anthropometric measurements for a second time. All participants
309 then completed the SUS and were debriefed at the end of the session.

310 Analysis Plan:

311 Confirmatory Analysis:

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

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

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

332 Planned Exploratory analysis:

333 To explore the moderating influence of the user characteristics on app engagement in predicting
 334 changes in dietary intake, weight and per cent body fat, moderation analyses in PROCESS were
 335 conducted (Hayes, 2012). Any baseline characteristic identified in the confirmatory correlations as
 336 being associated with app user ratings or health outcomes were examined as a potential moderator
 337 of the relationship between app engagement and changes in dietary intake, weight and per cent
 338 body fat. All analyses were conducted using IBM SPSS 22.0.

339 **Results:**

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

341 **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)

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

352

353 Confirmatory Analysis:

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

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

364

365 **Table 2:** Mean (SD) scores for app usability and total number of interactions with the app features
366 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)

367 *Note:* SUS (System Usability scale - scores over 60 indicate an acceptable system score); Mind-set
368 task entries (the total number of times the responses on the Why task were inputted – participants
369 were asked to do this at least once at the beginning but were told they could change these answers
370 at any point); Chat head notification responses (the total number of times the cue reminder

371 notification was responded to); Crave-buster use (the total number of times the crave buster
372 function was accessed); Food log use (the total number of times a food log entry was made); Total
373 engagement (the total number of times the app was engaged with across all of the above functions);
374 Efficacy beliefs (A scale that measures the extent to which an individual believed that the app helped
375 them to reach their goal).

376 To examine changes in dietary intake for food-log users (N= 11) versus non-food log users (N= 60), a
377 mixed model MANOVA was conducted (see Table 3 for mean (SD) dietary intake pre and post app
378 use). Mean pre-post intake of calories, fat, sugar, fruit and vegetables were the within subject
379 variables and food log versus non-food log use was the between subject variable. The model was not
380 significant for pre-post differences in intake of any of the foods ($F(1,33) = .58$; $p = .45$; $f = .11$), there
381 was no two-way interaction between pre-post food intake with food log use ($F(1,33) = .56$; $p = .46$;
382 $f = .11$), and no three way interaction between food type, pre-post app use and food log use ($F(4,30)$
383 $= .10$; $p = .98$; $f = 0$).

384 To examine changes in weight and percent body fat for food log users versus non-food log users, a
385 mixed model MANOVA was conducted. Pre-post measures were the within subject variables (see
386 Table 3 for mean (SD) anthropometric measures pre and post app use) and food log use was the
387 between subject variable. The model was not significant for pre-post differences in anthropometric
388 measures ($F(1, 59) = 2.83$; $p = .10$; $f = .23$) but there was a significant interaction between pre-post
389 measures and food log use ($F(1, 59) = 6.26$; $p = .02$; $f = .30$), and a significant three-way interaction
390 between anthropometric measures, pre-post app use and food log use ($F(1, 59) = 6.24$; $p = .02$;
391 $f = .30$). Follow up T-tests were conducted to probe the three way interaction, however no significant
392 differences were found ($p > .10$). Trends indicated that the only comparison that appeared to
393 demonstrate any change over time was for food log users, who showed a reduction in percent body
394 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
395 in weight was detected from pre (M (SD) = 77.93 (17.98)) to post (M (SD) = 77.01 (16.67)); $p = .21$;
396 $d = .20$) app use. Similarly, for non-food-log users no pre-post changes in either percent body fat (pre-
397 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
398 use M (SD) = 72.40 (15.28); post-app use M (SD) = 72.18 (14.88); $p = .32$; $d = .20$) were evident.

399 **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)

400

401 Planned Exploratory Analysis:

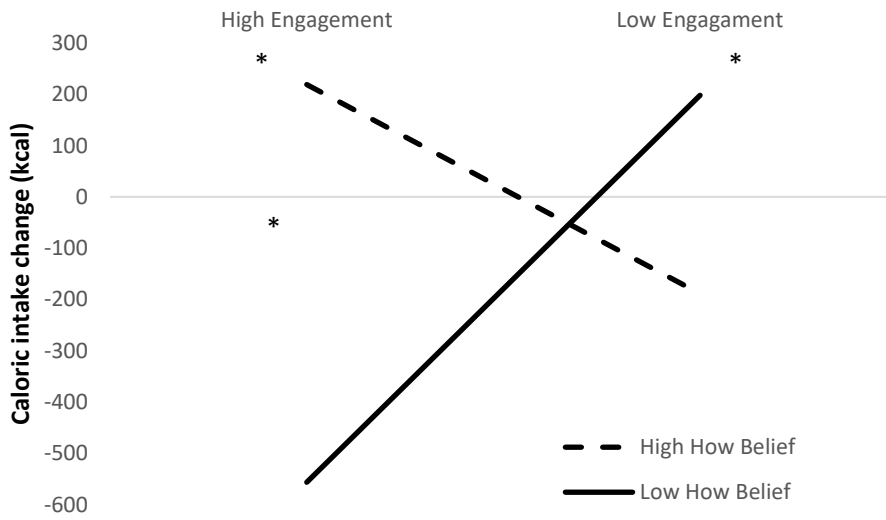
402 Moderation:

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

406 Neither How Construal Belief nor total app engagement directly predicted change in any dietary
 407 intake measures, weight or percent body fat ($p > .05$). How Construal Belief did not significantly
 408 moderate total app engagement for changes in weight ($t = .13$, $p = .18$; $f^2 = .04$), percent body fat ($t =$
 409 $.06$, $p = .95$; $f^2 = 0$), salt ($t = .95$, $p = .35$; $f^2 = .02$), sugar ($t = 1.14$, $p = .26$; $f^2 = .03$), fruit ($t = 1.27$, $p = .21$; $f^2 = .04$)
 410 and vegetable ($t = .77$, $p = .44$; $f^2 = .01$) intake. However, How Construal Belief did significantly moderate
 411 total app engagement in predicting changes in caloric ($t = 2.53$, $p = .02$; $f^2 = .12$; 95% CIs = .40 -3 .59) and
 412 fat intake ($t = 3.87$, $p = .0004$; $f^2 = .30$; 95% CIs = .06 - .20). See Figures 2 and 3 respectively.

413

414

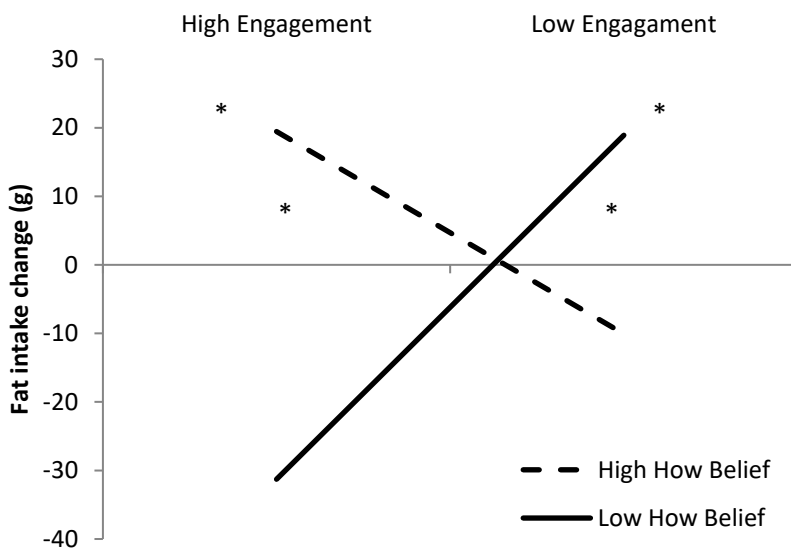


415

416 **Figure 2:** Change in caloric intake (kcal) after app use. High and Low Engagement and How Beliefs

417 indicate slopes +/- 1 SD from the mean. *p<.05

418



419

420 **Figure 3:** Change in fat intake (g) after app use. High and Low Engagement and How Beliefs indicate

421 slopes +/- 1 SD from the mean. *p<.005

422 Individuals who showed high engagement with the app and who have low (versus high) How
423 Construal Beliefs showed a significant decrease in caloric and fat intake. In contrast to this, high
424 (versus low) engagement with the app predicted a significant increase in intake for those who have
425 high How Construal Beliefs. For individuals who were low in How Construal Beliefs, low (versus high)
426 engagement with the app also resulted in significant increases in intake.

427 **Discussion:**

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

441 The high user ratings indicated on the System Usability Scale suggest that the app was considered
442 both usable and acceptable. This is in line with recent studies showing the feasibility of theory-based
443 mHealth apps (Jake-Schoffman et al, 2018; Robinson et al, 2013; Whitelock et al, 2019; Sze et al.,
444 2015) and adds weight to the continued development of mHealth approaches to healthy eating and
445 weight loss. However, these kinds of apps have previously received only satisfactory usability scores
446 (e.g. van Beurden et al, 2019) and can had low retentions rates (e.g. Ogden et al, 2019), indicating
447 low engagement. The user rating scores and app engagement varied widely across our current

448 sample. Such variation across previous studies may have been the result of the failure to personalise
449 the app to the user. Kliemann et al (2019) reported that the users in their study felt that a more
450 personalised approach would have been beneficial in encouraging engagement with their app.
451 Lending weight to this argument, the app used in our study provided personalised decision support
452 (in the form of the individuals specific reasons for why they want to eat more healthily) and we
453 demonstrated high retention rates (87%).

454 Although our app provided personalised decision support we still found variation in user ratings. It
455 was recently suggested that current mHealth apps are limited by their failure to consider the
456 characteristics of the users (Gorini et al., 2018). We explored if user characteristics were related to
457 the user experience of the app and found a significant correlation between baseline 'How' construal
458 beliefs and the user rating scores in our sample, where low baseline belief in the value of being told
459 'how' to eat more healthily was related to higher user ratings for this app. Given that our app did not
460 implement any features that helped users to know how they may achieve their healthy eating goals,
461 this stands to reason - if the user felt that knowing how to achieve a goal is useful then the app (not
462 having this feature) was rated less favourably. On the other hand, if the user had a low belief in the
463 usefulness of knowing how to achieve their healthy eating goal, then the absence of this in our app
464 resulted in higher user ratings. This supports the suggestion that the characteristics of the user, in
465 this case their construal beliefs, can explain some of the variation in their subjective experience of an
466 app.

467 We did not find any pre-post differences in any of the health outcomes (weight, percent body fat
468 and food intake) over the eight week trial. This is contrary to recent research which has shown
469 changes in weight and/or diet using theory led mHealth apps (Jake-Schoffman et al, 2018; Ogden et
470 al, 2019; van Beurden et al, 2019). However it is worth noting that these trials were conducted over
471 a twelve week period and so the effects may be more likely to emerge over this longer time period.
472 On the other hand, inconsistent findings are reported for diet and weight change by two systematic
473 reviews of more tailored apps (Ryan et al, 2019; Mandracchia et al, 2019).

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

481 We also examined whether total app engagement (number of interactions with the app over the
482 trial period) predicted changes in weight, percent body fat and dietary intake and whether this was
483 moderated by baseline construal belief in 'How'. We found app engagement predicted changes in
484 mean caloric and fat intake but that this was moderated by baseline construal beliefs. The tendency
485 to have low confidence in knowing 'how' to achieve a goal is an influential characteristic for the
486 effectiveness of this app. In this case, a low 'How' construal belief, when combined with increased
487 engagement with the app resulted in significant reduction in mean calorie and fat intake. This
488 suggests that for these individuals, high engagement with the app was beneficial. Contrary to this
489 and perhaps even more interesting is the finding that for individuals who had stronger construal
490 beliefs in the usefulness of knowing 'How' to achieve their healthy eating goals, increased
491 engagement with the app actually led to significant increases in caloric and fat intake. This suggests
492 that engagement with this app may not just be ineffective for these individuals, but may actually
493 have adverse consequences for their healthy eating goals. This has important implications for
494 mHealth design and future research in this area. These findings are again in line with the evidence
495 that construal beliefs predict the success (or not) in dieting and that individual differences in these
496 beliefs predict body mass index among those who are motivated by dieting goals (MacGregor et al
497 2017). Individuals who have a tendency to believe in the usefulness of knowing 'How' to achieve
498 their goals appear to be more vulnerable to weight gain and less successful overall in implementing
499 dietary changes. They therefore represent a vulnerable group for whom higher construal support

500 cues, as delivered by our app, are not helpful and may in fact be detrimental to diet goals. We
501 observed high retention rates with 71 of the original 82 participants who attended the first session,
502 also completing the final session after eight weeks, thus indicating high levels of engagement with
503 the app. Although the participants were paid to take part in the trial, it is important to note that the
504 payment was made regardless of completion and is therefore not likely to be a reason for high
505 retention. It is also worth noting that as part of the inclusion criteria the participants had to be
506 willing to trial the app for eight weeks. This may have resulted in a sense of obligation to the trial
507 that may not replicate in the real-world and highlights the importance of the next step being a full
508 randomised controlled trial of the app. The sample itself is a notable strength for this study, with a
509 wide BMI and age range and being composed of both males and females. Furthermore, the
510 participants were not a student sample and were recruited from the community and university staff.
511 A further strength to this study was that the app was developed using an informed iterative process,
512 involving users and experts at every stage of development, which was likely to have contributed to
513 high user and acceptability scores. Although our app targeted the pre-meal period 10-15 minutes
514 before the specific meal times of each individual, making it a tailored approach, this relatively short
515 time period may not allow for meals that require more planning or for grocery shopping. Although
516 our app includes a 'cravebuster' that could be used during such times, we did not include a specific
517 function for sending reminders during grocery shopping. This would be a useful addition to future
518 development of this app.

519 The low return-rate and self-report nature of the online food diaries, as well as the low number of
520 participants selecting to use the food log in the app limit the reliability and power of the analysis to
521 detect the small to medium main effects expected. A fully randomised controlled trial with
522 individuals being assigned to food log/non-food log groups with a large enough sample to allow for
523 self-report error and high attrition rates in online food diaries would be advisable. Furthermore, an
524 exploration of which user characteristics differ between those who choose to use the food log and
525 those who do not would be of benefit in future research to inform more tailored interventions. The

526 sample size for the exploratory moderation analysis is also small for these types of analyses, but the
527 promising results suggest the need for confirmatory research in a larger sample.
528 The novel consideration of the users' characteristics and the application of Construal Level Theory to
529 a mHealth app for the first time make this study a significant advancement in knowledge. The
530 exploratory findings that engagement with the app was either helpful or harmful depending on the
531 users baseline construal beliefs also represents a potentially significant advancement for mHealth
532 development. We recognise that a limitation to this study is the lack of a control group and
533 conclusions made here now need to be confirmed in follow-up randomised controlled trials. The
534 ethical considerations of potentially poor outcomes for some users will need to be carefully
535 considered and the development of alternative mHealth interventions that target those users who
536 did not benefit from our app in its current form is recommended.
537 In conclusion, our data show that a novel mHealth app rooted in psychological theory shows
538 promise for assisting dietary change and weight loss, but future development should consider the
539 characteristics of the user for optimal support and effectiveness.

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