Baltic Journal of Health and Physical Activity

Volume 16 | Issue 3 Article 9

2024

Does virtual reality allow for a reliable assessment of reaction speed in mixed martial arts athletes?

Jacek Polechoński
Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland, j.polechonski@awf.katowice.pl

Alan Langer
Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland, langermma@gmail.com

Petr Stastny
Charles University, Faculty of Physical Education and Sport, Department of Sport Games, Czech Republic, stastny@ftvs.cuni.cz

Marcin Zak
Department of Sport Theory, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland, m.zak@awf.katowice.pl

Izabela Zając-Gawlak
Institute of Physiotherapy and Health Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland, i.zajac-gawlak@awf.katowice.pl

See next page for additional authors

Recommended Citation

Polechonski J, Langer A, Stastny P, Zak M, Zajac-Gawlak I, Maszczyk A. Does virtual reality allow for a reliable assessment of reaction speed in mixed martial arts athletes?. Balt J Health Phys Act. 2024;16(3):Article9. https://doi.org/10.29359/BJHPA.16.3.09

Does virtual reality allow for a reliable assessment of reaction speed in mixed martial arts athletes?

Abstract

Introduction: The immersive virtual reality (VR) might bring a new reliable approach to diagnosing motor abilities. Therefore, the main goal of this research was to check the intertrial reliability and diagnostic possibility (reaction time, movement time, lateral differences) of VR for upper limb movements in a group of mixed martial arts (MMA) athletes, and to evaluate whether distractors influence the complexity of the whole reaction. Material and methods: Twenty-six MMA athletes (age 27.1 ± 5.4 years, body mass 77.6 ± 9.3 kg, height 179.2 ± 5.7 cm, training experience 6.7±4.3 years) performed two reaction tests for their upper limbs (four tests were made for the ICC calculation) with wireless autonomous VR. Results: The ICC values ranged from 0.751 to 0.872 in simple reaction speed and 0.709 to 0.909 in complex reaction. No significant differences were observed between the reaction of the right and the left upper limbs. Distractors were shown to negatively affect the speed (*d* = 1.2) and reaction time of complex reactions (*d* = 1.3). Conclusions: The implemented VR measurement system allows for a reliable assessment of simple and complex reaction speed and its components (reaction time, movement time) for upper limb strikes and covers in MMA athletes. MMA reaction time of upper limbs is laterally balanced in MMA athletes. The disruptor causes a large decrease in reaction speed and prolongs the reaction time. Therefore, a test with a disruptor might have the potential to recognize performance level and athletes' reaction abilities.

Keywords

MMA, VR, physical activity, FitLight Trainer, BlazePodTM

Authors

Jacek Polechoński, Alan Langer, Petr Stastny, Marcin Zak, Izabela Zając-Gawlak, and Adam Maszczyk

Baltic Journal
of Health and Physical Activity
e-ISSN 2080-9999

Article

Does virtual reality allow for a reliable assessment of reaction speed in mixed martial arts athletes?

Jacek POLECHOŃSKI[1] *, Alan LANGER[2], Petr ŠŤASTNÝ[3], Marcin ŻAK[4], Izabela ZAJĄC-GAWLAK[5], Adam MASZCZYK[6]

1 Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland; ORCID 0000-0002-3294-7800
2 Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland;
3 Charles University, Faculty of Physical Education and Sport, Department of Sport Games, Czech Republic; ORCID 0000-0003-2841-374X
4 Department of Sport Theory, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland; ORCID 0000-0003-3184-0937
5 Institute of Physiotherapy and Health Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland; ORCID 0000-0002-7546-8199
6 The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland; ORCID 0000-0001-9139-9747

* Correspondence: Dr. Jacek Polechoński, e-mail: j.polechonski@awf.katowice.pl

Abstract: Introduction: The immersive virtual reality (VR) might bring a new reliable approach to diagnosing motor abilities. Therefore, the main goal of this research was to check the intertrial reliability and diagnostic possibility (reaction time, movement time, lateral differences) of VR for upper limb movements in a group of mixed martial arts (MMA) athletes, and to evaluate whether distractors influence the complexity of the whole reaction. Material and methods: Twenty-six MMA athletes (age 27.1 ± 5.4 years, body mass 77.6 ± 9.3 kg, height 179.2 ± 5.7 cm, training experience 6.7±4.3 years) performed two reaction tests for their upper limbs (four tests were made for the ICC calculation) with wireless autonomous VR. Results: The ICC values ranged from 0.751 to 0.872 in simple reaction speed and 0.709 to 0.909 in complex reaction. No significant differences were observed between the reaction of the right and the left upper limbs. Distractors were shown to negatively affect the speed (d = 1.2) and reaction time of complex reactions (d = 1.3). Conclusions: The implemented VR measurement system allows for a reliable assessment of simple and complex reaction speed and its components (reaction time, movement time) for upper limb strikes and covers in MMA athletes. MMA reaction time of upper limbs is laterally balanced in MMA athletes. The disruptor causes a large decrease in reaction speed and prolongs the reaction time. Therefore, a test with a disruptor might have the potential to recognize performance level and athletes' reaction abilities.

Keywords: MMA, VR, physical activity, FitLight Trainer, BlazePod™.

Citation: Polechonski J, Langer A, Stastny P, Zak M, Zajac-Gawlak I, Maszczyk A. Does virtual reality allow for a reliable assessment of reaction speed in mixed martial arts athletes?. Balt J Health Phys Act. 2024;16(3):Article9. https://doi.org/10.29359/BJHPA.16.3.09

Academic Editor: Agnieszka Skrendo-Maciejewska

Received: May 2024
Accepted: August 2024
Published: July–September 2024

Publisher's Note: BJHPA stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Immersive virtual reality (VR), in which individuals are isolated from visual stimuli from their surrounding environment and they perceive artificially generated images, sounds, and even tactile sensations, is finding increasingly wider applications in sports and physical recreation. Applications that allow for engaging in various forms of physical activity (PA) within a limited space are being developed. Additionally, an increasing number of training devices (e.g., stationary bikes, treadmills, rowing simulators, etc.) are integrating with VR setups. It turns out that such forms of PA may not only have health benefits due to the relatively high intensity of physical exertion, but they also exhibit a high level of attractiveness for users [1–3]. There are even reports suggesting that PA may provide a greater flow experience than similar exercises in the real world [4]. Researchers are also interested in analyzing the movements of individuals in virtual environments [5–7]. VR technology offers potential and seemingly broad opportunities for assessing movement parameters and motor abilities, especially coordinative ones. It allows for creating test scenarios in any desired manner, and thanks to precise sensors found in controllers, goggles, or VR-compatible devices (e.g., haptic suits and gloves, body-mounted sensors), accurate measurements of movement parameters can be made. Initial studies suggest that such measurements can be accurate and reliable [8].

It seems that motor tests developed in VR may have an advantage over traditional ones, especially concerning the assessment of coordinative abilities. Typical test tasks have certain flaws and limitations that virtual environments may eliminate. Coordinative abilities are mostly assessed through laboratory tests (e.g., Vienna Test System) [9, 10] and motor tests [11, 12], primarily designed for school physical education and sports. While the former allow for precise measurements, they are based on motor activities that do not necessarily reflect sports performance. They are often performed in a seated position and rely on fine motor skills (movements of hands and fingers within a relatively small range). The latter, on the other hand, are less precise and do not guarantee high measurement accuracy, full objectivity, or repeatability of the tests. Therefore, the use of VR technology in motor fitness assessment appears to be a unique and groundbreaking solution compared to existing diagnostic tools burdened with the aforementioned limitations. It is highly likely that tests implemented in a virtual environment will allow for the precise evaluation of global movement patterns, thus combining the merits of laboratory and motor tests.

In sports disciplines where continuous monitoring and assessment of coordinative abilities based on fundamental movement patterns are particularly important, mixed martial arts (MMA) can be mentioned. The success of MMA fighters largely depends on their quick reaction to visual stimuli, manifested, depending on the situation, by executing dynamic evasions, strikes, or throws. Punches play a significant role alongside kicks as the most effective techniques for ending a fight by knockout [13]. Therefore, dynamic shoulder flexion as a reaction to a visual stimulus (e.g., opponent dropping their guard) is an extremely desirable movement pattern for MMA fighters that needs to be perfected in their training process. Diagnostics and monitoring of training progress in this regard are also important. Currently, there are few measuring devices enabling precise assessment of reactions to visual stimuli manifested by global movements such as punches or kicks, which are reflected in sports combat. Partial solutions include the so-called Light Sport Training Systems (LSTS), systems designed for improving and diagnosing cognitive abilities by visual stimulation using a set of touch-sensitive wireless light pods, the operation of which can be programmed through appropriate applications and control devices [14, 15]. Since it is possible to set the illuminating pods in various positions, coaches can use LSTS for training specific movement patterns [16]. Among the known training-diagnostic solutions of this type are FitLight Trainer™ (FitLight Corp, Ontario, Canada) and BlazePod™ (Play Coyotta Ltd, Tel Aviv, Israel). Despite the great potential of such solutions both in motor diagnostics [15–18] and in supporting the training process [19–23], these solutions have certain limitations. Their placement in space can be problematic as they require a suitable mounting system. Moreover, they only allow assessing the reaction speed without a possibility to assess its components: reaction time (RT) and movement time (MT). Therefore, it is impossible to determine the moment when the movement was initiated, only the time it was completed. Users may also hesitate to strike the pod dynamically, which can lead to reflexive movement inhibition in its final phase. These problems can be avoided in a virtual environment, where virtual pods can be placed anywhere in space, and using sensors in controllers can determine the moment of movement initiation (RT), its duration (MT), and their sum – reaction speed. Furthermore, users will not feel apprehensive about contacting the virtual pod, allowing the strike to be executed at maximum speed, undoubtedly affecting the accuracy of the measurement. The virtual measurement environment also allows for creating various test scenarios and isolates from interfering factors.

The VR might bring new a reliable approach to diagnosing motor abilities which can be used as a training and performance assessment tool. Therefore, the main goal of the research was to check the intertrial reliability and diagnostic possibility (reaction time, movement time, lateral differences) of VR for upper limb movements in a group of mixed martial arts (MMA) athletes and to evaluate whether distractors influence the complexity of the athlete's reaction.

2. Materials and methods

2.1. Participants and research methods

Twenty-six individuals regularly practicing MMA were examined (age 27.1 ± 5.4 years, body mass 77.6 ± 9.3 kg, height 179.2 ± 5.7 cm, training experience 6.7 ± 4.3 years). Four athletes declared left-handedness, while the rest were right-handed. The recruitment took place in sports clubs in the Silesian region (Poland). Volunteers who met the following criteria were included in the study: a minimum of 2 years of systematic MMA training, good overall health, athletic experience, abstaining from intense physical exertion within 12 hours prior to the study, no use of substances or medications that could affect their ability to react quickly. As the measurements were conducted in VR, the absence of motion sickness, epileptic episodes, and sensitivity to flashing lights were additional inclusion criteria for the tests. Participants had previous experience with VR, but none of them declared regular use of this technology.

Participants had not previously used the software used in the study either. The research procedure was approved by the Research Ethics Committee of the Jerzy Kukuczka Academy of Physical Education in Katowice. Additionally, participants were informed about the purpose and course of the tests, as well as the option to withdraw from the study at any time without giving a reason. The tests were conducted in the MMA & Performance training studio in Świętochłowice (Poland).

The research was part of a larger project funded by the National Center for Research and Development from EU funds under project No. POIR.01.01.01-00-0365/20 "Development of methods for studying and shaping coordinative abilities along with a dedicated set of training methods in boxing using virtual reality."

A wireless autonomous VR headset Oculus Quest 2 (Facebook Technologies, LLC. 1 Hacker Way, Menlo Park, CA 94025, USA) consisting of a head-mounted display (HMD) and controllers was used for VR projection during the study. The software was developed according to our own idea using the Unreal Engine 4 to create visualizations in a virtual environment, on which proprietary tests for measuring reactions were based. Before starting the measurements, participants were instructed on how to use the VR projection equipment and the application. Two tests were used in the study. The first one assessed simple reaction to visual stimuli, and the second one assessed choice reaction. Since the reaction was to be manifested by performing a dynamic arm extension (movement similar to a straight punch in boxing), the tests were tentatively named: "Upper limb extension in VR – simple reaction" and "Upper limb extension in VR – choice reaction". In both tests, participants' task was to react to the illumination of a virtual disk (20 cm in diameter) located 30 cm in front of them. The participants' reaction was to perform a dynamic arm extension and intersect the surface of the disk (Fig. 1). The tests were conducted in a standing position, with feet placed shoulder-width apart, upper limbs bent at the elbow joints, vertically positioned, and hands clenched on controller handles held at the chin level (boxing guard with symmetrical arms, without torso rotation). To precisely position the upper limbs, two semi-transparent virtual spheres with a diameter of 15 cm were generated, into which the participants inserted their hands, causing a change in their color. The simple reaction test was performed separately for the right and left hand (Fig. 1). In assessing the choice reaction, two variants of test tasks were used: I – without a distractor, and II – with a distractor (red color). In the first variant, two different responses to the signal were possible: when the disk illuminated yellow, the participant performed an extension of the right arm, whereas when it illuminated blue, the participant performed an extension of the left arm. In the second variant of the test, a randomly generated red color also appeared, which the participant was not to react to (Fig. 2). During all tests, reaction speed and its components (RT and MT) were calculated.

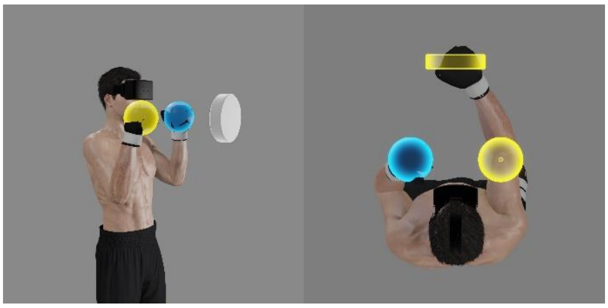

Figure 1. Visualization of the test used to examine simple reaction in VR

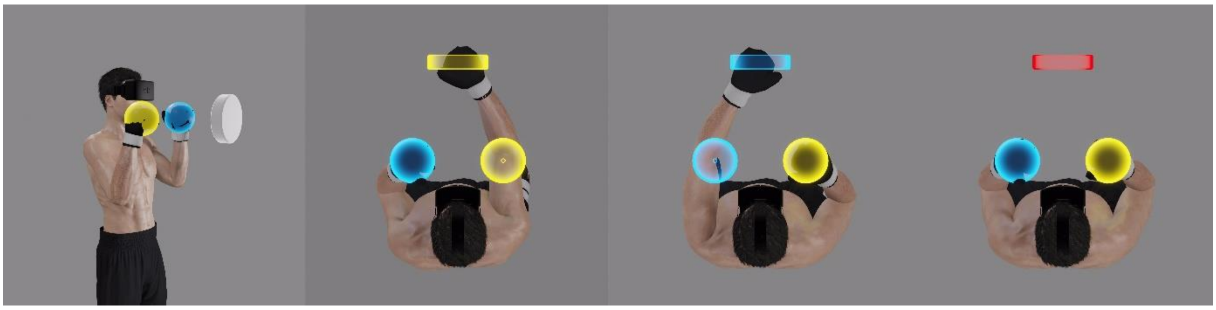

Figure 2. Visualization of the test used to examine complex reaction in VR

The reaction time was measured from the moment the disk illuminated to the moment the fist intersected the surface of the sphere. The movement time was the time elapsed from the intersection of the surface of the sphere by the fist to the moment the hand intersected the surface of the disk. The program recorded the times of individual reactions in milliseconds (ms). The signal appeared randomly at intervals of 2–6 seconds. The type of stimulus was also randomly generated, with an equal number of each type of signal. The next stimulus was generated after the participant reacted to the previous one. Participants performed a trial test consisting of 6 stimuli. Then they proceeded to three separate actual trials, each consisting of 12 stimuli, with results recorded. For each trial, the mean was calculated, excluding two extreme values. The results obtained in the subsequent three measurements were used to assess the reliability of the tests. Additional statistical analyses were conducted based on the mean values of results obtained in individual tests.

2.2. *Statistical analysis*

To assess the reliability of the measurements, intraclass correlation (ICC) procedures were used [24]. A 2-factor model with mixed effects was applied, where object effects are random and position effects are fixed, utilizing the absolute agreement definition of intraclass correlation. Reliability was assessed for a single measurement.

The significance of the intraclass correlation coefficient (ICC) was examined using an F-test. ICC values at or above 0.90 are considered very high, 0.80–0.89 are considered high, 0.70–0.79 are considered adequate, 0.60–0.69 are marginal, and 0.59 or lower are considered low [24, 26]. Normality of distribution was assessed using the Shapiro-Wilk test. The significance of differences in the obtained results was evaluated using either Student's t-test or the Wilcoxon test depending on the distribution of the data. The effect size was estimated using Cohen's d or the rank-biserial correlation coefficient (*rrb*). The study considered a *p*-value of less than 0.05 as statistically significant. Statistical computations were performed using IBM SPSS and Jamovi software.

3. Results

For simple reaction time and its components, ICC values for the right upper limb ranged from 0.751 to 0.872, while for the left arm, they ranged from 0.772 to 0.792. Slightly higher measurement reliability was observed in tests of choice reaction. In trials conducted without distractors, the ICC values for choice reaction time and its components ranged from 0.839 to 0.848. The highest measurement reliability characterized two of the analyzed parameters of choice reaction tests with distractors: reaction time (ICC = 0.902) and reaction speed (ICC = 0.909). Regarding the movement time of the arm extension, the reliability was significantly lower (ICC = 0.709) (Table 1).

Participants achieved better results in tests performed with the right upper limb, although the observed differences were not statistically significant for two out of three analyzed parameters: reaction time ($p = 0.548$; $rrb = -0.140$) and reaction speed ($p = 0.084$; $rrb = -0.39$). However, the mean movement time of the right arm extension was significantly shorter ($p = 0.006$) than of the left arm, although the observed difference (Dif. = 7.311 ms) should be considered as average ($d = -0.587$) (Table 2).

Clear differences were observed when comparing the results obtained by MMA athletes in both choice reaction tests. Distracting stimuli significantly prolonged the reaction time ($p < 0.001$; $d = -1.294$) and reaction speed ($p < 0.001$; $d = -1.205$), while significantly shortening ($p = 0.031$) the arm extension time by 3.106 ms, indicating an average difference ($rrb = 0.487$) (Table 3).

Table 1. Intraclass correlation coefficients (ICC) for VR reaction tests performed by MMA practitioners

Parameter	Simple reaction		Complex reaction	Complex reaction + Distractor
	right	left		
Reaction time	0.751 (0.585–0.869)	0.772 (0.619–0.881)	0.839 (0.720–0.918)	0.902 (0.823–0.951)
Movement time	0.778 (0.625–0.884)	0.775 (0.621–0.883)	0.848 (0.735–0.923)	0.709 (0.526–0.844)
Reaction speed	0.872 (0.774–0.936)	0.792 (0.647–0.892)	0.846 (0.732–0.922)	0.909 (0.834–0.955)

Legend: Reported values are intraclass correlation coefficient – ICC and 95% confidence interval (95% CI). CI – confidence interval; All ICC are at 0.001 *p* value.

Table 2. Comparison of simple reactions of the right and left upper limbs in MMA athletes

Parameter	Right upper limb		Left upper limb		Dif.	Effect size	*p*
	$\bar{x}$ [ms]	SD	$\bar{x}$ [ms]	SD			
Reaction time	406.098	42.248	416.001	49.405	-9.903	-0.140^{rrb}	0.548
Arm extension movement time	48.877	13.408	56.188	18.099	-7.311	-0.587^{d}	0.006
Reaction speed	453.673	52.284	472.188	59.683	-18.515	-0.39^{rrb}	0.084

Legend: $\bar{x}$ – arithmetic mean; SD – standard deviation; Dif. – difference of arithmetic means; *rrb* – Wilcoxon rank-biserial correlation coefficient; *d* – Cohen's *d*; *p* – *p* value.

Table 3. Impact of distracting stimuli on choice reactions of MMA athletes

Parameter	Without DS		With DS		Dif.	Effect size	*p*
	$\bar{x}$ [ms]	SD	$\bar{x}$ [ms]	SD			
Reaction time (ms)	534.441	69.532	570.616	72.165	-36.175	-1.294^{d}	< 0.001
Arm extension movement time (ms)	56.780	18.025	53.674	13.706	3.106	0.487^{rrb}	0.031
Reaction speed (ms)	591.22	77.806	624.288	80.030	-33.068	-1.205^{d}	< 0.001

Legend: DS – distracting stimuli; $\bar{x}$ – mean; SD – standard deviation; Dif. – difference between means; *rrb* – Wilcoxon rank-biserial correlation coefficient; *d* – Cohen's *d*; *p* – *p* value

4. Discussion

The implemented immersive VR measurement system allows for reliable assessment of reaction speed and its components (RT and MT) among MMA athletes based on the standard arm extension pattern. Depending on the measured parameters, ICCs assumed appropriate (adequate), high, and in some cases very high values. For simple reaction tests, ICC values ranged from 0.751 to 0.909, while for choice reaction tests without distracting stimuli, they ranged from 0.839 to 0.848, and with distracting stimuli, they ranged between 0.709 and 0.909. The observed measurement reliability is comparable to computer tests used for reaction assessment. In our own research involving MMA athletes, computer tests assessing reactions to visual stimuli yielded ICCs in the ranges of 0.743–0.836 [3] and 0.800–0.845 [2]. Similar ICC values were also obtained in studies involving youth, healthy adults, and recreational athletes using laboratory tests based on the use of an electronic interactive light board called the "Dynavision D2" [27–29]. The authors of those studies indicate measurement reliability ranging from 0.75 to 0.92 ICCs, which is similar to the range obtained in our research. Considering that the implemented immersive VR tests demonstrate measurement reliability comparable to computer and laboratory tests, they can be considered reliable measurement tools and, to our knowledge, are the first system enabling the assessment of reaction speed and its components in a virtual environment based on global movements. Although similar VR reaction measurement systems with similar measurement reliability values (ICC values ranging from 0.710 to 0.805) have recently emerged, they are based on fine motor skills (motor response involves pressing a button held in a hand controller) and do not allow for MT assessment [2, 3].

Another aim of the research was to compare the reactions of the right and left upper limbs of MMA athletes to visual stimuli. In the case of reaction speed and RT, no significant differences were observed depending on with which limb the movement was performed. However, significant differences were observed in MT. The recorded difference was not large enough to significantly affect the reaction speed. It appears from the available literature that different authors' opinions are divided regarding the dominance of the right or left upper limb in terms of reaction speed. Some studies suggest that left-hand reactions are faster than right-hand reactions [30–34], while others indicate the opposite [35, 36]. It can be speculated that the lower MT value observed in our research may result from the fact that the majority of the participants were right-handed athletes.

The influence of distracting stimuli on the choice reactions of MMA athletes was also examined. Under the influence of disturbing factors, both RT and reaction speed were significantly prolonged. This observed relationship was predictable, as cognitive and perceptual processing speed are directly related to the complexity of stimuli [37]. Furthermore, according to Hicks' law, increasing the number of choices increases the decision-making time [38]. The negative impact of visual distraction on RT is also confirmed by studies of other authors [39]. However, the significant shortening of the arm extension time in tests with distracting stimuli is somewhat puzzling and difficult to interpret. Perhaps the use of additional stimuli diversified the performed tasks and increased the athletes' motivation to act, which positively influenced the speed of executed movements. These assumptions, however, require empirical confirmation and may suggest further research directions.

The potential of immersive VR is beginning to be recognized by specialists involved in motor preparation for improving performance and shaping and diagnosing motor abilities [2, 3, 40–45]. There are training programs that allow for various forms of physical activity in VR. However, there are currently few applications implemented in the virtual environment for assessing athletes' motor potential. Due to the possibilities offered by VR, this area should be researched, explored, and utilized. The software presented in this study is one of the first applications allowing for a diagnosis of athletes' potential in terms of reaction speed and its components (RT and MT). It also enables assessment of simple and choice reactions. Moreover, the measurements concern global movement patterns characteristic of athletes, distinguishing them from typical computer reaction tests based on fine motor skills, which do not have relevance to sports activities. Our proposed technological solution can serve as a guideline for creators of similar measurement systems implemented in virtual environments, which will be useful in the training process for diagnosing motor fitness and monitoring athletes' progress. Finally, it is worth noting that VR technology is rapidly evolving and improving. Sensors used in VR kits are becoming more precise, the processing power of processors is increasing, and the efficiency of systems is improving, while new peripheral devices using haptic solutions are emerging. All of this contributes to the constant growth of VR technology's potential, and it seems that it will find increasingly wide application in various areas of human life, including sports activities.

5. Conclusions

In conclusion, this research indicates that the proprietary measurement system implemented in VR enables reliable assessment of simple and choice reaction speed and its components (RT and MT) based on the fundamental arm extension pattern for individuals training in combat sports. Comparing simple reaction speed and RT of the right and left upper limbs of the studied MMA athletes, no significant differences in results were observed regarding which limb the movement was performed with. However, a statistically significant, albeit small, difference in results between both upper limbs was observed in terms of MT, which was shorter for the right limb. This may be due to the fact that right-handed individuals dominated the studies. Distracting stimuli determine the choice reaction of the studied athletes. Under the influence of additional visual signals, both RT and reaction speed were significantly prolonged. Conversely, the arm extension time was significantly shortened in tests with distracting stimuli, which is difficult to interpret unambiguously. Perhaps the use of distracting stimuli diversified the performed tasks and increased the athletes' motivation to act, resulting in an increased arm movement speed, but this assumption requires further research confirmation.

References

1. Banos RM, Escobar P, Cebolla A, Guixeres J, Alvarez Pitti J, Lison JF, Botella C. Using virtual reality to distract overweight children from bodily sensations during exercise. Cyberpsychol Behav Soc Netw. 2016;19(2):Article2. DOI: 10.1089/cyber.2015.0283
2. Polechonski J, Kostorz K, Polechonski P. Using ankle weights as an effective way to increase the intensity of physical activity while playing immersive virtual reality games on an omnidirectional treadmill. Appl Sci. 2023;13(20):Article20. DOI: 10.3390/app132011536
3. Polechonski J, Langer A. (2022). Assessment of the relevance and reliability of reaction time tests performed in immersive virtual reality by mixed martial arts fighters. Sensors (Basel, Switzerland). 2022;22(13):4762. DOI: 10.3390/s22134762
4. Polechonski J, Szczechowicz B, Rysnik J, Tomik R. Recreational cycling provides greater satisfaction and flow in an immersive virtual environment than in real life. BMC Sport Sci Med Rehabil. 2024;16(1):31. DOI: 10.1186/s13102-024-00818-4
5. Jochymczyk-Wozniak K, Nowakowska K, Polechonski J, Sładczyk S, Michnik R. Physiological gait versus gait in VR on multidirectional treadmill-comparative analysis. Medicina (Kaunas, Lithuania). 2019;55(9):517. DOI: 10.3390/medicina55090517
6. Jurkojc J, Wodarski P, Michnik R, Marszalek W, Slomka KJ, Gzik M. The use of frequency analysis as a complementary and explanatory element for time domain analysis in measurements of the ability to maintain balance. J Hum Kinet. 2021;76:17–129. DOI: 10.2478/hukin-2021-0004
7. Wodarski P, Jurkojc J, Bieniek A, Chrzan M, Michnik R, Polechonski J, Gzik M. The analysis of the influence of virtual reality on parameters of gait on a treadmill according to adjusted and non-adjusted pace of the visual scenery. International Conference on Information Technologies in Biomedicine. 2019: 543–553. DOI: 10.1007/978-3-030-23762-2_48
8. Langer A, Polechonski J, Polechonski P, Cholewa J. Ruler drop method in virtual reality as an accurate and reliable tool for evaluation of reaction time of mixed martial artists. Sustainability. 2023;15(1):Article1. DOI: 10.3390/su15010648
9. Gierczuk D, Ljach W. Evaluating the coordination of motor abilities in Greco-Roman wrestlers by computer testing. Hum Mov. 2018;13(4):323–329. DOI: 10.2478/v10038-012-0037-y

10. Matczak D, Wieczorek M. Effective motor learning and coordination abilities of girls and boys aged 9–10. J Educ Health Sport. 2023;8(1):Article1. DOI: 10.12775/JEHS.2023.18.01.006
11. Machowska-Krupa W, Cych P. Differences in coordination motor abilities between orienteers and athletics runners. Int J Environ Res Public Health. 2023;20(3):2643. DOI: 10.3390/ijerph20032643
12. Olajos AA, Takeda M, Dobay B, Radak Z, Koltai E. Freestyle gymnastic exercise can be used to assess complex coordination in a variety of sports. J Exerc Sci Fitness. 2020;18(2):47–56. DOI: 10.1016/j.jesf.2019.11.002
13. Pinto FCL, Neiva H, Nunes C, Marques MC, Sousa AC, Marinho DA, Branquinho L, Ferraz R. Ultimate full contact: fight outcome characterization concerning their methods, occurrence times and technical-tactical developments. Int J Environ Res Public Health. 2020;17(19):7094. DOI: 10.3390/ijerph17197094
14. Ezhov, A., Zakharova, A., and Kachalov, D. (2021). Modern Light Sport Training Systems: Critical Analysis of Their Construction and Performance Features: Proceedings of the 9th International Conference on Sport Sciences Research and Technology Support, 2021; 123–129. DOI: 10.5220/0010677900003059
15. Flôres FS, Lourenço J, Phan L, Jacobs S, Willig RM, Marconcin PEP, Casanova N, Soares D, Clemente FM, Silva AF. Evaluation of Reaction Time during the One-Leg Balance Activity in Young Soccer Players: A Pilot Study. Children (Basel, Switzerland). 2023;10(4):743. 10.3390/children10040743
16. Hoffman JR. Evaluation of a reactive agility assessment device in youth football players. J Strength Condition Res. 2020;34(12):3311–3315. DOI: 10.1519/JSC.0000000000003867
17. Chander H, McCrory A, Chandler SJ, Freeny S, Griffith A, Burch R, Strawderman L, Knight AC. Noise interference impacts simple and choice response times during a lower extremity cognitive–motor task. Clin Transl Neurosci. 2023;7(1):Article 1. DOI: 10.3390/ctn7010004
18. Lowell RK, Conner NO, Derby H, Hill CM, Gillen ZM, Burch R, Knight AC, Reneker JC, Chander H. Quick on your feet: modifying the star excursion balance test with a cognitive motor response time task. Int J Environ Res Public Health. 2023;20(2):1204. DOI: 10.3390/ijerph20021204
19. Forni F, Farinini E, Leardi R, Rinaldo A. Effects of visual training on motor performance in young tennis players using FitLight trainer. J Sport Med Phys Fitness. 2022;62(4):585–592. DOI: 10.23736/S0022-4707.21.12145-0
20. Hassan AK, Alhumaid MM, Hamad BE. The effect of using reactive agility exercises with the FITLIGHT training system on the speed of visual reaction time and dribbling skill of basketball players. Sports (Basel, Switzerland). 2022;10(11):176. DOI: 10.3390/sports10110176
21. Potisaen J, Potisaen T, Srimuang T. Effect of BlazePod training program optimization on agilities and leg muscle strength among male volleyball players. J Exerc Physiol Online. 2023;26(4):79–88.
22. Silvestri F, Campanella M, Bertollo M, Albuquerque MR, Bonavolonta V, Perroni F, Baldari C, Guidetti L, Curzi D. Acute effects of fitlight training on cognitive-motor processes in young basketball players. Int J Environ Res Public Health. 2023;20(1):817. DOI: 10.3390/ijerph20010817
23. Wasik J. Chosen aspects of physics in martial arts. Arch Budo. 2009;5:11–14.
24. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropractic Med. 2016;15(2):155–163. DOI: 10.1016/j.jcm.2016.02.012
25. Cole WR, Arrieux JP, Schwab K, Ivins BJ, Qashu FM, Lewis SC. Test–retest reliability of four computerized neurocognitive assessment tools in an active duty military population. Arch Clin Neuropsychol. 2013;28(7):732–742. DOI: 10.1093/arclin/act040
26. Lezak MD, Howieson DB, Bigler ED, Tranel D. Neuropsychological assessment. Oxford: Oxford University Press, 2012.
27. Gray HN, Williams RM, Valovich MTC, Bay RC. Establishing reliability of a reaction time testing battery in high school athletes. Athl Train Sport Health Care. 2021;13(4):e168–e175. DOI: 10.3928/19425864-20200310-01
28. Picha K, Quintana C, Glueck A, Hoch M, Heebner NR, Abt JP. Reliability of 5 novel reaction time and cognitive load protocols. J Sport Rehabil. 2018;27(5):1–4. DOI: 10.1123/jsr.2018-0042
29. Wells AJ, Hoffman JR, Beyer KS, Jajtner AR, Gonzalez AM, Townsend JR, Mangine GT, Robinson EH, McCormack WP, Fragala MS, Stout JR. Reliability of the dynavision™ d2 for assessing reaction time performance. J Sport Sci Med. 2014;13(1):145–150.
30. Al-Hashel JY, Ahmed SF, Al-Mutairi H, Hassan S, Al-Awadhi N, Al-Saraji M. Association of cognitive abilities and brain lateralization among primary school children in Kuwait. Neurosci J. 2016: 6740267. DOI: 10.1155/2016/6740267
31. Badau D, Baydil B, Badau A. Differences among three measures of reaction time based on hand laterality in individual sports. Sports. 2018;6(2):Article2. DOI: 10.3390/sports6020045

32. Boulinguez P, Barthelemy S, Debu B. Influence of the movement parameter to be controlled on manual RT asymmetries in right-handers. Brain Cogn. 2000;44(3):653–661. DOI: 10.1006/brcg.2000.1234
33. Darbutas J, Juodzbaliene V, Skurvydas A, Krisciunas A. Dependence of reaction time and movement speed on task complexity and age. Medicina (Kaunas, Lithuania). 2013;49(1):18–22. DOI: 10.3390/medicina49010004
34. Yamauchi M, Imanaka K, Nakayama M, Nishizawa S. Lateral difference and interhemispheric transfer on arm-positioning movement between right and left handers. Perceptual Motor Skill. 2004;98(3 Pt 2):1199–1209. DOI: 10.2466/pms.98.3c.1199-1209
35. Asai T, Sugimori E, Tanno Y. Two agents in the brain: Motor control of unimanual and bimanual reaching movements. PloS One. 2010;5(4):e10086. DOI: 10.1371/journal.pone.0010086
36. Mieschke PE, Elliott D, Helsen WF, Carson RG, Coull JA. Manual asymmetries in the preparation and control of goal-directed movements. Brain Cogn. 2001;45(1):129–140. DOI: 10.1006/brcg.2000.1262
37. Lang A. The limited capacity model of mediated message processing. J Communication. 2000;50(1):46–70. DOI: 10.1111/j.1460-2466.2000.tb02833.x
38. Gignac G, Vernon P. Reaction time and the dominant and non-dominant hands: An extension of Hick's Law. Pers Indiv Differ. 2004;36:733–739. DOI: 10.1016/S0191-8869(03)00133-8
39. Holahan CJ, Culler RE, Wilcox BL. Effects of visual distraction on reaction time in a simulated traffic environment. Hum Fact. 1978;20(4):409–413. DOI: 10.1177/001872087802000404
40. Petri K, Emmermacher P, Danneberg M, Masik S, Eckardt F, Weichelt S, Bandow N, Witte K. Training using virtual reality improves response behavior in karate kumite. Sport Eng. 2019;22(1):2. DOI: 10.1007/s12283-019-0299-0
41. Qian J, McDonough DJ, Gao Z. The effectiveness of virtual reality exercise on individual's physiological, psychological and rehabilitative outcomes: A systematic review. Int J Environ Res Public Health. 2020;17(11):Article11. DOI: 10.3390/ijerph17114133
42. Todorov K, Manolova A, Chervendinev G. Immersion in virtual reality video games for improving physical performance measures: A review. 2019 27th National Conference with International Participation (TELECOM). 2019, 35–38. DOI: 10.1109/TELECOM48729.2019.8994884
43. Tuz J, Maszczyk A, Zwierzchowska A. The use of characteristics and indicators of body composition as predictors in the identification of the angle values of the physiological curvatures of the spine in sequential objective testing – Mathematical models. Balt J Health Phys Act. 2023;15(1):Article2. DOI: 10.29359/BJHPA.15.1.02
44. Parraga-Montilla JA, Cabrera Linares JC, Jimenez Reyes P, Moyano Lopez M, Serrano Huete V, Morcillo Losa JA, Latorre Roman PA. Force–velocity profiles in CrossFit athletes: A cross-sectional study considering sex, age, and training frequency. Balt J Health Phys Act. 2023;15(1):Article5. DOI: 10.29359/BJHPA.15.1.05
45. Motahari-Nezhad H, Zare F, Akbari H, Sadeghdaghighi A. Health outcomes of Fitbit, Garmin or Apple Watch-based interventions: A systematic review of systematic review. Balt J Health Phys Act. 2022;14(4):Article8. DOI: 10.29359/BJHPA.14.4.08

Author Contributions: Study Design, JP, AL, and IZ-G; Data Collection, JP, AL, PS, MZ, IZ-G, and AM; Statistical Analysis, JP and AM; Data Interpretation, JP, AL, PS, and MZ; Manuscript Preparation, JP, PS, MZ, IZ-G, and AM; Literature Search, JP, AL, MZ, and IZ-G; Funding Acquisition, JP, AL, PS, MZ, IZ-G, and AM. All authors have read and agreed to the published version of the manuscript.

Funding: The research was part of a larger project funded by the National Center for Research and Development from EU funds under project No. POIR.01.01.01-00-0365/20 "Development of methods for studying and shaping coordinative abilities along with a dedicated set of training methods in boxing using virtual reality."

Institutional Review Board Statement: The research procedure was approved by the Research Ethics Committee of the Jerzy Kukuczka Academy of Physical Education in Katowice.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Additionally, participants were informed about the purpose and course of the tests, as well as the option to withdraw from the study at any time without giving a reason.

Data Availability Statement: Data available from the corresponding author on request.

Conflicts of Interest: The authors declare no conflict of interest.