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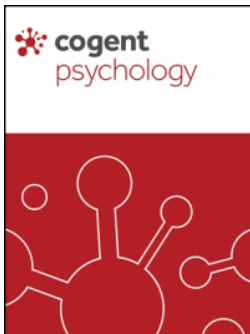
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## HEALTH PSYCHOLOGY | REVIEW ARTICLE

# Using virtual representations in mHealth application interventions for health-related behaviour change: A systematic review

Lauren Taylor<sup>1\*</sup>, Hannah Ranaldi<sup>2</sup>, Aliya Amirova<sup>3</sup>, Louisa Zhang<sup>2</sup>, Ayan A Ahmed<sup>2</sup> and Bridget Dibb<sup>2</sup>

**Abstract:** Many mobile health (mHealth) application interventions include virtual representations of the self in varying forms, such as agents, or avatars to initiate health behaviour change. This review aimed to determine: (i) which virtual representations are effective in mHealth application interventions, and (ii) whether any studies implemented specific mechanisms (the psychological causes of change) and behaviour change techniques (BCTs) to influence positive behaviour change. Following PRISMA guidelines, a narrative systematic review of empirical studies was conducted from ten different databases (ranging from MEDLINE to Cochrane Library) from inception to December 2021. This included articles reporting a virtual representation of mHealth application intervention, published in English from any

### ABOUT THE AUTHORS

Lauren is a PhD Health Psychology student at the University of Surrey. Her research interests include digital health, mobile health applications, virtual reality, and health behaviour change.

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Ayan is a PhD Cognitive Psychology student at the University of Surrey. Her research interests include investigating the long-term impact of khat use on neurocognitive processes.

Hannah is a Health Psychologist. Her research interests include digital health, and leading digital behaviour change interventions.

Louisa is a PhD Health Psychology student at the University of Surrey. Her research interests include exploring the associations between university students' heart rate variability, mood and stress.

Bridget (PhD, University of Surrey) is a Senior Lecturer in Health Psychology at the University of Surrey. Her research interests include investigating how people experience, adjust to and cope with living with rare chronic illness (such as Misophonia, HIV, Spinal cord injury, Meniere's disease) and factors that are important for this process.

### PUBLIC INTEREST STATEMENT

There have been examples of previous literature discussing the influences of avatars in changing health behaviours, however, no review has focused on a variety of virtual representations in mHealth app contexts or investigated the mechanisms and digital features that are effective in mHealth application interventions. Many mobile health application interventions include virtual representations of the self in varying forms, such as agents or avatars as elements of change influence to initiate behaviour change. The mechanisms (the psychological causes of change) underlying the interventions, behaviour change techniques (BCTs) and the digital features that drive behaviour change have not been fully explored by previous research, in addition to the digital features that drive behaviour change. Overall, the findings suggested that virtual representations in mHealth app interventions may positively influence health behaviour change. However, there is limited evidence available to determine to which these influences are a result of the virtual representations, or the intervention design. In the end, appropriate recommendations have been forwarded in this paper for future mHealth interventions that include virtual representations.

time point, which addressed and reported a variety of outcome health behaviours. Information on sample characteristics, study conditions, mechanisms and BCTs, results, and conclusions were extracted. Quality and risk of bias were assessed using the Mixed Methods Appraisal and Cochrane Risk of Bias Tools. Out of the 2,579 original search results, five eligible studies (total participants = 509), with low to moderate quality were included. It was found that customisable virtual representation mHealth interventions were most effective in encouraging behaviour change and app adherence. These interventions included mechanisms such as motivation, feedback, self-image, and BCTs such as goal setting, and self-monitoring. The current evidence suggests that virtual representations in mHealth app interventions may positively influence health behaviour change. However, there is limited evidence available to determine to which these influences are a result of the virtual representations, or the intervention design.

**Subjects: Mobile Systems; Human Computer Intelligence; Communication Technology; Health Psychology**

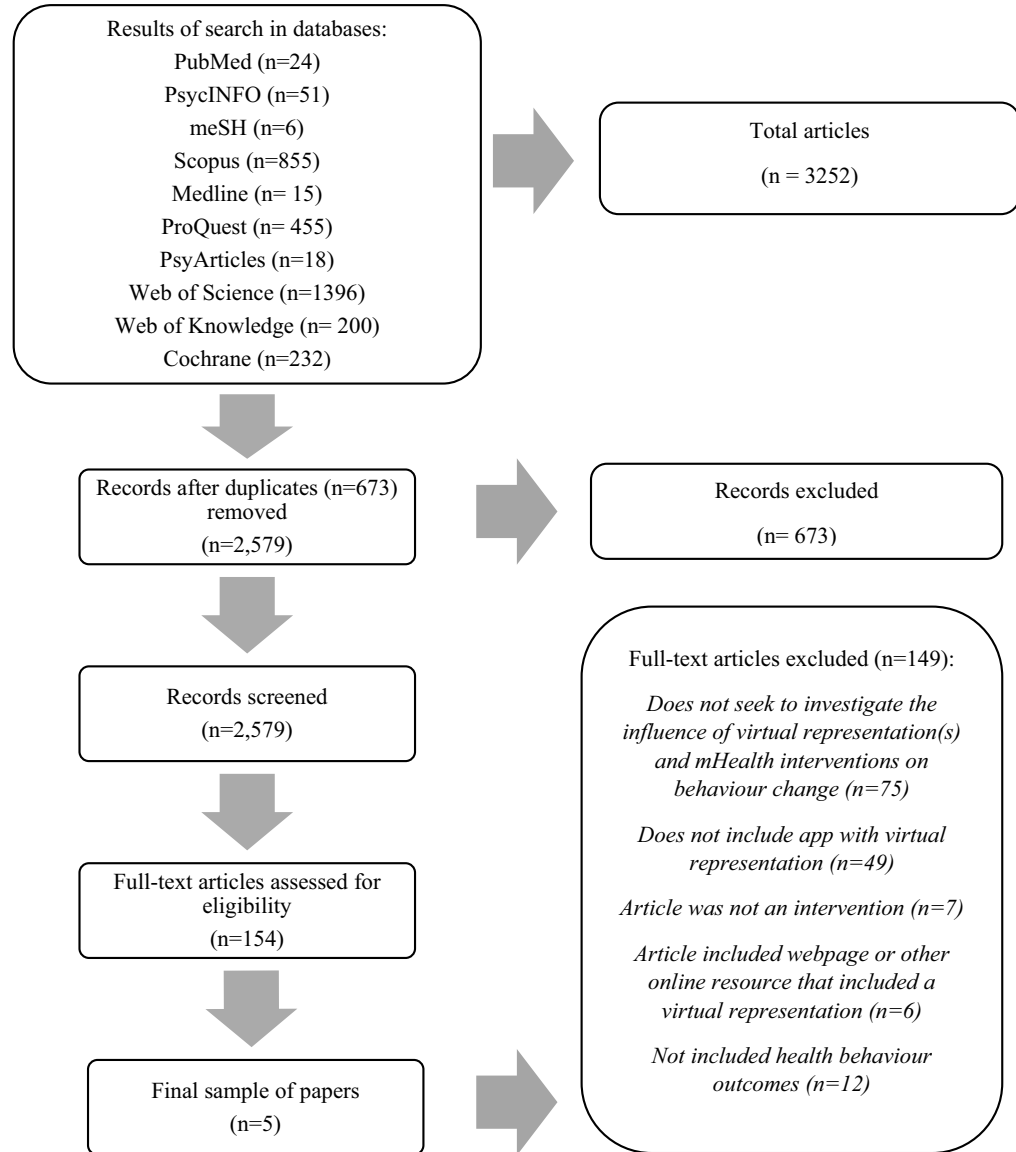
**Keywords: Systematic review; mHealth; Applications; Intervention; Virtual representation; Avatar**

### Introduction

Advances in technology, and the availability of smartphones, has meant that animated virtual representations can be easily incorporated on such devices to deliver health information that is aimed at improving knowledge and behaviour change (Ahn, xxx; Jones & Petrie, 2017). An example of a virtual representation is a virtual human, which is a highly realistic representation of a person (Nowak & Fox, 2018). Previous research shows that the relatability of a virtual human is associated to physical realism (how lifelike it appears), behavioural realism (how authentic its actions are), and anthropomorphism (how similar it is to human morphology or behaviour) (Nowak et al., 2009). There is evidence that virtual representations of the self in varying forms can initiate health behaviour change (Fox et al., 2013; Gorisse et al., 2019; Nowak & Fox, 2018). Examples of these virtual representations include an agent or object representation that is not designed to look like the application user (Clark et al., 2016; Lim & Reeves, 2010; Nowak & Fox, 2018) and an avatar, a self-similar, or subject representation, which is created to look like the user (Clark et al., 2016). However, it is not known which type of virtual representation is the most effective in positive behaviour change (Nowak & Fox, 2018).

These representations are embedded within many mobile health (mHealth) applications, where they are optimised and portrayed realistically with the aim of influencing real-world behaviours (Bailenson et al., 2008; Blascovich et al., 2002; Fox & Bailenson, 2009). Virtual representations have the potential to promote a behavioural response from the user, such as motivating a person to adopt healthier lifestyle by encouraging physical activity or healthy eating (Clark et al., 2016; Brock et al., 2018). Currently, it is unclear within mHealth interventions which aspects of the virtual representation or which mechanism of change is targeting the behaviours identified for change. Determining the mechanisms of behavioural change is essential as this provides a more thorough understanding of how and why interventions achieve their effects, and this knowledge helps with the design of future effective interventions that will bring about the desired change (Murray et al., 2013). Thus, knowledge of the mechanisms will allow future interventions to be designed more efficiently to target factors known to cause changes in behaviour (Murray et al., 2013). As a result, this review will focus on how mHealth applications and/or virtual representations bring about intimation of the behaviour and support in its maintenance (Sittig et al., 2020).

**Figure 1. PRISMA Flow Diagram showing the pathway of study selection**



### **Rationale**

To our knowledge, this is the first narrative systematic review to focus specifically on mHealth application interventions that incorporate at least one virtual representation. Previous reviews have focussed on studies in virtual reality settings or evaluating the influence of the appearance of computer game play avatars (Clark et al., 2016; Horne et al., 2020; Rheu et al., 2020). In addition, there is no published in-depth investigation into the specific influences that the different types of virtual representations have in promoting positive health behaviours and reducing risk behaviours, despite an abundance of mHealth app interventions and commercial products aiming to elicit behaviour change (Miyamoto et al., 2016; Mummah et al., 2016). Therefore, this review included studies with non-clinical groups to understand influences on general health behaviours, rather than those relating to specific illness-self management. This review also focused on studies that included both risk behaviours and positive health behaviours, with varied intervention styles in targeting specific behaviours to change (Peltzer et al., 2016; Steptoe & Wardle, 1992).

### **Objectives**

This current review aimed to determine which virtual representations used in mHealth application interventions are effective in influencing health-related behaviours and outcomes. This review also aimed to understand whether there were any specific mechanisms and behaviour change techniques that were found to be effective in these interventions.

### **Methods**

The guidelines from the PRISMA statement were adhered to in the undertaking of this systematic review (Page et al., 2021).

### **Information sources**

Searches were run from inception to December 2021 on the following electronic databases MEDLINE, ProQuest, PsyArticles, PsycINFO, PubMed, meSH, Web of Science, Web of Knowledge, Scopus, Cochrane Library were searched for relevant material for inclusion (see Figure 1). Reference lists, chapters, and author websites were also consulted, but not grey literature.

### **Search strategy**

The search strategy was developed using the Population, Intervention, Comparison, Outcome, and Time (PICOT) template (Riva et al., 2012). Test runs of keywords, synonyms, and medical subject heading (MeSH) terms were run in several electronic databases. These preliminary actions were meant to identify the terms and databases that would yield appropriate articles. After these test runs were completed, we added new terms to the database searches that provided a more comprehensive set of studies for possible inclusion. The search strategy is reported in Supplement 1.

### **Eligibility criteria**

The interventions targeted in this review were mHealth apps that included a virtual representation, designed to monitor, or influence health behaviour change.

Specific inclusion criteria: articles were required to (i) be published in English, (ii) reported results of individuals that were not recruited from clinical settings because of their mental health diagnosis, (iii) be an mHealth app intervention that included a virtual representation, and (iv) report outcomes that included health behaviours or health risk behaviours. Any research was considered, including experimental and non-experimental studies, qualitative and mixed-methods studies, single-arm intervention studies, randomised and non-randomised trials.

### **Selection process**

Titles and abstracts and full-text articles identified using the digital search strategy were screened independently by two reviewers (LT, HR) to identify studies meeting the inclusion criteria. Eligibility of ambiguous studies and conflicts were discussed and resolved at research meetings. Disagreements between reviewers were resolved by consensus or by the decision of a third independent reviewer.

### **Data collection process**

The data was screened using a screening and selection tool developed by the researcher (LT), and the Template for Intervention Description and Replication (TIDieR) checklist (Hoffmann et al., 2016) (Supplement 2).

### **Data items**

The following information was extracted from the five included studies by two reviewers (LT and HR): data regarding first author, year of publication, country, sample size, and participant age. Behavioural measures, length of intervention, outcome measures, target health behaviours, mobile app technology, and virtual representation (agent or avatar) used were also extracted. If the appropriate level of information was unavailable, the data-extraction table states 'not specified'. Intervention

**Table 1. Study characteristics, key findings, and quality rating**

<b>(Reference) Authors</b>	<b>Design</b>	<b>Country</b>	<b>Participant Characteristics</b>	<b>Outcomes</b>	<b>Assessment time points</b>	<b>Summary of Key Findings</b>	<b>Quality Rating</b>	<b>Quality rating (comment)</b>
Ossolinski et al., (2017) (Ossolinski et al., 2017)	RCT (no control) comparing two groups using the Future Me app which portrays the effect of lifestyle on future personal appearance using input calorie & exercise information to predict future BMI. The two groups were: current & future self-image of self immediately (early intervention group) or after 8 weeks (delayed intervention)	Australia	N = 145 Aged >18 years; BMI > 25 kg/m <sup>2</sup> ; wanting to lose weight	Primary outcome: Weight loss over 16 weeks Secondary outcomes: Change in weight loss and waist circumference over 24 weeks	Baseline (0 weeks) and post-intervention (24 weeks)	Delayed intervention with personalised avatar future images at 8 weeks compared to beginning of intervention promoted greater weight loss At 24 weeks there was a significant change in weight overall, and a difference in rate of change between groups Men were found to lose more weight than women	Low	Missing data predicted via linear regression; high dropout rate despite small sample size; missing data predicted by not using 'real' data

(Continued)

**Table 1. (Continued)**

Reference Authors	Design	Country	Participant Characteristics	Outcomes	Assessment time points	Summary of Key Findings	Quality Rating	Quality rating (comment)
Fuchs et al., (2019) (Fuchs et al., 2019)	Single armed cross-sectional testing the effectiveness of the mobile food record checklists app which included a future-self avatar based on a participant's diet to reduce sodium intake. There were no comparator or control groups.	Switzerland	N= 28 (17 males, 11 females) Mean age=1985.6, (SD=9.59)	Primary outcome: Motivation, risk awareness, positive outcomes of change, self-efficacy in engaging in a healthier dietary behaviour Secondary outcome: Comparing pre and post measures for motivation, risk awareness, associate to positive outcomes of change, and dietary behaviours	Baseline (day 0) and post-intervention (day 8)	The avatar improved risk awareness, low-salt outcome expectations and intentions toward a balanced, low-salt diet	Low	Does not report all data (demographics and non-significant results); high dropout rate despite small sample size

(Continued)



**Table 1. (Continued)**

<b>(Reference) Authors</b>	<b>Design</b>	<b>Country</b>	<b>Participant Characteristics</b>	<b>Outcomes</b>	<b>Assessment time points</b>	<b>Summary of Key Findings</b>	<b>Quality Rating</b>	<b>Quality rating (comment)</b>
Dworkin et al., (2019) (Dworkin et al., 2019)	Single armed mixed methods study to evaluate the efficacy of the My Personal Health Guide app, which included a conversational agent to improve adherence to antiretroviral therapy in young African American men who have sex with men who are HIV positive. There were no comparator or control groups.	USA	N= 43 (HIV positive males) Aged 18–34, years (median = 29, no reported variance)	Primary outcome: ART adherence at baseline versus 3 months of exposure to app Secondary outcome: Acceptability	Baseline (0 weeks) and post-intervention (21 weeks)	Pill count adherence, knowledge of viral load, and CD4 count (immune system health) significantly improved Acceptability of the app was high All outcomes were measured via the app, and self-reported by the participant except for acceptability which was collected via check in calls	Moderate	Small sample size but low dropout rate; results only reported p values
Wonggom et al., (2020) (Wonggom et al., 2020)	Non-blinded (both participants and researchers) RCT comparing effectiveness of intervention group which received a combination of the usual care and an avatar app to control group which received usual care in promoting self-care behaviours and heart failure knowledge.	Australia	N= 36 (males = 20; females = 7) Mean age =65.5; (SD= 11.3)	Primary outcome: Heart failure knowledge Secondary outcomes: Heart failure self-care behaviours, HF-related readmission, and satisfaction	Baseline (day 0) follow-ups (30- and 90-days post intervention)	At 90 days, the intervention group participants had a higher increase in self-care behaviours and responses to symptoms compared with the control group High satisfaction with app	Moderate	Sample was not blinded which could have biased the results; more female than male participants

(Continued)

**Table1. (Continued)**

<b>(Reference) Authors</b>	<b>Design</b>	<b>Country</b>	<b>Participant Characteristics</b>	<b>Outcomes</b>	<b>Assessment time points</b>	<b>Summary of Key Findings</b>	<b>Quality Rating</b>	<b>Quality rating (comment)</b>
Mohan et al., (2020) (Mohan et al., 2020)	Mixed-methods six-week cross-sectional study comparing the effectiveness of the Nutriwalking app in promoting exercise with sedentary participants. There were no comparator or control groups. All participants interacted with an empathic agent, a non-empathic control agent, or a text-based control system.	USA	N= 21 diabetics (mean age 51 ± 8 years) No gender reported	Primary outcome: Weekly exercise and lifestyle behaviours Secondary outcome: Adaptability, suitability, and usability of the coach and app	Baseline (week 0) and post intervention (week 6)	Participants increased their weekly exercise volume in response to the empathetic coach's goal recommendations Participants who are very optimistic are less likely to be successful at recommended exercises Highly rated usability, adaptability, and suitability	Low	More of a focus on design, small sample size, limited reporting of results which makes it difficult to infer if there was truly an affect

**Table 2. Summary outcomes, statistical measures, and reported findings**

Reference (authors)	Outcome(s)	Statistic	Results		
			Baseline	Follow-up	p value
Ossolinski et al., (2017) (Ossolinski et al., 2017)	Weight change (baseline to post-intervention) between groups	% Reduction	-0.77%	-0.49%	0.018*
	Weight change (delayed-image vs early-image) between groups	% Reduction estimated using intention to treat (ITT)	-0.50%	-0.30%	0.007*
			Pre/ Post Avatar		p value
Fuchs et al., (2019) (Fuchs et al., 2019)	Self-reported sugar intake	Z-value	0.542		.58
	Self-reported salt intake	Z-value	2.204		0.027*
	Self-reported fruit and vegetable intake	Z-value	-0.586		.56
	Self-reported alcohol intake	Z-value	-0.259		.80
	Self-reported balanced diet	Z-value	-1.512		.13
	Observed sugar intake	Z-value	0.091		.30
	Observed salt intake	t-value	-1.062		.93
	Observed fruit and vegetable intake	Z-value	0.00		1
	Observed alcohol intake	Z-value	-0.914		.36
	Intention to pursue balanced diet	Z-value	1.95		0.051
	Intention to pursue low-sodium diet	t-value	2.748		0.007**
	Combined intention	t-value	2.925		0.011*
	Outcome expectancy unbalanced diets	Z-value	.262		.79
	Outcome expectancy sodium intake	Z-value	2.289		0.022*
	Self-efficacy	Z-value	-.36		.71
Risk awareness	t-value	5.299		0.000**	
			Delayed-image Group	Early Image Group	p value

(Continued)

**Table2. (Continued)**

Reference (authors)	Outcome(s)	Statistic	Results		
			Intervention Group	Usual Care Group	F value
Dworkin et al., (2019) (Dworkin et al., 2019)	Adherence, pill count, the number (%) of participants who are >80% adherent	N (%)	16 (61.5)	23 (88.5)	Non-significant
	Adherence, the number (%) of participants who are >90% adherent	N (%)	22 (68.8)	26 (81.3)	$p < 0.05^*$
			Intervention Group	Usual Care Group	F value
Wonggom et al., (2020) (Wonggom et al., 2020)	Knowledge, measured using the Dutch Heart Failure Knowledge Scale (DHFKS) in intervention and usual care groups	F-statistic (ANOVA), % increase (from baseline)	15.3%	3.5%	3.756
	Self-care behaviours, measured using, Self-care of Heart Failure Index (SCHFI; Version 6.2) in intervention and usual care groups	% Increase (from baseline)	11.9%	-4.3%	
	Healthcare use: HF-caused readmission including both emergency and elective admissions to hospital and unplanned visits to general physician units in intervention and usual care groups	HF-related general practitioner presentation, N	1	0	
		Emergency department presentation, N	1	0	
Hospital readmission, N		1	0		
			Post Avatar		$p$ value
Mohan et al., (2020) (Mohan et al., 2020)	Change in Regular aerobic exercise from baseline, measured in MET-min/week	Mean (SD)	392.25 (24.830)		$p < 0.001$

\*significant at 5% level \*\*significant at 1% level

T: paired samples t-test for normal distributions; W: Wilcoxon signed-ranks test; N: number of participants; SD: standard deviation

descriptions were annotated using Behaviour Change Technique Taxonomy, BCTTv1 (Michie et al., 2013) and mechanisms of action (Connell et al., 2019), and cross-checked by both reviewers.

**Table 3. Intervention characteristics**

<b>(Reference) Authors</b>	<b>Outcome</b>	<b>mHealth app and representation</b>	<b>Virtual Representation Manipulation</b>	<b>Behaviour change techniques (Michie et al., 2013)</b>	<b>Theory</b>	<b>Mechanisms of Action</b>
Ossolinski et al., (2017) (Ossolinski et al., 2017)	Weight loss	Future Me app, using computer-generated future self-image avatars	Self-resembling avatar	Self-monitoring (recording weight); Credible source (provision of leaflet containing online <i>imaginings of future outcomes</i> (provision of future self images); <i>Identification of self as role model</i> (future self image with a lower BMI)	Transtheoretical Model (Prochaska et al., 1994)	Self-image; Reinforcement; Motivation

(Continued)

**Table 3. (Continued)**

<b>(Reference) Authors</b>	<b>Outcome</b>	<b>mHealth app and representation</b>	<b>Virtual Representation Manipulation</b>	<b>Behaviour change techniques (Michie et al., 2013)</b>	<b>Theory</b>	<b>Mechanisms of Action</b>
Fuchs et al., (2019) (Fuchs et al., 2019)	Diet	Using the food record checklist app (mFRCL), an avatar-based system.	Customisable avatar	Self-monitoring (logging food consumption via app); Feedback on outcome(s) of behaviour (the avatar provides emotional feedback, in addition to messages presented on the app); Demonstration of behaviour (avatar demonstrates desired behaviours by eating fruits and vegetables); Prompts/cues (app sends reminders to log food); Comparative imaginings of future outcomes (avatar presented as looking healthy or unhealthy because of the logged foods); Identification of self as role model (customisable avatar to represent participant); Credible source (information from app provided by Swiss Society for Nutrition)	Health Action Process Approach (Schwarzer & Luszczynska, 2008)	Behavioural regulation; Self-image; Needs; Feedback processes; Reinforcement; Motivation

(Continued)

**Table 3. (Continued)**

<b>(Reference) Authors</b>	<b>Outcome</b>	<b>mHealth app and representation</b>	<b>Virtual Representation Manipulation</b>	<b>Behaviour change techniques (Michie et al., 2013)</b>	<b>Theory</b>	<b>Mechanisms of Action</b>
Dworkin et al., (2019) (Dworkin et al., 2019)	Treatment Adherence	Using an embodied conversational agent on the My Personal Health Guide app.	Customisable agent	Self-monitoring (logging pill count, viral load, and CD4 count in calendar on app); <i>Social support</i> (agent providing supportive feedback in response to participant answers); <i>Information about antecedents</i> (app provides advice relating to medication, side effects, and dosage for current treatment); <i>Prompts/cues</i> (reminder message alerts); <i>Credible source</i> (motivational statements containing educational information); <i>Verbal persuasion</i> (agent has capability (agent has verbal responses and greetings)	Information, Motivation, and Behavioural Skills Model of Adherence (Fisher et al., 2006) Technology Acceptance Model (Holden & Karsh, 2010)	Behavioural cueing; Motivation; Knowledge; Memory, attention, and decision processes

(Continued)

**Table 3. (Continued)**

<b>(Reference) Authors</b>	<b>Outcome</b>	<b>mHealth app and representation</b>	<b>Virtual Representation Manipulation</b>	<b>Behaviour change techniques (Michie et al., 2013)</b>	<b>Theory</b>	<b>Mechanisms of Action</b>
Wonggom et al., (2020) (Wonggom et al., 2020)	Knowledge	An avatar-based (using a nurse as a representation) on an education app	Customisable avatar	<i>Instruction on how to perform a behaviour</i> (information about self-care behaviours); <i>Information about health consequences</i> (information about heart failure and self-care behaviours to prevent this); <i>Credible source</i> (information provided in app is based on National Heart Foundation of Australia's booklet, Living Well with Heart Failure); <i>Identification of self as role model</i> (customisable avatar to represent participant)	Self-efficacy Theory (Bandura, 2011)	Feedback processes; Knowledge; Beliefs about consequences
Mohan et al., (2020) (Mohan et al., 2020)	Exercise	NutriWalking app and tailored coaching agent	Stranger-resembling agent	<i>Goal-setting</i> (participants asked to set exercise goals in app); <i>Review behaviour goal(s)</i> (app reviews exercise behaviours and provides new goal according to results); <i>Feedback on behaviour</i> (app provides feedback messages and advice to achieve goal); <i>Self-monitoring</i> (participants log exercise in app); <i>Graded task</i> (participants set exercise tasks in app)	Goal-setting Theory (Locke & Latham, 1994)	Needs; Feedback processes; Behavioural cueing; Goals; Behavioural regulation



### **Quality assessment and risk of bias**

Quality of study design, methods, and clarity of reporting were independently reviewed by two reviewers (LT and LZ) using the Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018). The MMAT includes a total of 25 criteria and two screening questions, as it is considered appropriate for the appraisal of qualitative, quantitative, and mixed methods studies. This tool has a methodological rating of 0, 25, 50, 75, and 100 (100 being the highest quality) for each study. A low-quality study was rated between 0% and 45%, a medium-quality study was rated between 45% and 75%, and a high-quality study was rated 75% and above. Studies were not routinely excluded based on the quality of the appraisal.

Two reviewers (LT and AA) independently assessed the risk of bias present in two randomised controlled trials (RCT; (Ossolinski et al., 2017; Wonggom et al., 2020)) using the Cochrane Risk of Bias tool, Version Two (Sterne et al., 2019). This tool was also included as it covers all fundamental bias mechanisms in RCTs. A low-risk study indicates the least bias (60% and above), a moderate-risk study (between 40% and 60%) is susceptible to some bias, and a high-risk study indicates significant bias and may invalidate the results (40% and below).

### **Synthesis methods**

Due to the small number of studies, broad research scope, and degree of heterogeneity in outcomes and methods, it was not possible to perform a meta-analysis, therefore a narrative approach was adopted (Petticrew & Roberts, 2008). The narrative synthesis of studies were grouped based on: (i) effectiveness of virtual representations in changing health behaviours, (ii) digital features and customisation, (iii) mechanisms of action, behaviour change techniques, and behaviour change (if any, or closest match), and (iv) acceptability, feasibility, and usability ratings by the user.

## **Results**

### **Study Selection**

Database searches yielded a total of 3,252 articles. After removing duplicates, a total of 2,579 titles and abstracts were independently screened against the inclusion and exclusion criteria. Of these, 154 were selected for a full-text review, and five were selected for inclusion in the review (Dworkin et al., 2019; Fuchs et al., 2019; Mohan et al., 2020; Ossolinski et al., 2017; Wonggom et al., 2020). The reasons for exclusion in the full-text review stage, and the review itself are detailed in the PRISMA flow diagram for study selection (Figure 1).

### **Study Characteristics**

Key study characteristics are presented in Table 1.

Two studies were conducted in the USA (Dworkin et al., 2019; Mohan et al., 2020), two in Australia (Ossolinski et al., 2017; Wonggom et al., 2020), and one in Switzerland (Fuchs et al., 2019). Two studies were Randomised Controlled Trials (RCT) (Ossolinski et al., 2017; Wonggom et al., 2020), and three studies used a cross-sectional design (Dworkin et al., 2019; Fuchs et al., 2019; Mohan et al., 2020). Study lengths ranged from eight days (Fuchs et al., 2019) to 90 days (Wonggom et al., 2020). Finally, three studies did not include a control group or routine arm for comparison (Dworkin et al., 2019; Fuchs et al., 2019; Ossolinski et al., 2017), compared to two studies that did (Mohan et al., 2020; Wonggom et al., 2020).

### **Sample Characteristics**

The total number of participants across all the studies was 509 (male = 247 and female = 262). The sample size in the individual studies ranged from 21 to 208 (median = 36; IQR = [28; 43]). Three of the studies focused on reducing behaviours, for example, weight reduction in overweight participants (Ossolinski et al., 2017), reducing diet and salt intake (Fuchs et al., 2019) and reducing sedentary behaviours for overweight participants (Mohan et al., 2020). Two of the studies focused on increasing behaviours, increasing heart failure knowledge and self-care behaviours for participants with previous

hospitalisation with heart coronary heart disease (Wonggom et al., 2020), and increasing treatment adherence for in men with HIV (Dworkin et al., 2019).

Three studies used customisable avatars that were designed as human-like representations (Fuchs et al., 2019; Ossolinski et al., 2017; Wonggom et al., 2020), to represent the user in either in real time (Wonggom et al., 2020), or by incorporating future self-images (Fuchs et al., 2019; Ossolinski et al., 2017). Two studies used computerised agents to promote behaviour change, in the form of a coach (Mohan et al., 2020), and as an interactive, customisable, image that provided participants with feedback (Dworkin et al., 2019).

### ***Risk of bias in studies***

Using the MMAT, all the included studies were of low or moderate quality (Table 1). The lower scores were attributed to poor reporting of research design, unclear or inconsistent findings, therefore questioning the validity and reliability.

After discussion of the Risk of Bias present in the two RCTs (Ossolinski et al., 2017; Wonggom et al., 2020), the overall risk of bias was 50% moderate risk (Ossolinski et al., 2017) and 50% low risk (Wonggom et al., 2020). Out of both studies, only one controlled for performance, selection, detection, and attrition bias with a pre-registered protocol (Wonggom et al., 2020). Participant selection bias was present in both studies, for example, one study recruited participants that had experienced heart failure, and may therefore have some knowledge of the condition prior to starting the trial (Wonggom et al., 2020). The other study recruited people wanting to lose weight, and enabled participants to select their own methods of weight loss, making it difficult to determine if the overall effectiveness of the intervention was a result of the exposure to future-self-images (Ossolinski et al., 2017). Only one study controlled for time-confounding variables by matching participants in exposed and unexposed groups (Wonggom et al., 2020). Other reasons suggesting incomplete implementation included high drop-out rates before the intervention was complete (Ossolinski et al., 2017). Missing outcome data was accounted for in both studies as the data were analysed according to the intention-to-treat principle.

### ***Results of syntheses***

All five studies reported a significant change in weight loss, medication adherence, diet, exercise, knowledge, and self-care behaviours, with a greater behavioural change with either an avatar (Dworkin et al., 2019; Fuchs et al., 2019; Wonggom et al., 2020) or agent (Dworkin et al., 2019; Mohan et al., 2020) (see Tables 1 and 2).

### ***Digital Features & Customisation***

Four studies enabled participants to customise their virtual representation to render a human-like appearance (Dworkin et al., 2019; Fuchs et al., 2019; Ossolinski et al., 2017; Wonggom et al., 2020). For example, two studies used customisable avatars, using input calorie and exercise information to predict future BMI, to represent a participant's future-self appearance to motivate behaviour change (Fuchs et al., 2019; Ossolinski et al., 2017). The weight loss RCT study adopted an immediate and delayed (eight weeks post weight loss programme commencement) avatar intervention approach with images of current and future selves (Ossolinski et al., 2017). The diet study also applied customisable features such as a walking stick to increase engagement, including coached messages and animations to highlight areas for personal improvement for participants (Fuchs et al., 2019). In comparison, the HIV treatment adherence study enabled participants to customise the agent's clothing, glasses, screen background and reward images; the agent could also speak the participant's name (Dworkin et al., 2019). Similarly, for another study, participants could make and customise their own avatar nurse presented on the study app (Wonggom et al., 2020). Another RCT study presented participants with a non-customisable coach that provided tailored feedback and information to participants based on their entered health goals and data (Mohan et al., 2020). Key findings are presented in Table 1.

### **Acceptability, feasibility, and usage**

Two studies reported virtual representation acceptability and usage as secondary outcome measures (Dworkin et al., 2019; Mohan et al., 2020). Other studies reported the overall engagement, enjoyment and satisfaction when using avatar apps in adopting new health recommendations (Fuchs et al., 2019) and assisting heart failure health problems (Wonggom et al., 2020). One study did not report any of the above (Ossolinski et al., 2017). See Table 1 for further information.

### **Effectiveness of virtual representations in changing health behaviours**

Key study findings are presented in Table 2. Screenshots from each of the applications are presented in the Supplementary files. Please note, one paper did not include an image of the app (Ossolinski et al., 2017).

### **Weight Loss**

One randomised controlled trial showed significant weight loss in the avatar intervention group (the 'Future Me' application) relative to the control group (Ossolinski et al., 2017). When starting their self-determined weight loss plans, participants either received a future self-image (as an individual body representation) at the beginning of the study (early-image group), or after 8 weeks (delayed-image group). Results showed that a greater rate of weight loss was seen with the delayed-image group completers. This suggests that the future self-image, shown to participants several weeks into their weight-loss attempt, served as an effective strategy in promoting weight loss. However, this research did not use a routine arm for comparison, making it difficult to determine why being presented with the future self-image at the beginning of the study did not promote behaviour change.

### **Diet**

One cross-sectional study focused on diet, included outcome expectancy, risk awareness, and the intention to decrease excessive salt intake as outcome measures (Fuchs et al., 2019). The avatar was presented on the food record checklist mHealth application as a 2D cartoon that provided informative and encouraging messages in the form of positive and negative feedback on the diet of the participant. The findings showed that the avatar intervention was successful in increasing 1) outcome expectancy in terms of positive low-salt dieting ( $p < 0.05$ ), 2) the awareness of risks related to a high salt diet ( $p < 0.001$ ), 3) the intention of participants towards a low-salt diet ( $p < 0.05$ ) from baseline and resulted in the overall reduction in salt intake (7.1%).

### **Exercise**

One cross-sectional study focused on exercise measured the effect of the intervention on sedentary behaviours and increasing weekly exercise volume on the Nutriwalking mHealth application (Mohan et al., 2020). The agent was presented as a coach that scheduled personalised goals for the participants, by projecting how long it would take to complete the individually targeted activities (including duration of exercise and step count). If the participants were unable to reach this goal, this would be revised to improve goal compliance, and monitors goal performance through various interactions in the application. The results showed that compared to baseline, participants significantly increased their weekly exercise volume (MET-mins/week = 0.618; SD = 0.119,  $p < 0.001$ ) in response to the coach's goal recommendations.

### **Heart Failure Knowledge and Self-care Behaviours**

One randomised controlled trial assessed knowledge about heart failure, its management, self-care behaviours and the reduction of health-care use (Wonggom et al., 2020). The knowledge that the avatar provided on an educational mHealth application was tailored to each participant. The participants were asked to report their understanding and knowledge of heart attack warning signs, heart attack signs and symptoms, what to do when having a heart attack. The nurse avatar in the app was designed to mimic real human interaction and which the authors suggested would promote engagement in app usage, reinforce learning, and improve participants' heart failure knowledge. The avatar included voice recordings and provided feedback on participant's answers. Compared to the control

group, those using the avatar app were found to have a significantly higher increase in knowledge score from baseline (mean change (control group) = 3.7%; N (%) (intervention group) = 22.2%,  $p < 0.05$ ), and self-care behaviours (mean change (control group) = 6.8%; N (%) (intervention group) = 11.0%,  $p < 0.05$ ). However, due to the small sample size, the authors were unable to conclude the effect of the app and the virtual representation. The authors also did not consider specific self-care behaviours, and strategies for supporting individuals' self-management ability is warranted.

### **Adherence to Antiretroviral Therapy**

One cross-sectional study aimed to improve medication adherence, self-efficacy, and health literacy by using an embodied conversational agent on the My Personal Health Guide application (Dworkin et al., 2019). The customisable agent contained audio-visual orientation instructions and included a scroll bar of 26 educational statements relating to healthy behaviours. The agent also enabled participants to track viral load and CD4 white blood cell count trends over time, with auditory feedback, and warning signs. In addition, the agent offered a spoken overview of medication side effects, dosage, instructions for adherence, and recorded participant data to produce a summary of their adherence data over time as a calendar. A total of 80% of the sample achieved a statistically significant increase in adherence levels (pill count) from baseline to follow-up (62% and 88%, respectively,  $p$ -value = 0.05). In addition, health literacy improved at follow up (10% increase for viral load; 30% increase for CD4 count; 90% increase for taking medication with food) compared to baseline. However, self-efficacy did not demonstrate improvement ( $p$ -value > 0.05).

### **Mechanisms of Action**

Twenty-one mechanisms were identified in total across all five studies (Connell et al., 2019). Commonly used mechanisms were 'Motivation' ( $n = 3$ ) and 'Feedback Processes' ( $n = 3$ ). Additional mechanisms such as 'Self-image' ( $n = 2$ ), 'Reinforcement' ( $n = 2$ ), 'Behavioural regulation' ( $n = 2$ ), and 'Knowledge' ( $n = 2$ ) were common features across the studies. Additional mechanisms included 'Needs' ( $n = 2$ ), 'Memory, attention, and decision processes' ( $n = 1$ ), 'Beliefs about consequences' ( $n = 1$ ), 'Behavioural cueing' ( $n = 1$ ) and 'Goals' ( $n = 1$ ) (see Table 3 for the full list).

### **Behaviour Change Techniques (BCT)**

Twenty-five BCTs were identified across ten BCT groups (Michie et al., 2013) (see Table 3 for full list). The most used BCT was 'Self-Monitoring of Behaviour' (2.3), featuring in four of the studies ( $n = 4$ ). Alternative approaches included 'Feedback on Behaviour' (2.2,  $n = 2$ ), 'Prompts/Cues' (7.1,  $n = 2$ ), 'Credible Source' (9.1,  $n = 4$ ), 'Comparative Future Outcomes' (9.3,  $n = 2$ ), and 'Identification of self as role model' (13.1,  $N = 4$ ).

## **Discussion**

### **Principle Findings**

The evidence presented in this narrative systematic review suggests that the inclusion of a virtual representation on an mHealth app could be beneficial to non-clinical users in changing health behaviours such as weight loss, treatment adherence, diet outcome expectancies and intention, as well as in educating participants about heart failure. Three studies used avatars (Fuchs et al., 2019; Ossolinski et al., 2017; Wonggom et al., 2020), and two studies used agents (Dworkin et al., 2019; Mohan et al., 2020). Three studies enabled participants to customise and personalise their virtual representation and were found to be more effective in promoting behaviour change and app adherence compared to those that did not at follow-up (32; 35; 37). However, it is important to acknowledge that the evidence is limited, and therefore should be interpreted with caution. In addition, this review also attempted to annotate the description of the interventions using the Behaviour Change Technique Taxonomy (Michie et al., 2013), and the mechanisms underlying each BCT. However, it was not possible to deduce which BCTs and mechanisms were the most effective as none of the studies clearly discussed this, and which behaviours are activated when the virtual representations are used.

### ***Behaviour Change Techniques***

The most used BCT, 'Self-Monitoring of Behaviour', occurred in four studies ( $n = 4$ ), as the features of these apps required participants to input and track their behaviours. In addition, other strategies such as 'Comparative Future Outcomes' (9.3) and 'Identification of self as a role model' (13.1) were present in most of the interventions. However, it was not possible to determine the effectiveness of the BCTs in this review due to the lack of evidence presented in each of the studies (Becker et al., 1977). In addition, there may have been other factors that could have influenced behaviour change that were not measured or accounted for, such as recruitment bias, where recruiting participants that who were more committed to using mHealth apps were recruited (Prochaska & Velicer, 1997).

### ***Mechanisms***

This review also considered the potential mechanisms that could have influenced behaviour change by the included studies. For example, it is possible that identification with an avatar or agent could be a potential mechanism that drives behaviour change as many participants in three of the studies (Dworkin et al., 2019; Fuchs et al., 2019; Wonggom et al., 2020) were able to design an image that represented their self-image in promoting behavioural regulation. Feedback could also reinforce a person's beliefs about consequences, such as consuming too much salt is bad for health; however, this requires further research as the changes were not conclusive a result of the feedback (Fuchs et al., 2019). In addition, tailoring via goal-setting in the exercise promotion study (Mohan et al., 2020) may have contributed as a motivational mechanism in encouraging participants to persist in exercising more. Therefore, self-monitoring and tracking are factors to consider as potential mechanisms that can be applied to virtual representations in fostering behaviour change or adherence.

### ***Comparison with prior work***

Despite a call for more research investigating the causal pathways behind this relationship, the evidence detailing these mechanisms is limited. The findings suggest that strategies such as self-monitoring, modelling behaviours, goal setting, and social comparison could be effective in enabling participants to track their own behaviours or status via the virtual representations; however, it is unclear which mechanisms are activated for example, motivation, goal setting, or awareness, when the avatar or agent is used, and which behaviours mapped onto the representations. As a result, this makes it difficult to specify what mechanisms or characteristics of virtual representations are linked to influencing behaviour change and app adherence.

Previous systematic reviews have focussed on avatars only, thereby limiting the understanding of the types of representations that are more effective in achieving a behaviour change (Lemenager et al., 2020). For example, another review (Rheu et al., 2020) investigated health-related interventions using avatars, identifying 18 studies in which avatars were applied to health-related behaviours. Despite highlighting six characteristics that may be manipulated in avatar-based interventions and concluding that a customisable avatar that is representative of the user is likely to be more effective promoting health-related behaviours, it focused only on two health behaviours (diet and exercise). Therefore, the physical appearance of a virtual representation could be a positive motivator for behaviour change and app adherence, but it is not clear as to why (Baylor, 2009). This is evident in another systematic review, in which avatars were regarded as mediators in positively impacting weight management achievement and improving motivation, but did not specify how or why and was restrictive in its target population, as it only focused on obese and overweight populations (Horne et al., 2020).

Previous research has also found that an individual's behaviour is likely to conform to their digital self-representation through observing an avatar that is representative or models certain behaviours (Fox et al., 2013; Yee et al., 2009). This was highlighted by many of the studies, which used virtual representations to model, or provide feedback about certain behaviours, such as visualising diet intake (Fuchs et al., 2019), with two studies using an embodied agent to provide advice in recreating desirable behaviours (Dworkin et al., 2019; Mohan et al., 2020). The term

*embodiment* is the perception of sensory feedback related to an individual's virtual, non-physical body, also known as a virtual representation, and the effect it has on the individual's cognition (Bailey et al., 2016). When users embody a virtual representation, they may experience the illusion that the external body of the avatar or agent temporarily belongs to themselves (Cassell, 2000). The influence on behaviour after controlling or embodying a virtual representation is referred to as the *Proteus Effect* (Yee, 2014; Yee & Bailenson, 2007). In addition, it is hypothesized that the *Proteus Effect* is explained by people evaluating themselves as an imaginary third party would, observing their own behaviours to explain what attitudes may have caused a person to react in a certain way (Yee & Bailenson, 2007). For example, this could be because of the appearance of the virtual representation in influencing user cognition and behaviour (Behm-Morawitz, 2013; Gorisse et al., 2019; Ratan et al., 2020; Yee et al., 2009). This is related to two studies that investigated the effect of the 'future idealised self' (Fuchs et al., 2019; Ossolinski et al., 2017) which promoted weight loss and dietary behaviours, and such representations may be a fruitful direction for future research.

### **Study Level Limitations**

The studies included in this systematic review have several limitations. The low-to-moderate quality, content, and delivery of the interventions, study time frames and participant demographics meant that direct comparison of results was not possible. Primarily, all the studies relied on subjective self-report classifications of a variety of behaviour change indicators, which could have led to over estimation of the behaviours (Sallis & Saelens, 2000). There was also evidence of bias in the interventions, due to a lack of controls, which may have contributed to a moderate risk of bias (Fuchs et al., 2019; Ossolinski et al., 2017; Schulz & Grimes, 2002; Wonggom et al., 2020).

The literature is also challenging to synthesise due to studies exploring a variety of influences of different virtual representations on different health behaviours, measures, methodologies, control variables, and analyses. There was considerable variation in each of the study designs, the type, and creation of the virtual representations and mHealth applications, the activities that participants performed with the virtual representation, and the methods used to measure the outcomes. The studies included in this review had small sample sizes, which limited the statistical power to detect significant differences, and limited the generalizability of the findings. Furthermore, there was a large variety of theories applied in designing the interventions across the included studies, which leads to varied constructs that had been measured (Kwasnicka et al., 2016). Another potential source of variation includes the level of interaction with the representations, for example, participants in three studies were able to customise their representation, but the degree of this was limited to what could be edited or changed, such as body shape, hair, facial features, clothing, and voice (Dworkin et al., 2019; Fuchs et al., 2019; Wonggom et al., 2020). Therefore, it would be beneficial to investigate this further to determine if specific customisation at certain time points could be mechanisms in influencing behaviour change.

In addition, the lack of control groups in four of the studies ( $n = 4$ ) also limits the ability to determine the overall impacts of virtual representations in changing health behaviours (Horne et al., 2020). However, four studies ( $n = 4$ ) explored the medium to long-term effects of using virtual representations on mHealth applications in changing behaviours (Dworkin et al., 2019; Fuchs et al., 2019; Mohan et al., 2020; Ossolinski et al., 2017), but there was only one study that included a follow up to determine the longitudinal effects of the intervention (Wonggom et al., 2020). Therefore, this may reflect the novelty of using virtual representations in mHealth applications, rather than the influence of the technology in changing health behaviours. In addition, the behavioural intervention content was poorly reported for all studies ( $n = 5$ ). However, the high and moderate risk of bias for the two randomised controlled trials (Ossolinski et al., 2017; Wonggom

et al., 2020) also suggests that care should be taken when interpreting the results, and it is

recommended that future researchers should implement bias reduction techniques, such as blinded assignment and randomisation, awareness checks, and adequate reporting of results, or to improve the reporting of their use in methods sections (Clark et al., 2016). As a result, more research is required to understand the impact and uses of using virtual representations in mHealth applications for behaviour change.

Attrition rate across the studies was varied, with reported mean attrition rates from 31% to 97% (Dworkin et al., 2019; Fuchs et al., 2019; Ossolinski et al., 2017; Wonggom et al., 2020). One study did not report withdrawal or adherence (Mohan et al., 2020). Aside from one study (Ossolinski et al., 2017), the interventions included in this review recruited relatively small sample sizes; however, reasonable attrition rates were achieved, particularly within the intervention arms. This suggests a varied interest and acceptability from participants in using virtual representations in mHealth app technologies as a tool to facilitate behaviour change and adherence. However, only two studies reported acceptability and overall usage (Dworkin et al., 2019; Mohan et al., 2020), which makes it difficult to evaluate the overall impact of virtual representations in mHealth interventions. Therefore, it would be beneficial for future interventions to report data, such as number of dropouts, treatment discontinuation, and other measurable variables such as side effects, satisfaction, and uptake rates, as users are less likely to adhere to an intervention if it is not acceptable to them (Sekhon et al., 2017). For example, a participant may believe the intervention itself is acceptable; however, they may disengage with the intervention if they believe that the treatment is no longer required (Sekhon et al., 2017).

#### **Review Level Limitations**

A strength of this review is the clear focus, comprehensive and easily replicable search strategy. Additionally, we systematically selected studies through the application of well-defined inclusion/exclusion criteria. However, the searches were limited to the English language, and no conference abstracts or grey literature pertinent to the review question were identified. In addition to the small number of included studies, the low quality of the studies limits the conclusions that can be made. For most of the studies, effect sizes could not be extracted from the data. As a result of this, the effect estimates could not be combined in a meta-analysis due to the high heterogeneity in the assessment and the reporting of the effects. Coding for BCTs from papers rather than full intervention manuals reduces reliability, and a lack of information regarding the presence of a BCT does not guarantee that one was not delivered in the intervention. Previous research has suggested that this is due to reports failing to provide adequate detail or precision to allow for robust BCT coding (Dombrowski et al., 2012; Taylor et al., 2012).

#### **Implications for future research and practice**

Our review suggests the potential moderators involved in each of the studies, such as appearance and similarity of virtual representations in user engagement and motivation to perform a task, but further evidence is needed before making suggestions for clinical practice. In addition, the studies did not report the specific mechanisms implemented by the virtual representations in influencing behaviour change or sought to investigate the underlying pathways for this relationship (Connell et al., 2019). More research outlining the mechanisms would help build an evidence base on what facilitation techniques are important in improving app design and delivery (Long et al., 2019). Therefore, more theoretical work is required to link virtual representations within the wider taxonomy of health-related behaviour change, and replication attempts are required to explicate the interaction between virtual representations on mHealth apps and real-world health-related behaviour (Clark et al., 2016). In addition, it would be beneficial to investigate the influences and the association of the Proteus Effect, and persuasion for virtual representations in mHealth applications as the current research did not investigate this.

#### **Conclusions**

Possible mechanisms are suggested within the research; however, the evidence is limited, and further work is needed to show the most effective mechanisms to inform future intervention

design. For example, further research into the effectiveness of customisable avatar or agent-based interventions which, includes mechanisms such as motivation, feedback, self-image, and BCTs such as goal setting, and self-monitoring could be beneficial in encouraging behaviour change and app adherence. Furthermore, interventions such as these need to be further investigated as to whether virtual representations on mHealth applications can be an effective medium to reach many people to remotely monitoring and promoting desired behaviours.

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#### Disclosure statement

No potential conflict of interest was reported by the author(s).

#### Data availability statement

The data that support the findings of this study are available from the corresponding author, Lauren Taylor (LT), upon reasonable request.

#### Abbreviations

**App:** Application  
**BCT:** Behaviour change technique  
**BCTT:** Behaviour Change Technique Taxonomy  
**mHealth:** Mobile Health  
**PRISMA:** Preferred Reporting Items for Systematic Review and Meta-Analyses  
**PROSPERO:** International Prospective Register of Systematic Reviews

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