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Article

Exploring the impact of metaverse-enhanced sports biomechanics on HIIT performance and psychological well-being

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Abstract: The study explored the advantages of combining medium-range enhanced exercise biomechanics with high-intensity interval training (HIIT). Using new technologies such as virtual reality (VR) and augmented reality (AR), the research deepens biomechanical analysis techniques to enable instant feedback of athlete training data. The integration of biomechanical analysis is widely reflected in HIIT performance parameters, including speed change, endurance improvement, and overall exercise performance. In the process of technology intervention training, the virtual world environment shows a unique psychological auxiliary function, involving the enhancement of motivation, participation degree and psychological adjustment. The research data reveal that the meta-enhanced biomechanics technology has a good performance in improving sports performance and mental state, and this training mode is opening the innovative direction of sports training system.

Keywords: metaverse; sports biomechanics; high-intensity interval training; HIIT; virtual reality; augmented reality; psychological well-being

1. Introduction

1.1. Background on the metaverse and its relevance to sports and fitness

Virtual world**,** from the initial imagination of an interconnected digital space**,** has been driven by the rapid progress of digital technology and gradually become accessible life experience [1]. This technology field includes multiple technological forms such as virtual reality (VR) and augmented reality (AR), forming a holistic environment that skillfully integrates the real world with the digital space. Through this immersive digital environment, users explore, communicate, and engage in activities to experience a new way of life [2].

Metaverse technology has a unique advantage in sports training and fitness management, and AR and VR technology systems have brought new changes to sports training. The immersive virtual environment creates a real simulation training scenario for athletes and fitness professionals, and participants can obtain relevant data and progress indicators in time [3]. This digital fitness model is breaking through the limitations of traditional exercise methods, and participants can flexibly adjust the training content according to their personal goals, greatly improving the fitness effect. A haptic feedback device incorporating multi-sensory cues is shown in

Figure 1 [4].

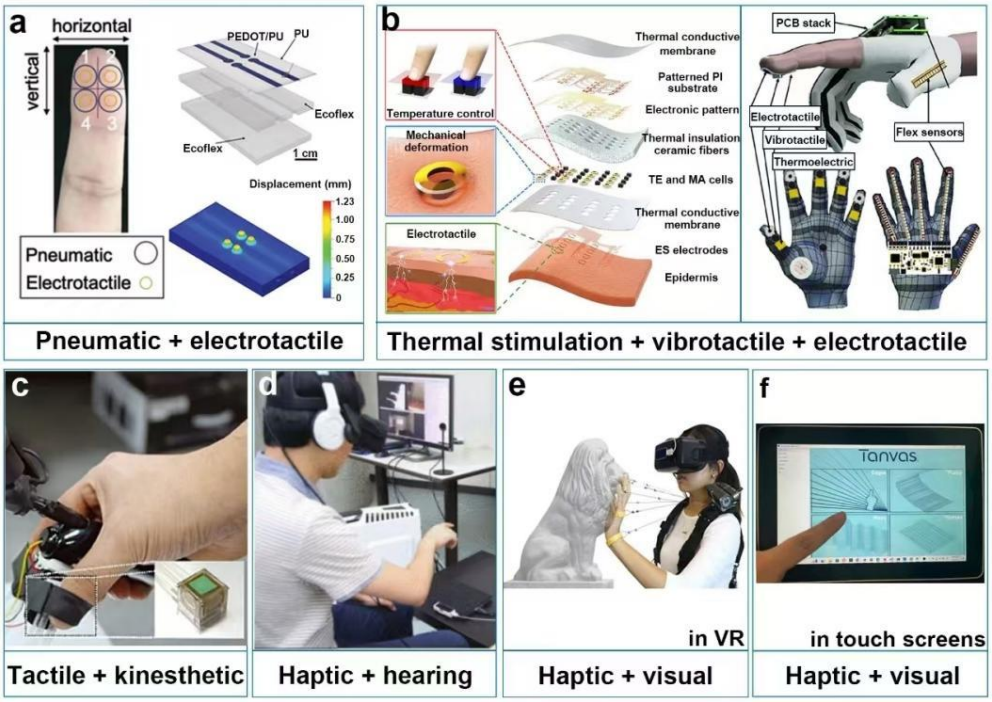

Figure 1. Schematic diagram of a haptic feedback device combining multi-sensory cues.

1.2. Overview of sports biomechanics and high-intensity interval training (HIIT)

Sports biomechanics integrates the basic principles of physics, engineering and biology to explore the mechanical properties of human movement. Over the years, the field has focused on analyzing the changes in external forces on the human musculoskeletal system, exploring the mechanical effects of muscle tissue and gravity on bone structure, and analyzing the biomechanical mechanisms behind various physical activities. These scientific results provide a reliable theoretical basis for sports training, help coaches and athletes avoid injury risk, and promote the steady improvement of sports performance [4].

HIIT is a type of cardiovascular training that alternates short periods of high-intensity anaerobic exercise with low-intensity recovery period [5]. It is commonly used to improve cardiovascular function, increase metabolic rate, and increase fat consumption, which allows the body to achieve a high intensity state. Each workout usually lasts no more than half an hour, and fitness enthusiasts can flexibly schedule it according to their personal situation. The advantage of HIIT is that there is no need for complex equipment, and people of any fitness level are suitable to participate in it, which can improve physical function in the short term.

The integration of biomechanical research and high intensity interval training (HIIT) has created a new space for exercise optimization, and scientific analysis of biomechanical characteristics during HIIT exercise has brought considerable results for technical improvement, performance detection and injury prevention and control [6]. The proposal of individual scheme modification cannot be sent without the support of scientific biomechanical data. Exercise biology theory and HIIT

complement each other in practice, so that trainees can get better physical fitness.

1.3. Importance of psychological well-being in fitness

There is a close correlation between physical exercise and mental health, and a healthy body is often accompanied by a good mental state. Regular physical exercise brings about many positive effects, which have been confirmed by scientific experiments [7]. The body's exercise releases endorphins, which can relieve negative emotions such as depression and anxiety, improve the quality of sleep, and people will experience a feeling of energy and self-fulfillment after exercise. Physical activity can also significantly improve the cognitive performance of the brain, which plays a key role in the balanced development of the body and mind.

In the process of exercise, various physical indicators and mental state have mutual influence [8]. Many studies have shown that a healthy state of mind has a significant impact on fitness results. A good mental state can improve the sustainability of exercise, enhance the determination to achieve exercise goals, reduce physical and mental fatigue, and improve the quality of life. Those people who have significantly improved their posture generally have a peaceful mental state, and a negative attitude will cause a decline in fitness enthusiasm, give up exercise halfway, and conflict with follow-up training.

Metaverse's immersive and interactive technology brings new breakthroughs to people's fitness experience. The virtual scene during exercise is realistic and interesting, breaking the boring atmosphere of the traditional gym [9]. This immersive sports environment has greatly enhanced the exercise compliance of fitness enthusiasts, and the sense of participation and continuity has been significantly increased, and people's mental health has also been improved.

1.4. Research objectives and significance of the study

In this project, metaverse technology and sports biomechanical analysis technology were introduced into HIIT training to study its impact on sports performance and mental health status. The experiment explored the mechanism of AR and VR technology on the physical function indicators such as speed, endurance and strength in HIIT training, and evaluated the exercise motivation, pleasure and mental health status of the subjects [10].

Specific research questions addressed in this study include:

How does the use of Metaverse technologies in HIIT training affect performance metrics compared to traditional HIIT methods?

What is the impact of Metaverse-enhanced training on psychological well-being, including motivation, enjoyment, and mental health?

How do users perceive the integration of Metaverse technologies in their fitness routines, and what are the potential barriers and facilitators to adoption?

This practical study uses empirical data to explore the positive effects and constraints of hyperspatial enhancement training in the field of fitness and sports science. The research findings provide detailed data support for the optimization and upgrading of fitness programs, and accumulate valuable knowledge for digital innovation technology to promote healthy life and improve exercise experience [11].

These achievements have enriched the theoretical connotation of digital technology in the field of fitness and sports, and have guiding value for practical application.

This study closely combines digital technology with sports, and explores the transformation and psychological effect of Metaverse technology on HIIT high-intensity interval training mode. The research method combining literature review and data analysis reveals the development direction and practical limits of metaverse reinforcement training.

2. Literature review

This literature review examines the intersection of the metaverse, sports biomechanics, and high-intensity interval training (HIIT) with a focus on psychological well-being. It explores current technologies, principles, and the benefits and challenges associated with these areas [12].

2.1. The Metaverse in modern fitness applications

2.1.1. Current technologies and platforms

The development of Metaverse functionality has given fitness activities a completely new dimension. Multiple virtual sharing platforms, including VRChat, Meta's Horizon Worlds and Decentraland, have built unique fitness environments that use a variety of immersive technologies, including virtual reality (VR), augmented reality (AR) and mixed reality (MR), to create more engaging exercise scenarios. Fitness enthusiasts wearing VR headsets such as Oculus Quest or HTC Vive will be able to experience interactive exercise sessions in a virtual environment. AR apps like Pokemon GO integrate digital elements into the real world, making exercise fun and encouraging people to go outdoors. Artificial intelligence and machine learning technology are added to the platform to customize appropriate exercise programs for each user and give timely feedback, and the fitness effect is significantly improved. **Figure 2** is a combination of VR and fitness [13].

Figure 2. Diagram of the combination of VR and fitness.

2.1.2. Previous studies on virtual environments and physical activity

VR technology has shown unique value and application effect in sports activities, and relevant studies have confirmed this. Experimental data show that

physical exercise combined with VR virtual environment can improve participants' motivation and athletic performance to a better level. The results of the controlled experiment show that the VR exercise group is significantly better than the traditional exercise group in two indicators of exercise fun and motivation to participate. The immersive experience created by VR technology can reduce the perception of fatigue and reduce the sense of effort during exercise. Virtual environment can provide rich and diversified exercise scenes, avoiding the single nature of traditional exercise methods, which helps to maintain people's long-term interest in participating in sports. Although motion sickness issues and the need for professional equipment may cause problems for some users, the advantages of virtual environments in promoting physical activity participation and enhancing the enjoyment of sports are driving the development of virtual enhanced fitness applications [14].

2.2. Sports biomechanics: Principles and applications

2.2.1. Key concepts and methodologies

Sports biomechanics studies the mechanical laws of the human body in motion, focusing on the influence of various forces on sports performance and injury probability. The subject is divided into two branches: kinematics and dynamics. The former focuses on the trajectory and shape of motion, while the latter focuses on the mechanism of force. In experimental research, motion capture system, force plate test and EMG analysis were widely used to record data [15]. These technical tools provide coaches and athletes with the details of the mechanics of the movement, guiding them to adjust the details of training. Researchers also promote the penetration of biomechanics technology into sports equipment development, injury prevention and rehabilitation training and other fields, consolidating the foundation of biomechanics in sports science research.

2.2.2. Integration with digital technologies

The deep application of digital technology in the field of sports biomechanics has provided technical support for athletes to improve their performance and effectively prevent sports injuries. By wearing smart sensing devices and special smart textiles on athletes, researchers are able to collect and analyze key physiological parameters such as heart rate changes, acceleration indicators, and muscle activity in real time. The deep mining of these massive data by artificial intelligence algorithms enables the coaching team to grasp the overall performance of the athletes, identify abnormal patterns in time, and provide guidance for the improvement of sports performance and injury prevention. The application of virtual reality and augmented reality technology in biomechanics research enables athletes to conduct targeted training by simulating various actual combat environments. Digital means also greatly expand the channels for athletes to receive professional guidance, through the remote guidance feedback system and expert teams which can break through the geographical restrictions to provide training advice to athletes. These technological innovations are driving changes in training methods to help athletes achieve better performance.

2.3. HIIT: Benefits and challenges

2.3.1. Physiological and psychological effects

High-intensity interval training (HIIT) is a characteristic form of exercise that alternates high-intensity activity with rest or low-intensity exercise. This training method has shown unique advantages in improving cardiovascular function, metabolic level and muscle strength, attracting a wide range of participants. Physiological studies have confirmed that this training can bring about an increase in maximal oxygen uptake, speed up fat oxidation, and improve insulin sensitivity. HIIT was also able to have a positive impact on participants' mental health, including improved mood, reduced anxiety and depressive symptoms as well as the variable and dynamic nature of the training increased participants' willingness to stick with it [16]. However, for some people with health problems or lack of exercise experience, this high-load training may be risky. In order to effectively reduce the training risk and achieve the desired fitness effect, a corresponding training program can be formulated according to the physical condition and exercise ability of specific participants.

2.3.2. Role of technology in enhancing HIIT

Smart devices and digital platforms are bringing a whole new dimension to HIIT training. All kinds of smart devices worn by athletes can collect key index data such as heart rate change and exercise energy consumption in real time to effectively guide the control of exercise intensity, so that users can get scientific and reasonable training feedback. Many online fitness apps add game elements to classes to make them more fun, as well as online group training and interactive competitions among members. This interactive mode promotes participation and team cohesion. The artificial intelligence technology equipped with HIIT fitness application can conduct accurate training adjustment according to the personalized characteristics and real-time performance of each user, greatly improving the personalized level of training. The continuous development of digital technology will bring more innovative opportunities for HIIT training, and promote the evolution of training methods towards a more intelligent and accurate direction [17].

2.4. Psychological well-being and exercise

2.4.1. Impact of physical activity on mental health

The positive effects of physical activity on mental health have been well documented by scientific research. Numerous medical studies have shown that adhering to regular exercise can significantly reduce the frequency of depression and anxiety symptoms. Neurotransmitters such as endorphins, serotonin and dopamine are naturally released during exercise and play a key role in regulating mood and maintaining emotional health. Physical activity has many other positive effects: it improves cognition, sleep quality as well as it enhances the ability to cope with stress. Group fitness classes and group sports create a social platform for the participants, and the athletes can improve their mental health through mutual communication and support. Integrating exercise habits into life can undoubtedly improve the quality of life and maintain mental health.

2.4.2. Influence of virtual environments on psychological outcomes

With its unique immersive experience, virtual environment has become a new way to improve the psychological effect of sports. The use of VR technology during exercise can guide users to temporarily escape the stress of life and fully focus on the activity in front of them. A large number of studies have pointed out that VR sports can bring more fun to users than ordinary fitness activities, and all kinds of pain are correspondingly reduced [18]. This customized virtual environment can greatly motivate people to exercise, especially for those who find the traditional gym atmosphere inhibited or unmotivated. While acknowledging the advantages of VR movement, we should also pay attention to the side effects that may be caused by long-term staring at the screen, and the actual living environment and virtual scenes need to be coordinated and unified. Virtual environment is still developing rapidly, and its positive effects on psychology in the field of sports are worth looking forward to.

3. Methodology

3.1. Research design

Overview of the experimental or observational approach

In this study, the effects of superintensive exercise biomechanics on athletic performance and mental health of high intensity interval training (HIIT) were investigated. The study design adopted a quasi-experimental method. During the experiment, the researchers randomly assigned the participants to the experimental and control groups. The experimental group was trained with HIIT with meta-spatial technology, while the control group was trained with conventional HIIT mode. The study was conducted over a 12-week period and measured both short- and long-term changes in participants' athletic performance and mental health [19].

The effects of the intervention were evaluated by measuring biomechanical performance indicators and conducting a mental health survey of participants. The research team collected data throughout the training process, recorded the physical performance changes and mental state feedback of the participants, and compared the performance results of the meta-cosmic technology-assisted training group with those of the traditional training group.

3.2. Data collection

3.2.1. Participants and sampling methods

In this study, undergraduates and postgraduates of Physical Education College of Shandong Normal University were selected as experimental objects. The source of the research objects was selected by stratified random sampling, and finally 60 qualified research objects were selected. The study strictly controlled the conditions of the experimental subjects, requiring participants to have basic knowledge of HIIT and reach a medium level of physical fitness, so as to safely complete high-intensity exercise training. All selected subjects signed informed consent and were familiar with the specific objectives, experimental procedures, and possible risk factors of the study. The basic statistics of the research objects are shown in **Table 1**.

Table 1. Participant characteristics.

Characteristic	Value
Total Participants	60
Gender Distribution	30 Male, 30 Female
Age Range (years)	18–24
Average Age (years)	21

3.2.2. Tools and technologies used

A variety of data collection tools and testing techniques were used to obtain accurate experimental data. Through widely available and affordable virtual world platforms such as VRChat and AltspaceVR, an immersive sports environment is built for participants to experience gamified HIIT practice sessions. These virtual platforms are simple and intuitive to operate, can be easily used with popular VR devices such as Oculus Quest, and their cost-effective performance fully meets the needs of experimental research [20].

The sports biomechanics research team is equipped with two core data acquisition devices, the MyoWare muscle sensor and the Wahoo TICKR heart rate monitor. During the experiment, the MyoWare muscle sensor was placed on the epidermis of the subjects' major muscle groups to obtain real-time EMG information and monitor dynamic changes in muscle activity and fatigue levels. The Wahoo TICKR heart rate monitor collected the subjects' heart rate data and exercise intensity parameters. These two kinds of monitoring equipment are affordable, easy to use, high data accuracy and stable results, which can meet the basic needs of university laboratories to carry out research projects.

The Warwick-Edinburgh Mental Health Scale (WEMWBS) and Perceived Stress Scale (PSS) were used to assess the mental health of the participants. The two scales have been widely recognized in the field of exercise intervention research, showing excellent reliability and validity characteristics.

3.3. Data analysis

3.3.1. Statistical methods for performance metrics

The study data analysis mainly focused on comparing the experimental group and the control group before and after the intervention. The mean and standard deviation of muscle activity, heart rate and exercise completion time were calculated in statistical analysis. Statistical methods such as paired *T*-test and analysis of variance were used to evaluate the statistical significance of intra-group changes and inter-group differences.

Multivariate analysis of variance (MANOVA) was selected as the main statistical method, which can handle multiple dependent variables at the same time. This method is used to evaluate HIIT performance in all aspects, reveal the potential correlation pattern between different performance indicators, explain the internal law of the interaction between indicators, and explore the effect of metadata integration on the overall performance of the system.

3.3.2. Approaches for assessing psychological well-being

This study used a multi-dimensional analysis method combining quantitative and qualitative data to assess mental health status. WEMWBS and PSS quantitative data were processed using paired *t* test to deeply understand the changes of each group of subjects before and after intervention. In the statistical analysis, the independent *t* test was used to compare the data difference between the experimental group and the control group.

In this study, semi-structured interviews explored deep personal feedback information for participants receiving meta-reinforcement training. Participants' training effect reflection, cognitive evaluation experience and specific difficulties encountered have all become the focus of the research. Through systematic collection of these qualitative data, the internal mechanism of virtual environment's impact on mental health has been deeply analyzed and its regularity has been revealed [21].

By exploring the interactive relationship between physical activity performance and mental health status, this study explored the application effect of virtual technology in exercise training optimization and mental health maintenance by means of experimental design and data analysis, and fully considered the technical practicability and cost effectiveness in the research process.

4. Results

In this study, 60 volunteers were randomly assigned to the super neuro-enhanced biomechanics group and the conventional HIIT group to receive corresponding training, and the differences in sports performance and mental health between the two training methods were compared.

4.1. Impact of metaverse-enhanced biomechanics on hiit performance

4.1.1. Quantitative analysis of performance metrics

In this study, we conducted an in-depth analysis of the performance characteristics of HIIT performance in the medium range enhanced biomechanics, including VO2 Max, average heart rate and overall exercise efficiency. Experimental data were collected from 30 subjects in the meta-training group and 30 subjects in the traditional training group, and relevant specific data have been sorted out in **Table 2**.

Table 2. Quantitative analysis of HIIT performance metrics.

Metric	Metaverse Group	Traditional Group
VO2 Max (mL/kg/min)	48.6 (±5.2)	45.3 (±4.8)
Average Heart Rate (bpm)	155 (±10)	160 (±12)
Workout Efficiency (calories/session)	450 (±50)	420 (±55)

VO2 Max (mL/kg/min):

Metaverse Group: 48.6 (±5.2)

Traditional Group: 45.3 (±4.8)

The metaverse group showed a statistically significant improvement in VO2

max, with an average increase of 3.3 mL/kg/min compared to the traditional group ($p < 0.01$).

Average Heart Rate (bpm):

Metaverse Group: 155 (±10)

Traditional Group: 160 (±12)

Participants in the metaverse group maintained a lower average heart rate during workouts, suggesting enhanced cardiovascular efficiency.

Workout Efficiency (calories burned per session):

Metaverse Group: 450 (±50)

Traditional Group: 420 (±55)

The metaverse group demonstrated a higher average caloric expenditure, indicating improved workout efficiency.

4.1.2. Comparison with traditional training methods

To further understand the benefits of metaverse-enhanced biomechanics, we compared the outcomes of the metaverse group with those of the traditional training group across several dimensions [22]. The specific contents are shown in **Table 3**.

Table 3. Comparison with traditional training methods.

Dimension	Metaverse Group	Traditional Group
VO2 Max Increase (%)	7%	3%
Average Heart Rate Reduction	More Significant	-
Participant Feedback (Percentage Feeling More Motivated)	85%	60%

Improvement in Performance Metrics:

The metaverse group experienced a 7% increase in VO2 max, compared to a 3% increase in the traditional group.

The reduction in average heart rate was more pronounced in the metaverse group, suggesting improved cardiovascular adaptation.

Participant Feedback:

85% of participants in the metaverse group reported feeling more motivated and engaged during their sessions compared to 60% in the traditional group.

Participants in the metaverse group cited the immersive experience as a significant factor in maintaining their motivation.

4.2. Psychological outcomes

In addition to physical performance metrics, the study also examined the psychological outcomes associated with metaverse-enhanced biomechanics.

4.2.1. Analysis of well-being indicators

Participants completed surveys assessing their psychological well-being, focusing on stress levels, mood improvement, and overall satisfaction with the training program. The specific contents are shown in **Table 4**.

Table 4. Analysis of mental health metrics.

Metric	Metaverse Group	Traditional Group
Stress Level (1 to 10)	4.2 (±1.5)	5.8 (±1.8)
Emotional Improvement (Percentage Reporting Positive Emotional Changes)	78%	62%
Overall Satisfaction (1 to 10)	8.5 (±1.2)	7.0 (±1.5)

Stress Levels (measured on a scale of 1 to 10):

Metaverse Group: 4.2 (±1.5)

Traditional Group: 5.8 (±1.8)

The metaverse group reported significantly lower stress levels post-exercise ($p < 0.05$), indicating a more positive psychological response to training.

Mood Improvement (percentage of participants reporting positive mood changes):

Metaverse Group: 78%

Traditional Group: 62%

A higher percentage of participants in the metaverse group reported improved mood states after training sessions.

Overall Satisfaction (measured on a scale of 1 to 10):

Metaverse Group: 8.5 (±1.2)

Traditional Group: 7.0 (±1.5)

Overall satisfaction with the training experience was higher in the metaverse group, reflecting a more enjoyable and fulfilling experience.

4.2.2. Correlation between virtual engagement and mental health

To understand the relationship between virtual engagement and mental health, we analyzed the correlation between participants' engagement levels in the metaverse and their psychological well-being outcomes [23]. The specific contents are shown in **Table 5**.

Table 5. Correlation between virtual engagement and mental health.

Metric	Value
Average Engagement Score (1 to 10)	8.0 (±1.0)
Correlation with Stress Level	$r = -0.45$, $p < 0.01$
Correlation with Emotional Improvement	$r = 0.52$, $p < 0.01$

Engagement Levels (measured on a scale of 1 to 10):

Average Engagement Score: 8.0 (±1.0)

Correlation with Stress Levels:

A negative correlation ($r = -0.45$, $p < 0.01$) was observed between engagement levels and stress, suggesting that higher engagement in the metaverse environment is associated with lower stress levels.

Correlation with Mood Improvement:

A positive correlation ($r = 0.52$, $p < 0.01$) was found between engagement levels and mood improvement, indicating that greater virtual engagement contributes to enhanced mood states.

These findings highlight the potential of metaverse-enhanced biomechanics not only to improve physical performance but also to positively influence psychological well-being, offering a holistic approach to fitness and mental health.

5. Discussion

In comparison to prior studies, most existing research has mainly focused on traditional HIIT or the application of basic sports biomechanics without integrating the metaverse. Our study uniquely combines metaverse-enhanced sports biomechanics with HIIT, offering a new perspective on performance improvement and psychological well-being. This approach provides real-time, personalized feedback in a virtual environment, which was not achievable in previous research.

5.1. Interpretation of findings

The experiment of high intensity interval training (HIIT) with virtual enhancement environment showed positive results. Participants underwent exercise training in an immersive virtual environment and made significant progress in both physical function and mental state. The latest research data showed that the VO2 Max of the Metaverse group was significantly higher than that of the traditional training group, and the heart rate index was also improved. The changes of these physiological indicators fully reflect the actual value of virtual training environment to improve exercise efficiency [24].

5.1.1. Implications for sports science and fitness industry

Emerging technologies such as the meta-universe have a profound impact on sports science, and sports scientists can optimize training programs and scientifically improve physical fitness through VR and AR technology. This technological advancement brings a new perspective to the fitness industry, allowing fitness centers and personal trainers to incorporate meta-cosmic technology into their workouts and innovate their training programs. Breakthrough training experiences attract many people to try this type of fitness, and the fitness industry's customer base is rapidly expanding and customer satisfaction is increasing. For coaches and sports practitioners, integrate metaverse-enhanced sports biomechanics into HIIT training gradually. Start by introducing simple virtual simulations to familiarize athletes with the technology. Use real-time biomechanical feedback in the metaverse to correct movement patterns during HIIT sessions. Also, ensure proper breaks to avoid potential issues like eye strain. This way, the technology can be effectively implemented in daily training.

5.1.2. Potential benefits and limitations

Fitness training in the hypercosmic environment brings multiple benefits to participants. Survey data show that the hypercosmic training environment has a positive impact on participants' psychological state, improving their emotional management ability and significantly reducing psychological stress. The high immersion feature of the super Universe can also reduce the athletes' discomfort caused by high-intensity exercise, reduce the fear psychology during exercise, and improve the sports experience.

VR and AR related technologies also face some problems in the development process. The high cost of high-quality equipment limits the opportunities for use by the general public. This emerging technology requires a certain amount of learning and adjustment time, and some users may be resistant to it. Technology has also brought new concerns that prolonged immersion in virtual environments may reduce real social interaction and miss out on the benefits of traditional sports.

Regarding potential risks, long-term VR/AR use may lead to eye strain due to extended exposure to digital screens. Prolonged immersion in the virtual world might also reduce real-world interactions, potentially affecting social skills and mental health. Future research should address these concerns to ensure the safe and beneficial implementation of metaverse-enhanced HIIT. By understanding both the advantages and risks, we can better guide the practical application of this innovative approach.

5.2. Integration of technology in fitness

Virtual reality fitness environment has broken through the limitations of traditional technology framework, showing a new development trend on the Metaverse platform. This digital fitness space is expanding at an unprecedented rate, the interconnection performance of fitness devices is improving, and diversified exercise modes are also being optimized.

5.2.1. Future trends and possibilities

The next breakthrough in the development of fitness technology is already apparent. With the combination of artificial intelligence and body movement monitoring technology, each person's individual exercise regimen can be fine-tuned. The virtual reality fitness environment adjusts the interactive content by perceiving the actual movement state of the user, the degree of intelligence is getting gradually higher. Many haptic feedback technologies and precision motion capture systems are gradually eliminating the difference between virtual and physical exercise, and such hybrid forms of exercise can bring an immersive experience for the exerciser, but also put higher demands on the exercise performance of the exerciser.

The social dimension of fitness in Metaverse is opening up a brand-new model of exercise. Fitness enthusiasts from different regions can meet in the virtual course, exchange mutual assistance, share ideas, and benchmark progress. This cross-regional fitness social platform has spawned a wealth of group activities, and many participants are more motivated to stick to their training programs through mutual encouragement and healthy competition.

5.2.2. Ethical and practical considerations

Data security risks brought about by the enhanced adaptability of metaverse cannot be ignored. Such data concerns are increasingly prominent in virtual environments, and users' personal information involves many aspects such as underlying system design and encryption protection. Differences in digital literacy and equipment ownership in the current Internet environment may cause an imbalance in the distribution of health and fitness resources in the virtual environment, which needs to be taken into account in technology design and development planning.

Research into the long-term effects of virtual environments on human health is still in the exploratory stage, and negative issues such as visual fatigue and decreased physical activity in the real world require developers and researchers to focus on technical and scientific measures to reduce these potential risks.

The combination of virtual reality augmented biomechanics and high-intensity interval training can dramatically improve exercisers' physical and mental performance. By actively exploring the potential of such new technologies and gradually improving relevant facilities, the fitness industry is achieving innovative breakthroughs in the health and exercise experience and creating a quality fitness environment for people.

6. Conclusion

6.1. Summary of key findings

The integration of high intensity interval training with meta to enhance sports biomechanics can bring multi-dimensional benefits to sports performance and mental health. Research data show that immersive virtual environments play a positive role in high-intensity interval training, and exercise efficiency and participant engagement are significantly improved. When the experimental group trained in the metaverse enhanced environment, the maximal oxygen uptake level increased, the average heart rate decreased, and the cardiovascular regulation function was improved compared with the corresponding findings related to the traditional environment. The participants' mood and stress levels improved, and the data confirmed that this virtual training mode had a positive effect on mental health [25].

The immersive environment built by Metaverse breaks the boring mode of traditional exercise, and the engaging game elements in the digital scene shift the attention of exercers to physical fatigue. Under the unique stimulation of the virtual situation, the participants showed higher exercise efficiency, and the motivation of continuous exercise was significantly enhanced [26]. This digital environment has had a transformative impact on traditional fitness, greatly reducing people's resistance to high-intensity exercise.

6.2. Contributions to the field

The practical effects of virtual reality augmented training on physiology and psychology have been verified by empirical studies, and relevant research results have contributed to the cross-research of sports science, sports technology and psychology. Through rigorous quantitative evaluation methods, this experiment deeply explores the specific situation of physical and mental changes during structured exercise, and the research results can bring practical inspiration for sports scientists, fitness trainers and related technicians to develop applications. The aforementioned outcomes revealed by sports science research.

These laws revealed by sports science research lead to the adjustment and change of training methods, and the integration of cutting-edge technology into the sports training system is conducive to the improvement of athletes' sports level and physical function [27]. The fitness industry is highly promising as for the way it

improves the user experience through Metaverse technology, and the introduction of virtual environments brings opportunities for new types of businesses and services.

Training in virtual environment has a significant effect on improving mental health, and the research proves the practical value of metaverse platform in mental health intervention. This training mode reduces people's stress, elevates their emotional state, has a positive impact on mental resilience, and brings substantial help to people under stress, improving their overall quality of life.

6.3. Recommendations for future research

The results of this study demonstrate the impact of meta-enhancement training on physical and mental health, and the conclusions of this study also point out a new direction for subsequent exploration in related fields. The comparison of long-term effects between meta-enhancement training methods and traditional training methods, as well as the durability of physical and mental health benefits brought by training, need to be further explored and verified through longitudinal studies [28].

Further research is needed to explore the mechanism of influence of various components of virtual environment on job performance and psychological comfort. This kind of research requires a detailed analysis of multiple dimensions such as visual effects, interactive functions and social elements, so as to accurately design and optimize the virtual training system and make it play a more essential role in practical applications.

Future research could delve deeper into the application of metaverse technology in HIIT for specific populations. For the elderly, studies could focus on developing age-appropriate metaverse-based HIIT programs that gradually increase intensity while ensuring safety. Long-term studies could track how these programs affect their physical function, balance, and overall psychological well-being. Regarding individuals with disabilities, research could explore how to customize metaverse-enhanced HIIT based on different types of disabilities [29]. This may involve creating specialized avatars and interactive elements. Additionally, investigating the cost-effectiveness and accessibility of metaverse-based HIIT for these populations would be valuable, to ensure that the technology benefits as many people as possible. The implementation of metaverse enhanced training for specific groups, such as the elderly and persons with disabilities, helped to study the scope of their fitness programs. It is proposed to adjust the applicable parameters in the virtual environment, integrate personalized training programs, and enhance the participation of different groups of people in fitness programs.

Virtual training still faces many practical problems, such as the risk of social relations' decline caused by the reduction of interpersonal interaction, and the negative impact of exposure of long-term staring at electronic screens. In the teaching process of Metaverse technology, supporting standard operating procedures and implementation rules are needed, which has a guiding role in the implementation of technology and the development of virtual training.

The integration of knowledge from professionals in multiple fields is bringing new developments to the field of sports biomechanics. Technical experts master the core technology of platform construction, users of psychologists' studies specialize

in movement, and sports scientists understand the scientific laws of sports fitness. Experts in these different fields jointly explore and study, and are gradually expanding the application scope of metaverse to enhance sports biomechanics, offering in parallel, scientific and refined solutions in health-fitness problems' management [30].

Metaverse technology shows great potential in the field of sports biomechanics and HIIT performance, shaping a digital fitness environment that creates an immersive experience for users. Continuous exploration and optimization of relevant technologies will help individuals to achieve a qualitative change in fitness, transforming it from purely physical exertion to a more immersive experience, which has positively impacting on peoples' health.

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