ImpulsePal: The systematic development of a smartphone app to manage food temptations using intervention mapping

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Abstract

Background: Impulsive processes driving eating behaviour can often undermine peoples' attempts to change their behaviour, lose weight and maintain weight loss.

Aim: To develop an impulse management intervention to support weight loss in adults.

Methods: Intervention Mapping (IM) was used to systematically develop the "ImpulsePal" intervention. The development involved: (1) a needs assessment including a qualitative study, Patient and Public advisory group and expert group consultations, and a systematic review of impulse management techniques; (2) specification of performance objectives, determinants, and change objectives; (3) selection of intervention strategies (mapping of change techniques to the determinants of change); (4) creation of programme materials; (5) specification of adoption and implementation plans; (6) devising an evaluation plan.

Results: Application of the IM Protocol resulted in a smartphone app that could support reductions in unhealthy (energy dense) food consumption, overeating, and alcoholic and sugary drink consumption. ImpulsePal includes inhibition training, mindfulness techniques, implementation intentions (if-then planning), visuospatial loading, use of physical activity for craving management, and context-specific reminders. An "Emergency Button" was also included to provide access to in-the-moment support when temptation is strong.

Conclusions: ImpulsePal is a novel, theory- and evidence-informed, person-centred app that aims to support impulse management for healthier eating. Intervention Mapping facilitated the incorporation of app components that are practical operationalisations of change techniques targeting our specific change objectives and their associated theoretical determinants. Using IM enabled transparency and provided a clear framework for evaluation, and enhances replicability and the potential of the intervention to accomplish the desired outcome of facilitating weight loss through dietary change.

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Background

Tackling obesity remains a public health priority. Excess weight has adverse consequences for health[1,2] and well-being[3,4] and has been associated with lowered life expectancy.[5] With two in three adults in the UK and western world living with overweight or obesity, it is one of the most costly preventable social burdens alongside smoking and excessive alcohol consumption.[6] The World Health Organisation defines overweight and obesity as excessive fat accumulation that may impair health[7] and a person's excess weight status is still commonly classified using the Body Mass Index (BMI).

This obesity epidemic is complex and multi-factorial, but a crucial contributor has been the consumption of excess energy without a response in energy expenditure.[8] Many people fail to meet the daily recommendations for healthy dietary intake[9] and one major risk factor contributing to the increased energy intake in the population, is the frequent consumption of (high) energy-dense food and drink items[8,10–13]. Following the British Nutrition Foundation, energy density refers to the amount of energy (i.e. calories) per gram of food. To achieve the same energy intake, energy-dense foods (e.g. food high in fat and sugar) need to be eaten in smaller volumes than those that are less energy-dense.[14] Energy-dense food and drinks that have been shown to be associated with increased energy intake include fast food,[15,16] snacks and sweets,[17,18] sugary soft-drinks,[19–22] and alcoholic drinks.[23,24] Moreover, experimental studies have shown that eating rate and energy density have independent yet additive effects on overeating (eg.,[25]). Thus, food items that are consumed quickly such as fast food, snacks, sugary drinks, which are generally consumed in between meals while "on-the-go", are considered key contributors to excess energy intake and are therefore important targets for change in weight management interventions.

The modern environment is sometimes referred to as "obesogenic" with cues and temptations[26] ever-present through increased food availability, food outlets, and 24/7 marketing and advertising. These cues trigger excess energy intake through increased eating opportunities and portion sizes[27–29] and contribute to the rising obesity prevalence.[10,30,31] However, there are differences in how susceptible people are to cues[32,33] and in the extent to which cues capture attention,[34,35] motivate towards immediate rewards, and trigger food consumption.[36] Genetic factors explain 40–70% of individual differences in BMI,[37] and these effects are partially mediated by differences in self-control towards food (i.e. disinhibited eating).[38–40] Thus ones genetic make up could be making it more difficult to resist the food temptations in our environment. Individual-level interventions to alter behaviour should support people to manage and override their, in part genetic, responses to the obesogenic environment.

To maximise the efficacy of behaviour change interventions, the application of appropriate theory is advocated as an integral step in intervention development and evaluation.[41,42] A systematic review of reviews[43] highlighted that self-directed weight management interventions have been predominantly based on social-cognitive and motivational theories (e.g. Theory of Planned Behaviour[44] and the Transtheoretical Model[45]). The common assumption in these theories is that behavioural action is determined by deliberative, intentional processes. However, despite strong intentions to lose or maintain weight, people still commonly fail to lose weight, or subsequently regain weight that had been lost (e.g.[46]). Similarly, research has shown that though many people intend to cut down and reduce their snack consumption, strong habits can prevent them from achieving that goal.[47,48] This finding is supported by literature showing that dieting intentions alone are often not sufficiently effective for regulating consumption behaviour.[49–51]

More appropriate theoretical insights for weight management intervention development may come from recent advances in "dual-process" approaches to human behaviour such as the Reflective Impulsive Model([52]), the Temporal Self-Regulation Theory (TST[53]) and the Context, Executive, and Operating Systems model (CEOS;[54]). These approaches propose that in addition to deliberative intentional determinants, behaviour is influenced by unconscious, swift-acting, automatic, impulsive processes which are triggered by situational cues. The influence of impulsive processes on behaviour is supported by research showing that implicit attitudes and beliefs are positively correlated with food choice and eating behaviour.[55] Such processes often reflect deeply ingrained behavioural habits which are resistant to change. However, recent research suggests that these processes may be modifiable.[56,57] Consequently, research to identify effective strategies for addressing the impulsive determinants of behaviour to improve health outcomes, has increasingly been advocated.[58,59]

It is not only important to identify or develop, effective weight management interventions, but also to ensure they are scalable and cost-effective. One way of maximising scalability is offering self-directed interventions[43] using the internet and digital devices. For example, app-based interventions to improve diet, physical activity, and sedentary behaviour have shown modest evidence for the efficacy for non-communicable disease prevention and provide the opportunity to intervene or provide support in the context of real-life situations where real-time decision making occurs.[60] In addition to its scalability, using digital technology as a platform for intervention delivery has the potential of minimising variability in delivery fidelity (i.e. whether the intervention is delivered as intended). Such interventions using the internet and digital technology for health
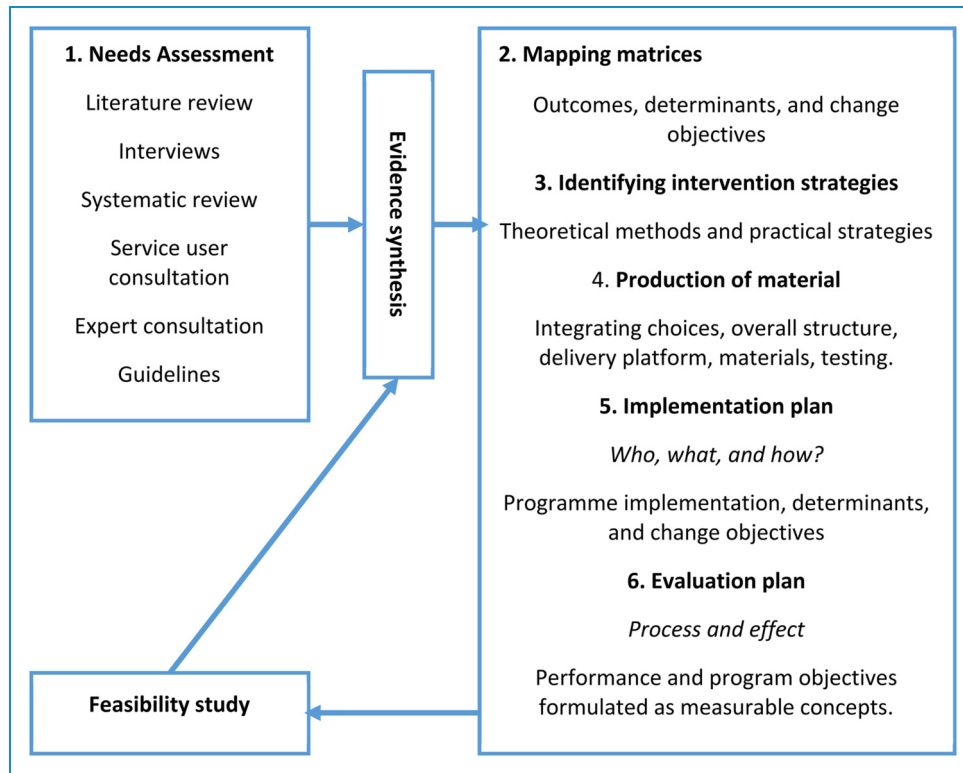
Figure 1. Intervention development process.

have been referred to as 'eHealth' interventions.[61] However, more recently, and specific to lifestyle interventions, the term digital behaviour change interventions (DBCIs) has emerged, which typically refer to the use of websites and smartphones as intervention delivery platforms.[62]

The aim of this paper is to describe the systematic development of a self-delivered smartphone app-based weight management intervention that targets impulsive processes to improve self-regulation of eating behaviour, with a view to facilitating weight loss. However, it is important to note that decisions regarding the delivery platform and theoretical underpinnings were informed by the needs assessment activities as described below.

Methods and results

An overview of the development process is provided in Figure 1. We used Intervention Mapping (IM),[63] which is a well-established and widely used framework for developing health behaviour change interventions (e.g.[64–68]) and had been used previously by members of the research team.[67,69] The IM protocol provides a structured approach to making intervention design decisions that are based on theory, evidence, and an appropriate range of stakeholder perspectives. The protocol comprises six consecutive yet iterative steps: (1) needs assessment; (2) identification of

performance objectives and change objectives; (3) selection of theory-based methods and practical strategies; (4) development of intervention programme materials; (5) development of an adoption and implementation plan; and (6) development of an evaluation plan. Reporting of methods and results in the following section is structured in line with these six steps to describe work undertaken between September 2012 (beginning of Needs Assessment) to September 2015 (finalisation of evaluation protocol).

Needs assessment – step 1

Step 1: methods. The main aims of the needs assessment were to specify the programme outcome (core output Step 1) and to identify the potential targets for behaviour change, their associated modifiable, determinants, and an appropriate platform for intervention delivery, to help inform Steps 2 and 3 respectively.

Intervention development group. A multi-disciplinary intervention development group (n = 8) comprising behaviour change experts (4), neuro-cognitive psychologists (2), and app programmers (2) was assembled to guide the process. The app programmers joined the group after early work suggested an app-based delivery platform would be most suitable. The team was led by a behavioural scientist and discussed weight management, and barriers
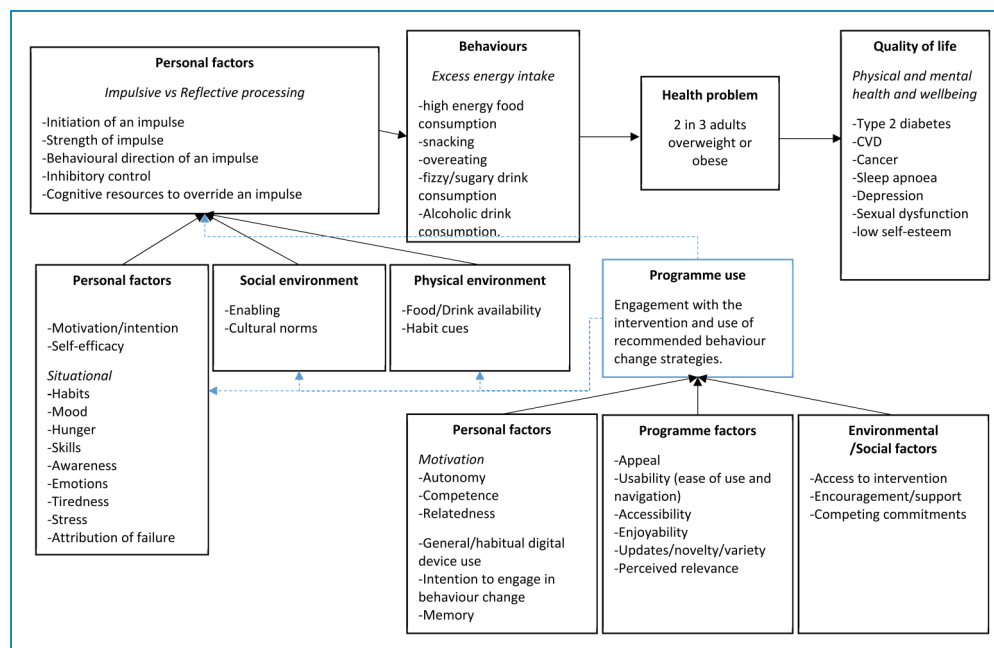
Figure 2. Logic model of the problem and impulsePal.

and facilitators to weight management, based on data from various sources:

(a) A qualitative study to explore perceptions of and experiences with existing web-based weight management interventions among general practice patients with a BMI of over 25 kg/m^2 who indicated a desire to lose weight.[70]

(b) Patient and public advisory group (n = 10) and expert group (n = 10) consultations. Members from an existing local group advising on weight loss and weight loss maintenance were invited to a specific consultation for this project. A separate group of experts (n = 10) were invited through network emails and consisted of people with expertise in behaviour change theory, change techniques, eHealth, and the development of weight management and other behaviour change interventions. Both consultations discussed facilitators and barriers to the reduction of unhealthy eating behaviours identified in the literature and qualitative study, and whether there was anything missing. They also focused on potential strategies to facilitate impulse management and prioritising potential targets for change to help inform Step 3. These groups did not comprise participants taking part in the research.[71]

(c) an informal review of the literature was undertaken on (i) factors affecting eating behaviour, (ii) factors influencing engagement with digital interventions, and (iii) current national guidance for weight management interventions.

(d) a *de novo* systematic review of techniques targeting impulsive processes that drive eating behaviour, to explore if and how such determinants might be modifiable.[72]

Synthesis of needs assessment data. To synthesise the evidence and recommendations from the above sources, summary reports and findings were thematically analysed. The focus was on specifying the overarching programme outcome and identifying (a) potential performance objectives, (b) their associated modifiable determinants, and (c) potential strategies. Using triangulation,[73] the sources were assessed for agreement, disagreement, or silence in relation to the identified potential performance objectives (See Table S1 in the Additional File). Areas of disagreement were discussed in the intervention development group to identify the causes of disagreement and to seek resolution. The resulting themes and categories were organised into a logic model of the problem (See Figure 2).

Step 1: results

Specification of the programme outcome. Overall, the intervention development group agreed that the programme's health outcome should be weight loss and prevention of weight (re)gain in adults who are at increased risk of health conditions associated with excess fat accumulation (i.e. a BMI of 25 kg/m2 and over for a white European population, or 22 kg/m2 and over for African-Caribbean / Black Caribbean population). Based on literature linking dietary behaviours to weight gain (See Background) and the continued struggle to change

Table 1. Example performance objective cross-referenced to determinants.

Performance objectives	Determinants		
	Initiation of impulse	*Strength of impulse*	*Inhibitory control*
PO1. Individual reduces weekly frequency of unhealthy snack/food consumption	I.I. 1. Prevent initiation of impulse to eat unhealthy snack /food.	S.I. 1. Reduce strength of impulse to eat unhealthy snack /food.	I.C.1. Engage inhibitory control to inhibit behavioural responses towards unhealthy snack /food.
	I.I. 2. Initiate impulse to engage in alternative /healthier action.	S.I. 2. Engage strategies to cope with the strength of an impulse to eat unhealthy food /snack without eating.	
	I.I. 3. Identify personal cues /triggers that initiate impulses to eat unhealthy snacks and food.	S.I.3 Identify where strong impulses /cravings to eat unhealthy snack /food may occur.	

dietary behaviour even with available support as reported in the qualitative interviews,[70] reduction in dietary intake was adopted as the overall behavioural programme outcome.

Behaviours leading to excess energy intake. Based on the agreement among all sources, including literature presented above, the intervention development group agreed that to support weight management, key behavioural risk factors to be addressed were (a) unplanned eating and/or drinking (i.e. snacking), (b) type of food or drink consumed (e.g. palatable high energy food and drink), and (c) amount consumed in one sitting (i.e. overeating). The expert consultation and research literature also highlighted that alcoholic drinks are not only high in energy, but their consumption also acts as a potential facilitator of overeating and unplanned snacking and is, therefore, a risk factor for excessive energy intake (e.g.[23]).

Impulsive processes. Early discussions with the intervention development group based on theory[52,54,74] and research literature cited above, acknowledged the importance of managing impulsive processes that facilitate excess energy intake. These processes can result in mindless eating, including making unhealthy food choices and overeating, particularly if there are deficits in executive functioning, or if self-control resources are depleted (e.g.[33,75–77]). The strength of the impulse to be controlled also influences the behavioural outcome. The stronger the impulse, the greater the likelihood of self-regulation failure.[78] In addition, there are factors that affect whether an impulse is triggered in the first place such as food availability, portion size[79]), habit cues,[80] and other situational cues.[81] This need to address impulsive processes that guide behaviour also came across strongly in the consultation groups and the qualitative study.[70] Both members of

the advisory group and participants in the qualitative study highlighted that they felt that current interventions were not providing support to deal with eating too much in one go (e.g. portion size) and temptation resistance for unhealthy snacking as these were often experienced as automatic, habitual, or mindless behaviours. The systematic review identified various techniques addressing impulsive processes working through different mechanisms. For example, impulsive processes could be modified directly, by changing their initiation, strength, or motivational direction. However, they may also be overridden or otherwise managed by cognitive resources.[72] Such processes may therefore indeed be modifiable.

Situational cues. Impulsive processes are proposed to guide behaviour based on hedonic reward-based motivations or habitual routines and are triggered and maintained by situational cues, such as tempting stimuli.[74,82] The literature (See Background), consultation groups, and intervention development group considered the modern obesogenic environment with its abundance of eating-related situational cues, to be a crucial influence on the initiation and maintenance of food-related impulses. Moreover, elements of the situation may result in difficulty in overriding the impulsive processes. For example, in situations when resources required for the reflective processes to run in order to be able to override the impulsive processes, are depleted. These include times of stress, tiredness, when engaged in multiple tasks (busy), and when trying to regulate behaviour or emotions (e.g. quitting smoking or resisting food temptations or trying not to get angry).[83,84] When these resources are depleted people are more likely to give into food temptation and consume excess energy.[77,85,86]

Figure 3. The impulsePal App.

The consultation groups also stressed that social situations are considered to be barriers to healthier eating, particularly where unhealthy food or drink consumption frequently occurs (e.g. celebrations). In such situations, individuals are not only confronted with food cues in the environment but are also having to deal with social norms and pressures. The consultation groups expressed there was a lack of confidence to resist such social influence and lack of motivation to adhere to healthier behaviours in these contexts.

In-the-moment accessibility. It was suggested that as impulsive processes drive behaviour on a moment-to-moment basis, any intervention targeting such processes related to eating behaviour would benefit from being accessible at any time. However, the delivery methods of traditional weight management interventions (e.g. group-based, face-to-face) do not allow for the provision of in-the-moment intervention. The intervention development group highlighted smartphone technology as a promising delivery platform as people tend to have their phone with them most of the time and look at it frequently.[87–89] This pattern of smartphone use means that the intervention could be accessed whenever and wherever the user requires it, allowing for the provision of the desired "in-the-moment support". App-based delivery was also supported by the consultation groups and qualitative study in which some participants mentioned this would offer a solution to overcome barriers to accessing and engaging with weight management interventions.[70] Aside from being accessible, potentially cost-effective and scalable, mobile technologies such as smartphones have sensors which could identify when a person may be most

vulnerable to influences that lead to unhealthy behaviours (e.g. Global Positioning System (GPS)). Moreover, digital interventions have been shown to be effective in modifying a range of health behaviours.[90]

Programme engagement. At the time this needs assessment had been conducted, level of engagement with an intervention had been positively linked to physical health outcomes.[91–93] However, low-use of internet-based interventions was (and continues to be) a challenge in many behavioural domains (e.g. eating, smoking, condom use, alcohol consumption[94]). The qualitative study conducted as part of this needs assessment[70] identified a range of facilitators of, and barriers to, using web-based weight management interventions such as the appeal of the interface, the effort required to engage with the tool and strategies, usability, choice of information and strategies available, ease of access to the intervention, general internet device use, novelty and variety, perceived relevance of target audience, ongoing motivation to change and motivation to engage with the intervention. Similar influences on engagement were found in a related qualitative study with a younger community-based sample focused specifically on app-based interventions.[95]

Specification of outcomes, performance objectives and change objectives – step 2

Step 2: methods. The second step involved the detailed specification of who and what needed to change, and how that would lead to the programme outcome being achieved. The potential performance objectives identified in the needs assessment (above) were examined by the intervention development group and the patient and public advisory group, to assess

which objectives to prioritise. The prioritisation task involved individually rating the top three most important (and achievable) objectives. The performance objectives were formulated in a measurable way and were then further scrutinised, to identify the specific impulsive (and other) determinants related to that behavioural objective. This task included reflecting on potentially modifiable determinants identified in Step 1. This stage in the mapping process required that change objectives were selected and clear specifications were made, to reflect actual changes that needed to occur in the modifiable determinants for the performance objective to be achieved. This specification task involved creating a matrix where performance objectives were cross-referenced with modifiable determinants and change objectives were formulated in the intersecting cells (see Table S2 in the Additional File).

Step 2: results. The prioritisation task highlighted that, from the advisory group perspective, reductions in overeating (i.e. "Individual reduces frequency of overeating episodes (over a 28 day period)") and unhealthy food choices were the most important achievable objectives. Resisting unhealthy snacks (i.e. high calorie but low nutritional value) appeared second to least frequently in the "top three"s. In consultation with the intervention development group and as a result of further discussion with the advisory group, this was later rephrased to combine with reducing unhealthy food choices (i.e. "Individual reduces weekly frequency of unhealthy snack/food consumption"). Sugary, fizzy, and alcoholic drink consumption was reported in the qualitative study as a problem, but had not initially been proposed to the advisory group as a separate standalone objective. However, the research literature provided a strong rationale for minimising the consumption of sugary and alcoholic drink consumption (e.g.[21,23]). Therefore, the intervention development group included this as a specific performance objective (i.e. "Individual reduces weekly fizzy drink consumption." and "Individual reduces weekly alcoholic drink consumption."). Finally, to minimise barriers to uptake and use of the intervention and its strategies, programme engagement was specified from the outset as a key performance objective (i.e. "Individual effectively engages with the intervention).

The next task in Step 2 was to specify how these performance objectives were to be achieved. Table 1 shows selected examples of change objectives for one of the performance objectives cross-referenced with a selection of the associated determinants. The full Intervention Map, including all other objectives, can be seen in Additional file 1.

Selection of theory-based methods and practical strategies – step 3

Step 3: methods. The third step of IM involves choosing intervention techniques to influence the change objectives.

For each determinant of each change objective, change techniques likely to alter the determinant were selected.[63] The selection of techniques drew on a *de novo* systematic review conducted during the needs assessment to identify impulse management techniques[72] focusing on techniques which showed promising evidence for change in weight, eating behaviour, and /or craving strength or frequency. A framework of theoretical behaviour change processes (the Theoretical Domains Framework),[96] and a taxonomy of 93 behaviour change techniques[97] were also consulted. Techniques were selected based on the evidence for the techniques in their ability to modify specific determinants (as identified in the systematic review[72] and subsequent literature[98–100]), the expert knowledge of the intervention development group, and the possibility of delivering the technique via a smartphone app. To address the final performance objective: "Individual effectively engages with the intervention", reviews on strategies and features to improve engagement[101–103] and literature on gamification[104] were consulted.

Step 3: results. Six key impulse management techniques were selected from the systematic review;[72] (a) visuospatial loading (e.g.[105,106]), (b) inhibition training (e.g.[98,99,107]), (c) implementation intentions,[107,108] (d) mindfulness-based strategy (e.g. acceptance[109,110]), (e) physical activity,[111,112] and (f) situational priming.[81,113] These techniques were selected on the basis of the quality of (1) the evidence identified in the systematic review,[72] (2) subsequently available evidence (i.e. published following completion of the systematic review e.g.[98–100]), and[3] evidence outside of the scope of our de novo review.[81,113–116]

To optimise engagement, the intervention development group decided to include persuasive system design features (i.e. reminders) and interactive elements. The intervention is also required to foster a sense of autonomy, relatedness, and competence to enhance motivation to engage with the intervention, through offering choice, using language and examples that were relatable and conveyed empathy, and incorporating a navigational flow and presentation that is intuitive and similar to other frequently used apps.

How the selected intervention techniques and strategies relate to each specific change objectives and their determinants is illustrated in the intervention map (Table S2). We describe our practical applications of these selected techniques below in Step 4.

Creating the programme – step 4

Step 4: methods. The next step in the IM process was to create an organised, structured programme. This step entailed defining the scope and the limitations of the intervention, translating the change techniques selected and specified in step 3 (see above) into specific programme

materials and identifying appropriate and feasible delivery methods.

The intervention development group discussed and guided the scope, selection of operational strategies, the feasibility of delivery via a smartphone app, and sequencing of the intervention components. Discussions with the app developers focussed on the practicalities of each technique and their form within the intervention. Members from the public and patient advisory group (n = 6) provided initial feedback on the textual content of a prototype app, the clarity of the written instructions, the flow of navigation, and any technical issues that arose. Usability and navigational issues were further assessed via individual "thinking aloud" testing sessions with two of the available advisory group members, during which they were asked to continuously verbalise their thoughts as they moved through the prototype app. Any issues or misunderstandings were noted and addressed prior to developing the first fully functional (Android) version of the ImpulsePal app. This section describes the resulting app programme in detail following the Template for Intervention Description and Replication (TIDieR) checklist.[117] For a briefer intervention description, please see.[118]

Step 4: results. The ImpulsePal app-based intervention was designed to be entirely self-delivered and interactive, allowing users to identify and specify personal barriers to unhealthy eating, identify strategies to overcome these barriers, and to track the usefulness of any impulse management techniques that they tried. Users register with a username and password. On successful registration, an additional thumbnail is added to users' smartphone home screen which functions as the "Emergency Button". Finally, users are presented with the app's welcome page, which provides information about what eating-related impulses are, when they might be triggered, and how they might be perceived (e.g. temptation, craving, desire). It also provides information about how users can identify their own triggers and a brief introduction to the app: "*This app will help you manage your impulses to avoid unhealthy eating. You will find a variety of tips and tricks from brain training to defence strategies such as if-then planning which you can apply in the heat of temptation.*" The introduction is followed by a page asking users about their main motivation for losing weight and their key struggles in weight loss. Once users have entered this information, they are directed to the main menu. The main menu (See Figure 3) acts as the home screen for the app and displays navigational buttons to return to the information about the app, the motivations page, and self-monitoring statistics on the user's progress with developing "temptation resistance". This main menu also displays navigational buttons to the five key components of the app: (1) Brain Training, (2) My Plan, (3) Urge Surfing, (4) Danger Zones, and (5) Emergency Button. These are the operationalisations

(practical applications) of the evidence-based techniques selected in Step 3 and are described in turn below. Issues identified following feedback from the public and patient advisory group on the prototypes is summarised in Table S3 in the Additional file which highlights the actions taken.

Brain training operationalises the inhibition training technique as used by van Koningsbruggen and Veling and colleagues.[107,119] This technique, as described in earlier literature, had been proposed to strengthen inhibitory control but it appears to work via reductions in impulse strength through devaluation of the trained foods and potentially the training of an automatic stopping association.[120] In the instructions, users are informed that the brain training will help them inhibit motor impulses that are triggered when they see food. This training involves a Go/No-go task[98,99,107,119] and is presented as a game which provides feedback in the form of scores. During the game, users are presented with images of unhealthy foods and neutral images. Only one image is presented on the screen at any given time and 100 ms following presentation of an image a Go or No-go cue is presented. These cues are displayed as a green "Go" sign and red "Stop" sign, with neutral images consistently paired with a Go sign and unhealthy food images with the Stop sign. When a green Go sign appears on the screen, users need to touch the side of the screen where the image appeared. They are instructed to withhold touching the screen when a red Stop sign appears. Images are presented at random and before the next image is presented, users are provided with performance feedback, with points given based on their correct response and reaction time. Two points are deducted for an incorrect response. All users are encouraged to play the 5-min brain training game three times per week for four weeks and are prompted to engage with the feature via in-app reminders, if the game has not been played on two consecutive days during the first four weeks.

My Plan operationalises implementation intentions in the form of if-then plans.[108] This component presents users with a form where plans can be selected or created. Users are instructed to keep their overall goal in mind and to think of situations that could prevent them from achieving their goal. They are offered existing if-then plans which include common situations where people may struggle with eating-related impulses ("ifs") and responses to deal with those situations ("thens"), which were derived from the two consultation workshops and the qualitative study. In addition, users are also provided with the option to create their own if-then plans. Multiple if-then plans and amendments can be made and saved at any time.

Urge Surfing[121] was selected as it aims to help users deal with in-the-moment temptations and cravings through acceptance of thoughts and feelings. This technique is the practical application of the mindfulness-based strategies selected in Step 3. This component provides users with

information on how and when urge-surfing can be used and textual instructions which follow the steps: **S**top, **T**ake a breath, **O**bserve and imagine, and **P**ractice and proceed. The instructions encourage users to imagine cravings to be like waves which may build over time, but eventually subside and pass. Users are also encouraged to practice this technique in the absence of a craving.

Danger Zones makes use of smartphones' location function (GPS) to enable users to create location and time specific (situational) cues for themselves (thereby operationalising the cueing or priming technique[81]). This component requires users to identify their own "high-risk situations" for unhealthy eating that are location and time specific. Once a location has been selected on the map, users can link the particular location to their own specified goal for the location, which requires identifying the problem and problem-solving in advance. Whenever the smartphone location service detects that the smartphone has entered the selected location, the app sends a notification which is presented in the notification bar. This notification reminds users of their specified goal for that particular location. The Danger Zones component also allows users to select "time boundaries" to more precisely define the high-risk situation, making it context specific. For example, if the location is only ever a personal trigger for unhealthy behaviour during lunch hours, then a notification outside these hours would not be helpful.

The Emergency button is a separate function of the app which enables users to access strategies to deal with the craving "in-the-moment", and (following such events) to record which strategy was chosen and how well the strategy worked. Users are encouraged to use the emergency button whenever they experience a strong craving or temptation. On pressing the emergency button, users are presented with a message congratulating them on putting their impulse on hold. The background of this screen consists of dynamic visual noise in the form of television static, which provides the visuospatial loading.[105] The next screen displays options for accessing My Plan (if-then planning), brain training (inhibition training), or urge surfing (mindfulness-based strategy) to choose from. Fifteen minutes after an emergency button event (e.g. when a user has indicated that a craving or temptation is particularly strong and that they required extra help), the app sends a notification that asks users about the strength of their craving at the time. Users are prompted to respond by rating their craving from 0–100 using a slider displayed on a visual analogue scale ranging from "very weak" to "extreme" craving. The craving scale is followed by a question about whether they were (a) successful, (b) partly or mostly successful or (c) not successful in resisting the urge to eat. The answer to this question is recorded and followed up with an associated message (e.g. congratulatory message or a message normalising a lapse and to encourage learning from the experience and continuing to practice). The statistics page supports self-monitoring of "temptation resistance" and is found in the main menu. This statistics page displays the number of uses of the emergency button for the week and in total. It also displays the success rate for resisting cravings or temptations in relation to their usage of the if-then plans, brain training, and urge surfing following the emergency button events. Users are encouraged to try all techniques and use their statistics to review which techniques are most useful for them personally.

Adoption and implementation plan – step 5

Step 5: methods. In this penultimate step, an adoption and implementation plan was created. This step was informed by literature about factors influencing digital technology uptake and use. However, addressing challenges around adoption and implementation also involved including strategies within the intervention to facilitate sustained engagement which had already been addressed (See Steps 2, 3, and 4). The intervention does not require a programme facilitator, therefore no facilitator training is required. However, because of this, the intervention needed to be very clear and self-explanatory. These issues were addressed in Step 4. Thus, Step 5 primarily focused on how ImpulsePal could be distributed.

Step 5: results. The UK user base for smartphones reached 81% of the population in 2016 (91% among 18–44 year-olds) and smartphone use continues to permeate daily life.[122] Thus, the potential reach of a smartphone-based behaviour change intervention is substantial. However, there are various facilitators and barriers to digital weight management intervention uptake and engagement.[70,95] These were taken into account throughout development (See Steps 2, 3, and 4).

In relation to distribution and uptake, ImpulsePal will be made available from commonly used app stores. We may issue press releases to raise awareness. Moreover, local organisations with whom we are already working and have requested the use of ImpulsePal, will be encouraged to refer people. Findings from a longitudinal qualitative evaluation of a national digital health innovation programme in the UK[123] also highlighted that accreditation and clinical endorsement may strongly influence the adoption and implementation of digital technologies. To facilitate uptake in the longer term, we therefore plan to get the ImpulsePal app evaluated within the NHS following their guidance in the Mobile Health space for developers[124] to get ImpulsePal validated, safety checked, and ultimately hosted on the NHS Digital Health Apps Library.[125]

Evaluation plan – step 6

Step 6: methods. The final step of the IM process involved creating an appropriate evaluation plan. The transparent

documenting of a behaviour change intervention enabled by the Intervention Mapping process, facilitates this. The Logic Model (Figure 2) and detailed Intervention Map (See Table S2) provide the outcomes and processes of interest and therefore inform the design of any evaluation of the intervention.

Step 6: results. The initial evaluation of the intervention was a feasibility study incorporating two cycles of action-research to refine the intervention in close collaboration with its intended users. The measures selected map onto the intervention's effects on the health-related outcome (objective weight change), the programme objectives (self-reported eating and drinking behaviour using a food frequency questionnaire,[126] questions relating to overeating occurrences,[127] and measures assessing engagement - objectively assessed through app usage statistics and explored in semi-structured interviews). The feasibility study also explored the mechanisms of action through semi-structured interviews and questionnaires tapping into intermediary outcomes such as impulsiveness,[128] reactivity to the food environment and situational cues,[126,129] strength of cravings and temptations (assessed using an event-related ecological momentary assessment requesting a rating on a VAS scale), and self-efficacy in managing situations where impulse triggers are commonly present. The design and methods of this feasibility evaluation and its findings are reported in detail elsewhere[118] and showed that both the intervention and the trial procedures are feasible to implement and that they are acceptable to the participants. The next phase of the evaluation is to progress to a fully powered randomised controlled trial (RCT) to investigate the effectiveness of the intervention and further process evaluation to investigate the mechanisms of action.

Discussion

This paper describes the systematic development of a smartphone app-based weight management intervention, ImpulsePal. To our knowledge, ImpulsePal is one of few apps to date[130,131] designed to target impulsive processes in order to facilitate dietary behaviour change. The app was iteratively developed using the Intervention Mapping (IM) protocol[63] and offers a multipronged approach to targeting impulsive processes. IM enabled us to consider behaviour change theory, incorporate evidence-based change techniques, and co-create the app-based intervention with potential end-users and experts in a systematic way.

The importance of providing clarity and transparency in the development and description of an intervention is increasingly recognised (e.g.[132–134]) and several studies have been published in recent years which have adopted similar, comprehensive and structured approaches to

intervention development and this is a crucial advancement in the field (e.g..[64,135,136]) Such a systematic and comprehensive approach to development and evaluation, as well as clear reporting of intervention content is particulary unusual for app-based behaviour change interventions.[137] Although the process is time-consuming and can be resource- intensive, its systematic approach ensured that all ImpulsePal components were practical translations of change techniques that targeted our specific change objectives and thus the associated determinants of the behavioural targets. Using this approach enhanced transparency, provided a clear framework for evaluation and process evaluation, and facilitates replicability. It also maximises the potential of the intervention to accomplish the desired outcome of weight loss.

Unlike most other digital weight loss interventions,[43] ImpulsePal is designed to address both impulsive and reflective processes. As well as regularly used features such as action-planning and self-regulation tools,[138] ImpulsePal provides in-the-moment support where temptations cause difficulty for successful self-regulation[78] and offers evidence-based strategies to manage impulsive and automatic behaviour.[52,58,74] This approach acknowledges that good intentions are not always enough to prevent lapses and therefore that additional support may be required at crucial times. A smartphone-app delivery platform allows the provision of 24 h easy access to the intervention and the inclusion of an "Emergency Button" feature emphasises this element of the programme.

Strengths and limitations

This is one of few studies to describe in detail the systematic development of a smartphone-app based behaviour change intervention and offers a comprehensive description of the intervention according to the TIDieR check list.[117] It used rigorous methods to move from a sound theory and evidence base to practical intervention techniques and strategies, whilst incorporating strong patient and public involvement to ensure the perspectives of the target population were accounted for.[41,139] Although the intervention has been developed in a UK context, it may be suitable (with proper translation and adaptation) for use in a wide range of countries and cultures. There is no evidence that impulsive processes are culturally patterned (although triggers may be culturally specific, the process itself is not), and the app does not include any country-specific information content. One element that would particularly require cultural adaptation is the Go/No-go task which includes pictures of common foods eaten in the UK.

Various frameworks are available for intervention developers (for a recent overview see[140]) to guide the development process such as the Medical Research Council (MRC) Framework for developing and evaluating complex interventions,[141] the behaviour change wheel,[142]

and IM.[63] Although, the MRC Framework[42] recommends that interventions are described comprehensively and that the mechanisms by which they work are made explicit throughout their development, this framework does not offer detailed guidance on how to achieve this. The behaviour change wheel, is a well-established and often-cited method for intervention development which uses the COM-B model of behaviour (Capacity, Opportunity, Motivation, Behaviour) to guide the process. However, this framework is limited to a single unifying theory whereas Intervention Mapping allows developers to draw on a range of theoretical approaches depending on the behavioural targets and their modifiable determinants identified in the needs assessment, thus making this approach more specific to the behaviour, population, and context in which the intervention is to be implemented. Although not published when development of the intervention commenced, the approach taken was broadly in line with the more recent guidance for the development of digital behaviour change interventions[62,143] and has integrated elements that have been recommended in the Person-Based Approach[139] such as in-depth qualitative research at various stages of development (i.e. semi-structured interviews Stage 1 and think-aloud interviews Stage 4).

Several limitations need to be acknowledged regarding the use of IM. Firstly, although one of the core strengths of IM is its iterative and comprehensive nature which ensures a thorough development process grounded in theory and evidence, on the flipside, as has been reported in other development studies using IM,[64,144] it is a time-consuming and resource-intensive process. Secondly, definitions of what constitutes a performance objective, a determinant or behaviour change technique can become blurred. Using a behaviour change technique can be considered a behaviour in itself and could, therefore, be mapped with its own *determinants*. This can make it difficult to distinguish where mapping of the active ingredients in the intervention ends, and considerations regarding receipt and enactment (i.e. appropriate implementation of the techniques by individuals) begin.

Despite the systematic steps and transparency enabled by the IM protocol, it is probable that a different intervention development group using the same methods would produce a different intervention. Throughout the process, decisions were based on available evidence, appropriate expertise (behaviour change experts, app developers, neuroscientists), experience (Patient and Public advisory group), and practical considerations. Thus, intervention development is a function of these variables and the interaction between those involved in collective decision-making at a particular point in time. We attempted to document and justify decisions made throughout the process as much as possible using reports, synthesis tables, and triangulation, however, a tool has recently been developed to aid the documentation of justifications and decisions during

intervention development enabling an even clearer documentation trail of the process.[145,146]

It is also important to acknowledge the limitations of the ImpulsePal intervention. Firstly, although some of the techniques do not require motivation to be effective (e.g. Go/No-go task[107]) the use of the strategies by an individual may still be influenced by their motivation to lose weight and therefore willingness to change.[95] Though strategies have been incorporated to increase motivation to engage with the intervention among those who want to lose weight,[70,147] this app may not be appropriate for those who are at risk of weight-related health issues but are not motivated to manage their weight through dietary change. Although this development study accommodates for the perspectives of the target population throughout the development stages, enabled by the Patient and Public advisory group, qualitative study and qualitative literature, this development work would have benefitted from following the Person-Based Approach[139,148] which was published after work reported here had already been completed. The person-based approach complements theory and evidence-based approaches and uses in-depth qualitative research to accommodate for the target user's perspectives to optimise the acceptability of and engagement with the intervention platform and behaviour change strategies.

Secondly, the technological landscape is ever-changing. The intervention may currently be appropriate and fully functional, but it is important that it evolves with technological advances and the way people engage with technology, when required. Finally, smartphone apps generally have short life spans. Of 26,176 apps which had peak monthly users in 2011, 2012, and 2013, half lost 50% of their peak number of users within 3-months after reaching that peak usage, although apps used for news and health lose users at a slower rate.[149] However, ImpulsePal has incorporated techniques which do not rely on app use once initially learnt. Moreover, our intention is to support people in getting better at managing the impulsive processes involved in eating behaviour as opposed to enticing the app user to rely solely on the intervention.

Future directions

Further research is now needed to assess the effectiveness and cost-effectiveness of the ImpulsePal intervention. A feasibility randomised controlled trial showed that both the intervention and trial are feasible to implement and acceptable to participants.[118] Funding will now be sought for a fully-powered randomised controlled trial. Beyond this, further research should include assessment of the effectiveness of the intervention on weight loss maintenance as behavioural interventions are only moderately effective in attenuating weight regain by about 1.6 kg at 12 months (e.g.[150]). Moreover, ImpulsePal consists of multiple strategies, using factorial designs evaluating individual

intervention components and interactions in terms of effectiveness may inform refinements to the intervention for the optimisation of outcomes such as dietary change, weight loss or weight loss maintenance.[151] Relatedly, such optimisation might require a personalised approach. For example, what works for one individual might not necessarily work in the same way for someone else. N-of-1 randomised trials could help inform who might benefit from which particular technique which would help with personalisation of the intervention.[152] The ImpulsePal app also provides a great platform to potentially conduct Ecological Momentary Assessment[153] which involves repeated sampling of the participants' current behaviours and experiences (e.g. strength of eating impulses) in real-time and natural environments. Texted prompts, or in-app notifications (as are used in ImpulsePal), asking about frequency and strength of cravings at periodic intervals (e.g.[154]) or at context specific occurrences (i.e. when cravings or temptations are strong enough to trigger the individual to use ImpulsePal's emergency button) may provide a better measurement of craving as opposed to the use of retrospective questionnaires.

Conclusions

ImpulsePal is a novel, theory and evidence informed, person-centred app to improve impulse management and promote healthier eating for weight management. Intervention Mapping was a useful framework for helping to develop this intervention.

Abbreviations

BMI   Body Mass Index
DBCI   Digital behaviour change intervention
IM   Intervention Mapping

Additional material

Additional file 1.pdf – Table S1 Triangulation, Table S2 Intervention Map, Table S3 Key changes after prototype testing.

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