Original Paper

Authors: Jorge Encantado\textsuperscript{1,2}, António L. Palmeira\textsuperscript{3}, Carolina Silva\textsuperscript{4}, Falko F. Sniehotta\textsuperscript{5,6}, R. James Stubbs\textsuperscript{7}, Maria João Gouveia\textsuperscript{2}, Pedro J. Teixeira\textsuperscript{1}, Berit L. Heitmann\textsuperscript{8,9}, Marta M. Marques\textsuperscript{1,4}

Affiliations:
\textsuperscript{1}Centro Interdisciplinar para o Estudo da Performance Humana (CIPER), Faculdade de Motricidade Humana, Universidade de Lisboa, Cruz Quebrada, Portugal
\textsuperscript{2}APPsyCI – Applied Psychology Research Center Capabilities & Inclusion, ISPA – Instituto Universitário, Lisboa, Portugal
\textsuperscript{3}Centro de Investigação em Desporto, Educação Física, Exercício e Saúde (CIDEFES), Universidade Lusófona, Lisboa, Portugal
\textsuperscript{4}Trinity College Dublin, ADAPT SFI Research Centre & Trinity Centre for Practice and Healthcare Innovation, College Green, Dublin 2, Ireland
\textsuperscript{5}Institute of Health & Society, Faculty of Medical Sciences, Newcastle University, Newcastle, United Kingdom and NIHR Policy Research Unit Behavioural Science
\textsuperscript{6}University of Twente, Faculty of Behavioural, Management and Social Sciences, The Netherlands
\textsuperscript{7}School of Psychology, Faculty of Medicine and Health, University of Leeds, Leeds, United Kingdom
\textsuperscript{8}Research Unit for Dietary Studies at The Parker Institute Bispebjerg and Frederiksberg Hospital, part of the Copenhagen University Hospital – The Capital Region, Denmark
\textsuperscript{9}The Department of Public Health, Section for General Medicine, University of Copenhagen, Copenhagen, Denmark

Title: What goes on in digital behaviour change interventions for weight loss maintenance targeting physical activity: A Scoping Review
Abstract

**Background:** Behavioural interventions for weight loss maintenance have shown beneficial effects for weight loss maintenance. While the digital upgrade of behavioural interventions brings an enormous potential to tackle public health challenges, there is limited knowledge about the components of these interventions, i.e., its content, delivery and the theoretical approaches.

**Objective:** To identify the core components of digital behaviour change interventions for weight loss maintenance targeting physical activity, in terms of: i) Behaviour Change Techniques; ii) Mechanisms of Action; iii) Modes of Delivery; iv) Dose; and v) Tailoring/Personalisation. In addition, the links between these components were investigated.

**Methods:** A literature search was performed in 5 electronic databases: PubMed; Embase; CINHAL; PsycINFO, and Web of Science. Two reviewers independently screened the identified papers and extracted data related with the study characteristics and behaviour change techniques, mechanism of action, mode of delivery, dose, and tailoring, using standardized classifications whenever available (e.g., behaviour change techniques taxonomy).

**Results:** Seventeen articles reporting eleven original studies were selected. Two studies were protocols, nine studies presented results for weight change and all but one showed no significant differences between the intervention and control groups. Eight studies (73%) provided adequate information on Behaviour Change Techniques. Five studies (45%) provided partial information about how the Behaviour Change Techniques were linked to mechanisms of action, and only one study (0.9%) described these links for all the techniques. Around half of the studies reported the modes through which behaviour change techniques were delivered. Descriptions of dose were present in most studies, but with minimal information. The use of tailoring or personalisation approaches was mentioned in eight studies (73%), but descriptions of what was tailored and how were minimal.

**Conclusions:** The compilation of information regarding intervention components was difficult due to the lack of information and systematisation in reporting across papers. This is particularly true for the reporting of the links between behaviour change techniques and the other core intervention components. This information is crucial to help us understand in the context of behaviour change interventions what works or does not work, how it works and why.

**Keywords:** Digital behaviour change intervention; Weight loss maintenance; Physical activity; Behaviour Change Techniques.
Introduction

Obesity is related to an increased risk of development of major non-communicable diseases, namely cardiovascular diseases, type 2 diabetes, and some types of cancers [1,2]. A meta-analysis of worldwide weight control attempts (72 studies; n = 1,189,942) showed that 42% of adults from the general population and 44% from ethnic minority populations are trying to lose weight, and 23% reported trying to maintain their weight annually [3].

While behavioural interventions have shown beneficial effects in the short term in reducing weight, most people experience longer-term weight regain, hindering the health benefits associated with weight loss [4,5]. It is therefore crucial to implement behavioural interventions that successfully promote weight loss maintenance (WLM), i.e., intentional loss of weight of at least 10% of one’s body weight that is successfully kept off for at least one year [6]. Besides healthy dietary behaviours, a core behaviour to be targeted in WLM interventions is physical activity (PA) [7,8]. It is documented that for every additional 10 mins of total PA there is a decrease in the risk of weight management lapses by 1% [9]. Further, physically active individuals (> 60 min of daily PA) with overweight seeking weight loss have a lower risk of lapse (5%) when compared with inactive individuals (12% risk) [9]. Recent reviews focusing on the strategies used by successful weight loss maintainers highlighted the beneficial role of physical activity (PA) [3,10].

Digital Behaviour Change Interventions (DBCIs), defined as coordinated sets of activities or products designed to change specified behavioural patterns (e.g., physical activity) of an individual, group or population through digital technology such as mobile apps, wearable technology (e.g., activity trackers), or websites [11] are a viable option for WLM as they have great potential to improve efficiency of behavioural interventions in the long term, with high reach, precision and scalability [12].

The literature of weight management is extensive and findings on DBCIs for weight loss are promising (e.g., [13-17]). However, in the context of WLM, the few existing reviews have reported positive albeit often small effects of DBCIs with considerable between-study variability. In a recent review of systematic reviews [18], web-based interventions for weight loss and WLM were more effective than minimal or control conditions, but results were inconsistent across reviews that compared with non-web-based interventions. Contrastingly, in the Hutchesson’s and colleagues [19] systematic review including seven DBCIs for WLM, six studies (86%) did not find significant differences on pre- and post-intervention weight
change between DBCIs and control (self-directed, no intervention, written materials or general health related messages). In another review by Beleigoli and colleagues [14] including 11 studies, sensitivity analysis showed that there was greater weight loss in the web-based intervention groups in comparison with non-technology intervention group in studies with less than 6 months follow-up (MD –2.13; 95% CI: -2.71 to -1.55) but no differences were found when follow-up exceeded 6 months (MD -1.7; 95% CI: -2.1 to 1.76).

To be able to develop and implement effective DBCIs for WLM, we need to identify what are the components included in these interventions, what is the evidence and the theoretical underpinnings of the choices made in the selection of these components, and how they are linked. By components of behaviour change interventions, we are referring to: i) the intervention content i.e., the behaviour change techniques (BCT) that are implemented (e.g., goal setting), ii) the theoretical principles that contextualized the technique (e.g., self-efficacy), and iii) the way(s) through which the interventions are delivered (e.g., using an app).

The development of standardised classifications and descriptions of intervention components, through taxonomies and ontologies facilitate the identification, description and reporting of the components of behaviour change interventions, facilitating comparison and accumulation of evidence. The Behaviour Change Techniques Taxonomy v1 is probably the best-known example [20] of a classification system describing the content of behaviour change interventions. Building on this work, the Human Behaviour-Change Project [11,21], proposed to develop a Behaviour Change Intervention Ontology to classify and organise other components of behaviour change interventions (such as the setting, delivery, and behaviours), with the aim of creating automated evidence searching, synthesis and interpretation to answer questions that are variants of “What works, compared with what, how well, with what exposure, with what behaviours (for how long), for whom, in what settings and why?”

None of the systematic reviews of DBCIs targeting PA in WLM contexts [13-19,22-24] describe these components in detail (except for BCTs) and do not provide an overarching mapping of the links between the core components of the interventions. This knowledge may inform us about the current state of evidence and knowledge gaps.
Aim
The aim of this scoping review was to identify and describe the core components of DBCIs for WLM targeting physical activity. Specifically, the objectives of the present review were to:

1. Identify the content of these interventions (i.e., which BCTs have been reported to be delivered), and how this content was reported to be delivered (mode of delivery, dose, and tailoring).
2. Identify the hypothesised theoretical principles (mechanisms of action) that support the choices for the content and delivery of the DBCIs.
3. Examine the links between these components that are reported in the literature and how these are described, i.e., if based on conceptual approaches and/or evidence.

Methods

Search strategy
This review is reported in accordance with the PRISMA extension for Scoping Reviews guidelines (PRISMA-ScR) [25], and the protocol is publicly available in the Open Science Framework repository (OSF Protocol). Despite the planned use of motivational behaviour change techniques [26], due to the residual presence of such techniques we decided to use only the Behaviour Change Techniques (BCT) Taxonomy v1 [20].

A comprehensive literature search was conducted in 5 electronic databases: PubMed; Embase; CINHAL; PsycINFO, and Web of Science. In addition, we performed a manual cross-referencing of bibliographies cited in previous reviews [14,22,23,27]. The search strategy included terms related with i) the concept (DBCIs designed to support weight loss maintenance, defined as interventions containing at least one component delivered via the internet) and ii) the context (DBCIs for weight loss maintenance targeting physical activity). The search was updated in January 2021 (search terms and information on excluded studies are available at Supplementary File 1).

Eligibility criteria
Protocols and reports of intervention studies published in English and using any type of experimental designs were selected for this review. There were no restrictions with respect to the length of the intervention and assessment time point(s). Interventions had to explicitly report: i) using a digital or web-based component to deliver the intervention; ii) being aimed
at weight loss maintenance; iii) targeting physical activity as a main behavioural target; iv) include samples of adults (≥ 18 years old) who had lost weight prior to entering the study, i.e., adults in weight loss maintenance. Studies that included pregnant or post-partum women, individuals with eating disorders, major depressive or anxiety disorders, as well as individuals participating in interventions including surgical or pharmacological components were excluded.

Data extraction
The study characteristics extracted for each study were: i) bibliographic information (authors, year of publication, and reference), ii) country where the study took place, iii) sample characteristics (sample size, gender, age, body mass index), iv) study design, v) intervention characteristics (name, aim, length of intervention and follow-up), and vi) results for the outcomes of interest (weight, physical activity).

Further, the following characteristics were coded for its presence/absence:

a. Behaviour Change Techniques: Labels and descriptions of BCTs were identified and extracted from the included studies and then coded using the Behaviour Change Techniques Taxonomy (BCTT) v1 coding guidance [20]. The BCTTv1 provides an extensive list of 93 clearly labelled, well-defined BCTs, clustered into 16 exclusive groupings.

b. Mechanisms of Action (MoA): Information on the theoretical principles were extracted using the list of mechanisms of action from Carey and colleagues [28]. This list includes 26 mechanisms of action taken from the 14 theoretical domains as described in the Theoretical Domains Framework [29] and the 12 most frequently occurring mechanisms derived from a set of 83 behaviour change theories [30].

c. Mode of Delivery (MoD): Information about MoDs were extracted using the MoD Ontology v1 developed by Marques et al. [31]. This ontology presents a four-level hierarchical structure comprising 65 modes of delivery, organised by 15 upper-level classes: Informational, Environmental change, Somatic, Somatic alteration, Individual-based vs Pair-based vs Group-based, Uni-directional vs Interactional, Synchronous vs Asynchronous, Push vs Pull, Gamification, Arts feature.

d. Dose: Information about dose was extracted based on the elements of intensity ((what is the intensity with which the intervention is being delivered) described by Dombrowski et al. [32]: duration of intervention, number of contacts, length of contacts, frequency, spacing (e.g., constant, variable), and sequencing of BCTs.
e. Tailoring: Defined as the process by which a behaviour intervention is selected or modified based on characteristics of the population or context [21] we coded if i) the intervention used any features of tailoring, and ii) the description of the tailoring process.

Data was extracted independently by two researchers (JE, CS). Disagreements on the information extracted and categorization were decided through discussion with a third author (MM). The information extracted was inserted in an excel format table with the indication of the exact part of the paper where the information could be found.

First, information about overall use of BCTs, MoAs, MoD, Dose, and Tailoring components were extracted regarding the intervention conditions. Second, each BCT description was specifically screened and classified as including or not including information about the links with each component: MoAs, MoD, Dose, and Tailoring.

Data Synthesis

Information on extracted intervention characteristics was summarized and is presented in supplementary tables: Summary (Supplementary File 2), MoD (Supplementary File 3), and Dose (Supplementary File 4). Due to the methodological nature of the present review of mapping key constructs and their relationships and identify gaps in existing research, a qualitative approach was used to categorize the information in each category originated from the selected taxonomies and ontologies [20,28,31,32]. When suitable, a quantitative summary is presented using descriptive statistics. A “mapping” overview table was developed to summarize conclusions from the extracted information and to highlight the relationships between concepts of analysis (BCTs, MoAs, MoDs, Dose, and Tailoring). This approach was used to adequately summarize the intervention design decisions. The following criteria were used: the description of each BCT was extracted (Supplementary File 5) and analysed (Supplementary File 6) in terms of its implementation (reported or not); the link with MoA (reported or not); the link with MoD (reported or not); the link with Dose (reported or not); Tailoring components (if it was used or not). For each study we calculated the overall prevalence for each category based on BCTs descriptions.
Results

Study characteristics
The literature search yielded a total of 688 articles (PubMed $k = 64$; Web of Science $k = 242$; PsycINFO $k = 76$; Embase $k = 247$; CINHAL $k = 59$). One additional article was identified through manual searching. Duplicates were removed, and abstracts were screened based on the predefined criteria of inclusion. Fifty-six articles were left for full-text screening. Seventeen articles reporting on eleven intervention studies were selected for this review (fig. 1).

**Fig 1. Here**

Study characteristics are summarized in table 1. Seventeen articles reporting eleven studies were included. Seven articles were study protocols, and ten intervention reports (i.e., reporting main effect or secondary analysis). One study was reported in 4 articles [33-36]. Two trials had only the protocol paper published at the moment of the submission of the current review [37,38]. All studies were RCTs of various types (i.e., parallel RCTs, factorial, etc.). About one third of the studies ($k = 4, 36\%$) were part of larger trials containing an initial weight loss program. Most studies were conducted in English-speaking countries ($k = 9, 82\%$). Sample size ranged from 49 [39] to 880 [35] participants (median = 95). Duration of the studies ranged from 3 months [40,41] to 30 months [35] (median = 12). Nine of the eleven studies have reported results concerning weight change, the majority of which showed no significant differences between the intervention and control groups. The exception was the trial by Thomas and colleagues [39], in which the intervention group maintained an average weight loss of 10%, significantly greater than the comparative group. Physical activity outcomes were reported in six interventions, of these three reported no significant differences between groups [41-43], two observed a decrease in physical activity in the group receiving DBCI in comparison to those receiving personal contact [35,44], and one study found a small significant difference in which the intervention group was significantly more physically active than the control group [45,46].

Table 1. Study characteristics

<table>
<thead>
<tr>
<th>Authors, year</th>
<th>Country</th>
<th>Name/Reference</th>
<th>Design</th>
<th>Sample</th>
<th>Length of</th>
</tr>
</thead>
</table>

[33-36]
<table>
<thead>
<tr>
<th>Study</th>
<th>Country</th>
<th>Intervention Type</th>
<th>Control Group</th>
<th>N</th>
<th>Age (SD)</th>
<th>BMI (range)</th>
<th>Female (%)</th>
<th>Follow-up (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brindal et al., 2016; Brindal et al., 2019</td>
<td>Australia</td>
<td>Motimate Parallel RCT (1 IG, 1 CG)</td>
<td></td>
<td>88</td>
<td>45.1 (13.9)</td>
<td>20.9 to 60.8</td>
<td>75%</td>
<td>3 months (3 months)</td>
</tr>
<tr>
<td>Collins et al., 2010; Collins et al., 2017</td>
<td>Australia</td>
<td>CTRN1261000 0197033 RCT (1 IG, 1 CG)</td>
<td></td>
<td>227</td>
<td>42.3 (10.1)</td>
<td>30.4 (4.1)</td>
<td>56%</td>
<td>12 months</td>
</tr>
<tr>
<td>Coughlin et al., 2013; Brantley et al., 2008; Funk et al., 2010; Stevens et al., 2008</td>
<td>United States of America</td>
<td>WLM Website BFS RCT (2 IG, 1 CG)</td>
<td></td>
<td>880</td>
<td>55.9 (8.7)</td>
<td>30.9 (4.7)</td>
<td>35.7% Female</td>
<td>30 months</td>
</tr>
<tr>
<td>Espel-Huynh et al., 2019</td>
<td>United States of America</td>
<td>Refresher Weight Loss Pragmatic type 2 effectiveness implementation hybrid design (2 IG, 1 CG)</td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
<td>12 months</td>
</tr>
<tr>
<td>Evans et al., 2015; Sniehotta et al., 2019</td>
<td>United Kingdom</td>
<td>NuLevel Randomized superiority trial (1 IG, 1 CG)</td>
<td></td>
<td>288</td>
<td>41.8 (11.5)</td>
<td>30.9 % female 77.5%</td>
<td></td>
<td>12 months</td>
</tr>
<tr>
<td>Gerber et al., 2013</td>
<td>United States of America</td>
<td>Exercise Ur Faith RCT (1 IG, 1 CG)</td>
<td></td>
<td>88</td>
<td>50(8)</td>
<td>32.4</td>
<td>Female 100%</td>
<td>9 months</td>
</tr>
<tr>
<td>Leahey et al., 2016</td>
<td>United States of America</td>
<td>Providence RCT (2 IG, 1 CG)</td>
<td></td>
<td>75</td>
<td>48.5 (10.7)</td>
<td>31.5 (5.8)</td>
<td>Female 85.3%</td>
<td>10 months</td>
</tr>
<tr>
<td>Nakata et al., 2019</td>
<td>Japan</td>
<td>UMIN RCT (1 IG, 1 CG)</td>
<td></td>
<td>95</td>
<td>55.9 (6.1)</td>
<td>28.3 (2.8)</td>
<td>62.1% Female</td>
<td>24 months</td>
</tr>
<tr>
<td>Scott et al., 2019</td>
<td>Denmark, Portugal, United Kingdom</td>
<td>NoHoW 2x2 RCT (3 IG, 1 CG)</td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
<td>6 months (12 months)</td>
</tr>
<tr>
<td>Thomas et al., 2011</td>
<td>United Kingdom</td>
<td>Weight Loss Clinics RCT (1 IG, 1 CG)</td>
<td></td>
<td>49</td>
<td>44.7 (13.6)</td>
<td>32.9 (10)</td>
<td>NR % female</td>
<td>6 months</td>
</tr>
</tbody>
</table>
Behaviour Change Techniques

All studies reported the use of behavioural techniques (full details available in Supplementary File 5), although only three [38,41,46] reported using the BCTTv1 [20] to classify them. Eight studies did describe with satisfactory detail all the used BCTs (k = 8; 73%) whereas three studies did it for some BCTs but not for all. Overall, thirty-six BCTs were used across the studies. Some interventions implemented the same BCT multiple times, using more than one MoD (e.g., participants instructed to self-monitor outcomes of behaviour during a face-to-face contact or via email) or for different behaviours and/or health outcomes (e.g., implementing goal setting for weight or for expended calories). The study that reported using more BCTs was NuLevel [46], ten times more (n = 30) than the study with the least number of BCTs reported (n = 3) [38]. On average 12 BCTs were reported per study. The most frequently reported BCTs were self-monitoring of outcome(s) of behaviour (n = 9) and prompts/cues (n = 8). Seven studies reported goal setting of behaviour (PA), self-monitoring of behaviour (PA), feedback on outcome of behaviour (weight), and social support (unspecified). Problem solving and feedback on behaviour (PA) were reported in six studies. The remaining BCTs were dispersed across studies.

Mechanisms of Action

Overall, twenty hypothesised MoAs were reported across seven studies (k = 7; 73%). The most frequently reported was Behavioural Regulation (k = 7; 64%) defined as the behavioural, cognitive and/or emotional skills for managing or changing behaviour [28], followed by Social Influences (i.e., interpersonal processes that can cause oneself to change one’s thoughts, feelings or behaviours) (k = 5; 45%), and then by Skills, and Environmental Context and Resources each one reported in four studies (k = 4; 36%). The study with more theoretical principles reported was NuLevel [46] with fifteen, followed by Motimate [41] with twelve. Next, with smaller numbers, the study by Scott and colleagues [38] reported three MoAs and Wing and colleagues [44] reported only one. Four studies did not report any MoA (k = 4; 36%) [37,39,42,43].
Modes of Delivery

Only one study was entirely digital and automated [38]. The other ten studies also included non-automatic distant human interaction and four of these reported additional face-to-face interaction for delivering intervention content [35,39,46,47]. Most studies used mobile devices or desktop computers as a mean to deliver the intervention content ($k = 9$ desktop enabled; $k = 1$ mobile first [41]. The exception was the study by Gerber and colleagues [42], which used Home TV videos (DVR) to deliver the intervention content. The most frequently used form of communication was email ($k = 9$, 81%), followed by audio calls or messages ($k = 7$, 64%). Three studies used video call/messages (e.g., 1-minute videos with intervention content) (27%) [37,38,42] and three others used text/instant messages (27%) [41,45,48,49]. Only three studies provided wearable technology to monitor physical activity, i.e., activity monitors (27%; [38,43-45]), and four studies provided wireless weighing scales (36%; 38,43-45]). All but one study provided also provided a weighing scale to the control group [43]. Two studies included printed materials [44,45]. All interventions were delivered individually. In addition, one intervention included dyadic communication (i.e., peer support; [47]) and two others in person group sessions [35,47]. All studies used one-way interactions and mostly using asynchronous communication (e.g., email). Additionally, more than two thirds used synchronous and reciprocal interactions (e.g., phone calls) ($k = 8$; 73%). Most of the reviewed studies used push message ($k = 9$; 82%) or pull message ($k = 9$; 82%), either to communicate with the participants or to deliver reminders or behavioural prompts to report data, or to adhere to behavioural monitoring. Regarding the format of the content delivered, all studies used written content, six studies reported also using audio content (55%), and three studies included video content (27%). Images or visual elements were used by 55% of the included studies ($k = 6$), usually in the form of self-monitoring graphs. None of the interventions used gamification features. For full details please refer to Supplementary File 3.

Dose

Five studies (45%) provided detailed information about the duration of the contacts and interactions [35,42,43,45,47]. Two studies reported the order of presentation of intervention content [37,45] (full details in Supplementary File 4). The duration of delivery of each BCT was only reported in the NuLevel trial (10 minutes for each module of intervention) [45]. The frequency of delivery ranged from daily ($k = 4$; 36%), weekly ($k = 5$; 45%), and monthly contacts ($k = 5$; 45%).
Overall, the number of contacts was poorly reported, or insufficient details were provided. The “WLM Website BFS” intervention [35] reported one face-to-face orientation session and one reorientation group session at the twelfth month; the “Motimate” intervention [41] reported to have five clinic visits over the period of twenty four weeks; the NoHoW trial [38] was reported to have twenty six automatically delivered emails; the study by Nakata and colleagues [43] reported twenty four monthly personalized text messages; and Thomas and colleagues [39] reported that the Weight Loss Clinics study had twenty six email contacts with each participant plus six emails asking weight.

Tailoring
The use of tailoring was mentioned in eight studies (73%), but descriptions of what was tailored and how it was tailored were minimal. Some studies used automated tailored feedback from reports or data retrieved from sensors, others provided tailored content based on weight related changes (e.g., traffic light system that triggers personalised content based on weight variation).

Links between Behaviour Change Techniques and other intervention components
Most of the studies reported to some extent the information on how BCTs were implemented (i.e., how they were translated into functionalities and content presented to users), what were the hypothesised theoretical principles, how they were delivered (MoD), and with what dose and (Fig. 2; for full details see Supplementary File 6). However, only one study described the links between all BCTs and theoretical principles [45], four studies described it partially, but from these, two studies reported links for only a third of the used BCTs. This means that less than half of the studies reported some information about the link between BCTs and theoretical principles (k = 5, 45%).

**Figure 2 here**

Even though the language used was not standardized across papers, we identified that 55% (k = 6) of the studies described the MoD for each BCT. However, the other five remaining studies did not describe it for all reported BCTs (Fig 2; for full information for each BCT please refer to Supplementary File 6). Six studies (55%) reported frequency of delivery of all BCTs (e.g., weekly, daily). Lastly, for tailoring, no study fully described the tailoring
Discussion

This scoping review identified the various components used in digital behaviour change interventions (DBCI) for weight loss maintenance (WLM) targeting physical activity. By systematically extracting and classification the intervention components from identified studies we aimed to provide an overview on the current state of DBCIs reporting, identify gaps in the literature, and provide new insights on the need to use formal ways of reporting intervention components to facilitate accumulation of evidence and inform future intervention development.

Half of the reported BCTs were reported on two studies. On the other hand, a small number of the 36 BCTs were considered essential to be implement in DBCIs for weight loss maintenance, for example, the self-monitoring of outcomes of behaviour BCT was used in 82% of the studies reviewed and the prompts/cues in 73%. Overall, there is a trend to favour the use of BCTs that are related to the Self-Regulation Theory, such as goal setting of behaviour, self-monitoring of behaviour and feedback on outcome of behaviour (included in 64% of the studies). This is consistent with the literature as frequent self-monitoring is associated with better weight management [50,51]. However, most studies did not provide monitoring technology and relied on self-reported data to monitor behaviours, define goals, and to provide feedback to participants.

Seven studies fully reported theoretical principles on intervention design but two just identified the underlying theory and did not provided further information on the hypothesised mechanisms of action targeted by the intervention. Indeed, only five studies provided specific information about the links between the hypothesised MoAs and BCTs, that is, provided some extent of information on which MoAs were hypothesised to be impacted by the selected BCTs. Even though these relationships BCTs-MoAs are identified as fundamental to inform the intervention design and understand why an intervention is effective in achieving the behavioural change targets, only one study [45] provided proper detail on this.

It seems that the technological capabilities of DBCIs are not being used to its full potential as the studies relied heavily on static written content. Only 6 studies took advantage of audio features and only 3 used videos to deliver intervention content. This might be a result of the

procedures for all BCTs and the study with the best description considering all used BCTs was the NuLevel [45] (83%).
limits of the existing technology at the time of intervention development (about half the studies were published before 2015). There is great potential of the technological features available through digital platforms that allow enhanced user engagement and increased effectiveness in delivering complex and dynamic intervention techniques (e.g., individual, and contextual adaptation and tailoring). Optimization designs such as micro-randomized trials may contribute to harness all the potential of DBCIs by providing the means to test more granular aspects of each component of the intervention and further help to refine behaviour change theories and assigned intervention content [52].

Furthermore, papers reviewed did not systematise the information on the dose of the intervention. Few studies reported systematically the information about the number of modules or materials, and there were limited descriptions of the dose of the BCTs, i.e., when it was delivered, the frequency, and its intensity. Similarly, few studies reported unequivocally the number of contacts and/or the duration/length of each type of contact (email, text-message, phone call, etc). The only paper that described the intervention components with some detail and in a structured form (including almost all categories of the ontologies used in this review) was the NuLevel protocol [45].

Few studies reported on tailoring features, and from the studies using this feature, only few explained the decision process of personalized feedback and prompts (e.g., [35]) going beyond the indication of the use of “personalized” or “tailored” or “individualized reports/feedback”. Only “NuLevel”, “NoHoW” and “Motimate” interventions broadly addressed the mechanics underlying the decisions of personalised feedback, there is a need for future studies to distinguish between automated feedback and human feedback (even if it is not face-to-face) and provide information about tailoring variables and the methods used for tailoring or personalisation (e.g., data-driven).

Finally, most studies compared digitally delivered interventions (either as a stand-alone MoD or as a complementary platform) against other types of traditional MoDs (group, phone call, consultation plus digital). The testing of the differential effects of various digital MoDs and the other components was not addressed by any study. On the other hand, while most studies clearly reported BCTs and in some cases used standardised guidelines, there were serious limitations in the reporting of other interventions components, namely the ways through which the intervention content was delivered (i.e., MoDs) and its dose. In fact, very few studies systematically described the links between BCTs and the other intervention
components. Intervention content underreporting undermine comparability across interventions, and replication. Indeed, several researchers identified this gap before [53-55]. This was the first review with the specific intent to provide an overarching mapping of how these components are brought together in DBCIs for WLM targeting PA, to inform us about the current state of evidence beyond the effectiveness (Does it work?).

Strengths and Limitations
This scoping review main strength is the classification of DBCIs components in a systematic manner using recommended taxonomies and ontologies, therefore contributing to the identification of knowledge gaps, and improvement of intervention reporting and design. This work allowed us to pinpoint two main gaps in the DBCI literature. First, the difficulty in extracting information from published literature in a systematic and objective manner, given the heterogeneity with which intervention components are described. Second, even when the components of the DBCI were reported, the links between these components were not fully described. Whether the intervention is effective or not, with no information on these links between the components we cannot know with a sufficient degree of certainty why the intervention outputs are as they are. If the ultimate goal of DBCIs/Digital behavioural research is to understand what works, for whom, when, and why, we need, as researchers, to standardize methods of reporting interventions’ components.

Despite ontologies for Dose and for Tailoring are not yet available we used existing frameworks to guide our analysis [32], and important efforts are being made by the Human Behaviour Change Project working group to develop an ontologies for these components [21,56] that will allow an update of our work in the future. While this scoping review implemented a comprehensive literature search, it only included published RCTs studies. Expanding this search to computer science databases (e.g., ACM Digital library), app libraries, and grey literature, could provide valuable information on how DBCIs are described in a different scientific field and to more detailed descriptions of interventions that are sometimes provided in unpublished documentation. Another limitation we would like to highlight is that it was out of the scope of this review to examine which components and/or links between components were associated with the effects of interventions. Nonetheless, the extensive data extraction conducted allowed us to verify that the limited number of interventions plus the limitation on the descriptions of its components would not allow us to conduct this analysis. Furthermore, we did not assess the methodological quality of the
studies due to the nature of this review, focusing on the quality and congruence of the intervention content and components rather than the quality of the methodological procedures.

Conclusions
This scoping review identified which core components of DBCIs for WLM focusing on physical activity are reported, which links between components and BCTs are reported, and the level of detail of these reporting procedures. This is one of the first efforts to systematically describe a vast range of components of these DBCIs and identify in which domains the intervention development and reporting procedures need more attention. By identifying the extent by which components are adequately described, and the heterogeneity of this reporting procedures across studies, this work contributes to expand our knowledge on what is being done regarding DBCIs for WLM and what needs to be improved in future studies.

Acknowledgements
All authors contributed to the review protocol. JEP, CS and MMM conducted the searches, the screening, and the extraction of information from the selected papers. JEP and MMM drafted the manuscript. All authors reviewed and approved the manuscript.

Funding
Marta Marques is funded by a Marie-Sklodowska-Curie (EDGE) Fellowship programme (grant agreement No. 713567).

Conflicts of Interest
RJS consults for Slimming World through Consulting Leeds, which is a wholly-owned subsidiary of the university of Leeds. Slimming World was a former partner in NoHoW. MMM and GH has previously consulted for Slimming World, who was a former partner in NoHoW project. All other co-authors have no conflicts of interest to declare.

Abbreviations
BCT: Behaviour Change Techniques
BCTTv1: Behaviour change techniques taxonomy version 1
DBCI: Digital Behaviour Change Intervention
MoA: Mechanisms of Action
MoD: Mode of Delivery
PA: Physical Activity
PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews
RCT: Randomized controlled trial
WLM: Weight loss maintenance
References


50. Frie K, Hartmann-Boyce J, Jebb S, Oke J, Aveyard P. Patterns in Weight and Physical


