Multimodal Technologies and Interaction

Review

The Use of Immersive Technologies in Karate Training: A Scoping Review

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Abstract: This study investigates the integration of immersive technologies, primarily virtual reality (VR), in the domain of karate training and practice. The scoping review adheres to PRISMA guidelines and encompasses an extensive search across IEEE Xplore, Web of Science, and Scopus databases, yielding a total of 165 articles, from which 7 were ultimately included based on strict inclusion and exclusion criteria. The selected studies consistently highlight the dominance of VR technology in karate practice and teaching, with VR often facilitated by head-mounted displays (HMDs). The main purpose of VR is to create life-like training environments, evaluate performance, and enhance skill development. Immersive technologies, particularly VR, offer accurate motion capture and recording capabilities that deliver detailed feedback on technique, reaction time, and decision-making. This precision empowers athletes and coaches to identify areas for improvement and make data-driven training adjustments. Despite the promise of immersive technologies, established frameworks or guidelines are absent for their effective application in karate training. As a result, this suggests a need for best practices and guidelines to ensure optimal integration.

Keywords: immersive technologies; virtual reality; karate training; sports; head-mounted displays

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1. Introduction

VR is a computer-generated simulation that offers a visually immersive and controlled environment, allowing users to both perceive and interact within this virtual world. This technology has the unique ability to provide modifications and experiences that are not feasible in the real world, stimulating all the senses of the user. Also, this technology can deceive the brain's predictive coding mechanism, resulting in a real sense of presence, where individuals feel as if they are inhabiting the virtual body and space [1].

The most common virtual reality applications used in most studies involve CAVE, a huge cube containing screens that users can enter physically, and VR head-mounted display (VR-HMD), such as HTC Vive or Oculus Rift. The VR-HMD is a wearable device with an eye-covering display, allowing users to experience the virtual world in stereoscopic vision [2].

This technology is used effectively in various fields, such as education, medicine, and sports. There are several advantages to using virtual reality devices in sports (see Table 1) [3]. The greatest advantage of VR lies in its ability to provide athletes with an infinite number of repetitions and modifications to present scenarios under unchanging conditions. This feature is favorable as it allows athletes to have personalized training sessions that focus precisely on their technical, tactical, and motor skills while competing against a virtual opponent. Another benefit of VR in sports training is that athletes can train at any time and place, making it easy to integrate their training schedule with their other obligations. Furthermore, it is ideal for practicing motor imagery and managing physiological stress in competition situations, improving performance, and reducing stress in demanding sports scenarios [4]. Also, the combination of eye-tracking technology with VR creates new opportunities to improve interaction techniques, image presentation, and visual perception analysis—all of which have a big impact on training scenarios for athletes [5]. Finally, VR can be a beneficial instrument for coaches and teams, facilitating the development of improved strategies and tactics [1].

Table 1. The benefits of the use of VR in sports.

Benefits of VR in Sports	
✓ Infinite repetitions	✓ Eye-tracking integration
✓ Personalized training	✓ Beneficial tool for coaches
✓ Training, regardless of weather conditions	✓ Improves decision-making processes
✓ Motor imagery practice	✓ Adaptation to competitive scenarios

Augmented reality (AR) is a technology that delivers required information or messages to users by utilizing various technologies. This technology combines the real environment with virtual components in real-time. The main aim of AR is to integrate virtual information with the physical environment to improve perception and interaction with the real world. The use of wearable devices, such as mobile or AR glasses, allows the user to see both the surrounding physical environment and the digital objects [6].

The sports sector is an ideal space for exploring the potential of AR technology to provide significant benefits in sports training. Experts in some branches of sports have recognized that the positive impacts of simultaneous information streaming on ongoing activities can be enhanced by the support of information technologies. The opportunities presented by AR technology can be exploited to increase the effectiveness of athletes' training programs and improve their performance. In addition, AR technology presents an opportunity to improve communication between athletes and the public, whether they are attending sports events on-site or through various media [7]. Furthermore, it is important to incorporate elements of visual, auditory, and tactile feedback into AR systems to improve the user experience and understanding of complex sporting concepts. Different means are being used to allow athletes to interact with AR systems (see Table 2) [8]. Finally, developments in AR technology have significantly improved the field of sports broadcasting, offering viewers a more immersive and engaging experience, especially through see-through AR video with a mobile phone [9].

Table 2. Means of user interaction with AR systems.

Mean	Function
Motion Detection	This input method involves capturing the users' movements via cameras or sensors
Target (camera aiming)	It is necessary to point the camera or sensor at a target to then start capturing information input triggers in the system
GPS	Uses geolocation and movement to generate input data for the system
Rotational Controls (gyroscope)	Uses the movement of the device itself to generate input data
Character movement controls (arrow)	Uses directional controls to provide input data
Menu/dialog box	Data entry to the system through interaction with dialog boxes containing questions and options to answer

Mixed reality (MR) allows the integration of virtual elements into the real world, enabling users to engage with these elements according to their environment. It is characterized by the convergence of VR and AR, thus creating an interactive environment for the user. Potential applications are used in various fields such as in the field of sports [10]. These applications can be used to watch games, thus enhancing the fans' experience [11], to offer training in situations where conventional methods are impractical, such as scenarios involving danger or high costs that would otherwise hinder traditional training approaches [12], and to aid in the rehabilitation of athletes, specifically in the context of martial arts [13]. Martial arts include historical combat techniques adapted to modern sporting and fitness contexts. These practices offer a form of exercise that not only contributes to physical well-being but also has profound significance. The term "martial arts" is a broad label that encompasses a variety of distinct disciplines. For example, karate focuses on perfecting striking techniques using hands and feet (see Table 3) [14]. In contrast, styles such as judo and jujitsu emphasize fighting techniques such as wrestling moves, joint locks, and throws. Contemporary styles such as mixed martial arts (MMA) and boxing take a hybrid approach, combining the techniques into a cohesive system [15].

Table 3. Definition and requirements of karate.

Karate	
Definition	• Scoring in karate: head and trunk kicks, throws • Controlled contact: avoid hard hits, except extremities • Contest round duration: 3 min • Early fight end: athlete scores 6–8 points • Head protection not worn by athletes
Physiological and Biomechanical Demands on Athletes	• Intensity • Dynamic techniques demand agility, speed, flexibility, endurance • Performance factors: technique, mental discipline, strategy • Athlete profiles: low body fat due to weight cycling • Short–duration intense fights: rapid exercise shifts • High heart rates, lactate response during fights • Emphasis on kick techniques for scoring • Performance linked to body height, lower limb flexibility • Muscular strength, power for attacks • Quick upper limb reaction for defense

Karate involves repetitive patterns of strikes and defensive movements in a competitive environment characterized by constantly changing conditions. Karate includes three elements: kihon, kata, and kumite. Kihon includes fundamental elements such as hand placement, thrusting, punching, kicking, maintaining good posture, and performing jumping techniques. The more a practitioner practices these basic techniques, the more precise the movements and control become. On the other hand, kata represents predetermined movements derived from combat scenarios but performed without an opponent. It involves sequences of movements derived from kihon and combined into engaging routines. Finally, kumite includes karate sparring and uses the offensive and defensive techniques acquired through kata practice. In kumite, practitioners engage in offensive confrontations to gain points from opponents during matches. Kumite training involves both practicing with a partner and practicing alone [16]. Karate athletes must react quickly, using both defensive and offensive tactics, which require quick and efficient performance. Plyometric exercises (broad jumps, clap push-ups, long jumps, etc.) are the most appropriate training method for karate athletes, but further research is needed for new methods, such as virtual reality training [17].

This scoping review's main purpose is to analyze the role of immersive technologies in enhancing the learning experience and skill acquisition within karate training. By exploring the application of VR, AR, and MR in karate training, the primary goal of this research is to understand how these technologies affect engagement, technique learning, and overall performance. Subsequently, the paper presents the remaining research questions regarding the different parameters of this sport:

RQ1: How are immersive technologies currently being integrated and utilized in the training and practice of karate?

RQ2: What is the documented impact and effectiveness of immersive technologies on the performance of athletes practicing karate? What are the perceived benefits and potential barriers?

RQ3: What existing training protocols incorporate immersive technologies for karate practitioners, and what are their specific components?

RQ4: How do immersive technologies effectively create life-like and interactive experiences for athletes and coaches in karate?

RQ5: What specific hardware and software solutions are most utilized to facilitate immersive experiences in the training and performance assessment of karate athletes?

RQ6: Are there established frameworks guiding the effective application of immersive technologies in the context of karate, and if so, what do they entail?

2. Materials and Methods

The scoping review protocol was preregistered through an open-ended registration on OSF on 10 February 2024 (https://doi.org/10.17605/OSF.IO/F5Q8E). The structure of this article followed the reporting guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols Extension tailored for Scoping Reviews (Table S1) [18].

2.1. Search Strategy

A comprehensive literature search was carried out in August 2023 in IEEE Xplore, Web of Science, and Scopus databases. The search was performed for all articles published to date and sorted by most recent to least recent. The keywords used in this search strategy, according to the Medical Subjects Headings (MeSH), were (martial arts OR karate) AND ("extended reality" OR "virtual reality" OR "immersive virtual environment" OR "head mounted display" OR "augmented reality" OR "mixed reality" OR "hybrid reality").

2.2. Inclusion and Exclusion Criteria

The publications included in this study are restricted to peer-reviewed articles found in journals or conference proceedings, which is a common practice in immersive technologies. These articles must be written in full in the English language and have been published from the year 2013 onward. The selected publications needed to meet the following criteria:

(1) Inclusion of qualitative and quantitative studies
(2) Inclusion of adolescents aged 13 years and older
(3) Utilization of technologies such as VR, AR, MR, HMDs, CAVE, or Kinect (RGB-D technology)
(4) For each article included in this review, two essential criteria were mandatory: the presence of a virtual environment (VE) and an evaluation of real-world sports performance both before and after VE training. To be classified as a VE within this review, all of the following elements had to be present: (i) the presentation or projection of an image, such as through a head-mounted display (HMD) or a Cave Automatic Virtual Environment (CAVE) or other immersive system; (ii) interactive functionality allowing tracking of the user's movements within the environment; (iii) the provision of sensory feedback, which could include visual, auditory, or haptic feedback; and (iv) the utilization of software to generate three-dimensional depth cues.

Articles were excluded from the review if they were referring to another martial art and if there was no use of immersive technology. Also, dissertations or reviews and articles written in languages other than English and written before 2013 were rejected.

2.3. Identification of Studies

The scoping review was conducted in several steps. Initially, duplicate studies were removed. Subsequently, a review of titles was performed to identify studies that met the inclusion criteria. Abstracts and full text were obtained from the remaining articles. During the abstract or full-text review, articles were either included in the review or excluded based on specific criteria outlined previously.

2.4. Quality Assessment

Individual study quality was assessed independently by one reviewer using the Mixed Methods Appraisal Tool (MMAT). The MMAT serves as a valuable resource for critically assessing studies employing quantitative, qualitative, and mixed methods. Its purpose is to address the unique challenges posed by the critical appraisal process in systematic reviews that involve a combination of research approaches. The most recent version of MMAT (version 2018) permits to appraise the methodological quality of five categories of studies: qualitative studies (5 criteria), randomized controlled trials (RCTs) (5 criteria), non-randomized studies (5 criteria), quantitative descriptive studies (5 criteria), and mixed methods studies (5 criteria). MMAT was designed so that one set of criteria can be used to assess either a qualitative or a quantitative study. When evaluating mixed methods studies, three sets of criteria are applied: one for the qualitative component, one for the quantitative component (choosing between RCTs, non-randomized studies, or quantitative descriptive studies), and a set specifically for mixed methods. Each criterion is rated using a categorical scale (yes, no, cannot tell), and the total count of "yes" ratings is used to determine an overall score [19].

2.5. Data Extraction

The information extracted from the selected studies comprised participant demographic details, information (authors, year, country), elements concerning the research's structure (study design, aim, conditions, variables/measure, key findings), and specific information following the research questions formulated.

3. Results

The initial database search retrieved a total of 63 articles from the IEEE Explore database, 37 from the Web of Science, and 65 articles from the Scopus database, resulting in a combined total of 165 articles. After eliminating duplicate entries, the number of articles was reduced to 106. In the next stage, 49 articles were rejected based on the title of the studies, as they did not refer to the use of immersive technologies or to a martial art other than karate, resulting in 57 articles being reviewed, either by reviewing the abstracts or the full text. Finally, seven articles were selected to be included in this systematic review based on the inclusion and exclusion criteria. The details of the search results are summarized in Figure 1.

3.1. Study Quality and Characteristics

The studies included in this review utilized a range of research designs, such as experimental [20–24]. The studies were conducted from 2018 to 2022, a finding which is in full agreement with the results of a recent bibliometric analysis [25]. Most of the studies, with regards to the main variables included, followed a quantitative methodology [20,21,23,26,27], one followed a qualitative methodology [22], and one was a mixed-method study [24]. Most of the studies demonstrated good methodological quality in terms of design, data collection, and reporting (for more details, see Appendix A). However, some studies lacked detailed information on participant demographics [20,24].

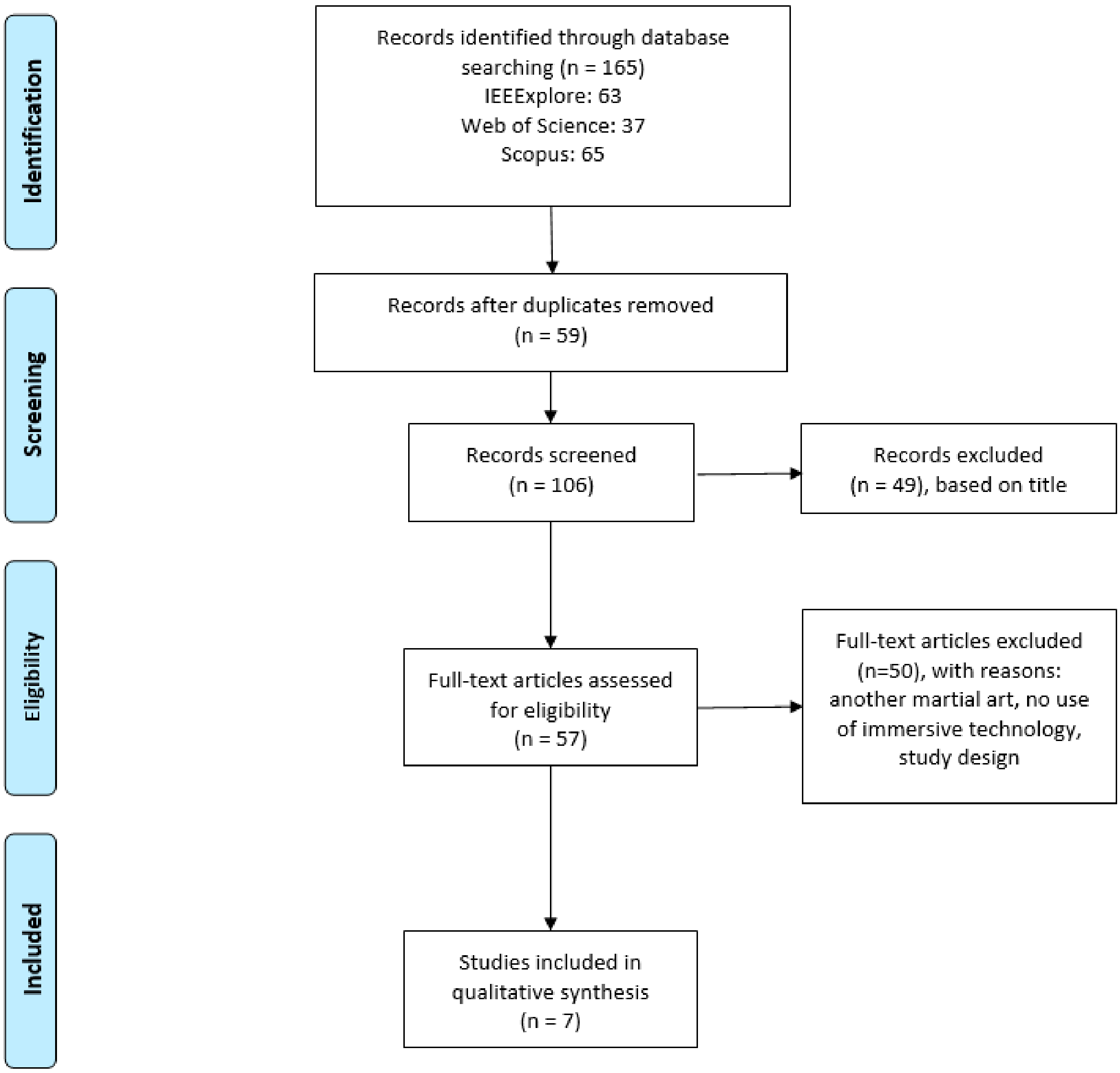

Figure 1. Flow diagram of study selection.

The assessment instruments and methodologies utilized in these studies exhibited a diverse spectrum, featuring techniques such as reaction time assessments [20,21,26], motion capture technology [20,23,27], performance analysis [21,26], scoring systems [23], and qualitative evaluations [22,24]. A summary of the key characteristics and relevant findings of each of the included articles is included in Table 4.

Table 4. The studies' characteristics.

Authors	Year	Number of Participants	Gender	Age	Location
Emad et al. [20]	2020	N/M [5]	N/M	N/M	Egypt
Pastel et al. [23]	2022	83	Both	M: 22.82 ± 3.11	Germany
Petri et al. [24]	2018	6 (3 athletes and 3 experts)	Both	Range 24–31 (athletes) Experts: N/M	Germany
Petri et al. [26]	2019	29	Both	Range 13–17	Germany
Ritter et al. [27]	2022	27	Both	M: 17.4 ± 3.52	Germany
Witte et al. [21]	2022	27	Both	Range 17–26	Germany
Zhang et al. [22]	2018	10	Both	Range 21–56	Germany

[5] N/M: Not Mentioned, M: Mean.

3.2. Participants Characteristics

The total number of participants in these studies was 242. In these seven studies, the primary participants were predominantly karate athletes. There were only two cases where coaches and experts were part of the study [22,24]. Across the seven studies, the gender representation among participants remained consistent. Most studies featured a mix of male and female participants, while only one [20] did not explicitly mention the gender of the participants. Finally, most of the studies were conducted in Germany [21–24,26,27], while only one was conducted in Egypt [20]. For more information regarding demographic data, age, the number of participants, and the country of the research conduction, refer to Table 4.

For the continuation of the work, a summary of the key characteristics and relevant findings of each of the included articles is included in Table 5, and the results of the research were grouped to have data that answer the research questions that have been set.

- RQ1: How are immersive technologies currently being integrated and utilized in the training and practice of karate?

The studies included in this review primarily utilize VR technology in the context of karate training and practice. While there may be some elements of AR and MR mentioned in the studies, VR is the dominant immersive technology used to create life-like training environments, assess performance, and enhance skill development in karate athletes. Refs. [21,26] showcased the potential of VR training with HMDs in offering karate athletes a heightened sense of realism during training. This immersion in life-like virtual environments closely resembling actual competitive scenarios allows athletes to practice and refine their techniques effectively.

Furthermore, [21] emphasized the precision and comprehensiveness of performance evaluation facilitated by VR training. Through meticulous motion capture and recording, this technology offers detailed feedback on aspects such as technique, reaction time, and decision-making. Ref. [20] further emphasized the potential benefits of immersive technologies by investigating the representation of right and wrong actions in karate through the iKARATE system. This system enabled users to perform sequences of moves that were accurately detected by a Kinect system, achieving an impressive average accuracy of 90% in recognizing and classifying movements correctly. This demonstrates the precision and effectiveness of immersive systems in assessing technique and execution. Immersive technologies are instrumental in simulating authentic attacks and interactions, with studies introducing autonomous virtual characters like “KaraKter” [24], Autonomous Character (AC) [22] and employing motion-capturing technology for real-time analysis of karate movements [26]. This feature substantially enhances the authenticity of training scenarios. Also, karate athletes preferred using an HMD over a CAVE against AC [22].

Moreover, immersive systems have emerged as effective tools for assessing karate performance parameters, including response time, response quality, and the type of response [26,27]. Hybrid training approaches, combining VR experiences with conventional training methods [21,23], demonstrate the potential to maximize training benefits and enhance athletes’ responses. User acceptance and experience are key considerations [24,26], with positive user feedback contributing to the sustainability of these training methods.

In addition, research indicates that skills acquired through VR training can effectively transfer into real-world karate settings, emphasizing the potential of immersive technologies in expediting skill acquisition and improvement within the discipline [22,23].

Table 5. Characteristics of the design, aims, conditions, variables/measures, and key findings of the included studies.

Authors	Year	Study Design	Aims	Conditions	Variables/Measures	Key Findings
Emad et al. [20]	2020	Quantitative study	To investigate right and wrong actions in a direct way through iKARATE	User performs sequence of moves that are detected by Kinect system	Accuracy and precision of karate movements/IKARATE system	iKARATE system achieved an average accuracy of 90% in recognizing and classifying right and wrong actions in a direct way
Pastel et al. [23]	2022	Quantitative study	To examine whether VR can be used to acquire a special combat technique	2 groups conducted VR training (one whole-body visualization and the other having only visualized the forearms) 1 group passed through a video-based learning method 1 control group had no intervention.	Upper and low body performance fist poses/scoring system on visual analysis and motion capture technology	VR training seems to be as effective as video training VR training can be a viable and effective method for karate practitioners to learn and transfer specific combat techniques into real-world practice
Petri et al. [24]	2018	Mixed methods study	To develop an autonomous character that performs attacks against a freely moving athlete	Selection of relevant karate techniques, development of a decision system, creation of an animated model of the AC CAVE and HMD for Virtual Environment	Realism, interaction, and preferences of AC in VEs (CAVE and HMD)/interviews	Karate experts preferred using a Head-Mounted Display (HMD) over a CAVE (Cave Automatic Virtual Environment) training HMDs are found to offer greater immersion and freedom of movement.
Petri et al. [26]	2019	Quantitative study	To investigate the effects of virtual reality on sports-specific response behavior of karate athletes.	Virtual Reality training	Reaction time and motor response/ Reaction time tests and motion capture technology	VR training improves the response behavior of karate athletes
Ritter et al. [27]	2022	Quantitative study	To compare the response behavior of karate kumite athletes when facing a critical attack from both a real opponent in the real world and a virtual opponent in a VR environment	Real-World (RW): In this condition, the karate kumite athletes are exposed to real opponents who perform the karate attack Kizami-Zuki (KZ). The athletes respond to these real-world attacks. Virtual Reality (VR) Condition: In this condition, the karate kumite athletes were placed in a virtual environment where they respond to virtual karate attacks generated by virtual opponents.	Response time, response quality, and kind of response/Video-based movement assessment	The ‘time of response’ and ‘kind of response’ for karate kumite athletes in virtual reality are like that in the real world.
Witte et al. [21]	2022	Quantitative study	To examine the results of the combination of conventional and VR training in karate athletes	VR group: VR training using a Head Mounted Display (HMD) combined with conventional training Conventional training group: Conventional training	Response time and response quality/ timing equipment and performance analysis	VR group improvements in response time No improvements in response quality for either group Athletes provided positive feedback regarding the integration of VR training into conventional training.
Zhang et al. [22]	2018	Qualitative study	To explore the potential of KaraKter as an autonomous opponent and training aid for karate athletes	KaraKter was designed to perform karate-specific movements and execute adequate attacks based on the behavior of a human athlete	Feedback on Karakter’s realism, interaction, and participants’ personal preferences/qualitative assessments	Athletes accept KaraKter as an actual opponent. Experts rated the system to be useful

- RQ2: What is the documented impact and effectiveness of immersive technologies on the performance of athletes practicing karate? What are the perceived benefits and potential barriers?

VR training has been utilized to improve the response behavior of karate athletes. These technologies offer a platform for athletes to practice responding to specific karate attacks, enhancing their reaction times and overall responsiveness [26,27]. More specifically, [27] found that the time of response and kind of response for karate athletes in virtual reality is like that in the real world, but response quality was better in the VR environment (p value < 0.001). A previous study found that VR training is also useful for improving the general response behavior in terms of kind and time of response in young karate athletes, especially in the Gyaku-Zuki (GZ) and Kizami-Zuki (KZ) attacks [28]. Regarding these attacks, athletes who had to react to attacks of a virtual opponent in a VR environment showed a significantly better response in terms of the time of response compared to athletes who reacted to these attacks in a physical environment. With regards to GZ, the p value is <0.001, and regarding KZ, the p value = 0.001. As far as response quality is concerned, no differences were found between the two groups [21]. Response time is a physical ability associated with human performance and can be defined as the time between the presentation of a stimulus and the subsequent behavioral response. In karate training, the need to respond quickly and accurately to the quality of external stimuli that appear, intrinsic to the interaction with an opponent, is an important element that leads to winning a match [29].

Both HMDs and the iKARATE system have been employed to enhance specific karate skills and techniques. Athletes can practice and refine their movements in a controlled virtual environment, contributing to skill development [20,22,23]. Also, VR technology, along with autonomous virtual characters, allows athletes to engage in realistic attack simulations. These simulations replicate the intensity and unpredictability of real-world karate matches, providing athletes with valuable practice opportunities, such as analysis of anticipatory cues [22,24]. Another important benefit of using these technologies is that the skills acquired through immersive training appear to transfer effectively to real-world karate settings [26,27], providing athletes with precise feedback on their movements and techniques [20,21]. Furthermore, the participants of the studies found these training methods engaging and enjoyable, which can contribute to increased training adherence and motivation [22,26].

While immersive technologies offer several benefits in karate training, it is crucial to identify potential barriers to their integration. One significant concern is the risk of cybersickness, as highlighted in studies like [21,26]. In another study, nevertheless, the athletes did not verbally report discomfort and did not have to stop testing; it was assumed that the actual cybersickness occurred only to a minor extent under VR conditions through an HMD display and marginally affected the athletes in their response tasks [27]. The sensation of cybersickness can hinder the effectiveness of training and the overall experience for every person who uses an HMD [30], including karate athletes. Striking the right balance between virtual and physical training is another challenge that karate practitioners and coaches need to navigate. As mentioned by [27], training in VR requires some familiarity; thus, it is not possible to create a context that provides guidelines for mixing virtual and real worlds, as the needs of each athlete are individualized. Also, over-reliance on immersive technologies may neglect essential aspects of physical training and traditional coaching methods, impacting the development of skills that cannot be learned in the virtual environment (e.g., self-control). Therefore, while the benefits of immersive technologies in karate training are promising, careful consideration and management of these barriers are crucial for successful implementation.

- RQ3: What existing training protocols incorporate immersive technologies for karate practitioners and what are their specific components?

In the studies included in this review, there are some protocols adopted by the researchers. These training protocols mainly concern the development of skills, the response time to an attack, and, more generally, the response behavior to an attack and the recording of movement by means of immersive systems. Based on this, two protocols were formulated:

(i) Virtual Reality (VR) Training for Response Behavior			
Who	**What**	**Condition**	**Purpose**
Karate athlete	Wears HMD	Virtual environment for simulating virtual attacks by virtual opponents. RGB-D technology and video-based movement analysis tools to detect and evaluate karate movements performed by users.	To improve motor skills and response behavior
(ii) Hybrid Training with VR and Conventional Methods			
Who	**What**	**Condition**	**Purpose**
Karate athlete	Wears HMD	Short but intense VR training sessions using head-mounted displays (10 min) with conventional training (80 min)	Focus on specific skills or scenarios, enhancing overall skill development

- RQ4: How do immersive technologies effectively create life-like and interactive experiences for athletes and coaches in karate?

On the one hand, coaches can use this data to identify areas for improvement and adjust during training. On the other hand, athletes feel as though they are in an actual competition or sparring session, which can enhance their mental preparation and composure during real matches. Also, there are systems, like the iKARATE system, that allow users to perform sequences of moves that are detected by Kinect systems, providing immediate feedback on the correctness of their actions [20]. While there may be minor issues like cybersickness [27], the overall impact on karate training appears to be positive, with athletes and coaches appreciating the advantages these technologies bring to the sport. The main advantage is the implementation of diverse training methods with virtual characters acting as opponents, thus increasing the motivation and duration of concentration in an exercise [22,23,27].

- RQ5: What specific hardware and software solutions are most utilized to facilitate immersive experiences in the training and performance assessment of karate athletes?

The studies included in this review reveal that within the domain of karate training and performance assessment, several prevalent hardware and software solutions are commonly employed to enable immersive experiences. These solutions encompass a range of technologies and tools that contribute to the creation of interactive training environments for karate athletes. These technologies play a pivotal role in enhancing the training experience, providing real-time feedback, and facilitating performance assessment (see Table 6).

Table 6. Types of systems and functions.

Author/Year	System	Function
Petri et al., 2019 [26]	HMD (Oculus Rift DK2 and Hand targets)	Adding sense of reality
Emad et al. 2020 [20]	iKARATE system	Representing right and wrong actions in a direct way
Witte et al., 2022 [21]	HMD (HTC Vive Pro Eye)	Evaluating standard of action
Pastel et al., 2022 [23]	HMD (HTC Vive Pro Eye)	Adding sense of reality
Zhang et al., 2018 [22]	Virtual environment	Adding sense of reality
Petri et al., 2018 [24]	HMD (Oculus Rift DK2) and CAVE	Adding sense of reality
Ritter et al., 2022 [27]	Virtual environment	Adding sense of reality

Thus, regarding hardware solutions:

➢ HMDs like Oculus Rift DK2 and HTC Vive Pro Eye are frequently used to provide full immersion [21,23,24,26]. These devices offer high-quality, 3D visual feedback, enhancing the sense of reality during training.
➢ Motion Capture Systems, such as those using Vicon cameras and real-time tracking technology, are employed to record and replicate karate-specific movements [22,24]. These systems enable the creation of realistic virtual opponents and avatars.
➢ Kinect systems: Systems like iKARATE use RGB-D technology for tracking and assessing users' movements and techniques [20]. This facilitates real-time feedback and evaluation of karate moves.

Regarding software solutions:

➢ Virtual Characters and Avatars: Autonomous virtual characters like KaraKter and AC are used to simulate realistic opponents in VR settings [22,24]. These characters are programmed to perform karate-specific actions, providing interactive training experiences. Also, platforms are used to create virtual environments and interactive training scenarios [27].
➢ Visual and Auditory Feedback Systems: Immersive systems provide both visual and auditory feedback to athletes during training [21]. This multisensory feedback enhances the overall training experience and assessment.
➢ Performance Assessment Algorithms: Advanced algorithms and scoring systems are used to evaluate the quality of movements and techniques [20,23]. These algorithms provide objective assessments of athletes' performance.

- RQ6: Are there established frameworks guiding the effective application of immersive technologies in the context of karate, and if so, what do they entail?

Based on the findings from the seven articles and considering the heterogeneity in their methodologies and research objectives, it becomes evident that there is limited evidence of established frameworks specifically guiding the effective application of immersive technologies in the context of karate. While these studies offer valuable insights into the integration of immersive technologies into karate training, they do not explicitly reference standardized frameworks or guidelines for their implementation. Certain common principles and considerations can emerge from these studies, which are described in detail in the previous RQs. Making a link to the framework created by [31], a framework can be proposed for the training of karate athletes and the use of VR systems.

This framework demonstrates that involvement in a VR sports task leads to various outcomes, some of which occur at the same time as the task and others afterward. The VR system includes four key components: the VR environment, the specific sports task within VR, the athlete, and the non-VR environment. The VR environment, being unique to VR sports applications, has been the primary focus of research. The second component, the nature of the sports task used, varies depending on the specific application and can range from endurance-based sports to skill-based sports. The third component relates to athlete characteristics, including skill level and competitiveness. These athlete characteristics can act independently or interact with other elements within the VR system to influence outcomes. The fourth component includes real-world environmental factors in which the athlete performs the task. Factors such as ambient temperature, humidity, and the time of day can be present and impact outcomes. Based on the interaction relationship between the four elements of the model and the findings of this systematic review, the following is proposed (see Figure 2).

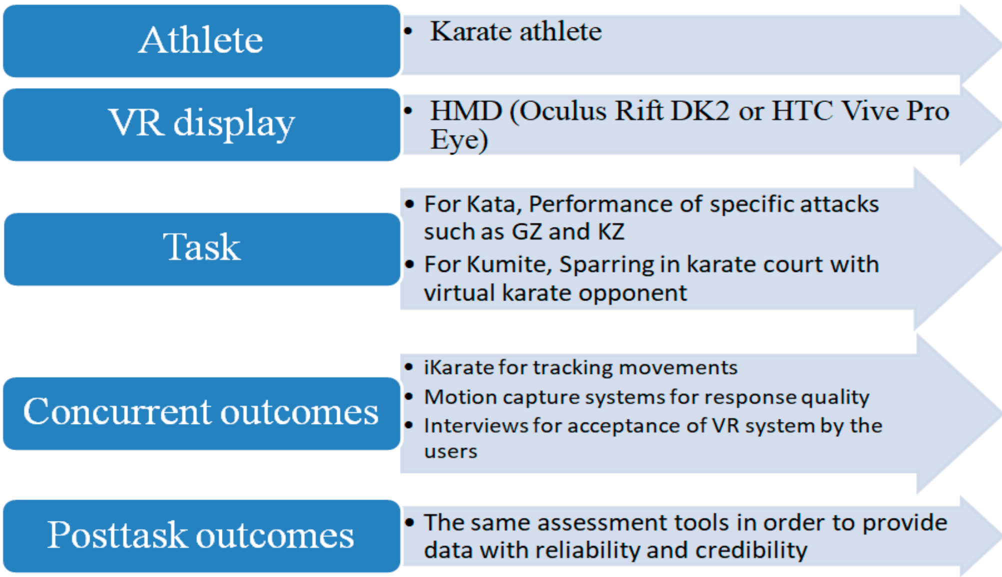

Figure 2. A framework for integration of VR in karate training.

4. Discussion

This study adds several valuable insights (see Table 7 to the existing literature on the use of XR technologies, specifically VR, in karate practice and teaching, as it is a recurrent theme in the studies that were analyzed. The main purpose of VR, which is often activated by head-mounted displays (HMDs), is to create realistic training conditions, evaluate performance, and improve skill development. This technology gives karate practitioners a greater sense of reality during training, allowing them to practice effectively and improve their techniques. In general, sports training is a continuous process between an athlete and his/her coach. This process involves four phases: planning, realization, control, and evaluation. The end goal of a training session is the perfection of the athlete's abilities, in other words, reaching their natural potential [32]. VR in karate training can be successfully and safely integrated into these components to maximize athletes' overall response. To develop motor skills, one vital element is the level of anticipation, which is important to forecast the opponents' intentions [28]. Through this review, it was found that VR training can contribute to this element.

Table 7. What does the study add to the literature?

• The integration of VR in karate training is effective in enhancing response time, motor skills, and overall karate proficiency.
• The creation of autonomous characters that mimic movements of karate athletes in the virtual environment is effective for training athletes in relation to their opponents.
• There is a need to recognize and address challenges in the integration of XR technology into karate training, including issues such as cybersickness and the necessity to find the right balance between virtual and physical training.

Furthermore, motion capture and recording technologies in VR provide detailed feedback on various aspects such as technique, reaction time, and decision-making. This level of precision enables athletes and coaches to identify areas for improvement and make data-driven adjustments to training. Karate athletes can also benefit from the realistic training scenarios created by VR, which mimic actual competitive situations.

According to the interviews used in the studies, user feedback indicates that karate athletes find immersive training methods engaging and enjoyable. This positive user experience can contribute to increased training adherence and motivation. The immersive nature of these technologies makes training sessions more interactive and exciting, which can be particularly appealing to younger athletes.

Although the benefits of immersive technologies in karate training are promising, there are some notable challenges to consider. One of the primary concerns is the risk of cybersickness, which can affect some users when using HMDs. Another challenge highlighted in the discussion is the need to strike the right balance between virtual and physical training. While immersive technologies offer valuable benefits, they should complement, rather than replace, essential aspects of physical training and traditional coaching methods. Skills that require physical presence, such as self-control and physical conditioning, cannot be fully developed in a virtual environment.

One notable observation is the absence of established frameworks or guidelines for the effective application of immersive technologies in karate. The reviewed studies do not explicitly reference standardized frameworks. This suggests that there may be a need for the development of best practices and guidelines to ensure the optimal integration of immersive technologies into karate training.

Several limitations were found in this study. Initially, the inclusion and critical analysis of only seven studies pose limitations to the generalizability of our findings and may prevent a comprehensive exploration of potential applications or challenges in the wider context. It is important to emphasize that research in this area remains at a primary stage and, therefore, may affect the wider applicability of our results. Another limitation of this study is that many of the studies included small sample sizes, which can limit the generalizability of their findings. Also, karate athletes who participated in these studies may not represent the broader karate community. Some studies had a short-term focus, examining the immediate effects of immersive technology on karate performance. The long-term impacts and sustainability of such training methods might be fully explored. Some studies might lack control groups or fail to compare immersive technology-based training with traditional training methods (except one). This makes it difficult to determine whether the improvements observed are solely due to immersive technology or other factors. As mentioned in some studies, participants may experience cybersickness or motion sickness when using VR headsets. This can affect the quality of their training experience and performance. Furthermore, the search for this review was conducted in only three databases, resulting in the possibility that there were additional articles that were not found. Finally, the articles were limited to the English language, and taking advantage of the fact that most of the studies were conducted in Germany (and probably in the German Language), this suggests that some high-quality studies may have been missed due to the inclusion criteria.

Future research in this area should aim for larger and more diverse participant samples, long-term studies, rigorous experimental designs, and a deeper exploration of ethical and user acceptance issues. Additionally, assessment tools with reliability and validity can provide a more comprehensive understanding of the feasibility of integrating immersive technologies into karate training and practice. Also, the studies included user acceptance, which was assessed only according to data from the interviews used. It is suggested that the Technology Acceptance Model (TAM) be used to examine the perceived usefulness, perceived ease of use, and perceived enjoyment of karate athletes in the use of immersive technologies, in future studies. In addition, studies with the implementation of AR or MR systems in karate training or fan experience are suggested. Finally, the field of view (FOV) should be considered by developers of immersive systems in future studies, as immersive HMDs often feature a limited field of view.

5. Conclusions

In conclusion, this systematic review provides a comprehensive overview of the integration of immersive technologies, particularly VR, as a new and developing field for karate training and practice. The study highlighted several key findings and valuable insights, adding to the existing literature and providing a basis for further research in this area. The primary focus of immersive technologies in karate is to create realistic training scenarios, evaluate performance, and enhance skill development. Virtual reality, often facilitated by HMDs, plays a central role in providing karate practitioners with a heightened sense of realism during training, effectively immersing them in life-like virtual environments. These technologies provide opportunities for athletes to practice and refine their techniques, improve response behavior, and transfer skills to real-life karate situations. The studies reviewed demonstrated the potential of immersive systems to improve various aspects of karate training, including response behavior, motor skills, and overall capacity. Motion capture technology, RGB-D technology, autonomous virtual characters, and real-time performance analysis are among the tools and methodologies used to create interactive and realistic training experiences. Importantly, athletes and coaches have provided positive feedback, highlighting the engaging and enjoyable nature of immersive training methods. However, there are challenges, such as the risk of cybersickness and the need to strike the right balance between the virtual world and the physical world. Addressing these challenges is crucial for successful integration. Also, despite promising findings, there is a notable absence of established frameworks or guidelines for the effective implementation of immersive technologies in karate. This suggests a potential pathway for future research to develop best practices and recommendations for optimal use of these technologies. In the future, it is recommended that researchers investigate larger and more diverse samples of participants, conduct long-term studies, and use rigorous experimental designs. In addition, assessing user acceptance using established models, such as the TAM, could provide deeper insights into the feasibility of adopting immersive technology in karate. The potential use of AR and MR systems in karate training and fan engagement also needs further investigation. Finally, future research to explore immersive technologies in other martial arts is needed to broaden the scope of the field.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/mti8040027/s1, Table S1: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist.

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Appendix A. Quality Appraisal of Included Studies Using the Relevant Questions from the Mixed Methods Appraisal Tool (MMAT) Version 2018

1. Qualitative study

Study	Questions of the MMAT Used				
	1.1. Is the qualitative approach appropriate to answer the research question?	1.2. Are the qualitative data collection methods adequate to address the research question?	1.3. Are the findings adequately derived from the data?	1.4. Is the interpretation of results sufficiently substantiated by data?	1.5. Is there coherence between qualitative data sources, collection, analysis, and interpretation?
Zhang et al., 2018 [22]	Yes	Yes	Yes	Yes	Cannot tell

2. Quantitative descriptive studies

Study	Questions of the MMAT Used				
	4.1. Is the sampling strategy relevant to address the research question?	4.2. Is the sample representative of the target population?	4.3. Are the measurements appropriate?	4.4. Is the risk of non-response bias low?	4.5. Is statistical analysis appropriate to answer the research question?
Emad et al., 2020 [20]	Cannot tell	Cannot tell	Yes	Cannot tell	Cannot tell
Pastel et al., 2022 [23]	Cannot tell	Yes	Yes	Cannot tell	Cannot tell
Petri et al., 2019 [26]	Yes	Yes	Yes	Cannot tell	Cannot tell
Ritter et al., 2022 [27]	Yes	Yes	Yes	Cannot tell	Yes
Witte et al., 2022 [21]	Yes	Yes	Yes	Cannot tell	Yes

3. Mixed methods study

Study	Questions of the MMAT Used				
	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?	5.2. Are the different components of the study effectively integrated to answer the research question?	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?
Petri et al., 2018 [24]	Yes	Yes	Yes	Yes	Yes

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