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A Literature Review of Type 2 Diabetes Support Using Extended Reality

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Abstract

Extended reality (XR) technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), have emerged as promising tools in the realm of healthcare education and support. XR offers immersive and interactive experiences that have the potential to enhance patient engagement and comprehension of intricate medical information. Moreover, it enables individuals to visualize the physiological impacts of type 2 diabetes, thereby facilitating a deeper understanding of the disease and its management. Additionally, XR can provide healthcare professionals with virtual scenarios to enhance their knowledge, skills, and confidence in treating and educating patients with type 2 diabetes. This review presents a comprehensive examination of studies that have employed XR technologies, evaluates the current research landscape in relation to expectations from a decade ago when portable XR started growing, and offers valuable insights into the challenges faced, along with recommendations for future approaches.

Keywords: extended reality; virtual reality; augmented reality; mixed reality; diabetes support

1. INTRODUCTION

By the most recent estimates, 28.7 million people in the U.S. have been diagnosed with diabetes, and an additional 8.5 million are believed to be living with undiagnosed diabetes. At the same time, ninety-six million people are estimated to have blood glucose levels in the range of pre-diabetes or categories of increased risk for diabetes. Thus, more than 133 million Americans are at risk of developing the devasting complications of diabetes (Centers for Disease Control and Prevention, 2022). Diabetes can lead to severe complications if not effectively managed.

Traditional methods of diabetes management typically involve medication, lifestyle modifications, and regular monitoring of blood glucose levels. Patients play a significant role in day-to-day decision-making about managing their diabetes, and appropriate self-management is central to long-term diabetes care. Diabetes self-management has been shown to reduce hemoglobin A1c and low-density lipoprotein cholesterol levels in patients with type 2 diabetes mellitus (Lorig et al., 2010). Diabetes self-management education and support are critical

elements of care for all people with diabetes and those at risk of developing the disease.

In the past decade, the advancement and proliferation of emerging technologies such as extended reality (XR) have offered new possibilities for improving the management and treatment of Type 2 diabetes.

Extended reality (XR), as an umbrella term to describe immersive technologies, covers virtual reality (VR), augmented reality (AR), mixed reality (MR), and everything in between (Milgram & Kishino, 1994), embraced a rapid evolvement in both hardware and software through the 2010s. These technologies have gained significant attention in various fields, including healthcare, due to their potential to enhance patient engagement, education, and self-management on the patient's side, as well as medical training and empathy promotion for healthcare professional's support (Ali et al., 2023; Mathew & Pillai, 2020). In terms of diabetes support, XR immersive technologies can offer interactive and engaging platforms for patients to better understand their condition, monitor their health metrics, and learn essential self-care practices, thereby serving as a potent tool for both the prevention and management of diabetes.

In order to investigate the current status of research on this topic, in this paper, we aim to: (1) identify and review the studies that adopted approaches using XR technologies in assisting in the patient care of type 2 diabetes, including self-management, training for behavior change, motivations, and community building, (2) discuss the gap between the expectations prior to the head-mounted immersive technology era and current status of the research in the field, and (3) contribute insight into the challenges and provide future directions that will benefit people suffer from type 2 diabetes.

2. BACKGROUND

In recent years, as XR is booming in numerous fields to assist traditional methods, researchers have designed numerous studies using XR technologies in healthcare and identified several characteristics that make XR suitable to be applied in the field: customizable scenarios that allow high requirement and full control; safety for simulating situations with hazard risk in real life; repetition and real-time feedback; immersive visualization and engagement; remote assistance and self-accessible. These characteristics enabled XR to be applied in a wide range of use cases, including but not limited to XR-assisted therapy, augmented surgeries, patient education for self-management, medical education and training, and diagnosis assistance (Andrews et al., 2019; Grewal et al., 2013; López-Ojeda & Hurley, 2021; Morimoto et al., 2022; Ong et al., 2021; Stone, 2020).

In 2017, Greenwood et al. (Greenwood et al., 2017) reviewed and evaluated technology-assisted education and support for diabetes, focusing on self-management solutions. The types of technology reported include mobile phones, secure messaging, and web-based information. None of the listed immersive technologies has been mentioned in the review, although it is expected that several pilot studies have been explored by researchers on this topic.

Vigersky (2011) summarized the management difficulties that society and patients with diabetes face, including limited resources, increasing complexity of management for patients on the healthcare provider side, and non-adherence of patients' self-management. The paper emphasized that technology-driven solutions, including virtual reality, may resolve the desperate need for support for patients and their providers. In addition, Ershow et al. (2011) also suggested possible use cases for XR applications, including but not limited to fostering health-related behaviors such as desirable eating and physical activity, motivating and educating, extending the availability and capacity of healthcare providers, fast-forward to the future, and social network capabilities. Therefore, we reviewed XR technologies being researched during the past decade to see what difficulties were addressed and what could be the next research direction after the rapid evolution of XR technologies.

3. METHODS

Search Strategy

To investigate new approaches and studies based on immersive technologies, we searched Google Scholar, IEEE Xplore, Scopus (Sage, Springer, Science Direct), PubMed, Taylor & Francis, Publisher of Open Access Journals, Wiley Online, and Web of Science for publications since the year of 2010. The chosen databases are commonly used in the healthcare and technology fields. The key search term was ("extended reality" OR "virtual reality" OR "augmented reality" OR "mixed reality") AND "diabetes." The references in the included full-paper articles were also screened for additional qualified studies.

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Screening Criteria
The review included articles that are:

- With full text written in English only.
- Addressing the population with type II diabetes.
- Using some form of immersive technologies as one of the methods, including VR videos and augmented reality (AR).
- Including studies related to training, education, self-management, motivation, and more.

Additional exclusion criteria include:

- Low-quality studies or review papers.
- Studies with no human subjects.
- Used virtual environment but not true XR technologies.

In our judgment of "true XR technologies," we place a strong emphasis on attaining a profound level of immersion, interaction, and integration. The authors conducted a meticulous evaluation and engaged in comprehensive discussions to collectively determine the inclusion or exclusion of specific studies.

All three authors searched and identified qualified studies, merged the identified articles, and performed cross-checking on the classification and assessment of the paper quality. By rating the quality of the papers, Our quality evaluation emphasized the study design and methodology, clarity in data portrayal, and an in-depth methodological description ensuring repeatability. High-quality studies typically showcased sound statistical analyses, alignment with contemporary literature, a structured writing style, and robust citations. Conversely, we omitted papers perceived as low-quality, primarily those with flawed study design, non-representative samples, missing controls, ambiguities in methods, or sparse citations.

4. RESULTS

The search yielded 174 potentially relevant articles, and 38 additional articles were added through references to relevant articles. As shown in Figure 1, the PRISMA search process was followed, and the numbers of inclusion and exclusion are reported at each step. Finally, 15 studies that focus on using XR technologies to benefit the care for people with type 2 diabetes were identified and reviewed in our review summary.

Out of the 15 studies being identified, nine used VR, two used AR, and four used MR. It is also worth noting that apart from the 15 studies we reviewed in this paper, we also found studies that used non-immersive virtual environments or virtual worlds (VW), i.e., Second Life and Diabetes Live. However, we consider these environments non-immersive, and thus, studies using Second Life or Diabetes Live were not included. Figure 2 depicts the number of studies under each category of platforms.

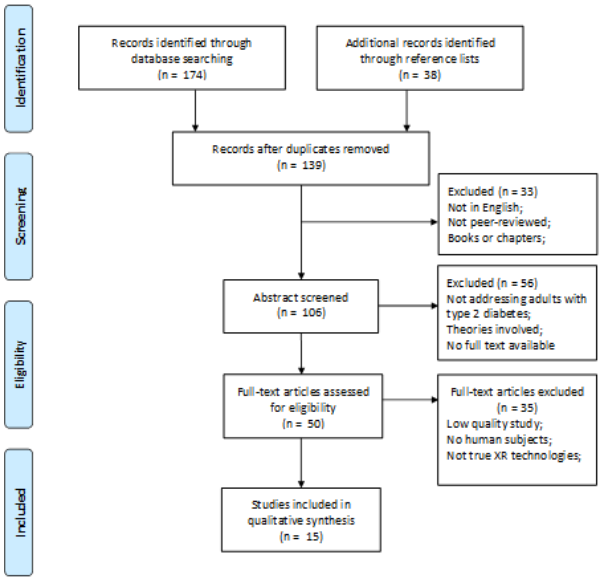

Figure 1. The Prisma Search Process (Liberati et al., 2009)

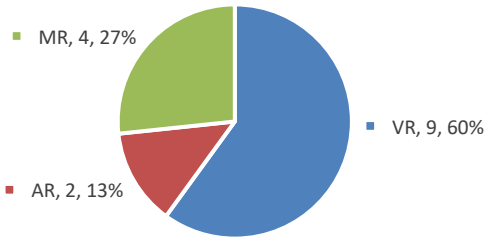

Figure 2. Studies by Platforms

We categorized the devices utilized in the studies under review, as depicted in Figure 3. One study employed wearable sensors, two leveraged Microsoft Kinect, three incorporated mobile devices for VR or AR displays, three adopted cinematic virtual reality (cine-VR), and six engaged with conventional interactive VR methodologies. Cine-VR typically involves extended programs with comprehensive storylines; participants immerse themselves but interact minimally, often taking quizzes following specific episodes. In contrast, interactive VR

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designs emphasize interactive functionalities and movement within a gamified environment.

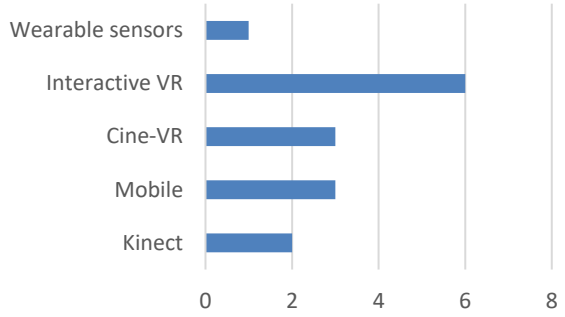

Figure 3. Studies by Devices

Regarding the countries of focus for the selected studies, researchers from the United States contributed the most, with seven studies on the subject. Figure 4 depicts the frequency of the countries of focus from the selected studies. Please note that one of them is a joint study with researchers from both Spain and Mexico (Neira-Tovar et al., 2023), so it is counted twice in Figure 3.

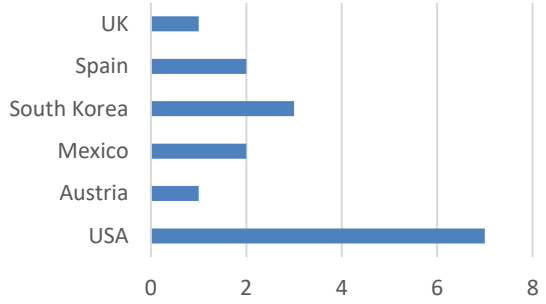

Figure 4. Countries of Focus

When it comes to the subject of the studies, it is not surprising that most of the publication venues are related to diabetes or public health. Among the 15 selected studies, four of them come from the Journal of Diabetes Science and Technology. JMIR Diabetes, the International Journal of Environmental Research and Public Health, and Diabetes each contributed two articles. The rest of the publication venues each contributed one article. Figure 5 depicts the frequency of publication venues from the selected studies.

In addition to traditional pre- and post-session questionnaires for collecting data, experimental designs of the identified studies often incorporate additional devices or technologies when using immersive technologies. Among the identified studies, Kinect and wearable devices (Ershow et al., 2011; Neira-Tovar & Elizondo Elizondo, 2018; Rizzo et al., 2011) are the most frequently used add-on devices.

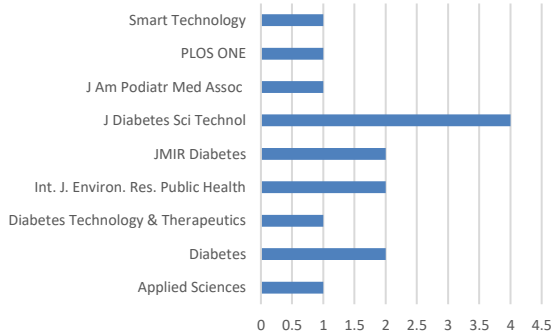

Figure 5. Frequency of Publication Venues

An article published in (2011), when the new generations of portable head-mounted VR technology started to bloom, anticipated the research challenges using the immersive technology and pointed out a few priority topics in development and evaluations in Obesity and Diabetes. Based on this article and observing the current review, we divided the identified studies into four categories based on the topics and discussed further in the following subsections.

Category	Targeted topics	References
Patient Education	Behavior Change	(Grewal et al., 2013) (Kim et al., 2021) (S. Lee & Shin, 2013) (Y. Lee et al., 2023) (Neira-Tovar et al., 2023) (Rizzo et al., 2011)
	Attitude	(Calle-Bustos et al., 2017) (Gibson et al., 2022) (Neira-Tovar & Elizondo Elizondo, 2018)
Healthcare Provider Support	Healthcare Provider Support	(Domhardt et al., 2015) (Beverly, Love, & Love, 2021; Beverly, Love, Love, et al., 2021; Beverly et al., 2022, 2023) (Mallik et al., 2022)

Table 1. Identified articles by topics

Behavioral Change

The most common research target and relatively easier to design is to use XR technologies for behavior change. In six of the identified studies, XR applications were explored to engage patients with Type 2 diabetes in simulated environments that mimic real-life situations, offering a unique platform for learning, practicing, and reinforcing

positive behaviors. XR can assist in modifying behaviors related to die (Kim et al., 2021), physical activity (Grewal et al., 2013; S. Lee & Shin, 2013; Neira-Tovar et al., 2023; Rizzo et al., 2011), medication adherence (Y. Lee et al., 2023), and self-care routines (Kim et al., 2021; S. Lee & Shin, 2013; Neira-Tovar et al., 2023), empowering individuals to make sustainable lifestyle changes that contribute to better diabetes management and overall well-being.
Most of the studies reported positive results that the body weight (Grewal et al., 2013; Kim et al., 2021), body fat (Kim et al., 2021), and blood glucose (Kim et al., 2021; Y. Lee et al., 2023) level were reduced, and the mobility and joints (Grewal et al., 2013) were improved. However, (Rizzo et al., 2011) pointed out that playing VR exergames still could not match the level of intensity of playing the actual sport. Meanwhile, a study targeting elderly adults concluded that VR exergames are feasible and effective for reducing the risk of falls in the elderly (S. Lee & Shin, 2013).

Attitude
Motivating patients with Type 2 diabetes to actively engage in their self-care routines and make healthy lifestyle choices is another crucial factor for successful disease management. XR technologies were explored to offer innovative solutions to enhance motivation in patients. Visual feedback, gamified challenges, and integrated virtual rewards can make diabetes education and self-management tasks more enjoyable and rewarding.

Moreover, XR can simulate realistic scenarios that allow patients to witness the long-term consequences of their actions, fostering a sense of personal agency and motivation to make positive changes in their diabetes management. In a study conducted by Calle-Bustos et al., (2017), researchers investigated the use of a mobile AR game for therapeutic education for children with diabetes. The game allows children to see virtual foods on a real dish, and the children had to choose the current carb choices among the options. Their results show that the AR-based game is a favorable and effective tool for diabetes education among younger children.

Similarly, Neira-Tovar and Elizondo Elizondo (2018) developed a VR game for the prevention of Type 2 diabetes. Their game utilizes both Oculus Rift and Kinect to keep track of player movements, and the gameplay requires players to perform various physical activities to complete minigames. The results from their pilot study suggested that participants were intrigued and motivated to continue playing the game. However, given the fact that the game was still in development, more rigorous testing should be performed once the game is completed to properly evaluate its effectiveness.

Gibson et al. (2022) conducted a study to investigate the effectiveness of using mobile VR and 360° video to motivate prediabetic patients among Hispanic adults and promote their enrollment in diabetes prevention programs. Their results suggest that mobile VR and 360° video had equal effects on participants' motivation, and there are other factors that may affect the participants' decision-making regarding enrollment in diabetes prevention programs.

Healthcare Providers Support
XR technologies are expected to support healthcare providers in delivering adequate care and support to patients with Type 2 diabetes. XR applications allow them to visualize and interact with virtual representations of patient data, treatment plans, and educational resources. Through XR, providers can better understand patients' needs and conditions, enhancing their ability to personalize care and education. Only one study among the identified studies was designed to help visualize and estimate patients' data and was not specifically designed for healthcare providers (Domhardt et al., 2015). In the future, researchers may put more effort into this approach, as XR can be an effective tool for visualization and representation.

Additionally, XR can facilitate virtual collaborations and training sessions among healthcare professionals, promoting knowledge sharing and best practices in diabetes management. For example, A pilot study was designed by Mallik et al. (2022) to evaluate the use of VR as a training tool for doctors in training. The VR was created to stimulate real-life diabetes emergencies.

Beverly et al. (2022, 2023; 2021; 2021) have conducted a series of studies on using cinematic VR training programs for healthcare providers to raise their awareness of discrimination and neglect toward elderly patients with diabetes, improve healthcare providers' cultural self-efficacy, empathy, and attitudes toward diabetes and diabetic patients.

5. DISCUSSION

In Section 2, we mentioned the anticipation among scholars in 2011 for XR technologies that could address and effectively tackle the

challenges faced in Type 2 diabetes care. By reviewing identified articles in the last decade, Section 4 categorized them into three prominent and extensively studied topics: patient education for behavior modification and attitude influence, as well as healthcare provider support through training and empathy promotion. Many reports claimed that their studies found positive results to show the effectiveness of using XR technologies to assist with diabetes. Despite the potential benefits, integrating XR technologies in Type 2 diabetes management still faces several challenges. The gap between the expected usage and advantages of XR in diabetes management is still yet to be bridged.

Rigorous research and clinical trials should be designed to test the effectiveness and safety of these technologies in improving health care through the identified approaches and reducing the burden of diabetes. Additionally, long-term studies with larger sample sizes are necessary to fully understand the efficacy, sustainability, and cost-effectiveness of XR interventions and management.

The reviewed studies primarily focus on the application of XR in contrast to the absence of technological intervention. Yet, there is a noticeable absence of comparative evaluations between XR in immersive gaming contexts and the use of analogous applications on non-immersive platforms, such as tablets and standard computers. As mentioned above, the cost associated with XR is a significant consideration. Therefore, prior to ultimately endorsing XR technology, it is essential to design more experimental studies to ascertain its relative efficacy against cost-efficient, non-immersive methodologies.

Nevertheless, there are still areas of exploration within XR technologies that hold great significance and feasibility but have yet to be investigated by researchers. For instance, social networking and cultural impact remain relatively unexplored. Living with Type 2 diabetes often entails feelings of isolation, but XR technologies have the potential to bridge geographical gaps by enabling virtual scenarios that facilitate social interactions. Individuals with Type 2 diabetes could connect with peers, healthcare professionals, and support groups within virtual spaces, fostering a sense of community and empathy. These virtual communities offer platforms for sharing cultural perspectives, experiences, knowledge, and emotional support, thereby promoting motivation, self-efficacy, and a profound sense of belonging. Therefore, we strongly encourage researchers to consider integrating this approach into future study designs.

Combining the information in the results of using XR for behavioral change, we suggest that when designing an exergame using XR technologies, we should carefully take age into account. When targeting relatively younger adults, XR exergames can complement instead of replacing regular exercise, especially in cultivating the habits of doing exercises. Full-body interactions are preferred in order to activate more body parts. When targeting elderly patients with diabetes who need more safety considerations in design, lower intensity of exercise and more education for medication needs and self-care routines may be emphasized in the design.

6. CONCLUSIONS

To sum up, the utilization of XR technologies in the management and treatment of type 2 diabetes shows promising potential. The reviewed studies demonstrated that XR technologies offer innovative opportunities to enhance patient education, including the change of behavior, attitude, and self-management, as well as to provide support to healthcare providers. Moreover, challenges were discussed, and possible future directions that will benefit communities of adults suffering from type 2 diabetes were suggested.

By addressing the existing limitations and conducting further research, we believe that healthcare providers and researchers can further unlock the full potential of XR in improving the health outcomes and quality of life for individuals with type 2 diabetes.

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