Experiencing Change: A Scoping Review of Behavior Change with Extended Reality

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Abstract

Despite decades of research, behavior change technologies remain limited in effectiveness because they mainly focus on offering information. Immersive technologies, such as extended, virtual, and augmented reality, promise to address this limitation by shifting from information-centric to experience-centric interventions. However, we do not know which technical and psychological components of immersive technologies make interventions effective. This scoping review of 53 articles analyzes how immersive technology components are linked to theory-informed behavior change techniques, summarizes their effectiveness, and synthesizes their unique advantages for experience-based immersive behavior change interventions. We offer both a formalization of the impact of immersive technology components on behavior change, and summarize practical suggestions for designing and systematically evaluating immersive behavior change interventions in a framework toward theory-driven Extended Reality behavior change interventions.

CCS Concepts

• **Human-centered computing → HCI theory, concepts and models**; **Mixed / augmented reality**; **Virtual reality**.

Keywords

Behavior Change, Extended Reality, Immersive Technologies, Behavior Change Interventions

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1 Introduction

Changing behavior is difficult. Decades of research have developed and studied behavior change technologies, such as wearables [30] and smartphones [63], that help people become more physically active [24], reduce digital distractions [67], or promote pro-environmental behavior [12]. Yet, summative reviews consistently report only modest effects on behavioral outcomes [37, 80]. One reason for this limited effectiveness is that behavior change interventions are predominantly information-centric [64], relying on reminders, notifications, or activity monitoring to deliver information [115]. However, information alone has limited impact on behavioral outcomes [3]. For instance, reminders typically achieve only small effects [37], and mobile app interventions generally show little evidence of sustained change or improved health outcomes in health-related behavior change [80]. Further supporting these findings, a recent review by Albarracín et al. [3] reported that behavior change interventions targeting knowledge or beliefs generally result in negligible effects. However, their review did not focus primarily on technological interventions.

Immersive technologies, such as virtual reality (VR) and augmented reality (AR), promise to overcome these limitations. For instance, rather than relying on reminders that appear only when a user checks their phone, AR can integrate behavioral cues into the user's immediate surroundings, making them more salient. In addition to making information more easily visible and accessible, immersive technologies can also create experiences that are impossible in the physical world, such as exposing the user to a future version of themselves or their environment. For example, AR could transport users to a world that shows the consequences of climate-harmful behavior by seeing their own house flooded. In VR, users could embody an avatar that not only looks like their aged self but also feels like it, letting them experience the effects of regular physical activity (or the lack thereof) on their future bodies. In particular, VR's ability to create "psychologically real" [13, 66] environments makes it promising for creating ecologically valid experiences, as already applied in clinical behavior change (e.g., VR exposure therapy [31, 99, 120]), and some individual studies in the domain of environmental behavior [92, 134]. Taken together, immersive technologies hold promise to revolutionize behavior change technologies, shifting from *information-centric* to *experience-centric* interventions.

However, currently we lack a comprehensive synthesis of how behavior change interventions have been implemented in VR and AR, which underlying processes they target, and how effective they are. Existing reviews on the topic focus on a subset of technologies, populations, or domains [18, 34], or pursue more specific outcomes through systematic reviewing rather than scoping of the literature [87]. In particular, we currently do not understand how technical and psychological qualities that are unique to immersive technologies influence behavioral change processes. Such a synthesis is essential to understand *what* makes immersive technologies

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work for behavior change, *why* that is the case, and *how effective* they are.

We answer these questions by a scoping review of behavior change interventions and their effectiveness in VR and AR. We review 53 papers published between 2002 and 2025 from disparate bodies of research (including computer science, environmental sciences, education, psychology, and medicine).

We first analyze which technical and psychological components of XR are used to design the behavior change interventions in the reviewed papers. We then relate the interventions to behavior change techniques [76] and mechanisms of action [15], describing their connection to established behavior change theory. In addition, we assess the effectiveness of the interventions. Finally, we highlight the key advantages that XR offers for supporting behavior change. The synthesis of effectiveness is encouraging: 70% of studies assessing short-term effectiveness report positive effects, while 67% of those evaluating long-term outcomes (ranging from two weeks to three months) indicate positive sustained impact. Furthermore, 47% of studies comparing XR-based interventions to non-XR counterparts found XR to be more effective. We found that often XR behavior change interventions rely on known behavior change techniques, such as showing information, not fully leveraging XR's capabilities. Furthermore, the interventions make multiple connections to behavioral mechanisms, making it difficult to disentangle separate causal relations. In response to this, we contribute a *Framework Toward Theory-Driven XR Behavior Change Interventions*, bridging behavioral sciences and HCI by making concrete suggestions on how to leverage XR capabilities for the design of behavior change interventions that are grounded in behavior change theory.

2 Background

We begin by summarizing the behavior change terminology used throughout the paper. Then, we review technology-supported behavior change interventions, followed by an overview of the state of the art of immersive technologies applied to behavior change.

2.1 Behavior Change Terminology

Behavior Change Theories and Models. Behavior change generally refers to observing a permanent change in a person's actions. Numerous models and theories aim to explain why behavior change occurs and how it can be influenced. They focus, for example, on general influences on behavior [29, 46], attitudes [2], or goals [145]. In our review, we combine a top-down and bottom-up approach by analyzing the theories referenced in the reviewed papers and relating them to Michie et al. [76]'s behavior change techniques and mechanisms of action. These frameworks have been used widely in the behavioral sciences and are valuable for discussions commonly targeting underlying behavioral processes.

Behavior Change Technologies. We adopt the definition by Hekler et al. [47], who describe behavior change technologies as "systems and artifacts developed to foster and assist behavior change and sustainment as behavior change technologies". In this review, we focus on one specific class of such technologies: extended reality or immersive technologies. More specifically, this review aims to inform about how effective and useful immersive technologies are for behavior change.

Behavior Change Interventions. Following Michie et al. [77], we define behavior change interventions as "coordinated sets of activities designed to change specified behavior pattern". In our context, XR technologies serve as the medium that implements these interventions.

Behavior Change Techniques and Mechanisms of Action. Various terms have been used to describe the underlying processes through which behavior change interventions are effective. For example, Albarracín et al. [3] use "behavioral determinants" to refer to "individual factors [...] at the center of behavioral prediction and change models". Other researchers refer to these underlying processes as "mediators" [47] or "influences". Michie and colleagues [1, 15] distinguish between *Behavior Change Techniques (BCT)* and *Mechanisms of Action (MoA)*. A BCT is defined as "a replicable component of an intervention designed to alter or redirect causal processes that regulate behavior" [15]. BCTs can either support factors that might promote a desired behavior or reduce ones that inhibit one from performing a wanted behavior. MoAs describe "processes through which individual BCTs have their effects". We use BCTs and MoAs to analyze the papers, as they offer detailed coding guidelines and nuances that support systematic classification.

Immersive Technologies. Immersive technologies refer to systems that partially or fully immerse users in spatial, digital environments. Virtual Reality (VR) fully replaces the physical world visually with a digital one, while Augmented Reality (AR) overlays digital content onto the physical environment [9]. Mixed Reality (MR) blends physical and digital elements along the reality–virtuality continuum [79]. However, its definition remains unclear [110]; it is often used to describe collaborative scenarios involving different immersive technologies [42]. Generally, the term Extended Reality (XR) is used as an umbrella term to refer to all these technologies. To cover the full range of immersive technologies, we include all mentioned terms as search terms. We refer to behavior change interventions implemented with immersive technologies as "XR interventions" throughout the remainder of the paper for brevity.

2.2 Technology-Supported Behavior Change

Using interactive technologies to support behavioral change processes has been a focus of researchers for many years. An early behavior change technology is *UbiFit Garden* [24], which encourages physical activity. It combines physical activity tracking with a digital garden on a person's mobile phone, which blooms depending on the user's physical activities. The system was generally perceived as motivating, especially connecting the physical activity to a personal device. The system illustrates common features of technology-supported behavior change, such as self-tracking devices and wearable, mobile devices with adaptive content. Behavior change technologies exist in many domains, such as physical activity and healthy food choices [69], mental health [59, 116], digital screen-time [67, 143], and sustainability behavior [142]. Many are based on tracking (monitoring) a user's behavior and giving them recommendations at certain times. For instance, a user might receive notifications about step counts, time spent on social media apps, time spent watching YouTube videos, etc. Others focus on tracking a user's behavior to restrict how much time is available for the behavior. For example, restricting how much time a user allows themselves to spend on social media [67, 68]. Often these technologies provide information about the behavior or explain to users how much they have engaged in that behavior. These interventions use information as the MoA. However, research in the medical domain has shown that interventions based on knowledge or information as the main target show only modest effects [37, 80]. A recent review by Albarracín et al. [3] confirmed that behavior change interventions that target information only marginally support behavioral outcomes. These findings suggest that *information-centric* approaches are of limited effectiveness, which motivates us to explore to what extent *experience-centric* behavior change approaches are effective.

One reason for the limited effectiveness might be that HCI behavior change interventions often do not use behavior change theory. Hekler et al. [47] analyzed how HCI researchers used behavioral theories in the design of behavior change technologies and made suggestions on how to use theory better in the design of them. Rapp and Boldi [94] took a contrary approach by studying the lived experience of behavior change technologies. They interviewed 23 people about their lived experience of using behavior change systems. One of their main findings is that behavior change technologies often ignore other aspects of life and are thus difficult to integrate into everyday life. They also noted that the behavior change technologies focused on "present behaviors, targeting a narrowed temporality that does not account for past experiences or distant futures", which is something that XR technologies suggest to overcome by moving from information-centric to experience-centric behavior change. Another work by the same group of researchers [95] argues that HCI behavior change technologies often see change as *externalistic*, among others, which is again an argument for current behavior change technologies focusing on technologies that provide change to the user externally, rather than helping them experience it internally.

2.3 Immersive Technologies and Behavior Change Reviews

A preliminary search for existing scoping reviews and systematic reviews on the topic of behavior change and extended reality has been conducted on JBI Evidence Synthesis[1], Cochrane Database of Systematic Reviews[2], PubMed[3], Web of Science[4], and Scopus[5]. Related reviews address a limited subset of the research covered in our review and fell broadly into three categories (1) papers focusing on a different technology range (e.g., specifically on VR or general technologies), (2) papers not specifically focusing on constructs related to behavior change (e.g., empathy), or (3) papers focusing on a specific population. Moreover, they provide little in-depth analysis of the XR experience and how and why XR qualities lead to successful behavior change. For example, Chin and Chow [18] presented a scoping review on technology-enabled interventions for sustaining behavior change in adolescents, while we do not focus on a specific population. Another example is the review by Felsberg et al. [34], which focuses on rehabilitation in neurologic populations and therefore covers a narrower scope than ours. Although its methodological approach is similar in analyzing behavior change techniques, we additionally examine XR-specific qualities and their relation to these techniques. The review by Paul Odenigbo et al. [87] on "Augmented and Virtual Reality-Driven Interventions for Healthy Behavior Change" focuses on health-related behavior change, while ours covers a broader range of behavior change domains. Furthermore, Paul Odenigbo et al. [87]'s review and ours follow different review methodologies, which pursue different goals, foci, and intended outcomes. Paul Odenigbo et al. [87]'s systematic review includes 19 papers published between 2011 to 2021, a relatively small number compared to the number our scoping review covers. Its focus is on an in-depth reporting of the individual studies, and its main findings concern the design layers and persuasive strategies of the interventions. In contrast, our focus lies on the theoretical grounding of the interventions in behavior change theory and on analyzing the specific qualities of XR used, rather than the implementation layers.

Wienrich et al. [133]'s work is closest to ours. They proposed a framework that captures psychological barriers hindering behavior change. *BehaveFIT* points out how features of immersive technologies can potentially overcome these barriers. The framework is designed based on an informal literature review and expert interviews. This connection of the psychological barriers to immersive features and perceptions is a good start for formalizing immersive technologies' components and their impact on factors that limit behavior change. Our work builds on *BehaveFIT*, using its psychological barriers to code the main advantages that XR provides in the reviewed papers.

3 Method

We conducted the scoping review in accordance with the JBI methodology for scoping reviews [89]. A scoping review is the most appropriate review type for our research objective, as we are looking for the nature and extent of evidence rather than a specific research question [112]. We developed an a priori protocol based on Cooper et al. [25] and Aromataris et al. [7].

3.1 Review Objective and Research Questions

The objective of this scoping review is to understand the extent and nature of evidence regarding the use of behavior change interventions in immersive technologies, including VR and AR. For simplicity, we use the term XR to refer to immersive technologies in the following. The review is driven by four research questions:

- **RQ_1** What technical features and psychological qualities of immersive technologies are used to design XR behavior change interventions?
- **RQ_2** What behavior change techniques (as classified by Michie et al. [76]) and mechanisms of action (as classified by Carey et al. [15]) are used in the design of XR behavior change interventions?
- **RQ_3** How effective are the XR behavior change interventions?

[1]https://journals.lww.com/jbisrir/Pages/default.aspx
[2]https://www.cochranelibrary.com/
[3]https://pubmed.ncbi.nlm.nih.gov/
[4]https://www.webofscience.com/
[5]https://www.scopus.com/

RQ$_4$ What are the reported unique advantages of using XR for behavior change?

3.2 Search Strategy

In line with the methodological purpose of scoping reviews, our approach prioritizes breadth of evidence. Accordingly, we defined generous search queries and applied minimal filters.

3.2.1 Search Queries. We combined keywords covering immersive technologies with keywords covering behavior change. To define the keywords for immersive technologies, we used the same approach as Hirzle et al. [50] and included the following XR-related keywords, in alphabetic order: “augmented reality”, “AR”, “extended reality”, “head-mounted display”, “head-up display”, “head-worn display”, “headset”, “HMD”, “immersive environment”, “mixed reality”, “virtual environment”, “virtual reality”, “virtual space”, “VR”, and “XR”. To cover the behavior change side, we included “behavior/behaviour change” and “behavioral/behavioural change”. At first we considered to take a more selective approach similar to Albarracín et al. [3], who combined the word “behavior” with other terms, such as “belief”, “attitude”, “norm”, or keywords from popular application areas, such as “physical activity” and “recycling or climate”. We chose to take a more general approach by only searching for “behavior change” because we did not want to restrict application areas or focus of behavior change on pre-defined concepts. Thus, the final query combined all XR keywords with all behavior change keywords using an `OR` operator within each keyword in the respective keyword sets and an `AND` operator between the keyword sets: `[XR keywords] AND [behavior change keywords]`.

3.2.2 Search. We searched the databases ACM Digital Library [6], IEEE Xplore [7], PubMed [8], and Web of Science [9] between April 4, 2025 and April 8, 2025. Using filters (*F*), the search was restricted to peer-reviewed full papers (no extended abstracts or protocols, *F1*) written in English (*F2*). We did not apply any restrictions to the time frame. The exact search queries and dates for each database are shown in Appendix B.

We selected Web of Science as our starting database because of its broad coverage across research areas, including Arts & Humanities, Life Sciences & Biomedicine, Physical Sciences, Social Sciences, and Technology [10]. However, because of reported inconsistencies in IEEE and ACM indexing [50, 98], we included these two publishers separately. Additionally, because Web of Science does not comprehensively index medical venues, which are relevant for behavior change publications, we added PubMed. Our rationale for choosing different databases for the main versus the initial search is described in Appendix A.

3.2.3 Sensitivity Analysis. To determine the usefulness of the search terms and the adequacy of the search query, we conducted a sensitivity analysis by checking if the search result included key articles that we identified through initial scoping of the literature. The key articles are marked in the supplementary material.

[6]ACM Digital Library: https://dl.acm.org, last accessed: April 8, 2025
[7]IEEE Xplore: https://ieeexplore.ieee.org, last accessed: April 8, 2025
[8]PubMed: https://pubmed.ncbi.nlm.nih.gov, last accessed: April 7, 2025
[9]Web of Science: https://www.webofscience.com, last accessed: April 4, 2025
[10]Web of Science Research Areas: https://webofscience.zendesk.com/hc/en-us/articles/38543541713169-Research-Areas, last accessed: November 17, 2025

3.3 Eligibility Criteria

We report the eligibility criteria based on the PCC (Population, Concept, Context) model as suggested by Peters et al. [90]. Since our question does not target a specific *population*, we do not define participant-related inclusion criteria. This scoping review focuses on behavior change interventions as *concept*, and immersive technology experiences, including virtual, augmented, extended, and mixed reality, as the *context*. Based on our research questions, we define the following inclusion (IC) and exclusion (EC) criteria. They were derived through an iterative process, which is explained in more detail in Subsection 3.4.

3.3.1 Inclusion Criteria (IC).

IC1 The article presents primary research on the use of a behavior change intervention implemented with immersive technology, with the goal of influencing a person’s behavior.
IC2 The article reports a measure of behavior or a measure related to behavioral change (e.g., intention, self-belief, self-regulation, motivation) as the primary outcome.

Based on these inclusion criteria, we developed three guiding questions to help with the screening process: (1) Does the paper use immersive technology, such as VR or AR?, (2) Does the paper employ a behavior change intervention or does it state that it aims to influence a behavior?, and (3) Does the study measure behavioral outcomes or a measure related to behavioral change (e.g., intention, motivation)? We define what constitutes an *intervention* as follows: Michie et al. [77] define behavior change interventions as “coordinated sets of activities designed to change specified behaviour patterns”. We follow this definition. In this review’s context, we define “sets of activities” as the paper needs to present an XR prototype designed to change an articulated behaviour. This excludes articles that do not present a prototype (e.g., articles that describe the conceptual design but not the actual implementation of a prototype). We do not impose any restrictions on the type of prototype (e.g., we include both hardware and software prototypes; prototypes may present a fully modeled 3D world or simply use a 2D overlay, such as a video).

3.3.2 Exclusion Criteria (EC). We used the following ECs to exclude papers that did not fit the inclusion requirements. We used them for both screening rounds, one based on title and abstract and one based on the full-text reading.

EC0 Duplicate
EC1 (filter) Not English
EC2 (filter) Articles in workshop proceedings, adjunct proceedings, posters, short paper, extended abstract, companion, book chapter
EC3 Synthesis articles, such as reviews [27, 28, 140], meta-analyses [83, 101], design frameworks [56, 144], or perspectives/position papers [88, 135]. Papers excluded under this criterion broadly fell into three categories: (1) papers focusing on a different technology range, (2) papers not specifically focusing on constructs related to behavior change, and (3) papers focusing

Table 1: Summary of the codes used for data extraction. See Appendix C for the code book including a description for each code.

Behavior Related	Extended Reality Experience	Outcome Measures and Results	Study Details
C1 Addressed Behavior	*C4* Technology	*C9* XR Measures	*C13* Study Design
C2 Connection to Theory	*C5* Device Used	*C10* Behavioral Measures	*C14* Sample Information
C3 Ethical Concerns	*C6* General XR Experience	*C11* Duration of Intervention	*C15* Population Information
	C7 Task	*C12* Results	
	C8 Practical Purpose of XR		

on a specific population. We discuss a representative subset in Subsection 2.3. *Rationale:* This ensures that we only include primary research as stated in *IC1*.

EC4 False positives: Articles using "behavior/behaviour" or "behavior change" not in the context of human behavior change (e.g., describing a system's behavior). For example, Taylor et al. [114] studied how insects would change their behavior depending on the type of feedback sensor used to detect their movement, which is non-human behavior.
Rationale: This ensures we only include papers on behavior change in the review's intended context.

EC5 Articles that do not apply a behaviour change intervention.
Rationale: Related to *IC1*, this criterion ensures we only include papers related to our concept. Excluded articles often present a prototype that does not constitute an intervention to change a behavior. For example, Ioannou et al. [54]'s findings suggest that augmentation of performance in VR can increase intrinsic motivation, perceived competence, and flow, and it "may also increase motivation for physical activity in general". However, the study does not investigate if the prototype (i.e., intervention in our terms) changes actual exercise behavior. Other articles may present the initial steps towards developing an intervention without having finished the intervention design (e.g., [62]).

EC6 Articles that do not report a behavior change study (e.g., protocols, pilot studies, user interface studies).
Rationale: Related to *IC1*, we ensure that included articles present primary research relevant to our concept. Some papers may develop a behavior change intervention but only report the user interface evaluation (not the evaluation of the behavior change intervention) or the design of the intervention without an evaluation in the article (e.g., [5, 81]).

EC7 Articles that conducted a study but did not apply a measure of behavior change or a measure related to behavioral change (e.g., intention, self-belief, self-regulation, motivation).
Rationale: This ensures we only include papers based on *IC2*.

EC8 Articles that do not use XR technologies for behavior change intervention.
Rationale: This excludes articles that use relevant terms in unrelated contexts. For example, "virtual environment" may refer to a simulation on a computer rather than an immersive technology (e.g., [125]) or an article may mention "VR" in relation to behavior change but does not implement XR interventions within its own study [8].

EC9 Articles that do not report a sufficient level of detail in either their behavior change intervention or study design to allow for accurate coding.
Rationale: This criterion also serves as a quality measure of the included studies.

3.4 Evidence Selection

We identified relevant papers through the search queries on relevant databases as reported in Subsection 3.2. The search retrieved 1454 articles. Next, we removed 93 duplicates based on an exact match of the DOI and title of the paper. If we found a duplicate title with different DOI, we kept the newer instance. To check duplicates, we used custom python scripts. Then, we double checked the retrieved entries for *EC1* and *EC2*, restricting the article language to "English" and the article type to "Full paper". These articles should be removed through filtering on the database websites but this is sometimes inaccurate. We removed 1 non-English article and 71 non-Full paper articles. The evidence selection process is shown in Figure 1.

First round of screening. We conducted the first round of screening based on title and abstract, employing all EC. 1290 papers were included for screening, which was conducted by two of the authors. They first screened the same 148 papers (12%) for calibrating their interpretation of the EC. During this phase, the authors met regularly to discuss alignment and uncertainties. After having screened all 148 papers, we calculated agreement on inclusion/exclusion using percentage agreement. The two authors first reached 77% agreement and then went through the papers again, increasing the number to 85% agreement before they then discussed the misalignments and took a decision together. The decision was either to include or exclude at this point. Being inclusive, we included papers we were uncertain about to check them more closely during the second screening phase. After the calibration, each of the authors screened a different set of 571 (44%) papers individually. For the 12% of papers that were used for screening calibration, 22.3% (33 papers) were included; of the 88% of papers that were screened individually, 17.5% (200 papers) were included, resulting in a total of 233 papers included for the second screening round.

Second round of screening. In the second round, the same two authors performed full text screening. This time they both screened all of the papers. The authors met regularly, after screening the same 50, 100, and then 233 of the papers to discuss discrepancies and align perspectives. After the second round of screening, 53 papers were included for data extraction.

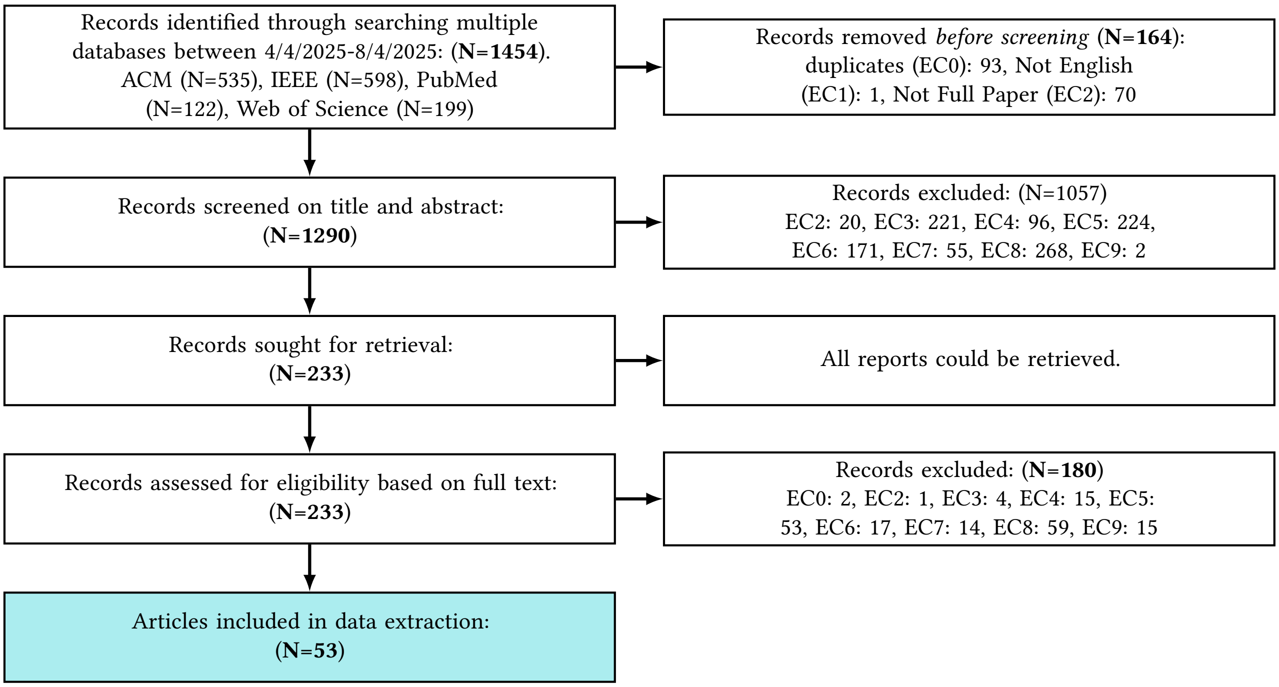

Figure 1: The PRISMA-ScR flowchart documents the scoping review process from identification of sources to the final sample of articles that are included for data extraction.

3.5 Data Extraction

3.5.1 Data Charting Table. The data charting table was developed iteratively over six months through regular discussions among all authors from April to September, 2025. During the screening process, we refined the coding scheme to ensure alignment with our research questions. The final data charting table (Table 1) comprises four main categories and 15 codes.

3.5.2 Extraction Procedure. For all codes, the authors selected quotes from the paper that were later analyzed for synthesis. We conducted dual extraction (i.e., two authors coded the articles independently and then merged their results) for 43% (23) of the articles. The remaining papers were split into two sets, with one authors coding 13 (25%) and the other 17 papers (32%). Before starting with the individual coding, both authors met for alignment after coding 5, 10, and all papers, to discuss and resolve discrepancies.

3.5.3 Analysis and Synthesis of the Evidence. We collected descriptive results of the papers and presented them in a combination of quantization and narrative synthesis, following the categorical reporting approach commonly done in HCI reviews [98]. We summarized behavioral domains based on *C1*, using the categories of Albarracín et al. [3] and explained ethical concerns mentioned in the papers *C3*. We also reported summative data, such as year of publication, technologies used (*C5*), and populations included in studies (*C15*).

For the analysis to answer the research questions, we summarized each paper in a conceptual figure inspired by Velloso and Hornbæk [123]'s approach of using causal models for theorizing in HCI. These figures capture each paper's *cause of interest* (AR/VR experience) and *outcome of interest* (measured behavior), and, where applicable, link design components to the underlying theory named by the authors. They also indicate details about the dependent variables and the intervention's effects. A conceptual example is shown in Figure 4 in Appendix C.1 and all figures are available in the supplementary material. Next, we describe the data analyzed and how we synthesized the codes to address our four research questions.

Technical and Psychological XR Components. To answer $\mathbf{RQ}_1$, we analyzed the codes *C4-C8*. Based on *C6* we analyzed how the virtual experience is connected to the physical world, and based on *C6* and *C7* we examined what type of elements were used to create the behavior change intervention. Paul Odenigbo et al. [87] also looked into how users interacted in XR for their systematic review. However, their description of user interaction considers the general interaction possibilities (e.g., interacting with items, buttons, or the environment), and we analyze how the elements users interact with are related to the behavior that is the focus of the intervention.

For the psychological components, we analyzed *agency* based on *C7* (i.e., if a user actively engaged in the XR experience). Also based on *C7*, we coded if the action a person performed in XR was actively or passively connected to the behavior. Furthermore, we coded the perspective through which users experience the behavior change intervention (e.g., if they have a body or not). We focused on these three components because they are related to agency, embodiment [61], and presence [108] – three key qualities of XR. Importantly, these qualities were often identified by the authors

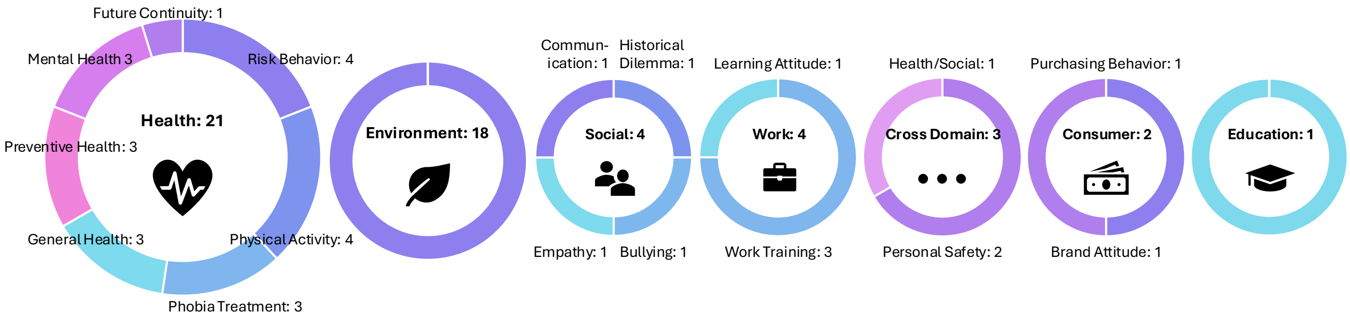

Figure 2: Overview of the behavioral domains into which the papers were grouped. The main domains, shown in bold at the center, are based on the classification by Albarracín et al. [3].

of the reviewed papers and were speculated to contribute to effective behavior change in XR. Several papers mentioned that XR can immerse the user in potential future scenarios, allowing them to experience them more "vividly" [19, 119]. What the authors describe here is *Presence* – the feeling of "being" in a virtual world [45], which stands in contrast to immersion that is often understood as describing the objective characteristics of a system [107]. However, only a fraction of the reviewed papers measured presence (17 papers). Among those, different instruments and sub constructs of presence were applied (e.g., igroup presence questionnaire [102, 129], Witmer and Singer's Immersive Tendencies Questionnaire [4, 111]). Therefore, we chose not to analyze presence as a separate component. As several survey articles argue (e.g., Xiao et al. [137] and Skarbez et al. [106]), presence is a multidimensional construct, and papers in our corpus employed heterogeneous instruments and sub constructs, preventing a valid comparison.

Behavior Change Techniques and Mechanisms of Action. To answer $\mathbf{RQ}_2$, we used top-down coding of the data extracted for *C2* and connected the data to the list of behavior change techniques (BCT) [76] and mechanisms of action (MoA) [15]. Paul Odenigbo et al. [87]'s review allocated persuasive design strategies, thus focusing on persuasive technology design. These are partially represented by BCTs and MoAs, for example "social learning" or "rewards" is present in both structures. However, the BCTs and MoAs are more extensive in their coverage and have been validated for other behavior change technologies, which is why we chose it as analytical approach for our review.

For the coding of C2, two authors extracted the theories explicitly cited by the researchers to explain why certain aspects of the XR intervention were effective. The MoAs were linked to the theories cited in each paper, where applicable, as these theories often connected the XR experience to the targeted mechanisms. MoAs were only assigned for explicitly stated theories. For assigning BCTs, first, two of the authors defined for each paper how its interaction is related to behavior change. We considered the following questions: (1) How does the person experience the behavior? , (2) Does the person engage in the behavior (active) or see the behavior performed (passive)?, (3) Does the person see consequences of the behavior, and if so are they personal or generalized; are they visualized immediately or delayed; are the consequences connected to the behavior they do in XR or are they visualized without performing the behavior?, (4) Where is the impact of the behavior shown (e.g., is it shown in the real world and close to the user, or is the user virtually teleported to a far away distance and/or time)? Two authors discussed the papers considering these questions together and agreed on each decision. Because coding was done collaboratively rather than independently, separate reliability checks were not necessary. One author then assigned each suitable BCT and MoA to each paper, following the coding guidelines for both as described in the available documents [11,12]. Finally, two of the authors went through the allocated BCTs and MoAs again, discussed them in detail, and reviewed the allocations with a third author. An overview of the mapping is shown in the supplementary material.

Effectiveness. To answer $\mathbf{RQ}_3$, we summarized *C9-C12*. We grouped the papers' effectiveness reports into two groups: (1) under *comparative effectiveness*, we summarized papers reporting a comparison of XR versus non-XR interventions, and (2) under *effectiveness over time*, we summarized the articles' results for pre-post measurements of short-term (i.e., post-measurement was applied directly after the intervention) and long-term effectiveness (i.e., a follow-up measurement was applied after an extended time after the intervention). Effectiveness was coded based solely on core behavioral measures that reflect the success of the intervention, other secondary measures were ignored. For example, in a study that aims to change people's unhealthy snacking behavior, the core measure is snack intake while other measures such as body ownership, perceived severity and perceived susceptibility are secondary measures because they do not directly reflect the success of the intervention[119]. We classified an intervention as effective only if it displayed statistically significant positive differences in these core outcomes. Due to high heterogeneity in study designs (e.g., within-, mixed-, and between-group designs with repeated measures, pre-post, and post-only measurement), we chose to report effectiveness as a binary variable. Because not all paper actually measured behavioral outcomes, we separated the ones that did from those measuring intention or related constructs. We grouped the papers into four groups: papers measuring behavioral outcomes (27), papers measuring intention (12), papers measuring behavioral outcomes in XR (e.g., driving

[11] BCT Taxonomy (vt1): https://www.bct-taxonomy.com/pdf/BCTTv1_PDF_version.pdf
[12] Mechanisms of Action: Supplementary File 2 of Carey et al. [15].

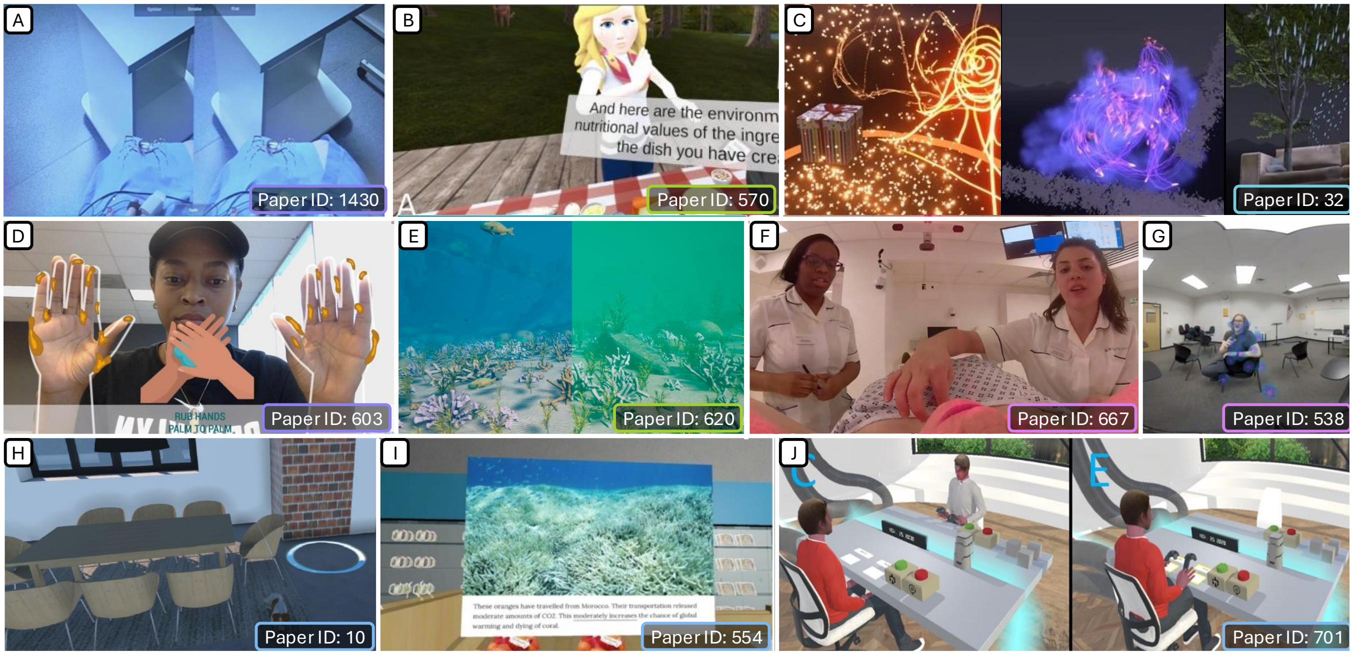

Figure 3: Ten examples of the reviewed papers. The papers with IDs 1430 [60] and 603 [104] are examples of Augmented Reality use. Jurcik et al. [60] show a realistic augmented spider for the treatment of arachnophobia (Fig. (A) © Jurcik et al. [60]); Seals et al. [104] visualize germs on a user's hands together with hand washing instructions to improve hygiene behavior (Fig. (D) © Seals et al. [104]). The papers with IDs 570 [93] and 620 [129] are examples of showing a time-projected world. In Plechatá et al. [93]'s work, participants' surroundings show climate change effects dynamically based on food choice in a cooking task (Fig. (B) © Plechatá et al. [93]); Weller et al. [129] shows a coral reef in healthy and decayed state to influence pro-environmental behavior (Fig. (E) © Weller et al. [129]). The papers with IDs 667 [33] and 538 [139] are examples of replicating the real world. Farmer et al. [33] show a first-person video of a cancer patient to increase breast self-examination behavior (Fig. (F) © Farmer et al. [33]); Xu and Dam [139] visualize how virus spreads from a person to increase Covid-19 protection behavior (Fig. (G) © Xu and Dam [139]). The papers with IDs 10 [4], 554 [72], and 701 [39] are examples of simulating the physical world. Alves and Esteves [4] expose participants to a virtual dog to reduce cynophobia (Fig. (H) © Alves and Esteves [4]); Meijers et al. [72] show impact messages of how products in a grocery store influence the environment (Fig. (I) © Meijers et al. [72]); In Ganschow et al. [39], participants have a conversation with an aged-morphed future self to improve future-directed decision making (Fig. (J) © Ganschow et al. [39]). The paper with ID 32 [127] is an example of creating an abstract world. It lets participants create virtual world to foster self-reflection. All images shown are published in open-access papers (Fig. (C) © Wagener et al. [127]). Please refer to Appendix D.1 for a detailed description of the licenses and the changes made to the original figures. A list of all paper IDs and their allocation to citations are given in Appendix D.

behavior in a VR driving simulator [23, 131]) (5), and papers measuring constructs related to behavior (e.g., attitudes [20, 138]) (9).

Unique Advantages of XR. To answer **RQ**$_4$, we summarized *C8* and used a combination of bottom-up and top-down procedures. We grouped the individual purposes stated by the authors using affinity diagramming (bottom-up). Then, we assigned a main advantage of XR to each paper based on the barriers in Wienrich et al. [133]'s framework (top-down). This analysis serves to highlight what XR's unique advantages are for implementing behavior change interventions and how to do that.

3.5.4 Critical Appraisal, Potential Bias, and Limitations. Although scoping reviews typically do not restrict evidence based on methodological quality [6], we included a critical appraisal step to ensure that our evidence summary is grounded in methodologically rigorous primary research. This is reflected in the exclusion criterion *E9*, which we introduced to exclude papers that were thematically relevant but lacked sufficient detail to extract data needed to address our research questions. To reduce bias in screening and data extraction, we conducted a calibration phase during the first screening round, applied dual-screening in the second phase, and performed dual-extraction for 43% of the included papers. To mitigate selection bias, we used a broad set of XR-related keywords. However, requiring "behavior change" as a fixed keyword likely excluded some relevant papers that did not explicitly use the term. The large drop from 1454 papers in the search result to 53 papers included for data extraction and analysis reflects our generous search strategy, which favored capturing a wide range of potential papers, even at the cost of a high number of false positives.

Table 2: Categorization of reviewed papers by their relation to the physical world (rows) and the types of elements used (columns). Bars within each cell represent the distribution of papers on short-term effectiveness. Papers that did not apply such a measure are indicated with ✖ and are not included in the distribution bars. Effectiveness is indicated as positive (▬), mixed (▬), or no effect (▬). The figure differentiates papers measuring behavioral outcomes from those measuring intention (*I*), behavior in XR (*XR*), and related constructs (*O* for other).

	Realistic elements	Abstract elements	Invisible elements	None
Augmenting physical world	*spider* [60]✔, *plants and animals* [65]✔, *rubbish to be sorted* [16]✔*(I)*, *medical staff* [26]✔, *historical figures* [48]✔*(O)*, *wild animals* [32]✔ , *trash cans* [100]✖	*facial expression representing emotions* [44]✔, *attention levels based on brainwave activity* [40]✔, *historical information, text-based* [48]✔*(O)*, *historical information* [109]✔*(O)*	*virus* [139]✔, *germs* [104]✖	
Creating abstract virtual world		*drawing in 3D and using 3D objects to create world* [127]✔*(O)*, *drawing in 3D and using 3D objects to create world* [126]✔✔*(O)*, *abstract "dream-like" environment, avatar faces* [55]✔✔*(O)*		
Time projection of physical world	*cooking utensils in kitchen, surrounding world changes based on food decisions* [93]✔, *hotel with two doors, based on the door chosen the world shows long-term effects of travel behavior on environment and working conditions* [96]✖*(I)*	*CO_2 balloons and numeric value, world changes based on projected CO_2 effects on environment* [134]✔*(I)*, *textual information, world shows long-term effects of travel behavior on environment and working conditions* [96]✖ *(I)*		[91]✔, [129]✖*I*, [92]✖
Simulating physical world	*school environment with bully, victim, bystander* [43]✔*(I)*, *audience in room, listening to presentation* [21]✔, *fire, smoke, house* [82]✔, *sales person in car salesroom* [102]✔*(O)*, *human patient* [138]✖*(O)*, *age-morphed future self across table* [39]✖, *dog and different indoor/outdoor environments* [4]✖*(XR)*, *plastic bottles in forest environment* [19]✖*(I)*, *dog on lawn* [58]✖, *dark street and harasser* [57]✖*(XR)*, *mooring dock* [70]✖*(I)*	*ghosts representing performance* [74]✔, *information and textual boxes* [82]✔, *gamified orbs and obstacles* [117]✔, *information about e-cigarettes* [130]✔*(I)*, *information about presentation* [21]✔, *information about speed in car* [131]✔*(XR)*, *environmental information about product* [72]✖, *perceptual effects of drugs* [122]✖, *social cues* [14]✖*(XR)*, *information about eco-driving* [23]✖*(XR)*, *statistical information* [19]✖ *(I)*		[103]✔, [20]✔ *(I)*, [132]✔, [118]✖ *(O)*, [111]✖, [119]✖, [36]✖
Replicating physical world	*recording of close other* [141]✔			[51]✔ *(I)*, [84]✖ *(I)*, [73]✖, [35]✖, [33]✖ *(I)*

4 Results

The papers were published between 2002 (1 paper) and 2025 (5 papers), with most published in 2024 (13 papers). 5 were published in 2023, 9 in 2022, 6 in 2021, and between 1 and 3 papers in each of the remaining years. Most papers were published in Computer Science venues (29), followed by Medical (10), Environmental Research (6), and Psychology (5). One appeared in a Learning venue, and two in General Science venues.

Figure 2 provides an overview of the distribution of papers across behavioral domains, based on the high-level categories by Albarracín et al. [3]. The most frequently addressed domain is *Health* (21 papers, 40%), followed by *Environment* (18 papers, 34%). The remaining 14 papers are distributed across *Social* (4, 7.5%), *Work* (4, 7.5%), *Cross: Health/Social* (3, 5%), *Consumer* (2, 4%), and *Education* (1, 2%). Regarding the technologies used (*C4* and *C5*), 13 papers (25%) employed AR, 39 (74%) used VR, and 1 paper (2%) incorporated both.

4.1 RQ_1 Technical Features and Psychological Qualities

Table 2 illustrates how the papers relate to the physical world and the elements depicted in the virtual environment. Together, these dimensions describe *how* the virtual world connects to the physical one and *what* it presents to implement behavior change interventions.

4.1.1 Relation to Physical World. We identified five conceptual categories, describing how virtual environments used for behavior change relate to the physical world. Figure 3 shows ten examples of papers grouped into the five categories. 12 papers (25% [13]) were categorized under *Augmenting the Physical World*, as they employed AR. By definition, their connection to the physical one is to overlay it with digital information.

Notably, we found no examples of removing or altering real-world elements, as explored in diminished reality [17]. The VR papers fell into four categories. The most common was *Simulating the Physical World* (26 papers), where virtual environments ranged from realistic [103, 118] to abstract representations [23, 74] of the physical world. This differs from the category *Replicating the Physical World* (7 papers), which involved direct recordings or reconstructions of real environments [33, 73]. A simple example is given by Hofman et al. [51], where participants watched a 360° video of the Great Barrier Reef, aimed at replicating "an actual snorkel" experience communicating the target of climate change effects to participants. In contrast, in [82] participants were immersed in a virtual home simulating the effects of a bushfire. This environment is simulating an actual house affected by the fire but is not modeled after an actual, existing one. Although this category could include modeled replicas of existing spaces, none were found in our corpus. 6 papers focused on a *Time Projection of the Physical World*, all depicting future scenarios. While the category potentially also includes visualizations of past environments, only future simulations appeared in our sample. For instance, in Pi et al. [91]'s work, participants traveled through time within a virtual home, experiencing the effects of climate change on their surroundings embodying three generations. Finally, 3 papers were grouped under *Creating an Abstract Virtual World*, where users actively constructed their own environments by drawing or generating virtual elements [55, 126, 127]. For example, Wagener et al. [126] asked participants to create a virtual environment expressing their emotions. Participants could use free-hand drawing or pre-defined objects to create their individual "mood world".

4.1.2 Elements Used in the Virtual World. In addition to implementing virtual worlds, many papers used specific virtual elements to implement behavior change interventions. We categorized such papers based on the types of elements used. This categorization was motivated by our interest in distinguishing papers that aimed to realistically simulate or replicate the physical world (i.e., primarily using VR as a simulation technology) and those that used XR to visualize or interact with information that would be impossible in the physical world (e.g., capturing one's emotions in a concrete object [126]).

A total of 21 papers used *Realistic Elements*. We named this category "realistic" because it contains elements that were part of the virtual world, fitting into the narrative and style of the virtual world. For example, Gu et al. [43] placed a globe and a calculator on the desk in the virtual classroom, which were well integrated into the school-bullying narrative. Within the virtual classroom, participants could interact with these objects, such as grabbing and throwing them at the victims to experience the role of bullies. For the 7 papers of this category that employed AR, the virtual elements were designed to realistically recreate aspects of the physical world. For example, Jurcik et al. [60] augmented a realistic looking spider over the physical world and Makransky and Klingenberg [70] used elements in the virtual world to increase safety training attitude in a virtual mooring training scenario. 19 papers visualized *Abstract Elements*. Of these, some papers visualized an abstract construct as concrete objects (e.g., drawing emotions and inner states of a person [126, 127]). One paper used "ghost" avatars to visualize a person's past performance [74], Wienrich et al. [134] visualized a person's CO_2 consumption with virtual balloons, Touloudi et al. [117] gamified abstract virtual shapes to enhance exercise performance, and Chirico et al. [19] visualized average plastic consumption as virtual plastic bottles. Other papers visualized abstract information in abstract form, such as textual overlays [96, 109] or graphical indicators of eco-driving scores [23], attention levels [40], or perceptual drug effects [122]. Two papers visualized *Invisible Elements*, such as viruses or germs, exaggerated for visibility [104, 139]. Finally, 15 papers did not use specific virtual elements, relying solely on the immersive environment to induce behavior change.

[13]Please note that due to rounding and the fact that some papers employ multiple technologies and strategies, the totals may not equal exactly 100%. For example, Xu and Dam [139] uses both VR to replicate the physical world and AR to augment the physical world. This also applies to the counting elsewhere, such as in the statistics of "Elements Used in the Virtual World" and "Mechanism of Action"

4.1.3 Psychological Qualities. Due to the large variety in measures used, we focus the reporting of the psychological qualities on three high-level constructs: agency, connection to behavior, and perspective.

We treat *Agency* as binary variable, coded as *active task* when participants performed some form of interaction and as *passive task* when they passively viewed the experience. 35 papers (66%) were coded as including an *active task* and 18 papers (34%) as including a *passive task*.

Connection to Behavior is also reported as a binary variable. We coded the XR experience as *active* connection to behavior when the action performed in XR is directly matched to the target behavior that is intended to change. This is most evident when participants in XR perform the very behavior that the study aims to change (e.g., practicing environmentally friendly cooking in VR to promote pro-environmental behavior [93]). On the other hand, the XR experience in a paper was coded as *passive* connection to behavior when a person's actions in XR were not directly related to the target behavior. This was typically the case for papers where participants did not practice the behavior intended to change. Instead, they were supposed to be indirectly influenced by their XR experience to promote behavior change. For example, participants in VR watched the decay of coral reef, which promoted pro-environmental actions [129]. 33 papers (62%) were coded as *active* and 20 papers (38%) as *passive*.

The third construct we called *Perspective*, and it refers to how the participants see the XR intervention. Papers could take one of three values: *First-person view*, *Embodied*, and *Mirror*. 41 papers (77%) used a *first-person view* where participants watched the scene from a egocentric perspective but did not embody an avatar. In 10 papers (19%) participants embodied a virtual body, and in 2 papers (4%) participants engaged in a *mirror* perspective, where they saw themselves either literally mirrored [104] or looked at a virtual representation of themselves from a third-person perspective [36].

Table 3: Distribution of papers by behavior change techniques (BCT) and mechanisms of action (MoA). The "Effectiveness" column shows the distribution of papers that measured positive (green), mixed (yellow), or no (red) effects in terms of short-term effectiveness of the behavior change intervention. Next to the number of papers in each category ("# Papers"), we show the ratio of how many papers measured short-term effectiveness (black) in contrast to how many did not (grey). The latter are not considered in the effectiveness bars.

BCT Category	Effectiveness	# Papers
BCT 5. *Natural Consequences*		31
BCT 6. *Comparison of Behavior*		16
BCT 2. *Feedback and Monitoring*		14
BCT 4. *Shaping Knowledge*		7
BCT 9. *Comparison of Outcomes*		7
BCT 11. *Regulation*		5
BCT 16. *Covert Learning*		5
BCT 7. *Associations*		4
BCT 10. *Reward and Threat*	....	3
BCT 13. *Identity*		3
BCT 15. *Self-belief*		2
BCT 8. *Repetition and Substitution*		2
BCT 1. *Goals and Planning*	....	1
BCT 3. *Social Support*	....	1
None		3

MoA	Effectiveness	# Papers
MoA 1. *Knowledge*		31
MoA 11. *Environmental Context and Resources*		21
MoA 22. *Feedback Processes*		21
MoA 6. *Beliefs about Consequences*		19
MoA 12. *Social Influences*		14
MoA 19. *Self-image*		11
MoA 26. *Perceived susceptibility/ vulnerability*		10
MoA 2. *Skills*		8
MoA 4. *Beliefs about Capabilities*		8
MoA 13. *Emotion*		6
MoA 3. *Social/Professional Role and Identity*		5
MoA 16. *Subjective Norms*		4
MoA 14. *Behavioral Regulation*		3
MoA. 18. *Motivation*		3
MoA 23. *Social Learning/Imitation*		3
MoA 17. *Attitude towards the Behavior*		2
MoA 9. *Goals*	....	1
MoA 15. *Norms*		1
MoA 20. *Needs*		1

4.2 RQ_2 Behavior Change Techniques and Mechanisms of Action

We summarized how the implemented behavior change interventions relate to the *Behavior Change Techniques (BCT)* defined by Michie et al. [76] and the *Mechanisms of Action (MoA)* by Carey et al. [15]. Table 3 shows an overview of the frequency of allocated BCT categories and MoAs and their effectiveness. As this view summarizes papers that measured behavioral outcomes and papers measuring intention or other constructs, we show a separate overview of papers that only measured a behavioral outcome in Table 4.

Starting with BCTs, the papers were grouped by the direction of change: 30 aimed to *perform a wanted behavior*, 21 aimed to *inhibit an unwanted behavior*, and 2 were unclear about the target of the direction. Table 5 provides an overview of the papers that employed the three most commonly used BCTs, detailing how each was implemented in relation to the physical environment.

Of the 16 high-level categories of the *Behavior Change Technique Taxonomy* [76], the papers covered 14. While the papers were coded on sub-category level (93 in total), we focus the reporting on the high-level categorization and refer the reader to the Appendix, where we list the sub-category allocations. The most frequent behavior change technique was *BCT 5. Natural Consequences* with 31 uses. For example, Seals et al. [104] showed how germs disappear from a person's hands when washing them correctly and Mulders and Träg [84] visualized a distant location (i.e., the rainforest) that was affected by climate-harmful behavior, to influence participants' pro-environmental behavior. 16 papers were classified as *BCT 6. Comparison of Behavior*. An example is given by Colley et al. [23] who used an eco-score to communicate eco-friendly car driving behavior in comparison to others driving around them, hoping to influence their behavior towards more eco-friendly driving. Michael and Lutteroth [74] implemented a system, where a person biked against their past and projected future versions, comparing their current performance with their past and potential future state. With 14 papers, the third most common BCT allocated is *BCT 2. Feedback and Monitoring*. For example, Yong et al. [141] implemented a conflict-resolution system, where close others can experience a conflict discussion from their partner's perspective. Participants first recorded the discussion and then viewed it from their partner's point of view. In Johnsen et al. [58] participants helped out training a virtual and overweight dog by increasing their physical activity. Their activities were monitored and they received indirect feedback by the dog's body changing in response to their physical activity. The other 11 BCT categories were represented with between one and seven papers in each category. The number of BCTs allocated

Table 4: Distribution of papers by behavior change techniques (BCT) and mechanisms of action (MoA). The "Effectiveness" column shows the distribution of papers that measured positive (green), mixed (yellow), or no (red) effects in terms of short-term effectiveness of the behavior change intervention. The figure only includes papers with a behavioral outcome. Next to the number of papers in each category ("# Papers"), we show the ratio of how many papers measured short-term effectiveness (black) in contrast to how many did not (grey). The latter are not considered in the effectiveness bars.

BCT Category	Effectiveness	# Papers	MoA	Effectiveness	# Papers
BCT 5. *Natural Consequences*		16	MoA 1. *Knowledge*		15
BCT 6. *Comparison of Behavior*		10	MoA 22. *Feedback Processes*		14
BCT 2. *Feedback and Monitoring*		9	MoA 6. *Beliefs about Consequences*		13
BCT 4. *Shaping Knowledge*		3	MoA 11. *Environmental Context and Resources*		10
BCT 9. *Comparison of Outcomes*		3	MoA 12. *Social Influences*		8
BCT 11. *Regulation*		2	MoA 26. *Perceived Susceptibility/Vulnerability*		8
BCT 16. *Covert Learning*		5	MoA 19. *Self-image*		6
BCT 7. *Associations*		1	MoA 4. *Beliefs about Capabilities*		5
BCT 10. *Reward and Threat*	. . . .	3	MoA 2. *Skills*		4
BCT 13. *Identity*		2	MoA 3. *Social/Professional Role and Identity*		3
BCT 15. *Self-belief*	. . . .	1	MoA 18. *Motivation*		3
BCT 8. *Repetition and Substitution*	. . . .	1	MoA 23. *Social Learning/Imitation*		2
BCT 1. *Goals and Planning*	. . . .	1	MoA 13. *Emotion*		2
			MoA 20. *Needs*		1
BCT 3. *Social Support*	. . . .	1	MoA 9. *Goals*	. . . .	1
			MoA 16. *Subjective Norms*	. . . .	1

to a single paper varied largely. On average, a paper was allocated to 2.0 (SD=0.9) BCT categories, varying from 1 (e.g., [32, 48]) to 5 [36, 58].

For the *Mechanisms of Action (MoA)*, we allocated on average 3.4 (SD=1.7) MoAs to a single paper, with allocations reaching from 0 [57, 60] to 8 [130]. Of the 26 MoAs in Carey et al. [15], we allocated 19. The most commonly allocated MoA, is *MoA 1. Knowledge* (31 papers), followed by *MoA 11. Environmental Context and Resources* and *MoA 22. Feedback Processes* with each 21 papers, and *MoA 6. Beliefs about Consequences* and *MoA 12. Social Influences* with 19 and 14 papers respectively. An example for the *knowledge* MoA is [130], where adolescents receive information about the risks of vaping in a VR scenario, where they practice rejecting incentives to vape. Thus, it combines informing participants about risks with environmental context and social influences, and is a good example of how often several MoAs can be applied as causes through which the intervention is effective. A good example for the MoA related to *environmental context and resources* is Chittaro et al. [20]'s work, where participants take a walk through a virtual cemetery or neutral public park. This intervention is meant to influence a person's attitudes towards risks, and indeed the cemetery group reported a higher perception of risk for hazardous behavior compared to the park group. This type of experience is a common example, where authors leverage the control over the environment they have with XR. Another example is the work by Plechatá et al. [93], where participants' environment would change around them as a reaction to the type of food they prepared virtually. Participants' collective action intentions and meat reduction intentions significantly increased through the intervention. An example for *feedback processes* is shown in Wienrich et al. [134], where participants saw virtual balloons filled with CO_2 based on their individual CO_2 footprint that was assessed in the beginning of the study. While the balloon visualization itself did not impact environmental self-efficacy more than a numerical value, displaying an extended feedback period (i.e., projecting the CO_2 levels for 1 compared to 3 years) did have an effect on environmental self-efficacy. Another interesting set of examples is in the *perceived susceptibility/vulnerability* category. Here, Seals et al. [104] aimed to increase health behavior, particularly hand hygiene behavior during Covid-19, by targeting the perceived threat-severity and perceived threat-susceptibility through visualizing germs on a user's hands with AR. The application was successful in increasing these variables through a combination of showing germs on a user's hands and seeing a self-reflection of themselves.

Table 5: Overview of works grouped by the three most common Behavior Change Techniques (BCTs, in rows), categorized according to how their presented XR behavior change intervention relates to the physical world (in columns). A visual summary of short-term effectiveness distribution is shown through bars at the top of each cell: ✔ for positive effects, ✓ for mixed results (i.e., some outcome variables showed a positive effect), and ✖ for no observed positive effect. The figure differentiates papers measuring behavioral outcomes from those measuring intention (*I*), behavior in XR (*XR*), and related constructs (*O* for other).

	AR	VR			
	Augmenting physical world	**Simulating physical world**	**Replicating physical world**	**Time projection of physical world**	**Creating abstract virtual world**
BCT 5. Natural Consequences	*Promoting proactive measures against Covid-19 by watching the virus spread from a person* [139]✔, *Increasing pro-environmental attitudes and behavior by showing affected biomes in immediate surroundings* [65]✔, *Reducing smartphone use of children by overlaying facial expressions communicating parents' emotions on doll* [44]✔, *Increase student interest and motivation in field trips showing additional information* [109]✓ *(O)*, *Increasing pro-environmental behavior and attitudes towards conservation work showing affected apes in immediate surroundings* [32]✓	*Reducing attitudes towards risk taking by walking through virtual cemetery* [20]✔ *(O)*, *Preventing e-cigarette use by practicing to reject offer* [130] ✔ *(I)*, *Preventing school bullying by experiencing perspectives of bully and victim* [43]✔ *(I)*, *Reducing speeding behavior through persuasive road marking system* [131]✓ *(XR)*, *Increasing personal response efficacy and environmentally friendly food choice by seeing environmental impact information in supermarket products* [72]✖, *Promoting pro-environmental behavior by exploring plastic-polluted sea* [111]✖	*Promoting pro-environmental behavior by virtually snorkeling through Great Barrier Reef* [51]✔ *(I)*, *Enhancing conflict resolution by taking other person's perspective* [141]✔, *Fostering environmental and biodiversity knowledge by virtually traveling to distant locations* [84]✖ *(I)*	*Promoting eco-friendly behavior by showing personal CO_2 footprint* [134]✔ *(I)*, *Promoting collective climate action by seeing immediate effects of food choice on environment* [93]✔, *Promoting pro-environmental attitudes by time traveling through climate change-affected world* [91]✔, *Promoting sustainable traveling behavior by comparing personal benefits to environmental effects* [96]✖ *(I)*	*Fostering self-reflection by creating personal environment reflecting challenges and emotions* [127]✔ *(O)*, *Promoting mental health by creating virtual world to express emotions* [126]✔
BCT 6. Comparison of Behavior	*Promoting recycling behavior by practicing sorting trash* [16]✔ *(I)*, *Managing attention by visualizing brainwave activity* [40]✔, *Increasing engagement in closed-loop communication behavior by practicing it* [26]✔	*Increasing physical activity by customizing workout sessions in VR* [117]✔, *Increasing physical activity by comparing performance against past and future states* [74]✔, *Practicing public speaking skills with virtual audience* [21]✔, *Practicing bushfire protection behavior through simulation* [82]✔, *Preventing e-cigarette use by practicing to reject offer* [130]✔ *(I)*, *Practizing nursing skills through simulation* [138]✖ *(O)*			
BCT 2. Feedback and Monitoring	*Reducing smartphone use of children by overlaying facial expressions communicating parents' emotions on doll* [44]✔, *Managing attention by visualizing brainwave activity* [40]✔	*Increasing physical activity by customizing workout sessions in VR* [117]✔, *Increasing physical activity by comparing performance against past and future states* [74]✔, *Practicing public speaking skills with virtual audience* [21]✔, *Treating fear of flying through desensitization training with physiological feedback* [132]✔, *Reducing speeding behavior through persuasive road marking system* [131]✓ *(XR)*	*Enhancing conflict resolution by taking other person's perspective* [141]✔	*Promoting eco-friendly behavior by showing personal CO_2 footprint* [134]✔ *(I)*	

4.3 RQ$_3$ Effectiveness

We summarized the papers' *effectiveness over time* and their *comparative effectiveness*. In our analysis of effectiveness, we did not consider studies that only reported structural equation modeling results (e.g., as in van der Waal et al. [119], where experiencing consequences leads to increases in perceived severity, which then has a mediating effect on snack intake), as these do not allow for a direct assessment of the effectiveness of XR interventions. The vast majority of the studies employed pre–post designs or between-group comparisons (with non-XR conditions), which allow for the direct assessment of XR intervention effectiveness. Not all 53 papers employed a behavioral measure. We identified a behavior–intention gap in 12 papers that measured intention to change behavior but not the behavior itself. Additionally, 5 papers measured behavioral outcomes in XR rather than in the physical world

Table 6: Distribution of papers by behavior/intention/measurement gap. The "Effectiveness" column shows the distribution of papers that measured positive ( ), mixed ( ), or no ( ) effects. Next to the number of papers in each category ("# Papers"), we show the ratio of how many papers applied a measure in the respective category in contrast to how many did not ( ). The latter are not considered in the effectiveness bars.

	Short-term Effectiveness (pre-post)		Long-term Effectiveness (pre-post)		Comparative Effectiveness	
	Effectiveness	# Papers	Effectiveness	# Papers	Effectiveness	# Papers
Behavior-Measurement		19/27		8/27		14/27
Behavior-Intention Gap		7/12		0/12		3/12
Behavior-Measurement Gap		1/5		0/5		1/5
Other Constructs		9/9		1/9		1/9

(behavior–measurement gap). Finally, 9 papers focused on behavior-related constructs such as attitudes [20, 118]. An overview of the categorization per paper is provided in the supplementary material. Table 6 summarizes the three effectiveness types (short-term, long-term, comparative) by outcome measure.

4.3.1 Effectiveness Over Time. 36 papers (68%) measured short-term effectiveness of the intervention with a pre-post design and 9 papers (17%) measured long-term effectiveness with a pre-post and follow-up design. Of the 36 papers that measured short-term effectiveness, 19 measured a behavioral outcome, of which 15 found a positive effect of the intervention on the intended behavior. Of the 7 papers measuring an intention, 5 measured a positive effect. Of the 9 papers that measured a related construct, such as attitudes, 5 found a positive effect. For example, Gweon et al. [44] found positive effects from an AR application that allowed parents to provide emotional feedback to their children regarding smartphone use. After a 2-week intervention, children showed significantly improved rule-compliance and a reduction in problematic behaviors. Three papers measuring short-term effectiveness with a behavioral outcome did not find an effect. For example, in Meijers et al. [72], the VR-based intervention offering impact messages about food choices did not directly lead to more sustainable purchasing behaviors after intervention. One paper reported mixed results in short-term effectiveness for a behavioral measure Dunn et al. [32] reported that their AR game was effective at increasing players' environmental knowledge and improving their pro-conservation attitudes but there was no significant change in players' intention to purchase environmentally friendly products. We provide a table summarizing all outcomes (behavioral, intention, and related constructs) separated by effectiveness measurement in Appendix 21.

Of the 9 papers that measured a long-term effect, 8 reported a behavioral outcome measure and 1 measured a related construct. 5 papers reported a positive effect on behavioral outcomes, 2 no effect, and 1 mixed results. Jurcik et al. [60] found that the effectiveness of their AR exposure therapy for spider phobia significantly improved over time, with participants showing even greater behavioral gains at the one-month follow-up than immediately after treatment.

4.3.2 Comparative Effectiveness. 19 papers (36%) measured the effectiveness of an XR intervention compared to a non-XR intervention. Of these, 14 measured behavioral outcomes, 3 measured intentions to change behavior, 1 measured behavior in XR, and 1 measured a related construct. Of the ones measuring a behavioral outcome, 8 reported positive effects, 5 reported negative effects, and one a mixed effect. Of the ones measuring intention, 2 measured a negative effect and one a mixed one, but none a positive effect. The non-XR interventions are typically non-immersive intervention techniques such as videos (e.g., [32, 35, 73]) or traditional teaching (e.g., [138]). For example, Wiederhold et al. [132] reported a positive effect on a behavioral outcome. The paper compared Virtual Reality Graded Exposure Therapy with traditional Imaginal Exposure Therapy for the treatment of fear of flying. In the XR intervention, participants were exposed to immersive virtual flight scenarios, while the non-XR group was instructed to simply visualize these scenarios in their mind. The study found a significant advantage for the XR intervention; at a three-month follow-up, 90% of participants in the VR therapy groups were able to fly, compared to only 10% of those in the imaginal therapy group.

We also found papers that measured the effectiveness of their intervention compared to another type or configuration of an XR intervention through post-intervention tests. These papers are not included in this analysis because, without a pre–post or baseline comparison, it is not possible to determine the absolute effectiveness of the XR intervention itself. For instance, Fox and Bailenson [36] conducted a series of studies comparing different configurations of an immersive virtual reality intervention designed to promote exercising. In their study, they tested whether using an avatar of the 'self' was more effective than an 'other', and whether reward (virtual weight loss) was more effective than punishment (virtual weight gain). The study found that participants exercised significantly more when viewing a virtual 'self' compared to an 'other', regardless of whether the consequence was a reward or punishment. However, this finding only establishes the relative advantage of a self-avatar over an other-avatar within an XR context, and it cannot determine the absolute effectiveness of the intervention itself, as no baseline for behavior was measured.

4.4 RQ$_4$ Unique Advantages of XR

We annotated one primary advantage for each paper, based on the psychological barriers in the BehaveFIT framework [133]. Around half of the papers (27) focused on visualizing behavioral consequences, primarily addressing the "temporal distance" and "spatial distance" barriers. The remaining papers (26) were categorized into visualizing abstract information (10), practicing the behavior (8), allowing gradual control of a stimulus influencing a behavior (5),

Table 7: Distribution of papers by the coded unique advantage of XR. The upper section focuses on papers with consequence-related focus, categorized by temporal and spatial distance to the consequence they show. Temporal distance is indicated by , while no distance is marked by . Similarly, spatial distance is represented by , and its absence by . These distances reflect challenges that XR technologies may help to overcome. The remaining icons serve to structure the figure and facilitate cross-referencing with the corresponding text. "# Papers" shows the number of papers in each purpose category and bars visualize their short-term effectiveness. The figure differentiates papers measuring behavioral outcomes from those measuring intention (*I*), behavior in XR (*XR*), and related constructs (*O* for other).

Unique Advantage of XR	Dimension	# Papers	Papers
Visualize currently occurring but spatially distant consequences of behavior		8	[51]✔ *(I)*, [65]✔, [32]✔, [84]✖ *(I)*, [111]✖, [129]✖ *(I)*, [73]✖, [35]✖
Visualize feedback by showing consequences based on actions in XR	/	6	[93]✔, [91]✔, [96]✖ *(I)*, [92]✖, [36]✖, [58]✖
Experience behavior and its consequences from different perspectives		5	[43]✔ *(I)*, [141]✔, [118]✖ *(O)*, [39]✖, [33]✖ *(I)*,
Visualize currently occurring and spatially close, but invisible consequences		4	[134]✔ *(I)*, [139]✔, [19]✖ *(I)*, [104]✖ *(I)*
Experience potential negative and dangerous consequences safely		2	[103]✔, [122]✖
Visualize temporally distant consequences		2	[20]✔ *(O)*, [119]✖
Visualize abstract information		10	[40]✔, [117]✔, [74]✔, [44]✔, [48]✔ *(O)*, [131]✔ *(XR)*, [109]✔ *(O)*, [72]✖, [23]✖ *(XR)*, [14]✖ *(XR)*
Practice the behavior		8	[26]✔, [21]✔, [82]✔, [130]✔ *(I)*, [16]✔ *(I)*, [138]✖ *(O)*, [100]✖, [70]✖ *(I)*
Gradually control the stimulus		5	[60]✔, [132]✔, [102]✔ *(O)*, [57]✖ *(XR)*, [4]✖ *(XR)*
Express and reflect abstract feelings		3	[127]✔ *(O)*, [126]✔ *(O)*, [55]✔ *(O)*

and expressing and reflecting on abstract feelings (3). Table 8 shows an overview of the distribution of papers into these categories.

The main advantages related to consequences combined different temporal and spatial components that makes it difficult (or impossible) to experience these consequences in "real life". For example, 8 papers used XR to visualize currently occurring but spatially distant consequences of a behavior ( ). For instance, Chirico et al. [19] visualized plastic consumption by showing plastic bottles in the user's immediate surroundings. It materializes a currently happening consequence in a concrete form by showing the average plastic consumption as plastic bottles in a natural environment. The experience does not include an active component though, so the person does not experience the plastic bottles as a direct consequence of an action performed in XR, rather it shows the generalized consequence of an occurring behavior (generalized as in showing plastic waste generated by a population and not an individual). The authors found that combining the plastic bottle visualization with a numerical one increased general attitudes toward the environment compared to a numerical visualization alone.

Another 6 papers used XR to visualize consequences as a direct feedback to an action in XR (/). These are cases where consequences typically occur in the future when accumulating the behavior over a longer time. However, in the presented interventions they occur in a "sped-up" way and are shown directly in the user's environment. They may also present a spatially distant consequence but can also show spatially close ones. In Fox and Bailenson [36], for instance, participants performed exercises in VR seeing a personal representation of themselves in front of them that visually gained or lost weight as a result of the action performed in VR, thus visualizing consequences that occur in the future in a sped-up way.

The researchers found an effect on exercise repetitions, which were higher in conditions where participants saw a self-representation. Papers in this category may also include behaviors that have accumulated effects that are spatially distant, such as Plechatá et al. [93], who show immediate environmental consequences as a feedback to food choice in a cooking task. However, the main focus is on the temporal domain as main advantage of XR.

Some 5 papers used XR to let participants experience their behavior and its consequences from different perspectives ( ). One such work is Gu et al. [43]'s experience on school bullying, where a participant's takes the bully's, victim's, or bystander's perspective to experience the consequences of their actions from different view points.

Another 4 papers visualized currently occurring but invisible consequences ( ), such as Xu and Dam [139]'s work on visualizing germs as discussed earlier in Subsection 4.1.2.

Two papers [103, 122] let participants intentionally experience negative consequences of their behavior immediately and in a safe way ( ). Schwebel et al. [103] let participants cross a busy road in VR while texting on their phone. The intention of the authors was to reduce distraction in street crossing behavior by exposing the participants to negative consequences thereof. Two weeks after the intervention participants self-reported to engage less in distracted pedestrian behavior. They also indicated that they were thinking more carefully about crossing streets while distracted. In Vankov et al. [122]'s VR experience participants could try out to drive a car under the influence of drugs. The VR experience visualized several perceptual effects of drugs like alcohol and cannabis, such as blurred vision. In a comparison to a group of participants who did not experience such effects, self-reported driving under the influence was not effected over the duration of three months.

Finally, 2 papers focused solely on visualizing temporally distant consequences ( ). In [20] participants took a walk through a cemetery with death-related cues to influence their attitudes towards risk taking. The temporal component here is to make a potential future consequence more salient to users. The experience was effective since it significantly increased risk perception in the cemetery scenario compared to participants who walked through a public park.

For the papers not related to consequences, ten used XR to display additional information while performing a behavior ( ). This might be information that is typically hidden but XR provides the possibility to visualize it in-sight (e.g., attention levels [40]) or information that visualizes abstract information, for example, visualizing the past performance while being physically active to improve performance [74].

8 papers used XR in a more traditional sense as simulation technology, letting participants practice a behavior ( ). They often highlight XR's capability to provide a replicable and controllable environment (e.g., [26, 70]), primarily to facilitate access to expensive equipment or complex, resource-intensive practice sessions, such as conducting a mooring operation [70]. An especially useful case is to practice responses to a behavior as prevention in a safe situation. For example, Weser et al. [130] allowed adolescents to practice how to refuse e-cigarettes. After the XR intervention, their knowledge increased, their perceived harms got heightened and their self-reported likelihood of use decreased.

5 papers leveraged XR's potential to gradually control a stimulus ( ), which is fundamental for exposure therapy. Here, XR allows participants to be gradually exposed to a triggering stimulus either in a fully virtual world [132] or by overlaying the physical world with a virtual stimulus, for example, a virtual spider in augmented reality that gradually moves closer to an arachnophobic patient [60]. Jicol et al. [57] was grouped into *gradual control over stimulus* but it overlaps with the practice category, because it simulates a street harassment situation and lets participants react to the harassment either actively or passively. Participants perceived VR to be significantly more useful than videos. Another example is experiencing a conflict resolution situation from the perspective of the person one is arguing with [141], as discussed earlier.

Finally, three papers leveraged XR's ability to give concrete form to abstract feelings or emotions ( ). Examples include Wagener et al. [126]'s Mood Worlds and Wagener et al. [127]'s use of virtual expressions to foster self-reflection.

5 Discussion

5.1 Discussion of Main Results

This paper was motivated by the emergence of XR-based behavior change interventions. It was particularly inspired by the compelling arguments made by several researchers (e.g., [11, 133]) about the many exciting opportunities XR offers, especially its potential to address limitations of traditional behavior change technologies. The most significant shift involves moving away from *information-centric* approaches, which have shown limited effectiveness [3], toward *experience-centric* approaches, as argued by HCI scholars researching behavior change technologies [94].

We examined technical and psychological XR components, behavior change theories (BCT and MoA), and the main advantages identified in the reviewed papers. We also assessed the reported effectiveness of these interventions. Our review highlights both the diversity and the breadth of the design space of XR interventions, demonstrating the potential of immersive technologies to visualize and support key aspects of intervention design. Regarding effectiveness, the results leave us optimistic, with 70% of the papers assessing short-term outcomes reporting positive and 11% mixed effects, and 67% of those evaluating long-term outcomes reporting positive and 11% mixed impacts. Comparisons between XR-based interventions and alternative technologies yielded slightly lower effectiveness, with 47% of the relevant studies reporting positive and 16% reporting mixed results. However, it is important to note that the comparison analysis is based on only 19 papers.

RQ_1. Most papers used VR as a simulation tool, replicating aspects of the physical world rather than exploiting its potential to influence perception. Implementations often used realistic or abstract elements, reflecting a conventional view of behavior change technologies. For instance, several papers visually illustrated how physical activity affects the body (e.g., [36, 119]), but none employed perceptual manipulations such as movement illusions [22] or weight manipulations [97]. This may be because most of the reviewed papers were published outside of HCI, highlighting a clear opportunity for the HCI community to contribute more substantially in this area.

Regarding psychological factors, our analysis focused on high-level constructs due to diverse study designs. Overall, XR appears underutilized in its potential to affect psychological outcomes.

RQ_2. Our analysis of BCTs and MoAs revealed a reliance on traditional approaches, with *Knowledge* being the most common MoA (31 papers). However, some papers leveraged XR's unique capabilities to visualize social or environmental consequences in users' surroundings. In addition, the BCT *comparison of behavior* was fairly populated, suggesting XR's suitability for illustrating alternative futures. AR-based interventions showed promising short-term effects, indicating that integrating virtual elements into physical environments may be a fruitful research direction. Conversely, *comparison of outcomes* had the fewest positive results, reinforcing that targeting behavior itself, rather than its outcomes, is generally more effective, consistent with prior findings in behavioral science [78].

RQ_3. We measured effectiveness as a binary variable and are optimistic about XR's potential, though measuring actual behavior change is challenging. For example, interventions targeting bullying [43] or street harassment [57] face ethical and logistical barriers leading many studies to measure intentions instead. However, intentions only weakly predict behavior, as a recent meta-analysis [128] found that even large intention shifts yield modest behavioral change.

Most papers included multiple measures, targeting different aspects of behavior. In our causal figures, we captured detailed information about each measurement and its respective effectiveness, as described in Subsection 3.5. For instance, some papers reported mediating factors (e.g., presence level [84] or self-efficacy ratings [92]) influencing behavior, which could not be captured within the scope of this high-level analysis.

RQ_4. We analyzed the main advantages of the reviewed papers using the psychological barriers outlined in Wienrich et al. [133]'s BehaveFIT framework. Reviewed papers often employed temporal and spatial strategies to make consequences more immediate. While the BehaveFIT barriers proved useful, they lacked the granularity needed to fully capture the nuanced ways in which consequences were implemented. To address this, we categorized the papers by XR's main advantage, which may serve as an initial step toward constructing a design space that maps the possibilities XR offers for implementing behavior change mechanisms. However, for such a design space to be practically useful, a more nuanced articulation of these dimensions is needed. The traditional focus is evident in this analysis too, with most papers falling into the category of *visualizing abstract information.* Often XR is used to make invisible information visible or to provide it in-context (e.g., showing the environmental impact of a product in a grocery store [72]). However, we believe that XR can go further. For example, some studies enabled participants to create their own virtual world based on virtual drawing of their inner states [126, 127].

5.2 How Extended Reality Can Support Behavior Change

Our review revealed that XR offers a broad design space for implementing behavior change interventions, yet most reviewed studies used XR primarily as a simulation tool rather than leveraging its unique experiential qualities. Below, we discuss ideas how XR can support behavior change through its advantages and qualities.

5.2.1 Which MoAs and BCTs are XR interventions useful for? While *Knowledge* was the most common MoA, XR offers many opportunities to target other mechanisms. For instance, *Feedback Processes* could leverage physiological sensors integrated into XR devices to provide dynamic, in-situ feedback, integrating the feedback with the actual action. Feedback mechanisms in XR are not limited to 2D overlays and could show past versions of the user as non-embodied avatars, such as the "ghosts" in Michael and Lutteroth [74]. Furthermore, feedback is not limited to the visual modality. users could embody previous versions of themselves and experience differences through redirection techniques. Similarly, *Self-image* and *Beliefs about Capabilities* could be reinforced by allowing users to perform actions in XR and then switch perspectives to observe themselves succeeding. For BCTs, XR is particularly promising for *Natural Consequences.* Most reviewed papers simulated distant environments, but XR could show consequences in users' immediate surroundings, for example, visualizing climate change effects on their own plants instead of on far-away flora and fauna or flooding their living room to depict rising sea levels. Personalization adds further potential to enhance existing mechanisms of behavior change: deterrent images on cigarette packs could be replaced with visual changes to the user's own body or hands when reaching for a packet.

5.2.2 How can the relation to the physical world support behavior change? Augmenting the physical world primarily targets a person's direct context, positioning the intervention directly in a person's surroundings. This might make behavior change faster and easier by relating it directly to a person's context, as discussed in the examples relating consequences above. It might also make the actions required for behavior change more salient and actionable. For example, one could augment specific targets (e.g., healthy food) in the environment and hide others (e.g., candy) when a person aims to learn a behavior (e.g., eating more healthy). That way AR interventions could use saliency manipulation [113] to decrease saliency of stimuli that might trigger a negative behavior or habit, or, alternatively increase saliency of stimuli triggering desired behavior.

Simulating and replicating environments was the most common technique for linking virtual and physical content. This approach could be extended by gradually adapting the simulated environment based on user feedback. Over time, simulations could transition into augmentations of the physical environment, moving from controlled setups in entirely virtual worlds toward experiences that are integrated into everyday life through AR.

Time projections of the physical world ere less explored than expected and deserve deeper exploration. Few studies examined this component in detail, including factors such as a person's degree of control over the time projections, which is connected to several of their actions (e.g., seeing their consequences immediately versus seeing them delayed). XR could enable mechanisms that let users 'travel through time' to experience the long-term impact of their behaviors across different environments. This approach holds significant potential for comparative studies, exploring how various future visualizations influence the perceived relevance of consequences.

Creating abstract virtual worlds remains underutilized, despite creating spatial imaginary or abstract worlds being one of the unique advantages of XR, and it is surprising to not see more research in this direction. Abstract virtual worlds could not only be used for visualizing abstract constructs as done in Wagener et al. [126]'s work but could also help people visualize difficulties throughout the behavior change process, focusing more on the visualization of the experience. Those worlds could also be explored collaboratively.

5.2.3 How can XR interventions support behavior change or habit formation over time? While short-term effects of XR interventions are promising, few studies examined long-term behavior change. However, XR might be particularly useful to support behavior change and habit formation over time. For example, devices could detect emerging habits and provide personalized suggestions, highlighting which habits to strengthen and where new behaviors could fit, following the argumentation that habits are the main driver for behavior change [3] and connecting new habits to existing ones is often more successful than establishing them alone. XR could also help bridge the intention–behavior gap by making intentions visible and salient in everyday contexts. Using self-avatars, the concept of self-future continuity [38] could be further explored. For instance, when struggling to adhere to a defined behavior, users could interact and converse with different versions of their future selves, embodying successful change.

5.3 Critical Perspective on When Extended Reality *Should* Be Used for Behavior Change

Our analysis highlights XR's advantages for behavior change. However, many papers still relied on more traditional approaches, often based on knowledge as the main mechanism and not entirely leveraging XR's potential. Given challenges such as VR sickness and general discomfort [49], limited accessibility [136], security and privacy risks [41, 71], and ethical concerns around perceptual manipulations [86], it is critical to discuss when does XR offer enough added value to justify its use for behavior change?

Few reviewed papers discussed ethical implications or moral concerns. Yet, there are many potential consequences on individual or societal level. The experiences presented in the papers focused on enabling positive behavior change, often without engaging in a critical perspective of potential negative effects. As some researchers argue, including XR into our daily life can have consequences on perceptual integrity [86] and the balance between the advantages and disadvantages need to be discussed in more detail. For VR, the DICE framework [10] suggests that we should use VR primarily for experiences that are Dangerous, Impossible, Counterproductive, or Expensive. Several papers align with this principle (e.g., [103] exposing users to distracted walking risks safely).

However, we argue that relying solely on DICE or functional comparisons fails to recognize the unique psychological qualities of XR and the advantages offered by them, such as presence and embodiment. While 2D displays can provide information about future consequences (e.g., visually displaying weight gain), they typically keep the user in a third-person perspective. In contrast, XR allows users to experience these consequences more vividly. For instance, van der Waal et al. [119] demonstrated that embodying an overweight avatar in VR, rather than simply observing, created a sense of virtual body ownership, which significantly increased the perceived severity of the health threat, which in turn motivated actual behavior change. This suggests that XR's unique advantage lies in its ability to bridge the gap between knowing a risk and feeling or *experiencing* it personally, transforming an abstract concept into a personal and tangible experience. However, we yet lack guidelines or evaluative principles that guide researchers when such experiences outweigh the negative components.

5.4 Toward Theory-Driven XR Behavior Change Interventions

As illustrated in our paper, XR provides a plethora of possibilities how to implement behavior change interventions, which is not available or possible using traditional intervention techniques. The almost limitless control it provides makes XR an ideal tool for behavioral experiments, and frequently argued in previous research [11, 13]. However, there is a significant gap between the potential of XR and its current application. While the design dimensions for XR interventions are seemingly infinite, our review shows that they are only sparsely utilized. Therefore, a concrete next step is to formalize this design space in order to create an actionable tool that enables behavioral science researchers to leverage XR to its full potential.

Similar to previous work analyzing how underlying processes (e.g., determinants [3], mediators [47], or our used BCTs and MoAs [15, 76]) are represented in behavior change interventions, we found that the proposed interventions included on average 2 BCTs and 3.4 MoAs. This makes it difficult to allocate effects to individual underlying mechanisms. This might be intentional but likely caused by a predominantly exploratory focus of the studies that often did not set out from a concrete BCT or other construct but used rather speculative argumentation for their concrete design. This is fine for an initial exploration of the design space of XR behavior change interventions. However, in the long-run it many individual techniques, which makes it difficult, if not impossible, to synthesize their effects in meta-analyses or other secondary research synthesis methods. This is surely a challenge for behavior change research in general. Take the simple quantity of behavior change theories and models (e.g., [75, 77, 124]). However, we argue that HCI or XR researchers should not try to reinvent the wheel here and document their point of departure by clearly identifying and reporting the theory or behavioral model they use for their work. Therefore, we make the following suggestions toward theory-driven XR behavior change interventions, addressed to researchers and practitioners and summarized in Table 8 and Table 9.

Our suggestions are grouped into *XR-related* suggestions, *theoretical grounding*, and *measures*. The part on theoretical grounding of behavior change interventions is not unique to our work, and has been stated before in HCI [47] and the behavioral research field [105]. However, our intention is that this work serves to bridge behavioral change theory with work on XR. Therefore, we repeat some longstanding recommendations from prior research with a particular focus on XR.

As noted throughout the paper, the heterogeneity of study designs and XR-related qualities prevented us from analyzing causal

Table 8: Framework for theory-driven XR behavior change interventions. Part 1.

	Topic	Suggestion
	Extended Reality/Immersive Technologies	
☑	Psychological XR Qualities	When designing a VR intervention consider effects of *Presence* (consider Xiao et al. [137]'s work of the construct's dimensions), *Agency*, *Perspective*, and *Connection to Action*, which emerged as core qualities with potential influences on XR outcomes.
☑	Participants' Engagement in Behavior in XR	Clearly state how participants experience the XR behavior change intervention (i.e., first-person vs. embodied vs. third-person). Participant engagement in the behavior emerged as a critical distinction but was rarely explicitly explained. For example, first-person view and owning a body in VR might appear similar in their effects on view point but are fundamentally different. Also explain how the actions performed in XR are connected to the intended behavior change and why. In particular, justify reasons for why participants passively experience or actively engage in the behavior and their expected effects.
☑	Multimodal Manipulations	Consider going beyond visual manipulations toward embracing XR's ability to influence perception in other modalities (e.g., haptic and auditory) and how they could be used for behavior change.The review revealed a lack of non-visual perceptual manipulations.
☑	Purpose of XR	Clearly articulate your intentions and arguments for using XR and relate them to the theoretical construct mention in *Theoretical Grounding*. Authors often provided immersion as reason, which is simply a definition of the technology and does not satisfyingly explain the need for using XR.

effects of XR features on behavioral outcomes. For example, whether presence or agency directly affect behavior change cannot be answered in this review because the available data do not support such conclusions. Our framework is therefore intended to guide researchers in designing XR interventions that enable systematic meta-analyses in the future. It summarizes the types of changes needed in reporting and targeting XR interventions to be able to synthesize causal effects.

5.4.1 Research Gaps. The framework summarizes the learning from our findings into suggestions on how to conduct XR behavior change intervention studies in a reliable and valid way. This process also let us to discover a number of research gaps, which we outline in the following.

Perspective. The point of view or perspective through which a person experiences a behavior should be further studied. Hoppe et al. [52] propose a continuum of viewing perspectives in VR including embodiment and view, which could be an interesting foundation for studying effect of viewing perspective on behavioral outcomes. This is related to studies on perspective-taking [121], which are an interesting overlap of behavior change and social psychology, both supported through XR.

Long-term effects of illusions. Another research gap is studying how perceptual manipulations or illusions, such as the embodiment illusion [61], influence behavior in a long-term perspective. While immediate effects were found in the reviewed papers, pro-longed results are necessary to fully evaluate their usefulness.

Multimodal manipulations. The reviewed studies relied heavily on the visual modality. Longstanding research efforts on other modalities, such as haptics [97] or movement illusions [22], are underutilized but could be useful for inducing behavior change, for example, by letting users practice a behavior.

Another example is the sense of embodiment. While some researchers looked into effects of embodying different avatars, seeing one's actions projects into the future, such as visualizing oneself performing a behavior, similar to Muresan et al. [85]'s work on feedforward movement visualization to reveal interaction possibilities.

The role of realism. Realism is a much discussed concept within the XR community. Generally, researchers have not reached a conclusive result how important realism is when it comes to visual photorealism. While XR does have the potential to create visually realistic avatars and environments, its importance to behavioral outcomes is understudied. It would be valuable to study realism as a main influencing factor on behavioral outcomes and to identify which dimensions of realism (e.g., visual realism, behavioral realism) predict behavioral change.

Ethical and societal implications. Ethical and societal implications are rarely discussed. As laid out in Subsection 5.3, few papers mentioned or explained ethical consequences. More research should go into discussing the impact of using XR illusions to influence a person's behavior. Important questions are, which behavioral use cases justify the use of XR? How long should XR interventions be

Table 9: Framework for theory-driven XR behavior change interventions. Part 2.

	Topic	Suggestion
	Theoretical Grounding	
☑	Grounding in Behavior Change Theory	Clearly state the behavior change theory you subscribe to (e.g., the BCT taxonomy [76]). Ideally, focus on one at a time or clearly describe how the individual ones will interact. We presented a general categorization of interventions into BCTs in Table 3 and a more detailed one into sub-categories in Appendix E.
☑	State Underlying Behavioral Processes	Determine and state the mechanisms through which your intervention is expected to change behavior and explain how the XR design targets them. Use structural classifications, such as Albarracín et al. [3]'s determinants or the MoAs [15] used here. Only through clear links of intended mechanisms, we can increase our knowledge about their effectiveness.
☑	Clarify Behavior-XR Hypothesis	Clarify the effect you hope to find by clearly connecting XR features to the behavior change theory they are based on and the measures obtained. We suggest to use causal models [123] or our figures in Appendix C.1 to help structuring this process.
	Measures and Study Design Considerations	
☑	Outcome Measure	Clearly differentiate measures between *behavioral outcome*, *behavioral intention*, and *behavioral outcome measured in XR*. More research should focus on comparing and relating them to each other. In particular, the link between behavior and intention seems weak [3, 128] but could be strengthened with XR by experiencing rather than receiving information about a behavior.
☑	Behavioral Time Frame	State the time frame over which you expect the behavior change to occur and explain why it is adequate. In particular, more studies need to focus on long-term behavior change, done by only few of the reviewed papers.
☑	Comparative versus Time Effectiveness	Clearly articulate if you aim to show that XR has an advantage over another technology (*comparative effectiveness*) or if you aim to show that it is effective to change a behavior over time, independent of another technology (*pre-post effectiveness*).
☑	Justify Measures	Justify the measures used to evaluate the behavior change and relate them to behavior change theory. The Human Behaviour Change Project [53] provides an excellent online tool for relating BCTs to MoAs, also listing corresponding measures. Explain how you deal with methodological problems, such as repeated exposure to questionnaires, potentially reducing reliability of effects.
☑	Combine Several Sources	If possible, combine several measures of a behavior, for example, combine objective and subjective measures to support reliability and robustness.
☑	Justify Study Design	Behavior is influenced by a variety of personal and environmental factors [46]. Justify the study design used. If you use a between-design make sure to match participants along critical dimension (e.g., prior exposure to behavior, XR experience) to avoid confounder effects.
☑	Novelty Effects	AR and VR are still emerging as consumer technologies and many people have not used them before. Make sure participants get enough practice with the technology to avoid a confounder effect of novelty.

recommended to be used? Do XR behavior change interventions lead to a new form of technology addiction?

5.5 Limitations and Future Work

This review covers only 53 papers, as we intentionally included only those explicitly mentioning "behavior change". We chose this approach to balance relevance and reduce false positives. Including terms that represent specific instances of behavior change, such as "exposure therapy" or "practicing behaviors", would likely have expanded the set of papers. However, doing so would have required selecting a representative, non-random subset of instances, which was not feasible at the outset, as identifying these main advantages of using XR for behavior change was one of our analysis goals. A systematic review focusing on the effects of specific behavior change instances would be a valuable next step for this work but seems currently impossible because of the variety of measures.

We labeled the BCTs and MoAs based on the arguments presented in the papers for using XR and the theories they referenced. However, we acknowledge that some BCTs and MoAs may have been assigned differently than intended by the original authors. Our aim was not to evaluate whether papers included direct statements about these elements but rather to gain an initial overview of how behavior change theory is currently applied in XR interventions. The primary goal was to analyze the summative evidence across studies.

Our choice of reporting effectiveness as binary variable does not allow for more detailed insights into how specific components of the interventions influence behavioral aspects. Due to the high heterogeneity of study designs, measures, targeted behaviors, it was, unfortunately, not possible to provide more fine-grained analyses of effectiveness. We made an attempt at analyzing XR-specific influence factors (e.g., agency and embodiment). However, due to the sparse data (cause by not all studies measuring these) the models did not converge (see Appendix G for details on the regression models). Research Gaps We analyzed complex psychological constructs (i.e., agency and embodiment) in a rather simplistic way by treating both as binary variables. We are aware that these constructs are more complex and multi-dimensional as the paper could consider. We hope that through our framework future studies follow a more structured and cohesive presentation, such that effects of these constructs can be analyzed more cohesively.

In future work, we plan to build on this review by further quantifying and formalizing the relationship between individual XR components and behavior change theories, with a focus on their effectiveness. Specifically, we aim to expand the regression analyses presented in Appendix G toward a meta-analysis of effects. However, this requires conducting a systematic review, which was beyond the scope of the current work.

6 Conclusion

This scoping review analyzed 53 XR behavior change interventions across technical and psychological XR components, behavior change theories, particularly behavior change techniques [76] and mechanisms of action [15], and identified their effectiveness and the unique advantages of XR for behavior change. We found that XR interventions are generally effective in the short term. Of the papers measuring short-term effectiveness, 70% showed positive and 11% partially positive effects. Of the 9 papers measuring long-term effects, 67% showed positive and 11% mixed results. While we set out to uncover how XR's unique capabilities, such as showing temporally or spatially distant consequences of a behavior directly in a user's environment or manipulating one's virtual body, are used to design behavior change interventions, we found that most XR interventions fell back into a known pattern of showing information as the main mechanism to influence behavior, only scratching the surface of what is possible with XR. Furthermore, due to the wide variety of measures and the lack of clearly stated theoretical grounding in behavior change theories in the reviewed papers, it remains difficult to summarize and explain causal effects. Addressing these limitations, we suggest a framework toward theory-driven XR behavior change interventions that covers both behavioral theory and XR details. With this framework, we aim to bridge behavioral sciences and HCI to foster more theory-driven XR behavior change interventions. It serves as a guideline for XR researchers to engage with behavior change theory, and for behavioral scientists to explore XR's broad design space and implementation possibilities.

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References

References marked with are in the set of reviewed papers.

[1] Charles Abraham and Susan Michie. 2008. A taxonomy of behavior change techniques used in interventions. *Health psychology* 27, 3 (2008), 379.

[2] Dolores Albarracin and Sharon Shavitt. 2018. Attitudes and Attitude Change. *Annual Review of Psychology* 69, Volume 69, 2018 (2018), 299–327. doi:10.1146/annurev-psych-122216-011911 Publisher: Annual Reviews Type: Journal Article.

[3] Dolores Albarracín, Bita Fayaz-Farkhad, and Javier A. Granados Samayoa. 2024. Determinants of behaviour and their efficacy as targets of behavioural change interventions. *Nature Reviews Psychology* 3, 6 (June 2024), 377–392. doi:10.1038/s44159-024-00305-0

[4] Inês Alves and Augusto Esteves. 2024. MeetingBenji: Tackling Cynophobia with Virtual Reality, Gamification, and Biofeedback. In *Proceedings of the 30th ACM Symposium on Virtual Reality Software and Technology* (Trier, Germany) *(VRST '24)*. Association for Computing Machinery, New York, NY, USA, Article 4, 9 pages. doi:10.1145/3641825.3687747

[5] Sonhaji Arif, Putra Uji Deva Satrio, Athika Dwi Wiji Utami, Trias Widha Andari, Amalia Hartiningrum, and Arda Surya Editya. 2024. Design and Development UI/UX on Simulation of Earthquake Mitigation Based Mobile Virtual Reality. In *2024 Seventh International Conference on Vocational Education and Electrical Engineering (ICVEE)*. 257–261. doi:10.1109/ICVEE63912.2024.10823698

[6] Hilary Arksey and Lisa O'Malley. 2005. Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology* 8, 1 (2005), 19–32. arXiv:https://doi.org/10.1080/1364557032000119616 doi:10.1080/1364557032000119616

[7] Edoardo Aromataris, Craig Lockwood, Kylie Porritt, Bianca Pilla, and Zoe Jordan. 2024. *JBI Manual for Evidence Synthesis.* JBI. doi:10.46658/JBIMES-24-01 Accessed: 2025-09-07.

[8] Jorge Arroyo-Palacios and Mel Slater. 2016. Dancing with Physio: A Mobile Game with Physiologically Aware Virtual Humans. *IEEE Transactions on Affective Computing* 7, 4 (2016), 326–336. doi:10.1109/TAFFC.2015.2472013

[9] Ronald T. Azuma. 1997. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments* 6, 4 (Aug. 1997), 355–385. doi:10.1162/pres.1997.6.4.355 _eprint: https://direct.mit.edu/pvar/article-pdf/6/4/355/1623026/pres.1997.6.4.355.pdf.

[10] Jeremy Bailenson. 2018. *Experience on demand: What virtual reality is, how it works, and what it can do.* WW Norton & Company.

[11] Jeremy N. Bailenson, Cyan DeVeaux, Eugy Han, David M. Markowitz, Monique Santoso, and Portia Wang. 2025. Five canonical findings from 30 years of psychological experimentation in virtual reality. *Nature Human Behaviour* 9, 7 (July 2025), 1328–1338. doi:10.1038/s41562-025-02216-3

[12] Manon Berney, Abdessalam Ouaazki, Vladimir Macko, Bruno Kocher, and Adrian Holzer. 2024. Care-Based Eco-Feedback Augmented with Generative AI: Fostering Pro-Environmental Behavior through Emotional Attachment. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 469, 15 pages. doi:10.1145/3613904.3642296

[13] Jim Blascovich, Jack Loomis, Andrew C. Beall, Kimberly R. Swinth, Crystal L. Hoyt, and Jeremy N. Bailenson and. 2002. TARGET ARTICLE: Immersive Virtual Environment Technology as a Methodological Tool for Social Psychology. *Psychological Inquiry* 13, 2 (2002), 103–124. arXiv:https://doi.org/10.1207/S15327965PLI1302_01 doi:10.1207/S15327965PLI1302_01

[14] LouAnne E. Boyd, Saumya Gupta, Sagar B. Vikmani, Carlos M. Gutierrez, Junxiang Yang, Erik Linstead, and Gillian R. Hayes. 2018. vrSocial: Toward Immersive Therapeutic VR Systems for Children with Autism. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3173574.3173778

[15] Rachel N Carey, Lauren E Connell, Marie Johnston, Alexander J Rothman, Marijn de Bruin, Michael P Kelly, and Susan Michie. 2018. Behavior Change Techniques and Their Mechanisms of Action: A Synthesis of Links Described in Published Intervention Literature. *Annals of Behavioral Medicine* 53, 8 (10 2018), 693–707. arXiv:https://academic.oup.com/abm/article-pdf/53/8/693/28943866/kay078.pdf doi:10.1093/abm/kay078

[16] M. Carmen Juan, David Furio, Leila Alem, Peta Ashworth, and Juan Cano. 2011. ARGreenet and BasicGreenet: Two mobile games for learning how to recycle. In *WSCG 2011: FULL PAPERS PROCEEDINGS*, G Baranoski and V Skala (Eds.). Sprinx Syst AS; Silicon Graph SRO; NVIDIA Corp; Microsoft SRO CR; ZONER Software AS; Dept Comp Sci & Engn, Fac Appl Sci, UNION AGENCY SCIENCE PRESS, NA MAZINACH 9, PLZEN, 322 00, CZECH REPUBLIC, 25+. 19th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision, Univ W Bohemia, Plzen, CZECH REPUBLIC, JAN 31-FEB 03, 2011.

[17] Yi Fei Cheng, Hang Yin, Yukang Yan, Jan Gugenheimer, and David Lindlbauer. 2022. Towards Understanding Diminished Reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 549, 16 pages. doi:10.1145/3491102.3517452

[18] Grace H.Y. Chin and Kenny K.N. Chow. 2023. Technology-Enabled Interventions for Sustaining Behaviour Change in Adolescents: A Scoping Review for Research Gaps. *Proc. ACM Hum.-Comput. Interact.* 7, CSCW2, Article 362 (Oct. 2023), 30 pages. doi:10.1145/3610211

[19] Alice Chirico, Giulia Wally Scurati, Chiara Maffi, Siyuan Huang, Serena Graziosi, Francesco Ferrise, and Andrea Gaggioli. 2021. Designing virtual environments for attitudes and behavioral change in plastic consumption: a comparison between concrete and numerical information. *Virtual Real.* 25, 1 (March 2021), 107–121. doi:10.1007/s10055-020-00442-w

[20] Luca Chittaro, Riccardo Sioni, Cristiano Crescentini, and Franco Fabbro. 2017. Mortality salience in virtual reality experiences and its effects on users' attitudes towards risk. *International Journal of Human-Computer Studies* 101 (2017), 10–22. doi:10.1016/j.ijhcs.2017.01.002

[21] Mathieu Chollet, Torsten Wörtwein, Louis-Philippe Morency, Ari Shapiro, and Stefan Scherer. 2015. Exploring feedback strategies to improve public speaking: an interactive virtual audience framework. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) *(UbiComp '15)*. Association for Computing Machinery, New York, NY, USA, 1143–1154. doi:10.1145/2750858.2806060

[22] Mantas Cibulskis, Difeng Yu, Erik Skjoldan Mortensen, Waseem Hassan, Mark Schram Christensen, and Joanna Bergström. 2025. Tendon Vibration for Creating Movement Illusions in Virtual Reality. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 1136, 16 pages. doi:10.1145/3706598.3714003

[23] Mark Colley, Jan Ole Rixen, Italgo Walter Pellegrino, and Enrico Rukzio. 2022. (Eco-)Logical to Compare? - Utilizing Peer Comparison to Encourage Ecological Driving in Manual and Automated Driving. In *Proceedings of the 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Seoul, Republic of Korea) *(AutomotiveUI '22)*. Association for Computing Machinery, New York, NY, USA, 24–33. doi:10.1145/3543174.3545256

[24] Sunny Consolvo, David W. McDonald, Tammy Toscos, Mike Y. Chen, Jon Froehlich, Beverly Harrison, Predrag Klasnja, Anthony LaMarca, Louis LeGrand, Ryan Libby, Ian Smith, and James A. Landay. 2008. Activity sensing in the wild: a field trial of ubifit garden. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Florence, Italy) *(CHI '08)*. Association for Computing Machinery, New York, NY, USA, 1797–1806. doi:10.1145/1357054.1357335

[25] Simon Cooper, Robyn Cant, Michelle Kelly, Tracy Levett-Jones, Lisa McKenna, Philippa Seaton, and Fiona Bogossian. 2021. An Evidence-Based Checklist for Improving Scoping Review Quality. *Clinical Nursing Research* 30, 3 (March 2021), 230–240. doi:10.1177/1054773819846024 Publisher: SAGE Publications Inc.

[26] Andrew Cordar, Adam Wendling, Casey White, Samsun Lampotang, and Benjamin Lok. 2017. Repeat after me: Using mixed reality humans to influence best communication practices. In *2017 IEEE Virtual Reality (VR)*. 148–156. doi:10.1109/VR.2017.7892242

[27] Pedro Henrique Barcha Correia. 2024. Adaptive Virtual Reality Solutions: A Literature Review. In *Proceedings of the 26th Symposium on Virtual and Augmented Reality* (Manaus, Brazil) *(SVR '24)*. Association for Computing Machinery, New York, NY, USA, 1–10. doi:10.1145/3691573.3691574

[28] Laura D Cosio, Oğuz 'Oz' Buruk, Daniel Fernández Galeote, Isak De Villiers Bosman, and Juho Hamari. 2023. Virtual and Augmented Reality for Environmental Sustainability: A Systematic Review. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 6, 23 pages. doi:10.1145/3544548.3581147

[29] Rachel Davis, Rona Campbell, Zoe Hildon, Lorna Hobbs, and Susan Michie. 2015. Theories of behaviour and behaviour change across the social and behavioural sciences: a scoping review. *Health Psychology Review* 9, 3 (2015), 323–344. arXiv:https://doi.org/10.1080/17437199.2014.941722 doi:10.1080/17437199.2014.941722 PMID: 25104107.

[30] Carolina Del-Valle-Soto, Juan Carlos López-Pimentel, Javier Vázquez-Castillo, Juan Arturo Nolazco-Flores, Ramiro Velázquez, José Varela-Aldás, and Paolo Visconti. 2024. A Comprehensive Review of Behavior Change Techniques in Wearables and IoT: Implications for Health and Well-Being. *Sensors (Basel, Switzerland)* 24, 8 (April 2024). doi:10.3390/s24082429 Place: Switzerland.

[31] Joann Difede and Hunter G. Hoffman. 2002. Virtual Reality Exposure Therapy for World Trade Center Post-traumatic Stress Disorder: A Case Report. *CyberPsychology & Behavior* 5, 6 (2002), 529–535. arXiv:https://doi.org/10.1089/109493102321018169 doi:10.1089/109493102321018169 PMID: 12556115.

[32] Matilda Eve Dunn, Gautam Shah, and Diogo Veríssimo. 2021. Stepping into the Wildeverse: Evaluating the impact of augmented reality mobile gaming on pro-conservation behaviours. *People and Nature* 3, 6 (2021), 1205–1217. arXiv:https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1002/pan3.10273 doi:10.1002/pan3.10273

[33] H. Farmer, E. Skoulikari, C. Bevan, S. Gray, K. Cater, and D. Stanton Fraser. 2024. Using narrative 360° video as a tool to promote breast self-examination. *VIRTUAL REALITY* 28, 1 (MAR 2024). doi:10.1007/s10055-023-00918-5

[34] Danielle T. Felsberg, Jaclyn P. Maher, and Christopher K. Rhea. 2019. The State of Behavior Change Techniques in Virtual Reality Rehabilitation of Neurologic Populations. *Frontiers in Psychology* Volume 10 - 2019 (2019). doi:10.3389/fpsyg.2019.00979

[35] Diana Fonseca and Martin Kraus. 2016. A comparison of head-mounted and hand-held displays for 360° videos with focus on attitude and behavior change. In *Proceedings of the 20th International Academic Mindtrek Conference* (Tampere, Finland) *(AcademicMindtrek '16)*. Association for Computing Machinery, New York, NY, USA, 287–296. doi:10.1145/2994310.2994334

[36] Jesse Fox and Jeremy N. Bailenson. 2009. Virtual Self-Modeling: The Effects of Vicarious Reinforcement and Identification on Exercise Behaviors. *Media Psychology* 12, 1 (2009), 1–25. doi:10.1080/15213260802669474

[37] Caroline Free, Gemma Phillips, Leandro Galli, Louise Watson, Lambert Felix, Phil Edwards, Vikram Patel, and Andy Haines. 2013. The Effectiveness of Mobile-Health Technology-Based Health Behaviour Change or Disease Management Interventions for Health Care Consumers: A Systematic Review. *PLOS Medicine* 10, 1 (01 2013), 1–45. doi:10.1371/journal.pmed.1001362

[38] Benjamin Ganschow, Liza Cornet, Sven Zebel, and Jean-Louis van Gelder. 2021. Looking Back From the Future: Perspective Taking in Virtual Reality Increases Future Self-Continuity. *Frontiers in Psychology* Volume 12 - 2021 (2021). doi:10.3389/fpsyg.2021.664687

[39] Benjamin Ganschow, Sven Zebel, Jean-Louis van Gelder, and Liza J. M. Cornet. 2024. Feeling connected but dissimilar to one's future self reduces the intention-behavior gap. *PLOS ONE* 19, 7 (07 2024), 1–15. doi:10.1371/journal.pone.0305815

[40] Eftichia Georgiou, Giorgos-Konstanditos Thanos, Tassos Kanellos, Adam Doulgerakis, and Stelios CA Thomopoulos. 2019. Evaluating the relation between the EEG brainwaves and attention measures, and the children's performance in REEFOCUS game designed for ADHD symptoms improvement. In *Smart Biomedical and Physiological Sensor Technology XVI*, Vol. 11020. SPIE, 189–198.

[41] Alberto Giaretta. 2024. Security and privacy in virtual reality: a literature survey. *Virtual Reality* 29, 1 (Dec. 2024), 10. doi:10.1007/s10055-024-01079-9

[42] Jens Emil Sloth Grønbæk, Juan Sánchez Esquivel, Germán Leiva, Eduardo Velloso, Hans Gellersen, and Ken Pfeuffer. 2024. Blended Whiteboard: Physicality and Reconfigurability in Remote Mixed Reality Collaboration. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 798, 16 pages. doi:10.1145/3613904.3642293

[43] Xiang Gu, Sheng Li, Kangrui Yi, Xiaojuan Yang, Huiling Liu, and Guoping Wang. 2023. Role-Exchange Playing: An Exploration of Role-Playing Effects for Anti-Bullying in Immersive Virtual Environments. *IEEE Transactions on Visualization and Computer Graphics* 29, 10 (Oct 2023), 4215–4228. doi:10.1109/TVCG.2022.3184986

[44] Gahgene Gweon, Bugeun Kim, Jinyoung Kim, Kung Jin Lee, Jungwook Rhim, and Jueun Choi. 2018. MABLE: Mediating Young Children's Smart Media Usage with Augmented Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–9. doi:10.1145/3173574.3173587

[45] Carrie Heater. 1992. Being there: The subjective experience of presence. *Presence Teleoperators Virtual Environ.* 1, 2 (1992), 262–271.

[46] Joe E. Heimlich and Nicole M. Ardoin. 2008. Understanding behavior to understand behavior change: a literature review. *Environmental Education Research* 14, 3 (2008), 215–237. arXiv:https://doi.org/10.1080/13504620802148881 doi:10.1080/13504620802148881

[47] Eric B. Hekler, Predrag Klasnja, Jon E. Froehlich, and Matthew P. Buman. 2013. Mind the theoretical gap: interpreting, using, and developing behavioral theory in HCI research. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 3307–3316. doi:10.1145/2470654.2466452

[48] Linda Hirsch, Robin Welsch, Beat Rossmy, and Andreas Butz. 2022. Embedded AR Storytelling Supports Active Indexing at Historical Places. In *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Daejeon, Republic of Korea) *(TEI '22)*. Association for Computing Machinery, New York, NY, USA, Article 22, 12 pages. doi:10.1145/3490149.3501328

[49] Teresa Hirzle, Maurice Cordts, Enrico Rukzio, Jan Gugenheimer, and Andreas Bulling. 2021. A Critical Assessment of the Use of SSQ as a Measure of General Discomfort in VR Head-Mounted Displays. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 530, 14 pages. doi:10.1145/3411764.3445361

[50] Teresa Hirzle, Florian Müller, Fiona Draxler, Martin Schmitz, Pascal Knierim, and Kasper Hornbæk. 2023. When XR and AI Meet - A Scoping Review on Extended Reality and Artificial Intelligence. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 730, 45 pages. doi:10.1145/3544548.3581072

[51] Karen Hofman, Gabby Walters, and Karen Hughes. 2022. The effectiveness of virtual vs real-life marine tourism experiences in encouraging conservation behaviour. *Journal of Sustainable Tourism* 30, 4 (2022), 742–766. arXiv:https://doi.org/10.1080/09669582.2021.1884690 doi:10.1080/09669582.2021.1884690

[52] Matthias Hoppe, Andrea Baumann, Patrick Chofor Tamunjoh, Tonja-Katrin Machulla, Paweł W. Woźniak, Albrecht Schmidt, and Robin Welsch. 2022. There Is No First- or Third-Person View in Virtual Reality: Understanding the Perspective Continuum. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 360, 13 pages. doi:10.1145/3491102.3517447

[53] Human Behaviour Change Project. 2025. Theory and Techniques Tool. https://theoryandtechniquetool.humanbehaviourchange.org/tool Accessed: 2025-09-11.

[54] Christos Ioannou, Patrick Archard, Eamonn O'Neill, and Christof Lutteroth. 2019. Virtual Performance Augmentation in an Immersive Jump & Run Exergame. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3290605.3300388

[55] Tatsuya Ito, Takeshi Kamita, Atsuko Matsumoto, Tsunetsugu Munakata, and Tomoo Inoue. 2018. Virtual Reality Course Based on the SAT Counseling Method for Self-Guided Mental Healthcare. In *2018 IEEE International Conference on Healthcare Informatics (ICHI)*. 299–306. doi:10.1109/ICHI.2018.00041

[56] Jade Jiang and Naseem Ahmadpour. 2022. Beyond Immersion: Designing for Reflection in Virtual Reality. In *Proceedings of the 33rd Australian Conference on Human-Computer Interaction* (Melbourne, VIC, Australia) *(OzCHI '21)*. Association for Computing Machinery, New York, NY, USA, 208–220. doi:10.1145/3520495.3520501

[57] Crescent Jicol, Julia Feltham, Jinha Yoon, Michael J Proulx, Eamonn O'Neill, and Christof Lutteroth. 2022. Designing and Assessing a Virtual Reality Simulation to Build Resilience to Street Harassment. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 117, 14 pages. doi:10.1145/3491102.3502129

[58] Kyle Johnsen, Sun Joo Ahn, James Moore, Scott Brown, Thomas P. Robertson, Amanda Marable, and Aryabrata Basu. 2014. Mixed Reality Virtual Pets to Reduce Childhood Obesity. *IEEE Transactions on Visualization and Computer Graphics* 20, 4 (April 2014), 523–530. doi:10.1109/TVCG.2014.33

[59] Gyuwon Jung and Uichin Lee. 2025. CounterStress: Enhancing Stress Coping Planning through Counterfactual Explanations in Personal Informatics. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 714, 20 pages. doi:10.1145/3706598.3713730

[60] Tomas Jurcik, Svetlana Zaremba-Pike, Vladimir Kosonogov, Abdul-Raheem Mohammed, Yulia Krasavtseva, Tadamasa Sawada, Irina Samarina, Nilufar Buranova, Peter Adu, Nikita Sergeev, Andrei Skuratov, Anastasia Demchenko, and Yakov Kochetkov. 2024. The efficacy of augmented reality exposure therapy in the treatment of spider phobia—a randomized controlled trial. *Frontiers in Psychology* Volume 15 - 2024 (2024). doi:10.3389/fpsyg.2024.1214125

[61] Konstantina Kilteni, Raphaela Groten, and Mel Slater. 2012. The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments* 21, 4 (2012), 373–387.

[62] M. T. E. Kouijzer, H. Kip, S. M. Kelders, and Y. H. A. Bouman. 2024. The introduction of virtual reality in forensic mental healthcare – an interview study on the first impressions of patients and healthcare providers regarding VR in treatment. *Frontiers in Psychology* Volume 15 - 2024 (2024). doi:10.3389/fpsyg.2024.1284983

[63] Neal Lathia, Veljko Pejovic, Kiran K. Rachuri, Cecilia Mascolo, Mirco Musolesi, and Peter J. Rentfrow. 2013. Smartphones for Large-Scale Behavior Change Interventions. *IEEE Pervasive Computing* 12, 3 (2013), 66–73. doi:10.1109/MPRV.2013.56

[64] Min Kyung Lee, Sara Kiesler, and Jodi Forlizzi. 2011. Mining behavioral economics to design persuasive technology for healthy choices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 325–334. doi:10.1145/1978942.1978989

[65] Maruša Levstek, Sarah Papworth, Andy Woods, Lucy Archer, Iqra Arshad, Klaus Dodds, Juliet S. Holdstock, James Bennett, and Polly Dalton. 2024. Immersive storytelling for pro-environmental behaviour change: The Green Planet augmented reality experience. *Computers in Human Behavior* 161 (2024), 108379. doi:10.1016/j.chb.2024.108379

[66] Jack M. Loomis, James J. Blascovich, and Andrew C. Beall. 1999. Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, & Computers* 31, 4 (Dec. 1999), 557–564. doi:10.3758/BF03200735

[67] Ulrik Lyngs, Kai Lukoff, Petr Slovak, Michael Inzlicht, Maureen Freed, Hannah Andrews, Claudine Tinsman, Laura Csuka, Lize Alberts, Victoria Oldemburgo De Mello, Guido Makransky, Kasper Hornbæk, Max Van Kleek, and Nigel Shadbolt. 2024. "I finally felt I had the tools to control these urges": Empowering Students to Achieve Their Device Use Goals With the Reduce Digital Distraction Workshop. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 251, 23 pages. doi:10.1145/3613904.3642946

[68] Ulrik Lyngs, Kai Lukoff, Petr Slovak, William Seymour, Helena Webb, Marina Jirotka, Jun Zhao, Max Van Kleek, and Nigel Shadbolt. 2020. 'I Just Want to Hack Myself to Not Get Distracted': Evaluating Design Interventions for Self-Control on Facebook. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3313831.3376672

[69] Blake M. DiCosola III and Gina Neff. 2022. Nudging Behavior Change: Using In-Group and Out-Group Social Comparisons to Encourage Healthier Choices. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 475, 14 pages. doi:10.1145/3491102.3502088

[70] Guido Makransky and Sara Klingenberg. 2022. Virtual reality enhances safety training in the maritime industry: An organizational training experiment with a non-WEIRD sample. *Journal of Computer Assisted Learning* 38, 4 (2022), 1127–1140. arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/jcal.12670 doi:10.1111/jcal.12670

[71] Mark McGill. 2021. White paper-the IEEE global initiative on ethics of extended reality (XR) report–extended reality (XR) and the erosion of anonymity and privacy. *Extended Reality (XR) and the Erosion of Anonymity and Privacy-White Paper* (2021), 1–24.

[72] Marijn H. C. Meijers, Eline S. Smit, Kelly de Wildt, Sonja-Greetta Karvonen, Demi van der Plas, and L. Nynke van der Laan. 2022. Stimulating Sustainable Food Choices Using Virtual Reality: Taking an Environmental vs Health Communication Perspective on Enhancing Response Efficacy Beliefs. *Environmental Communication* 16, 1 (2022), 1–22.

arXiv:https://doi.org/10.1080/17524032.2021.1943700 doi:10.1080/17524032.2021.1943700

[73] Marijn H. C. Meijers, Ragnheiður "Heather" Torfadóttir, Anke Wonneberger, and Ewa Maslowska. 2023. Experiencing Climate Change Virtually: The Effects of Virtual Reality on Climate Change Related Cognitions, Emotions, and Behavior. *Environmental Communication* 17, 6 (2023), 581–601. arXiv:https://doi.org/10.1080/17524032.2023.2229043 doi:10.1080/17524032.2023.2229043

[74] Alexander Michael and Christof Lutteroth. 2020. Race Yourselves: A Longitudinal Exploration of Self-Competition Between Past, Present, and Future Performances in a VR Exergame. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–17. doi:10.1145/3313831.3376256

[75] Susan Michie and Marie Johnston. 2012. Theories and techniques of behaviour change: Developing a cumulative science of behaviour change. *Health Psychology Review* 6, 1 (2012), 1–6. arXiv:https://doi.org/10.1080/17437199.2012.654964 doi:10.1080/17437199.2012.654964

[76] Susan Michie, Michelle Richardson, Marie Johnston, Charles Abraham, Jill Francis, Wendy Hardeman, Martin P. Eccles, James Cane, and Caroline E. Wood. 2013. The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions. *Annals of Behavioral Medicine* 46, 1 (03 2013), 81–95. arXiv:https://academic.oup.com/abm/article-pdf/46/1/81/21982931/12160_2013_article_9486.pdf doi:10.1007/s12160-013-9486-6

[77] Susan Michie, Maartje M. van Stralen, and Robert West. 2011. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science* 6, 1 (April 2011), 42. doi:10.1186/1748-5908-6-42

[78] Susan Michie, Robert West, Kate Sheals, and Cristina A. Godinho. 2018. Evaluating the effectiveness of behavior change techniques in health-related behavior: a scoping review of methods used. *Translational Behavioral Medicine* 8, 2 (April 2018), 212–224. doi:10.1093/tbm/ibx019

[79] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. 1995. Augmented reality: a class of displays on the reality-virtuality continuum. In *Telemanipulator and Telepresence Technologies*, Vol. 2351. SPIE, 282–292. doi:10.1117/12.197321

[80] Madison Milne-Ives, Ching Lam, Caroline De Cock, Michelle Helena Van Velthoven, and Edward Meinert. 2020. Mobile Apps for Health Behavior Change in Physical Activity, Diet, Drug and Alcohol Use, and Mental Health: Systematic Review. *JMIR Mhealth Uhealth* 8, 3 (March 2020), e17046. doi:10.2196/17046

[81] Béatrice Moissinac, Kimmy Hescock, Jon Dorbolo, Siew Sun Wong, and Melinda Manore. 2016. Strategies to Design a Mixed-Reality Immersive Environment and Influence Teen Health Behaviors. In *Immersive Learning Research Network*, Colin Allison, Leonel Morgado, Johanna Pirker, Dennis Beck, Jonathon Richter, and Christian Gütl (Eds.). Springer International Publishing, Cham, 17–28.

[82] Safa Molan and Delene Weber. 2021. Improving bushfire preparedness through the use of virtual reality. *International Journal of Disaster Risk Reduction* 66 (2021), 102574. doi:10.1016/j.ijdrr.2021.102574

[83] Nexhmedin Morina, Isabel Kampmann, Paul Emmelkamp, Corrado Barbui, and Thole H. Hoppen. 2023. Meta-analysis of virtual reality exposure therapy for social anxiety disorder. *Psychological Medicine* 53, 5 (2023), 2176–2178. doi:10.1017/S0033291721001690

[84] Miriam Mulders and Kristian Heinrich Träg. 2023. Presence and Flow as Moderators in XR-Based Sustainability Education. *Sustainability* 15, 23 (2023). doi:10.3390/su152316496

[85] Andreea Muresan, Jess Mcintosh, and Kasper Hornbæk. 2023. Using Feedforward to Reveal Interaction Possibilities in Virtual Reality. *ACM Trans. Comput.-Hum. Interact.* 30, 6, Article 82 (Sept. 2023), 47 pages. doi:10.1145/3603623

[86] Joseph O'Hagan, Jan Gugenheimer, Florian Mathis, Jolie Bonner, Richard Jones, and Mark McGill. 2024. A Viewpoint on the Societal Impact of Everyday Augmented Reality and the Need for Perceptual Human Rights. *IEEE Security & Privacy* 22, 1 (2024), 64–68. doi:10.1109/MSEC.2023.3333988

[87] Ifeanyi Paul Odenigbo, Alaa AlSlaity, and Rita Orji. 2022. Augmented and Virtual Reality-Driven Interventions for Healthy Behavior Change: A Systematic Review. In *Proceedings of the 2022 ACM International Conference on Interactive Media Experiences* (Aveiro, JB, Portugal) *(IMX '22)*. Association for Computing Machinery, New York, NY, USA, 53–68. doi:10.1145/3505284.3529964

[88] Susan Persky and Megan A Lewis. 2019. Advancing science and practice using immersive virtual reality: what behavioral medicine has to offer. *Translational Behavioral Medicine* 9, 6 (05 2019), 1040–1046. arXiv:https://academic.oup.com/tbm/article-pdf/9/6/1040/33131410/ibz068.pdf doi:10.1093/tbm/ibz068

[89] M.D.J. Peters, C. Godfrey, P. McInerney, Z. Munn, A.C. Tricco, and H. Khalil. 2024. Scoping Reviews. In *JBI Manual for Evidence Synthesis*, E. Aromataris, C. Lockwood, K. Porritt, B. Pilla, and Z. Jordan (Eds.). JBI. doi:10.46658/JBIMES-24-09

[90] Micah D.J. Peters, Casey Marnie, Andrea C. Tricco, Danielle Pollock, Zachary Munn, Lyndsay Alexander, Patricia McInerney, Christina M. Godfrey, and Hanan Khalil. 2020. Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis* 18, 10 (2020). https://journals.lww.com/jbisrir/fulltext/2020/10000/updated_methodological_guidance_for_the_conduct_of.4.aspx

[91] Yuke Pi, Xueni Pan, Mel Slater, and Justyna Świdrak. 2025. Embodied time travel in VR: from witnessing climate change to action for prevention. *Frontiers in Virtual Reality* Volume 5 - 2024 (2025). doi:10.3389/frvir.2024.1499835

[92] Adéla Plechatá, Marijke Hiltje Hielkema, Lisa-Marie Merkl, Guido Makransky, and Michael Bom Frøst. 2024. Shifting from Information- to Experience-Based Climate Change Communication Increases Pro-Environmental Behavior Via Efficacy Beliefs. *Environmental Communication* 18, 5 (2024), 589–609. arXiv:https://doi.org/10.1080/17524032.2024.2334727 doi:10.1080/17524032.2024.2334727

[93] Adéla Plechatá, Thomas Morton, and Guido Makransky. 2025. Promoting collective climate action and identification with environmentalists through social interaction and visual feedback in virtual reality. *Journal of Environmental Psychology* 102 (2025), 102526. doi:10.1016/j.jenvp.2025.102526

[94] Amon Rapp and Arianna Boldi. 2023. Exploring the Lived Experience of Behavior Change Technologies: Towards an Existential Model of Behavior Change for HCI. *ACM Trans. Comput.-Hum. Interact.* 30, 6, Article 81 (Sept. 2023), 50 pages. doi:10.1145/3603497

[95] Amon Rapp, Maurizio Tirassa, and Lia Tirabeni. 2019. Rethinking Technologies for Behavior Change: A View from the Inside of Human Change. *ACM Trans. Comput.-Hum. Interact.* 26, 4, Article 22 (June 2019), 30 pages. doi:10.1145/3318142

[96] Marion Rauscher, Armin Brysch, Anna Scuttari, and Marius Mayer. 2024. Sustainability Communication in VR Learning Environments for Perceptual and Behavioral Change: Raising Awareness of Sustainable Travel Behavior. In *XR and Metaverse*, M. Claudia tom Dieck, Timothy Jung, and Yen-Soon Kim (Eds.). Springer Nature Switzerland, Cham, 125–139.

[97] Michael Rietzler, Florian Geiselhart, Jan Gugenheimer, and Enrico Rukzio. 2018. Breaking the Tracking: Enabling Weight Perception using Perceivable Tracking Offsets. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3173574.3173702

[98] Katja Rogers, Teresa Hirzle, Sukran Karaosmanoglu, Paula Toledo Palomino, Ekaterina Durmanova, Seiji Isotani, and Lennart E. Nacke. 2024. An Umbrella Review of Reporting Quality in CHI Systematic Reviews: Guiding Questions and Best Practices for HCI. *ACM Trans. Comput.-Hum. Interact.* 31, 5, Article 57 (Nov. 2024), 55 pages. doi:10.1145/3685266

[99] BO Rothbaum, LF Hodges, R Kooper, D Opdyke, JS Williford, and M North. 1995. Effectiveness of computer-generated (virtual reality) graded exposure in the treatment of acrophobia. *The American journal of psychiatry* 152, 4 (4 1995), 626—628. doi:10.1176/ajp.152.4.626

[100] Philipp Schaper, Anna Riedmann, Sebastian Oberdörfer, Maileen Krähe, and Birgit Lugrin. 2022. Addressing Waste Separation With a Persuasive Augmented Reality App. *Proc. ACM Hum.-Comput. Interact.* 6, MHCI, Article 205 (Sept. 2022), 16 pages. doi:10.1145/3546740

[101] Miriam A. Schiele, Andreas Reif, Jiaxi Lin, Georg W. Alpers, Evelyn Andersson, Gerhard Andersson, Volker Arolt, Jan Bergström, Per Carlbring, Thalia C. Eley, Gabriel Esquivel, Tomas Furmark, Alexander L. Gerlach, Alfons Hamm, Sylvia Helbig-Lang, Jennifer L. Hudson, Thomas Lang, Kathryn J. Lester, Nils Lindefors, Tina B. Lonsdorf, Paul Pauli, Jan Richter, Winfried Rief, Susanna Roberts, Christian Rück, Koen R.J. Schruers, Christiane Thiel, Hans-Ulrich Wittchen, Katharina Domschke, Heike Weber, and Ulrike Lueken. 2021. Therapygenetic effects of 5-HTTLPR on cognitive-behavioral therapy in anxiety disorders: A meta-analysis. *European Neuropsychopharmacology* 44 (2021), 105–120. doi:10.1016/j.euroneuro.2021.01.004

[102] Elizabeth A. Schlesener, Vyomakesh Shivakumar, Dave Breeze, Brooke Rennison, Burak Soehmelioglu, and Sabarish V. Babu. 2025. 'Age Isn't Just a Number': Effects of Virtual Human Age and Gender on Persuasion, Social Presence and Influence in Interpersonal Social Encounters in VR. In *2025 IEEE Conference Virtual Reality and 3D User Interfaces (VR)*. 82–92. doi:10.1109/VR59515.2025.00033

[103] David C. Schwebel, Leslie A. McClure, and Bryan E. Porter. 2017. Experiential exposure to texting and walking in virtual reality: A randomized trial to reduce distracted pedestrian behavior. *Accident Analysis & Prevention* 102 (2017), 116–122. doi:10.1016/j.aap.2017.02.026

[104] Ayanna Seals, Monsurat Olaosebikan, Jennifer Otiono, Orit Shaer, and Oded Nov. 2021. Effects of Self-focused Augmented Reality on Health Perceptions During the COVID-19 Pandemic: A Web-Based Between-Subject Experiment. *J Med Internet Res* 23, 6 (29 Jun 2021), e26963. doi:10.2196/26963

[105] Paschal Sheeran and Thomas L. Webb. 2016. The Intention–Behavior Gap. *Social and Personality Psychology Compass* 10, 9 (2016), 503–518. arXiv:https://compass.onlinelibrary.wiley.com/doi/pdf/10.1111/spc3.12265

doi:10.1111/spc3.12265

[106] Richard Skarbez, Frederick P. Brooks, Jr., and Mary C. Whitton. 2017. A Survey of Presence and Related Concepts. *ACM Comput. Surv.* 50, 6, Article 96 (Nov. 2017), 39 pages. doi:10.1145/3134301

[107] Mel Slater et al. 1999. Measuring presence: A response to the Witmer and Singer presence questionnaire. *Presence: teleoperators and virtual environments* 8, 5 (1999), 560–565.

[108] Mel Slater, Sylvia Wilbur, et al. 1997. A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and virtual environments* 6, 6 (1997), 603–616.

[109] Markos Souropetsis and Eleni A. Kyza. 2025. CompARe: Design and Development of a Gamified Augmented Reality Learning Environment for Cultural Heritage Sites. *J. Comput. Cult. Herit.* 18, 1, Article 6 (Feb. 2025), 16 pages. doi:10.1145/3703917

[110] Maximilian Speicher, Brian D. Hall, and Michael Nebeling. 2019. What is Mixed Reality?. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3290605.3300767

[111] Carolin Straßmann, Alexander Arntz, and Sabrina C. Eimler. 2020. Under The (Plastic) Sea - Sensitizing People Toward Ecological Behavior Using Virtual Reality Controlled by Users' Physical Activity. In *2020 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. 166–173. doi:10.1109/AIVR50618.2020.00036

[112] Anthea Sutton, Mark Clowes, Louise Preston, and Andrew Booth. 2019. Meeting the review family: exploring review types and associated information retrieval requirements. *Health Information & Libraries Journal* 36, 3 (2019), 202–222. arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/hir.12276 doi:10.1111/hir.12276

[113] Jonathan Sutton, Tobias Langlotz, Alexander Plopski, Stefanie Zollmann, Yuta Itoh, and Holger Regenbrecht. 2022. Look over there! Investigating Saliency Modulation for Visual Guidance with Augmented Reality Glasses. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology* (Bend, OR, USA) *(UIST '22)*. Association for Computing Machinery, New York, NY, USA, Article 81, 15 pages. doi:10.1145/3526113.3545633

[114] Gavin J. Taylor, Angelique C. Paulk, Thomas W. J. Pearson, Richard J. D. Moore, Jacqui A. Stacey, David Ball, Bruno van Swinderen, and Mandyam V. Srinivasan. 2015. Insects modify their behaviour depending on the feedback sensor used when walking on a trackball in virtual reality. *Journal of Experimental Biology* 218, 19 (10 2015), 3118–3127. arXiv:https://journals.biologists.com/jeb/article-pdf/218/19/3118/1914931/jeb125617.pdf doi:10.1242/jeb.125617

[115] Kelly J Thomas Craig, Laura C Morgan, Ching-Hua Chen, Susan Michie, Nicole Fusco, Jane L Snowdon, Elisabeth Scheufele, Thomas Gagliardi, and Stewart Sill. 2020. Systematic review of context-aware digital behavior change interventions to improve health. *Translational Behavioral Medicine* 11, 5 (10 2020), 1037–1048. arXiv:https://academic.oup.com/tbm/article-pdf/11/5/1037/38275945/ibaa099.pdf doi:10.1093/tbm/ibaa099

[116] Xin Tong, Matthew Louis Mauriello, Marco Antonio Mora-Mendoza, Nina Prabhu, Jane Paik Kim, and Pablo E Paredes Castro. 2023. Just Do Something: Comparing Self-proposed and Machine-recommended Stress Interventions among Online Workers with Home Sweet Office. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 495, 20 pages. doi:10.1145/3544548.3581319

[117] Evlalia Touloudi, Mary Hassandra, Evangelos Galanis, Gerasimos Pinnas, Charalampos Krommidas, Marios Goudas, and Yannis Theodorakis. 2025. Effectiveness and acceptance of virtual reality vs. traditional exercise in obese adults: a pilot randomized trial. *Frontiers in Sports and Active Living* Volume 7 - 2025 (2025). doi:10.3389/fspor.2025.1520068

[118] Jun-Phil Uhm, Hyun-Woo Lee, Sanghoon Kim, and Jin-Wook Han. 2024. First-Person Experience in Virtual Reality Sport Advertisements: Transportation of Embodied Empathy. *PRESENCE: Virtual and Augmented Reality* 33 (07 2024), 269–286. arXiv:https://direct.mit.edu/pvar/article-pdf/doi/10.1162/pres_a_00426/2465355/pres_a_00426.pdf doi:10.1162/pres_a_00426

[119] Nadine Elisa van der Waal, Loes Janssen, Marco Otte, Marjolijn Antheunis, and Laura Nynke van der Laan. 2024. Shaping health behaviors beyond reality: A full body illusion to experience the consequences of unhealthy snacking. *Computers in Human Behavior* 160 (2024), 108376. doi:10.1016/j.chb.2024.108376

[120] Inge van Loenen, Willemijn Scholten, Anna Muntingh, Johannes Smit, and Neeltje Batelaan. 2022. The Effectiveness of Virtual Reality Exposure–Based Cognitive Behavioral Therapy for Severe Anxiety Disorders, Obsessive-Compulsive Disorder, and Posttraumatic Stress Disorder: Meta-analysis. *J Med Internet Res* 24, 2 (10 2 2022), e26736. doi:10.2196/26736

[121] Austin van Loon, Jeremy Bailenson, Jamil Zaki, Joshua Bostick, and Robb Willer. 2018. Virtual reality perspective-taking increases cognitive empathy for specific others. *PLOS ONE* 13, 8 (08 2018), 1–19. doi:10.1371/journal.pone.0202442

[122] Daniel Vankov, Ronald Schroeter, and Divera Twisk. 2021. Can't simply roll it out: Evaluating a real-world virtual reality intervention to reduce driving under the influence. *PLOS ONE* 16, 4 (04 2021), 1–17. doi:10.1371/journal.pone.0250273

[123] Eduardo Velloso and Kasper Hornbæk. 2025. Theorising in HCI using Causal Models. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 484, 17 pages. doi:10.1145/3706598.3713789

[124] Bas Verplanken and Sheina Orbell. 2022. Attitudes, Habits, and Behavior Change. *Annual Review of Psychology* 73, Volume 73, 2022 (2022), 327–352. doi:10.1146/annurev-psych-020821-011744 Publisher: Annual Reviews Type: Journal Article.

[125] Rina Machaca Viza, Fabian Hugo Rucano Paucar, and Fabiola Talavera-Mendoza. 2025. Impact of Serious Games on Teacher Training: An Analysis of Competence, Immersion, and Positive Emotions. *IEEE Access* 13 (2025), 17150–17160. doi:10.1109/ACCESS.2025.3526416

[126] Nadine Wagener, Jasmin Niess, Yvonne Rogers, and Johannes Schöning. 2022. Mood Worlds: A Virtual Environment for Autonomous Emotional Expression. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 22, 16 pages. doi:10.1145/3491102.3501861

[127] Nadine Wagener, Leon Reicherts, Nima Zargham, Natalia Bartłomiejczyk, Ava Elizabeth Scott, Katherine Wang, Marit Bentvelzen, Evropi Stefanidi, Thomas Mildner, Yvonne Rogers, and Jasmin Niess. 2023. SelVReflect: A Guided VR Experience Fostering Reflection on Personal Challenges. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 323, 17 pages. doi:10.1145/3544548.3580763

[128] T. L. Webb and P. Sheeran. 2006. Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. *Psychol Bull* 132, 2 (2006), 249–68. doi:10.1037/0033-2909.132.2.249 Webb, Thomas L Sheeran, Paschal Journal Article Meta-Analysis United States 2006/03/16 Psychol Bull. 2006 Mar;132(2):249-68. doi: 10.1037/0033-2909.132.2.249..

[129] René Weller, Joscha Cepok, Roman Arzaroli, Kevin Marnholz, Cornelia S. Große, Hauke Reuter, and Gabriel Zachmann. 2022. Effects of immersion and navigation agency in virtual environments on emotions and behavioral intentions. *Frontiers in Virtual Reality* Volume 3 - 2022 (2022). doi:10.3389/frvir.2022.893052

[130] Veronica U. Weser, Lindsay R. Duncan, Tyra M. Pendergrass, Claudia-Santi Fernandes, Lynn E. Fiellin, and Kimberly D. Hieftje. 2021. A quasi-experimental test of a virtual reality game prototype for adolescent E-Cigarette prevention. *Addictive Behaviors* 112 (2021), 106639. doi:10.1016/j.addbeh.2020.106639

[131] Isaac Wiafe, Elikem Doe Atsakpo, Charles Nutrokpor, Jaap Ham, and Stephen Gulliver. 2023. Design and Evaluation of a Persuasive Road Marking System for Controlling Speeding Behavior. In *Proceedings of the 26th International Academic Mindtrek Conference* (Tampere, Finland) *(Mindtrek '23)*. Association for Computing Machinery, New York, NY, USA, 35–44. doi:10.1145/3616961.3616967

[132] B.K. Wiederhold, D.P. Jang, R.G. Gevirtz, S.I. Kim, I.Y. Kim, and M.D. Wiederhold. 2002. The treatment of fear of flying: a controlled study of imaginal and virtual reality graded exposure therapy. *IEEE Transactions on Information Technology in Biomedicine* 6, 3 (Sep. 2002), 218–223. doi:10.1109/TITB.2002.802378

[133] Carolin Wienrich, Nina Döllinger, and Rebecca Hein. 2021. Behavioral Framework of Immersive Technologies (BehaveFIT): How and Why Virtual Reality can Support Behavioral Change Processes. *Frontiers in Virtual Reality* 2 (2021). doi:10.3389/frvir.2021.627194

[134] Carolin Wienrich, Stephanie Vogt, Nina Döllinger, and David Obremski. 2024. Promoting Eco-Friendly Behaviour through Virtual Reality - Implementation and Evaluation of Immersive Feedback Conditions of a Virtual CO2 Calculator. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 282, 9 pages. doi:10.1145/3613904.3642957

[135] Rua Mae Williams, Louanne Boyd, and Juan E. Gilbert. 2023. Counterventions: a reparative reflection on interventionist HCI. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 653, 11 pages. doi:10.1145/3544548.3581480

[136] Marvin Wolf, Kathrin Gerling, Dmitry Alexandrovsky, Merlin Steven Opp, and Jan Ole Rixen. 2025. Understanding Accessibility for Physically Disabled Users in VR: Interplay of Physical, Digital, and Experiential Layers. In *Proceedings of the 27th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '25)*. Association for Computing Machinery, New York, NY, USA, Article 5, 15 pages. doi:10.1145/3663547.3746357

[137] Cleo Xiao, Difeng Yu, Kasper Hornbæk, and Joanna Bergström. 2025. A Concept at Work: A Review of Motivations, Operationalizations, and Conclusions in VR Research about Presence. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 1145, 21 pages. doi:10.1145/3706598.3714279

[138] Xiwei Xiao, Yan Xiao, and Menchita F. Dumlao. 2024. Evaluation of Gamification on Surgical Nursing Course using Immersive Virtual Reality: A comparative

study. In *Proceedings of the 2023 4th International Symposium on Artificial Intelligence for Medicine Science* (Chengdu, China) *(ISAIMS '23)*. Association for Computing Machinery, New York, NY, USA, 614–620. doi:10.1145/3644116.3644217

[139] Zhan Xu and Linda Dam. 2024. Comparing virtual reality vs. augmented reality in promoting COVID-19 self-testing, vaccination, and preventive behaviors. *Digital Health* 10 (2024), 20552076241269587. arXiv:https://doi.org/10.1177/20552076241269587 doi:10.1177/20552076241269587

[140] Enes Yigitbas and Janet Mazur. 2024. Augmented and Virtual Reality for Diet and Nutritional Education: A Systematic Literature Review. In *Proceedings of the 17th International Conference on PErvasive Technologies Related to Assistive Environments* (Crete, Greece) *(PETRA '24)*. Association for Computing Machinery, New York, NY, USA, 88–97. doi:10.1145/3652037.3652048

[141] Seraphina Yong, Leo Cui, Evan Suma Rosenberg, and Svetlana Yarosh. 2024. A Change of Scenery: Transformative Insights from Retrospective VR Embodied Perspective-Taking of Conflict With a Close Other. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 919, 18 pages. doi:10.1145/3613904.3642146

[142] Sarah Zabel and Siegmar Otto. 2024. SustAInable: How Values in the Form of Individual Motivation Shape Algorithms' Outcomes. An Example Promoting Ecological and Social Sustainability. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 513, 11 pages. doi:10.1145/3613904.3642404

[143] Mingrui Ray Zhang, Kai Lukoff, Raveena Rao, Amanda Baughan, and Alexis Hiniker. 2022. Monitoring Screen Time or Redesigning It? Two Approaches to Supporting Intentional Social Media Use. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 60, 19 pages. doi:10.1145/3491102.3517722

[144] Zuoyi Zhang, Teng Han, John Swystun, Yumiko Sakamoto, and Pourang Irani. 2021. Design to Eat Smart: A Design Framework for Pervasive Interventions of Eating Habits. In *Proceedings of the 14th EAI International Conference on Pervasive Computing Technologies for Healthcare* (Atlanta, GA, USA) *(PervasiveHealth '20)*. Association for Computing Machinery, New York, NY, USA, 108–121. doi:10.1145/3421937.3421974

[145] Jun Zhu, Sruzan Lolla, Meeshu Agnihotri, Sahar Asgari Tappeh, Lala Guluzade, Elena Agapie, and Corina Sas. 2025. A Systematic Review and Meta-Analysis of Research on Goals for Behavior Change. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 375, 25 pages. doi:10.1145/3706598.3714072

A Scoping Review - Databases

The main search included the databases Web of Science, IEEE Xplore, ACM DL, and PubMed, while the initial search included Cochrane, PubMed, JBI, Web of Science, and Scopus. The main searched used different databases for the following reasons: Cochrane is indexed in PubMed, which we discovered after the initial search, so we only included PubMed for the main search. JBI specifically focuses on evidence synthesis. Therefore, it was relevant for finding potentially overlapping scoping reviews but not for the main search, where synthesis articles were excluded. Web of Science focuses more on high-impact journals compared to Scopus, which is why we chose it as the main database.

B Scoping Review - Search Queries

ACM Digital Library

- **Date**: April 8, 2025
- **Query**: Full text:((“virtual reality” OR “extended reality” OR “mixed reality” OR “augmented reality” OR “head-mounted display” OR “virtual space” OR “head-up display” OR “head-worn display” OR “headset” OR “HMD” OR “immersive environment” OR “virtual environment”) AND (“behavior change” OR “behaviour change” OR “behavioral change” OR “behavioural change”))
- **Search within**: Fulltext
- **Filters**:
  - **Content Type**: Research Article
  - **Publication type** (All Publications): Proceedings and Journals
- **Number of results**: 535
- **Number of removed for duplication**: 0
- **Number of included**: 535

IEEE Xplore

- **Date**: April 8, 2025
- **Query**: ((“Full Text Only”:“virtual reality”) OR (“Full Text Only”:“augmented reality”) OR (“Full Text Only”:“extended reality”) OR (“Full Text Only”:“mixed reality”) OR (“Full Text Only”:“head-mounted display”) OR (“Full Text Only”:“virtual space”) OR (“Full Text Only”:“head-up display”) OR (“Full Text Only”:“head-worn display”) OR (“Full Text Only”:“headset”) OR (“Full Text Only”:“HMD”) OR (“Full Text Only”:“immersive environment”) OR (“Full Text Only”:“virtual environment”)) AND ((“Full Text Only”:“behavior change”) OR (“Full Text Only”:“behaviour change”) OR (“Full Text Only”:“behavioral change”) OR (“Full Text Only”:“behavioural change”))
- **Search Within**: Full text
- **Filters**: select Conferences, Journals in check boxes
- **Number of results**: 633[14]
- **Number of removed for duplication**: 20
- **Number of included**: 578

PubMed

- **Date**: April 7, 2025
- **Query**: (“virtual reality” OR “extended reality” OR “mixed reality” OR “augmented reality” OR “head-mounted display” OR “virtual space” OR “head-up display” OR “head-worn display” OR “headset” OR “HMD” OR “immersive environment” OR “virtual environment”) AND (“behavior change” OR “behaviour change” OR “behavioral change” OR “behavioural change”)
- **Search Within**: All Fields
- **Filters**: None
- **Number of results**: 122
- **Number of removed for duplication**: 66
- **Number of included**: 56

Web of Science

- **Date**: April 4, 2025
- **Query**:(“virtual reality” OR “extended reality” OR “mixed reality” OR “augmented reality” OR “head-mounted display” OR “virtual space” OR “head-up display” OR “head-worn display” OR “headset” OR “HMD” OR “immersive environment” OR “virtual environment”) AND (“behavior change” OR “behaviour change” OR “behavioral change” OR “behavioural change”)
- **Search Within**: All Fields
- **Filters**:
  - **Document Types**: Article, Proceedings Paper
  - **Languages**: English
- **Number of results**: 199
- **Number of removed for duplication**: 7
- **Number of included**: 192

[14] Out of 633 initial search results, 35 records were excluded as they were identified as non-article content, such as conference program front matter and tables of contents. These records were not research articles and were excluded from further processing.

C Scoping Review - Code Book

C.1 Causal Figures for Coding

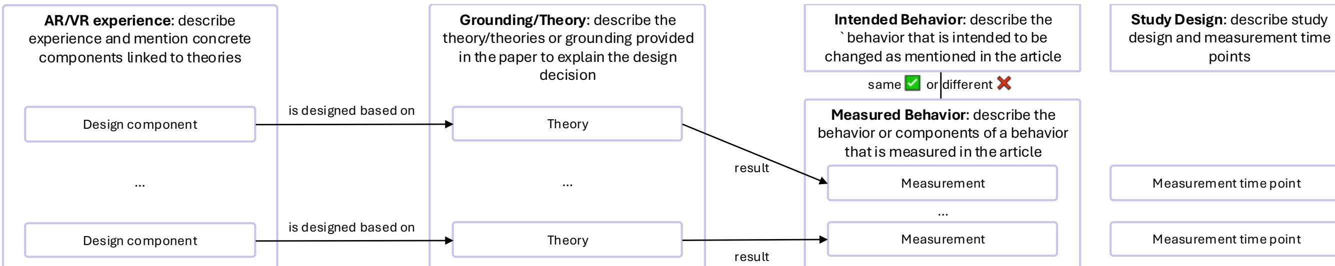

Figure 4: A generic figure illustrating how we used figures to describe each paper's *cause of interest* (AR/VR experience) and *outcome of interest* (measured behavior), linking design components to underlying theories. The figures also indicate how the theory's impact was measured and whether the behavior that was intended to be changed matched the measured behavior or the measured components.

C.2 Data Charting Table

Table 10: Codes and descriptions for coding process. For all codes, text was extracted from the papers.

Item	Description
Behavior Related	
C1 Addressed Behavior	Behavior that is the objective of the change.
C2 Connection to Theory	Connection of the behavior change intervention to theory, if applicable.
C3 Ethical Concerns	Any ethical concerns mentioned in the paper with regards to the behavior change intervention used or other parts of the work.
Extended Reality Experience	
C4 Level of Immersion	Describes the objective degree of being immersed in an extended reality, such as VR, AR, MR.
C5 Device Used	States the used device.
C6 General XR Experience	Describes the XR experience with a focus on how the experience related to behavior change.
C7 Task	Describes what the person who uses the XR experience does, for instance, this can be passively watching a video or actively interacting in the experience in a certain way.
C8 Practical Purpose of XR	Describes the purpose of XR as explained by the authors, for example, to allow physically impossible experience or see future consequences.
Outcome Measures and Results	
C9 XR Measures	Includes any measures applied to capture details about the XR experience, such as presence or simulator sickness.
C10 Behavioral Measures	Includes any measures the study applied to measure behavior or processes related to a behavior.
C11 Duration of Intervention	Explains how long the duration of the behavior change intervention is and when measures were applied.
C12 Results	Summarizes the key results related to the behavior change and XR measures.
Study Details	
C13 Study Design	Includes details about the experimental design, such as within/between/mixed participant design, number of factors, if any, and information about repeated measures, if applicable.
C14 Sample Information	Number of participants and participants demographics, including age and gender information.
C15 Population Information	Description of sample/population, details about how the study sample was characterized in relation to the behavior (e.g., in meat reduction studies often vegetarians were excluded), if applicable.

D Scoping Review - Paper List

Table 11: Overview of papers included in the review. Part 1.

Citation	Paper Title	Authors	Paper ID
[134]	Promoting Eco-Friendly Behaviour through Virtual Reality - Implementation and Evaluation of Immersive Feedback Conditions of a Virtual CO2 Calculator	Carolin Wienrich, Stephanie Vogt, Nina Döllinger, and David Obremski.	2
[4]	MeetingBenji: Tackling Cynophobia with Virtual Reality, Gamification, and Biofeedback.	Inês Alves and Augusto Esteves	10
[131]	Design and Evaluation of a Persuasive Road Marking System for Controlling Speeding Behavior	Isaac Wiafe, Elikem Doe Atsakpo, Charles Nutrokpor, Jaap Ham, and Stephen Gulliver	11
[127]	SelVReflect: A Guided VR Experience Fostering Reflection on Personal Challenges	Nadine Wagener, Leon Reicherts, Nima Zargham, Natalia Bartłomiejczyk, Ava Elizabeth Scott, Katherine Wang, Marit Bentvelzen, Evropi Stefanidi, Thomas Mildner, Yvonne Rogers, and Jasmin Niess.	32
[138]	Evaluation of Gamification on Surgical Nursing Course using Immersive Virtual Reality: A comparative study.	Xiwei Xiao, Yan Xiao, and Menchita F. Dumlao	65
[35]	A comparison of head-mounted and hand-held displays for 360° videos with focus on attitude and behavior change	Diana Fonseca and Martin Kraus	67
[57]	Designing and Assessing a Virtual Reality Simulation to Build Resilience to Street Harassment	Crescent Jicol, Julia Feltham, Jinha Yoon, Michael J Proulx, Eamonn O'Neill, and Christof Lutteroth.	84
[126]	Mood Worlds: A Virtual Environment for Autonomous Emotional Expression	Nadine Wagener, Jasmin Niess, Yvonne Rogers, and Johannes Schöning	93
[23]	(Eco-)Logical to Compare? - Utilizing Peer Comparison to Encourage Ecological Driving in Manual and Automated Driving	Mark Colley, Jan Ole Rixen, Italgo Walter Pellegrino, and Enrico Rukzio.	104
[14]	vrSocial: Toward Immersive Therapeutic VR Systems for Children with Autism	LouAnne E. Boyd, Saumya Gupta, Sagar B. Vikmani, Carlos M. Gutierrez, Junxiang Yang, Erik Linstead, and Gillian R. Hayes	125
[74]	Race Yourselves: A Longitudinal Exploration of Self-Competition Between Past, Present, and Future Performances in a VR Exergame	Alexander Michael and Christof Lutteroth	148
[44]	MABLE: Mediating Young Children's Smart Media Usage with Augmented Reality	Gahgene Gweon, Bugeun Kim, Jinyoung Kim, Kung Jin Lee, Jungwook Rhim, and Jueun Cho	201
[48]	Embedded AR Storytelling Supports Active Indexing at Historical Places	Linda Hirsch, Robin Welsch, Beat Rossmy, and Andreas Butz.	221
[21]	Exploring feedback strategies to improve public speaking: an interactive virtual audience framework	Mathieu Chollet, Torsten Wörtwein, Louis-Philippe Morency, Ari Shapiro, and Stefan Scherer.	308
[109]	CompARe: Design and Development of a Gamified Augmented Reality Learning Environment for Cultural Heritage Sites	Markos Souropetsis and Eleni A. Kyza	443
[100]	Addressing Waste Separation With a Persuasive Augmented Reality App	Philipp Schaper, Anna Riedmann, Sebastian Oberdörfer, Maileen Krähe, and Birgit Lugrin.	475
[111]	nder The (Plastic) Sea - Sensitizing People Toward Ecological Behavior Using Virtual Reality Controlled by Users' Physical Activity	Carolin Straßmann, Alexander Arntz, and Sabrina C. Eimler.	537
[139]	Comparing virtual reality vs. augmented reality in promoting COVID-19 self-testing, vaccination, and preventive behaviors.	Zhan Xu and Linda Dam	538

Table 12: Overview of papers included in the review. Part 2.

Citation	Paper Title	Authors	Paper ID
[65]	Immersive storytelling for pro-environmental behaviour change: The Green Planet augmented reality experience	Maruša Levstek, Sarah Papworth, Andy Woods, Lucy Archer, Iqra Arshad, Klaus Dodds, Juliet S. Holdstock, James Bennett, and Polly Dalton	539
[20]	Mortality salience in virtual reality experiences and its effects on users' attitudes towards risk	Luca Chittaro, Riccardo Sioni, Cristiano Crescentini, and Franco Fabbro.	548
[72]	Stimulating Sustainable Food Choices Using Virtual Reality: Taking an Environmental vs Health Communication Perspective on Enhancing Response Efficacy Beliefs	Marijn H. C. Meijers, Eline S. Smit, Kelly de Wildt, Sonja-Greetta Karvonen, Demi van der Plas, and L. Nynke van der Laan	554
[84]	Presence and Flow as Moderators in XR-Based Sustainability Education	Miriam Mulders and Kristian Heinrich Träg	560
[96]	Sustainability Communication in VR Learning Environments for Perceptual and Behavioral Change: Raising Awareness of Sustainable Travel Behavior	Marion Rauscher, Armin Brysch, Anna Scuttari, and Marius Mayer	562
[73]	Experiencing Climate Change Virtually: The Effects of Virtual Reality on Climate Change Related Cognitions, Emotions, and Behavior	Marijn H. C. Meijers, Ragnheiður "Heather" Torfadóttir, Anke Wonneberger, and Ewa Maslowska	565
[93]	Promoting collective climate action and identification with environmentalists through social interaction and visual feedback in virtual reality.	Adéla Plechatá, Thomas Morton, and Guido Makransky	570
[70]	Virtual reality enhances safety training in the maritime industry: An organizational training experiment with a non-WEIRD sample	Guido Makransky and Sara Klingenberg	579
[32]	Stepping into the Wildeverse: Evaluating the impact of augmented reality mobile gaming on pro-conservation behaviours	Matilda Eve Dunn, Gautam Shah, and Diogo Veríssimo	585
[19]	Designing virtual environments for attitudes and behavioral change in plastic consumption: a comparison between concrete and numerical information	Alice Chirico, Giulia Wally Scurati, Chiara Maffi, Siyuan Huang, Serena Graziosi, Francesco Ferrise, and Andrea Gaggioli	591
[104]	Effects of Self-focused Augmented Reality on Health Perceptions During the COVID-19 Pandemic: A Web-Based Between-Subject Experiment.	Ayanna Seals, Monsurat Olaosebikan, Jennifer Otiono, Orit Shaer, and Oded Nov	603
[82]	Improving bushfire preparedness through the use of virtual reality	Safa Molan and Delene Weber	606
[130]	A quasi-experimental test of a virtual reality game prototype for adolescent E-Cigarette prevention	Veronica U. Weser, Lindsay R. Duncan, Tyra M. Pendergrass, Claudia-Santi Fernandes, Lynn E. Fiellin, and Kimberly D. Hieftje	614
[129]	Effects of immersion and navigation agency in virtual environments on emotions and behavioral intentions	René Weller, Joscha Cepok, Roman Arzaroli, Kevin Marnholz, Cornelia S. Große, Hauke Reuter, and Gabriel Zachmann	620
[103]	Experiential exposure to texting and walking in virtual reality: A randomized trial to reduce distracted pedestrian behavior	David C. Schwebel, Leslie A. McClure, and Bryan E. Porter	626
[91]	Embodied time travel in VR: from witnessing climate change to action for prevention	Yuke Pi, Xueni Pan, Mel Slater, and Justyna Świdrak	629
[92]	Shifting from Information- to Experience-Based Climate Change Communication Increases Pro-Environmental Behavior Via Efficacy Beliefs.	Adéla Plechatá, Marijke Hiltje Hielkema, Lisa-Marie Merkl, Guido Makransky, and Michael Bom Frøs	636

Table 13: Overview of papers included in the review. Part 3.

Citation	Paper Title	Authors	Paper ID
[16]	ARGreenet and BasicGreenet: Two mobile games for learning how to recycle	M. Carmen Juan, David Furio, Leila Alem, Peta Ashworth, and Juan Cano	633
[51]	The effectiveness of virtual vs real-life marine tourism experiences in encouraging conservation behaviour	Karen Hofman, Gabby Walters, and Karen Hughes.	638
[122]	Can't simply roll it out: Evaluating a real-world virtual reality intervention to reduce driving under the influence	Daniel Vankov, Ronald Schroeter, and Divera Twisk	643
[141]	A Change of Scenery: Transformative Insights from Retrospective VR Embodied Perspective-Taking of Conflict With a Close Other	Seraphina Yong, Leo Cui, Evan Suma Rosenberg, and Svetlana Yarosh	647
[119]	Shaping health behaviors beyond reality: A full body illusion to experience the consequences of unhealthy snacking.	Nadine Elisa van der Waal, Loes Janssen, Marco Otte, Marjolijn Antheunis, and Laura Nynke van der Laan	656
[33]	Using narrative 360° video as a tool to promote breast self-examination	H. Farmer, E. Skoulikari, C. Bevan, S. Gray, K. Cater, and D. Stanton Fraser.	667
[40]	Evaluating the relation between the EEG brainwaves and attention measures, and the children's performance in REEFOCUS game designed for ADHD symptoms improvement	Eftichia Georgiou, Giorgos-Konstanditos Thanos, Tassos Kanellos, Adam Doulgerakis, and Stelios C. A. Thomopoulos	694
[39]	Feeling connected but dissimilar to one's future self reduces the intention-behavior gap	Benjamin Ganschow, Sven Zebel, Jean-Louis van Gelder, and Liza J. M. Cornet	701
[43]	Role-Exchange Playing: An Exploration of Role-Playing Effects for Anti-Bullying in Immersive Virtual Environments.	Xiang Gu, Sheng Li, Kangrui Yi, Xiaojuan Yang, Huiling Liu, and Guoping Wang	709
[36]	Virtual Self-Modeling: The Effects of Vicarious Reinforcement and Identification on Exercise Behaviors	Jesse Fox and Jeremy N. Bailenson	715
[132]	The treatment of fear of flying: a controlled study of imaginal and virtual reality graded exposure therapy	B.K. Wiederhold, D.P. Jang, R.G. Gevirtz, S.I. Kim, I.Y. Kim, and M.D. Wiederhold	744
[58]	Mixed Reality Virtual Pets to Reduce Childhood Obesity	Kyle Johnsen, Sun Joo Ahn, James Moore, Scott Brown, Thomas P. Robertson, Amanda Marable, and Aryabrata Basu	763
[26]	Repeat after me: Using mixed reality humans to influence best communication practices	Andrew Cordar, Adam Wendling, Casey White, Samsun Lampotang, and Benjamin Lok	854
[55]			962
[102]	'Age Isn't Just a Number': Effects of Virtual Human Age and Gender on Persuasion, Social Presence and Influence in Interpersonal Social Encounters in VR	Elizabeth A. Schlesener, Vyomakesh Shivakumar, Dave Breeze, Brooke Rennison, Burak Soehmelioglu, and Sabarish V. Babu.	1221
[118]	First-Person Experience in Virtual Reality Sport Advertisements: Transportation of Embodied Empathy	Jun-Phil Uhm, Hyun-Woo Lee, Sanghoon Kim, and Jin-Wook Han.	1308
[117]	Effectiveness and acceptance of virtual reality vs. traditional exercise in obese adults: a pilot randomized trial.	Evlalia Touloudi, Mary Hassandra, Evangelos Galanis, Gerasimos Pinnas, Charalampos Krommidas, Marios Goudas, and Yannis Theodorakis	1419
[60]	The efficacy of augmented reality exposure therapy in the treatment of spider phobia—a randomized controlled trial	Tomas Jurcik, Svetlana Zaremba-Pike, Vladimir Kosonogov, Abdul-Raheem Mohammed, Yulia Krasavtseva, Tadamasa Sawada, Irina Samarina, Nilufar Buranova, Peter Adu, Nikita Sergeev, Andrei Skuratov, Anastasia Demchenko, and Yakov Kochetkov	1430

D.1 License details for Figure 3

Licenses. Papers 1430 [60], 603 [104], 570 [93], 620 [129], 667 [33], and 701 [39] are published under the Creative Commons Attribution 4.0 International License (CC BY 4.0), URL: https://creativecommons.org/licenses/by/4.0/deed.en. Papers 538 [139] and 554 [72] are published

Usage of Figures. For paper 1430, we used Figure 2 without any modifications. We also added an overlay with the paper ID. For paper 603, we used Figure 2 without any modifications. We also added an overlay with the paper ID. For paper 570, we used Figure 1 A without any modifications. We also added an overlay with the paper ID. For paper 620, we used Figure 1. We cropped the figure and used only the two sub-panels on the left and right, removing the middle one. We also added an overlay with the paper ID. For paper 667, we used Figure 1. We did not make changes and added an overlay with the paper ID. For paper 701, we used Figure 1. We cropped the figure and used only two of the six sub-panels: the top-right and the top-center ones. We also added an overlay with the paper ID. For paper 538, we used Figure 1 without any modifications. We also added an overlay with the paper ID. For paper 554, we used Figure 1. We cropped the figure and only used the top right sub-panel. We also added an overlay with the paper ID. For paper 10, we used Figure 1. We cropped the figure and only used the top left sub-panel. We also added an overlay with the paper ID. For paper 32, we used Figure 8. We cropped the figure and used the top left, bottom left, and bottom right sub-panels. We also added an overlay with the paper ID.

E Results - BCT and MoA Coding

E.1 BCT Coding Results

E.2 MoA Coding Results

F Results - RQ3 - Effectiveness Summary

G Results - Logistic Regression

To assess whether any of the discussed influencing factors (BCTs, MoAs, technical factors, and psychological factors) affected the effectiveness of the interventions, we conducted mixed-effects logistic regression analyses. Due to sparse data for long-term and comparative effectiveness, we focused on short-term effectiveness and included only papers reporting a clear positive or negative outcome. The outcome variable *short-term effectiveness* was therefore transformed into a binary variable (effective/non-effective). We analyzed the data using generalized linear mixed-effects models (GLMM) with binomial link function using the glmer function from the lme4 package in R. We ran four models, one for the potential influence of the theories (BCT and MoA), one for the technical factors (relation to physical world and virtual elements), and two for the psychological factors (immersion and perspective, and agency and connection to action). For all four models, we specified paper ID as random intercept to account for potential clustering of observations. For each of the models, we specified the respective two factors (e.g., for theories that was BCT Category and MoA) as fixed effects. The models were specified with a binomial error distribution and a logit link function, appropriate for our binary outcome variable.

The models for the theories, the technical factors and immersion and perspective did not converge (see details below).

The model with *agency* and *connection to action* did converge and showed an effect (see Table 22). The intercept and both predictors showed significant effects. Having *agency* was associated with a decrease in log-odds, while performing an action that was connected to the behavior (*Connection to Action*) was associated with a strong increase. However, we note that these analyses are explorative. As indicated in the model results, there was considerable between-paper heterogeneity and the correlation matrix of the fixed effects indicated only moderate collinearity between predictors. Table 23 groups the papers with regard to agency and connection to action, and indicates their measured effectiveness.

G.1 Regression Model for Agency and Connection-to-Action

G.2 Regression Model for BCT and MoA

We fitted a generalized linear mixed model (GLMM) using maximum likelihood estimation via Laplace approximation to examine the association between behavior change technique categories (*BCTCategory*), mechanisms of action (*MoA*), and short-term effectiveness, accounting for clustering by paper including *PaperID* as a random intercept. The estimated variance of the random intercept was 85.44 (SD = 9.24), indicating substantial between-paper variability. However, the model failed to converge (optimizer: Nelder-Mead; convergence code: 4), with a degenerate Hessian matrix (3 negative eigenvalues), suggesting instability in parameter estimation. Several fixed-effect estimates had extremely large standard errors and non-significant z-values (all p-values > 0.9), indicating overparameterization and potential multicollinearity or sparse data issues.

G.3 Regression Model for Relation to Physical World and Virtual Elements

We fitted a generalized linear mixed model (GLMM) using maximum likelihood estimation via Laplace approximation to examine the relationship between the type of virtual environment (*RelationToPhysicalWorld*), the elements present in the virtual world (*ElementsInVirtualWorld*), and short-term effectiveness. The model included a random intercept for PaperID. The model yielded an AIC of 39.1 and a log-likelihood of −9.6. The estimated variance of the random intercept was 3445 (SD = 58.7), indicating substantial variability between papers. However, the

Table 14: Overview of BCT assignments to papers. Part 1

BCT	Citation	ID	BCT	Citation	ID
BCT 2.7 Feedback on outcome(s) of behavior	[134]	2	BCT 2.2 Feedback on behavior	[21]	308
BCT 5.2 Salience of consequences	[134]	2	BCT 4.1 Instruction on how to perform a behavior	[21]	308
BCT 5.3 Information about social and environmental consequences	[134]	2	BCT 6.1 Demonstration of the behavior	[21]	308
BCT 2.6 Biofeedback	[4]	10	BCT 5.3 Information about social and environmental consequences	[109]	443
BCT 7.7 Exposure	[4]	10	BCT 4.1 Instruction on how to perform a behavior	[100]	475
BCT 2.2 Feedback on behavior	[131]	11	BCT 6.1 Demonstration of the behavior	[100]	475
BCT 2.3 Self-monitoring of behavior	[131]	11	BCT 5.3 Information about social and environmental consequences	[111]	537
BCT 5.3 Information about social and environmental consequences	[131]	11	BCT 9.3 Comparative imagining of future outcomes	[111]	537
BCT 11.2 Reduce negative emotions	[127]	32	BCT 16.3 Vicarious consequences	[139]	538
BCT 5.6 Information about emotional consequences	[127]	32	BCT 5.2 Salience of consequences	[139]	538
BCT 4.1 Instruction on how to perform a behavior	[138]	65	BCT 5.3 Information about social and environmental consequences	[139]	538
BCT 6.1 Demonstration of the behavior	[138]	65	BCT 5.3 Information about social and environmental consequences	[65]	539
BCT 5.3 Information about social and environmental consequences	[35]	67	BCT 5.2 Salience of consequences	[20]	548
BCT 7.7 Exposure	[57]	84	BCT 5.3 Information about social and environmental consequences	[20]	548
BCT 11.2 Reduce negative emotions	[126]	93	BCT 5.1 Information about health consequences	[72]	554
BCT 5.6 Information about emotional consequences	[126]	93	BCT 5.2 Salience of consequences - not sure	[72]	554
BCT 2.2 Feedback on behavior	[23]	104	BCT 5.3 Information about social and environmental consequences	[72]	554
BCT 5.3 Information about social and environmental consequences	[23]	104	BCT 5.3 Information about social and environmental consequences	[84]	560
BCT 6.2 Social Comparison	[23]	104	BCT 5.2 Salience of consequences	[96]	562
BCT 2.2 Feedback on behavior	[14]	125	BCT 5.3 Information about social and environmental consequences	[96]	562
BCT 4.1 Instruction on how to perform a behavior	[14]	125	BCT 9.3 Comparative imagining of future outcomes	[96]	562
BCT 6.1 Demonstration of the behavior	[14]	125	BCT 5.2 Salience of consequences	[73]	565
BCT 2.2 Feedback on behavior	[74]	148	BCT 5.3 Information about social and environmental consequences	[73]	565
BCT 6.1 Demonstration of the behavior	[74]	148	BCT 5.2 Salience of consequences	[93]	570
BCT 2.2 Feedback on behavior	[44]	201	BCT 5.3 Information about social and environmental consequences	[93]	570
BCT 5.6 Information about emotional consequences	[44]	201	BCT 9.3 Comparative imagining of future outcomes	[93]	570
no BCT - indirect influence/priming	[48]	221	BCT 4.1 Instruction on how to perform a behavior	[70]	579
			BCT 6.1 Demonstration of the behavior	[70]	579

model exhibited numerical instability during estimation. Although the optimizer (Nelder-Mead) returned a convergence code of 0 (indicating convergence), the scaled gradient could not be evaluated, and the Hessian matrix was numerically singular, suggesting that parameters were not uniquely determined. This was reflected in extremely large standard errors and z-values near zero for most fixed effects, with p-values > 0.9. These issues indicate that the model is likely overparameterized or affected by sparse data, and the fixed-effect estimates should be

Table 15: Overview of BCT assignments to papers. Part 2

BCT	Citation	ID	BCT	Citation	ID
BCT 5.3 Information about social and environmental consequences	[32]	585	BCT 11.4 Paradoxical instructions	[122]	643
BCT 5.2 Salience of consequences	[19]	591	BCT 16.1 Imaginary punishment	[122]	643
BCT 5.3 Information about social and environmental consequences	[19]	591	BCT 13.3 Incompatible beliefs	[141]	647
BCT 16.3 Vicarious consequences	[104]	603	BCT 16.3 Vicarious consequences	[141]	647
BCT 5.2 Salience of consequences	[104]	603	BCT 2.2 Feedback on behavior	[141]	647
BCT 5.3 Information about social and environmental consequences	[104]	603	BCT 5.3 Information about social and environmental consequences	[141]	647
BCT 6.1 Demonstration of the behavior	[104]	603	BCT 5.4 Information about emotional consequences	[141]	647
BCT 6.1 Demonstration of the behavior	[82]	606	BCT 10.11 Future punishment	[119]	656
BCT 5.1 Information about health consequences	[130]	614	BCT 5.1 Information about health consequences	[119]	656
BCT 5.3 Information about social and environmental consequence	[130]	614	BCT 5.2 Salience of consequences	[119]	656
BCT 6.1 Demonstration of the behavior	[130]	614	BCT 5.3 Information about social and environmental consequences	[33]	667
BCT 8.1 Behavioral practice/ rehearsal	[130]	614	BCT 2.6 Biofeedback	[40]	694
BCT 5.3 Information about social and environmental consequences	[129]	620	BCT 6.1 Demonstration of the behavior	[40]	694
BCT 9.3 Comparative imagining of future outcomes	[129]	620	BCT 13.1 Identification of self as role model	[39]	701
BCT 11.4 Paradoxical instructions	[103]	626	BCT 13.3 Incompatible beliefs	[39]	701
BCT 16.1 Imaginary punishment	[103]	626	BCT 13.5 Identity associated with changed behavio	[39]	701
BCT 5.2 Salience of consequences	[91]	629	BCT 15.3 Focus on past success	[39]	701
BCT 5.3 Information about social and environmental consequences	[91]	629	BCT 5.1 Information about health consequences	[39]	701
BCT 5.6 Information about emotional consequences	[91]	629	BCT 5.2 Salience of consequences	[39]	701
BCT 4.1 Instruction on how to perform a behavior	[16]	633	BCT 5.3 Information about social and environmental consequences	[39]	701
BCT 6.1 Demonstration of the behavior	[16]	633	BCT 5.4 Information about emotional consequences	[39]	701
BCT 5.2 Salience of consequences	[92]	636	BCT 13.3 Incompatible beliefs	[43]	709
BCT 5.3 Information about social and environmental consequences	[92]	636	BCT 5.2 Salience of consequences	[43]	709
BCT 9.3 Comparative imagining of future outcomes	[92]	636	BCT 5.3 Information about social and environmental consequences	[43]	709
BCT 5.3 Information about social and environmental consequences	[51]	638	BCT 5.4 Information about emotional consequences	[43]	709
BCT 9.3 Comparative imagining of future outcomes	[51]	638			

interpreted with caution. We attempted alternative model specifications and optimizers to improve convergence and provide more stable estimates.

G.4 Regression Model for Immersion and Perspective

We fitted a generalized linear mixed model (GLMM) using maximum likelihood estimation via Laplace approximation to examine the relationship between immersion type (Immersion), perspective (Perspective), and short-term effectiveness. The model included a random intercept for PaperID. The model yielded an AIC of 29.5 and a log-likelihood of −9.7. The estimated variance of the random intercept was

Table 16: Overview of BCT assignments to papers. Part 3

BCT	Citation	ID	BCT	Citation	ID
BCT 10.11 Future punishment	[36]	715	BCT 4.1 Instruction on how to perform a behavior	[26]	854
BCT 10.9 Self-reward	[36]	715	BCT 6.1 Demonstration of the behavior	[26]	854
BCT 2.4 Self-monitoring of outcome(s) of behavior	[36]	715	BCT 11.2 Reduce negative emotions	[55]	962
BCT 5.1 Information about health consequences	[36]	715	BCT 15.1 Verbal persuasion about capability	[55]	962
BCT 5.2 Salience of consequences	[36]	715	BCT 9.1 Credible source	[102]	1221
BCT 6.1 Demonstration of the behavior	[36]	715	no BCT - indirect influence/priming/persuasion	[102]	1221
BCT 8.1 Behavioural practice and rehearsal	[36]	715	no BCT - indirect influence/priming	[118]	1308
BCT 2.6 Biofeedback	[132]	744	BCT 2.6 Biofeedback	[117]	1419
BCT 7.7 Exposure	[132]	744	BCT 6.1 Demonstration of the behavior	[117]	1419
BCT 1.1 Goal setting (behavior)	[58]	763	BCT 7.7 Exposure	[60]	1430
BCT 10.10 Reward (outcome)	[58]	763			
BCT 2.7 Feedback on outcome(s) of behavior	[58]	763			
BCT 3.1 Social support (unspecified)	[58]	763			
BCT 6.2 Social comparison	[58]	763			

4444 (SD = 66.67), indicating substantial between-paper variability. Although the optimizer (Nelder-Mead) returned a convergence code of 0 (indicating convergence), the model exhibited numerical instability. Specifically, the scaled gradient could not be evaluated, and the Hessian matrix was numerically singular, suggesting that parameters were not uniquely determined. This was reflected in extremely large standard errors and z-values near zero for most fixed effects, with p-values > 0.9. These issues indicate that the model estimates are not reliable, likely due to overparameterization, sparse data, or collinearity among predictors.

Table 17: Overview of MoA assignments to papers. Part 1

MoA	Theory in Paper	Citation	Paper ID
MoA 1. Knowledge		[134]	2
MoA 11. Environmental Context and Resources		[134]	2
MoA 22. Feedback Processes	spatial distance, psychological barriers	[134]	2
MoA 4. Beliefs about Capabilities	temporal distance, psychological barriers	[134]	2
MoA 6. Beliefs about Consequences	spatial distance, psychological barriers	[134]	2
MoA 1. Knowledge		[4]	10
MoA 22. Feedback Processes	physiological feedback	[4]	10
MoA 1. Knowledge		[131]	11
MoA 12. Social Influences	social facilitation	[131]	11
MoA 15. Norms	normative influence	[131]	11
MoA 22. Feedback Processes	self-monitoring	[131]	11
MoA 11. Environmental Context and Resources	art therapy	[127]	32
MoA 13. Emotion	counselling, positive psychology	[127]	32
MoA 14. Behavioral Regulation	counselling	[127]	32
MoA 17. Attitude towards the Behavior	counselling	[127]	32
MoA 19. Self-image	self-reflection, positive psychology	[127]	32
MoA 2. Skills		[138]	65
MoA 1. Knowledge		[35]	67
MoA 11. Environmental Context and Resources		[35]	67
MoA 22. Feedback Processes		[35]	67
MoA 11. Environmental Context and Resources	colour psychology	[126]	93
MoA 13. Emotion	mood induction procedure	[126]	93
MoA 14. Behavioral Regulation	autonomy	[126]	93
MoA 17. Attitude towards the Behavior	autonomy	[126]	93
MoA 19. Self-image	autonomy	[126]	93
MoA 1. Knowledge		[23]	104
MoA 12. Social Influences	social comparison	[23]	104
MoA 16. Subjective Norms	social comparison	[23]	104
MoA 22. Feedback Processes	social comparison	[23]	104
MoA 1. Knowledge		[14]	125
MoA 22. Feedback Processes	real-time feedback	[14]	125
MoA 1. Knowledge		[74]	148
MoA 12. Social Influences		[74]	148
MoA 18. Motivation		[74]	148
MoA 19. Self-image	Self Competition	[74]	148
MoA 22. Feedback Processes	Feedforward	[74]	148
MoA 4. Beliefs about Capabilities	self-efficacy	[74]	148
MoA 1. Knowledge		[44]	201
MoA 12. Social Influences	(parental mediation	[44]	201
MoA 22. Feedback Processes		[44]	201
MoA 23. Social Learning/Imitation		[44]	201
MoA 1. Knowledge		[48]	221
MoA 11. Environmental Context and Resources	affective narration, active indexing	[48]	221
MoA 13. Emotion	affective narration	[48]	221
MoA 1. Knowledge	situated learning theories, scaffolding	[109]	443
MoA 11. Environmental Context and Resources	construal level theory	[139]	538
MoA 12. Social Influences		[139]	538
MoA 26. Perceived Susceptibility/Vulnerability	construal level theory	[139]	538
MoA 6. Beliefs about Consequences	construal level theory	[139]	538
MoA 1. Knowledge		[65]	539
MoA 11. Environmental Context and Resources	connection with nature	[65]	539

Table 18: Overview of MoA assignments to papers. Part 2

MoA	Theory in Paper	Citation	Paper ID
MoA 11. Environmental Context and Resources		[20]	548
MoA 26. Perceived Susceptibility/Vulnerability	terror management theory	[20]	548
MoA 6. Beliefs about Consequences		[20]	548
MoA 1. Knowledge	impact messages: information on impact of product	[72]	554
MoA 6. Beliefs about Consequences	psychological barriers	[72]	554
MoA 1. Knowledge		[84]	560
MoA 11. Environmental Context and Resources		[84]	560
MoA 1. Knowledge		[96]	562
MoA 11. Environmental Context and Resources	awareness of consequences - theory of environmentally significant behavior	[96]	562
MoA 22. Feedback Processes		[96]	562
MoA 6. Beliefs about Consequences	awareness of consequences - theory of environmentally significant behavior	[96]	562
MoA 1. Knowledge		[73]	565
MoA 11. Environmental Context and Resources		[73]	565
MoA 13. Emotion	protection motivation theory, health belief-model, parallel processing model	[73]	565
MoA 26. Perceived Susceptibility/Vulnerability	protection motivation theory, health belief-model, parallel processing model	[73]	565
MoA 11. Environmental Context and Resources		[93]	570
MoA 12. Social Influences		[93]	570
MoA 22. Feedback Processes		[93]	570
MoA 3. Social/Professional Role and Identity		[93]	570
MoA 6. Beliefs about Consequences		[93]	570
MoA 2. Skills		[70]	579
MoA 1. Knowledge		[32]	585
MoA 11. Environmental Context and Resources		[32]	585
MoA 1. Knowledge		[19]	591
MoA 11. Environmental Context and Resources		[19]	591
MoA 1. Knowledge		[104]	603
MoA 11. Environmental Context and Resources		[104]	603
MoA 12. Social Influences	objective self-awareness theory: self-focused attention, social cognitive theory: vicarious reinforcement	[104]	603
MoA 19. Self-image	objective self-awareness theory: self-focused attention, social cognitive theory: vicarious reinforcement	[104]	603
MoA 26. Perceived Susceptibility/Vulnerability		[104]	603
MoA 6. Beliefs about Consequences		[104]	603
MoA 26. Perceived Susceptibility/Vulnerability	protective action decision model	[82]	606
MoA 1. Knowledge		[130]	614
MoA 11. Environmental Context and Resources	social cognitive theory	[130]	614
MoA 12. Social Influences	social cognitive theory	[130]	614
MoA 16. Subjective Norms	social cognitive theory	[130]	614
MoA 23. Social Learning/Imitation	social cognitive theory	[130]	614
MoA 3. Social/Professional Role and Identity	theory of planned behavior	[130]	614
MoA 4. Beliefs about Capabilities	theory of planned behavior	[130]	614
MoA 6. Beliefs about Consequences	theory of planned behavior	[130]	614
MoA 1. Knowledge		[129]	620
MoA 11. Environmental Context and Resources		[129]	620
MoA 26. Perceived Susceptibility/Vulnerability	vulnerability/susceptibility education	[103]	626
MoA 6. Beliefs about Consequences		[103]	626

Table 19: Overview of MoA assignments to papers. Part 3

MoA	Theory in Paper	Citation	Paper ID
MoA 1. Knowledge		[91]	629
MoA 11. Environmental Context and Resources	legacy thinking	[91]	629
MoA 12. Social Influences	legacy thinking	[91]	629
MoA 13. Emotion		[91]	629
MoA 22. Feedback Processes	legacy thinking	[91]	629
MoA 6. Beliefs about Consequences	legacy thinking	[91]	629
MoA 2. Skills		[16]	633
MoA 2. Skills		[16]	633
MoA 1. Knowledge		[92]	636
MoA 11. Environmental Context and Resources	experiential communication	[92]	636
MoA 22. Feedback Processes	experiential communication	[92]	636
MoA 4. Beliefs about Capabilities	self-efficacy	[92]	636
MoA 6. Beliefs about Consequences	experiential communication	[92]	636
MoA 26. Perceived Susceptibility/Vulnerability		[122]	643
MoA 6. Beliefs about Consequences		[122]	643
MoA 19. Self-image	perspective taking	[141]	647
MoA 22. Feedback Processes	recall	[141]	647
MoA 23. Social Learning/Imitation	perspective taking	[141]	647
MoA 3. Social/Professional Role and Identity	perspective taking	[141]	647
MoA 6. Beliefs about Consequences	recall	[141]	647
MoA 1. Knowledge		[119]	656
MoA 19. Self-image		[119]	656
MoA 26. Perceived Susceptibility/Vulnerability	parallel processing model	[119]	656
MoA 6. Beliefs about Consequences		[119]	656
MoA 1. Knowledge		[33]	667
MoA 19. Self-image	perspective-taking	[33]	667
MoA 26. Perceived Susceptibility/Vulnerability		[33]	667
MoA 6. Beliefs about Consequences		[33]	667
MoA 1. Knowledge		[40]	694
MoA 2. Skills	cognitive skill training	[40]	694
MoA 22. Feedback Processes	neurofeedback	[40]	694
MoA 19. Self-image	future self-continuity, perspective taking	[39]	701
MoA 22. Feedback Processes	future self-continuity	[39]	701
MoA 3. Social/Professional Role and Identity	perspective taking	[39]	701
MoA 4. Beliefs about Capabilities	future self-continuity	[39]	701
MoA 6. Beliefs about Consequences	future self-continuity	[39]	701
MoA 12. Social Influences		[43]	709
MoA 13. Emotion	cognitive dissonance	[43]	709
MoA 16. Subjective Norms		[43]	709
MoA 19. Self-image	perspective taking	[43]	709
MoA 22. Feedback Processes	cognitive dissonance	[43]	709
MoA 3. Social/Professional Role and Identity		[43]	709
MoA 6. Beliefs about Consequences		[43]	709
MoA 19. Self-image	vicarious reinforcement, self-other manipulation, social cognitive theory	[36]	715
MoA 26. Perceived Susceptibility/Vulnerability		[36]	715
MoA 4. Beliefs about Capabilities	vicarious reinforcement	[36]	715
MoA 6. Beliefs about Consequences		[36]	715
MoA 22. Feedback Processes		[36]	715
MoA 1. Knowledge		[132]	744
MoA 22. Feedback Processes	physiological feedback	[132]	744

Table 20: Overview of MoA assignments to papers. Part 4

MoA	Theory in Paper	Citation	Paper ID
MoA 12. Social Influences	vicarious experiences, reward, social cognitive theory	[58]	763
MoA 22. Feedback Processes	vicarious experiences	[58]	763
MoA 4. Beliefs about Capabilities	self-efficacy	[58]	763
MoA 6. Beliefs about Consequences	reward	[58]	763
MoA 9. Goals	reward	[58]	763
MoA 2. Skills		[26]	854
MoA 1. Knowledge		[102]	1221
MoA 12. Social Influences	persuasion	[102]	1221
MoA 19. Self-image		[118]	1308
MoA 1. Knowledge		[117]	1419
MoA 18. Motivation	self-determination theory	[117]	1419
MoA 20. Needs	self-determination theory, autonomy	[117]	1419
MoA 22. Feedback Processes	self-determination theory, competence	[117]	1419
MoA 2. Skills		[21]	308
MoA 22. Feedback Processes		[21]	308
MoA 2. Skills		[100]	475
MoA 12. Social Influences		[100]	475
MoA 16. Subjective Norms		[100]	475
MoA 18. Motivation	self-determination theory	[100]	475
MoA 1. Knowledge		[111]	537
MoA 11. Environmental Context and Resources		[111]	537
MoA 1. Knowledge		[51]	638
MoA 11. Environmental Context and Resources		[51]	638
MoA 1. Knowledge		[55]	962
MoA 4. Beliefs about Capabilities		[55]	962
MoA 12. Social Influences		[55]	962
MoA 14. Behavioral Regulation		[55]	962

Table 21: Distribution of papers by behavior/intention/measurement gap and effectiveness type, indicating the number of papers with positive, negative, or mixed effects.

		Short-term Effectiveness (pre-post)	Long-term Effectiveness (pre-post)	Comparative Effectiveness
Behavioral Outcome	Positive	15 (78.95%)	5 (62.50%)	8 (57.12%)
	Negative	3 (15.79%)	2 (25.00%)	5 (35.71%)
	Mixed	1 (5.26%)	1 (12.50%)	1 (7.14%)
	Measured	19	8	14
	Not Measured	8	19	13
Behavior-Intention Gap	Positive	5 (71.43%)	0	0
	Negative	2 (28.57%)	0	2 (66.67%)
	Mixed	0	0	1 (33.33%)
	Measured	7	0	3
	Not Measured	5	12	9
Behavior-Measurement Gap	Positive	0	0	0
	Negative	0	0	0
	Mixed	1 (100%)	0	1 (100%)
	Measured	1	0	1
	Not Measured	4	5	4
Other Constructs	Positive	5 (55.55%)	1 (100%)	1 (100%)
	Negative	2 (22.22%)	0	0
	Mixed	2 (22.22%)	0	0
	Measured	9	1	1
	Not Measured	0	8	8

Table 22: Results of the GLMM for testing the influence of agency and connection to action on short-term effectiveness . The model yielded an AIC of 27.4 and a BIC of 40.6, with a log-likelihood of −9.7. A variance of 4048 (*SD* = 63.62), suggesting considerable between-paper heterogeneity. Scaled residuals were minimal, and the correlation matrix of fixed effects indicated moderate collinearity between predictors, which may affect the stability of estimates.

	Estimate	Standard Error	z-Value	p-Value
(Intercept)	13.75	4.31 3.19	0.0014 **	
Agency Yes	-26.11	7.309	-3.57	0.0004 ***
Connection to Action Active	27.31	7.01	3.89	9.84e-05 ***

Table 23: Papers grouped into the factors agency and connection to action. ✔ indicates a measured short-term effect, ✖ indicates that an effect was tested but not found, ✓ indicates mixed results, and ✕ indicates that short-term effectiveness was not measured.

	Active Connection to Action	**Passive Connection to Action**
Agency	[26]✔, [126]✔, [55]✔, [40]✔, [43]✔, [117]✔, [74]✔, [134]✔, [21]✔, [127]✔, [82]✔, [130]✔, [103]✔, [16]✔, [93]✔, [131]✓, [109]✓, [138]✖, [72]✖, [96]✖, [70]✕, [92]✕, [122]✕, [100]✕, [14]✕, [36]✕, [58]✕, [57]✕, [4]✕, [23]✕	[48]✔, [20]✔, [102]✓, [111]✖, [39]✕
No Agency	[60]✔, [141]✔, [132]✔	[139]✔, [65]✔, [91]✔, [51]✔, [44]✔, [32]✓, [118]✖, [84]✖, [19]✕, [104]✕, [129]✕, [73]✕, [119]✕, [33]✕, [35]✕