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Assessment of the Validity and Reliability of Reaction Speed Measurements Using the Rezzil Player Application in Virtual Reality

Jacek Polechoński [1,*] and Agata Horbacz [2]

[1] Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education in Katowice, 40-065 Katowice, Poland
[2] Institute of Physical Education and Sport, Pavol Jozef Šafárik University, 04180 Kosice, Slovakia; agata.horbacz@upjs.sk
* Correspondence: j.polechonski@awf.katowice.pl

Abstract

Virtual reality (VR) is widely used across various areas of human life. One field where its application is rapidly growing is sport and physical activity (PA). Training applications are being developed that support various sports disciplines, motor skill acquisition, and the development of motor abilities. Immersive technologies are increasingly being used to assess motor and cognitive capabilities. As such, validation studies of these diagnostic tools are essential. The aim of this study was to estimate the validity and reliability of reaction speed (RS) measurements using the Rezzil Player application ("Reaction" module) in immersive VR compared to results obtained with the SMARTFit device in a real environment (RE). The study involved 43 university students (17 women and 26 men). Both tests required participants to strike light targets on a panel with their hands. Two indicators of response were analyzed in both tests: the number of hits on illuminated targets within a specified time frame and the average RS in response to visual stimuli. Statistically significant and relatively strong correlations were observed between the two measurement methods: number of hits ($r_S = 0.610$; $p < 0.001$) and average RS ($r_S = 0.535$; $p < 0.001$). High intraclass correlation coefficients (ICCs) were also found for both test environments: number of hits in VR (ICC = 0.851), average RS in VR (0.844), number of hits in RE (ICC = 0.881), and average RS in RE (0.878). The findings indicate that the Rezzil Player application can be considered a valid and reliable tool for measuring reaction speed in VR. The correlation with conventional methods and the high ICC values attest to the psychometric quality of the tool.

Keywords: reaction speed; coordination; virtual reality; reaction time; motor tests

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1. Introduction

Modern sport is characterized by a continuous pursuit of innovative technological solutions that support both training processes and the diagnosis of athletes' motor performance. One of the most dynamically developing areas in this context is the use of virtual reality (VR) in sport and physical activity (PA). In particular, VR is applied to develop motor, cognitive, and mental abilities, as well as to train strategies and tactics in immersive environments [1–5]. It is also used in motor learning [6–9] and in athlete rehabilitation [10–13]. Recent literature reviews show that most published studies demonstrate statistically significant training effects of VR interventions compared to traditional protocols [14]. Additionally, PA in VR is associated with high levels of enjoyment, which enhances the attractiveness and potentially the effectiveness of this form of exercise [15–18].

Immersive technologies also offer unique opportunities for assessing motor potential [8,19–21]. Motor tests developed in VR may offer advantages over traditional approaches, particularly for evaluating coordination abilities. Although traditional methods are well-established, they often present limitations in terms of cost, portability, equipment availability, and objectivity—many of which can be addressed by virtual environments. Coordination abilities are typically assessed through both precise laboratory-based tests [22–25] and simpler movement-based tests [26–28]. Laboratory tests allow accurate measurements but are mostly based on fine motor skills, are usually conducted while seated, and primarily involve finger or hand movements—thus failing to reflect typical athletic motion. Simpler tests, in contrast, often lack measurement precision and objectivity, which limits reproducibility. Considering these shortcomings, VR technology offers not only an innovative but also a potentially groundbreaking solution for motor diagnostics. VR-based fitness tests allow for precise measurement while replacing fine motor actions with global movement patterns, thus combining the advantages of laboratory and functional testing [20].

One of the most important coordination-related motor abilities for athletes is reaction speed (RS), as it determines success in many sports disciplines [21,29–32]. This is especially relevant in sports requiring quick responses to dynamic gameplay, such as team sports, tennis, or martial arts. RS includes not only simple responses to stimuli but also complex decision-making processes that must occur in extremely short timeframes. RS refers to the speed of response, or the rate at which we respond to a stimulus. Motor response speed depends on reaction time (RT) and movement time (MT) [33]. RT is the time between the appearance of an unexpected stimulus and the initiation of the correct motor response. MT is the time interval from the beginning to the end of the movement [34]. RT involves a multi-stage information processing process, starting with the generation of stimulation in the receptor, continuing through its transmission to the central nervous system and then to the motor center, where after forming an executive signal and transmitting it to the muscle it is stimulated, its tension changes, and movement is initiated. Depending on the variety of stimuli to which the individual is exposed, simple reaction time (SRT) and choice reaction time (CRT) are distinguished. In the former, there is a single signal and a required response. CRT, on the other hand, requires a different response to two or more stimuli [35]. The stimulus identification phase is believed to be the longest segment of information processing [36]. The number of processed stimuli lengthens RT, as demonstrated by numerous researchers [37]. This relationship is related to Hick's law, according to which an increase in the number of choices logarithmically increases the time to make a decision [38]. Therefore, complex reaction time, where the task is more difficult and requires a variety of actions in response to emerging stimuli, is longer than simple reaction time, regardless of whether the generated signal was visual, auditory, tactile, or mixed [39]. Classical reaction tests typically involve responding to a visual or auditory stimulus with a specific motor task [40,41], making them relatively straightforward to implement in immersive VR environments. Prototype tools for assessing RS in VR already exist [8,19–21,42]. This attests to the growing interest in methods that enable the assessment of reaction performance in immersive environments. Validation studies of these devices are promising, indicating relatively high validity and reliability of such solutions. However, a limitation is that they rely on research-grade VR systems rather than commercially available applications, which constrains practical use [8,19–21,42]. There are also commercially available solutions, such as the Rezzil Player application, which includes a "React" module offering various RS assessment modes. One of the test formats features a 3×3 target grid with randomly appearing light stimuli (illuminated virtual disks), which the user must hit with their hands. This setup enables assessment of both simple reaction speed and the ability to

quickly localize stimuli in space. This test closely resembles reaction assessments performed using the widely used SMARTFit diagnostic and training system, which is applied in therapeutic contexts [43,44].

The introduction of new diagnostic technologies in sport requires rigorous validation to confirm their validity and consistency. Without such validation, new diagnostic tools may produce misleading results and poor training decisions. It is crucial to compare the outcomes of novel instruments with established measurement standards. Validity refers to the degree to which a diagnostic tool actually measures the intended ability [45]. In the context of RS measurement in VR, validity means that test results correspond with the individual's actual reaction abilities. The nature of VR introduces several variables that can affect measurement outcomes, including system latency, differences in depth and distance perception, potential simulator sickness symptoms, and novelty effects. Reliability, on the other hand, refers to the consistency, stability, and repeatability of results under unchanged conditions [46].

So far, most studies on the use of VR in sport have focused primarily on training applications [7,14,47–53], while the diagnostic potential of VR remains underexplored [8,19–21]. There is thus a strong need for systematic validation studies to confirm or refute the diagnostic value of immersive technologies in sport. This study aims to fill this gap by comprehensively assessing the validity and reliability of the commercially available Rezzil Player application ("Reaction" module) for measuring RS in VR compared to results obtained using the standard SMARTFit diagnostic-training device in real-world (RE) settings. Additionally, we analyzed the correlation between two indicators of the assessed coordination ability in both tests—the number of hits on illuminated targets and the average RS to visual stimuli—and compared the RS results of participants between VR and RE conditions. The outcomes of this study may have practical implications for implementing VR technologies in training centers, sports clubs, and research institutions.

2. Materials and Methods

The study was conducted at the certified Laboratory of Research on Pro-Health Physical Activity at the Academy of Physical Education in Katowice (Quality Management System PN-EN ISO 9001:2015). A total of 43 physically fit university students participated in the study, including 17 women (age 23.0 $\pm$ 2.2 years, body mass 62.5 $\pm$ 11.3 kg, height 167.8 $\pm$ 6.3 cm) and 26 men (age 22.5 $\pm$ 2.2 years, body mass 81.8 $\pm$ 11.3 kg, height 180.0 $\pm$ 6.3 cm). Prior to the study, each participant was informed about the research procedures, objectives, and the intended use of the collected data. Participants were also informed of their right to withdraw at any time without providing a reason and without consequences. All participants gave written informed consent and signed a data privacy statement. The study was conducted in accordance with the Declaration of Helsinki and was reviewed and approved by the Research Ethics Committee of the Academy of Physical Education in Katowice (protocol 9/2018, 19 April 2018; protocol supplement KB/27/2022, 25 October 2022).

All tests were performed under standardized laboratory conditions (constant ambient lighting, no acoustic stimuli that could disturb the test, and a temperature 22 °C). Reaction speed in VR was assessed using a Meta Quest 2 headset (Meta Platforms, Menlo Park, CA, USA) and the Rezzil Player application (v.1.1.1265, Rezzil, Manchester, United Kingdom), available on the Meta store. This app includes several training modules for soccer, American football, and basketball, as well as a reaction speed training and diagnostic module called "Reaction," which was used in this study. It allows the evaluation of RS based on appearing light stimuli. The "Micro Wall" option was selected, where users must hit virtual red-light targets (approximately 10 cm in diameter) arranged in a 3 $\times$ 3 grid as quickly as possible

with either hand (Figure 1). The centers of the virtual targets were spaced horizontally by approximately 22 cm and vertically by approximately 38 cm. After a successful hit, the light turns off and another target lights up randomly. Each test lasted 60 s. The subjects stood at such a distance from the virtual grid that they could freely touch each of the nine targets with their right and left hands. Two output parameters were analyzed: the average reaction time (in seconds) and the number of target hits. The software measures RS with an accuracy of 0.001 s.

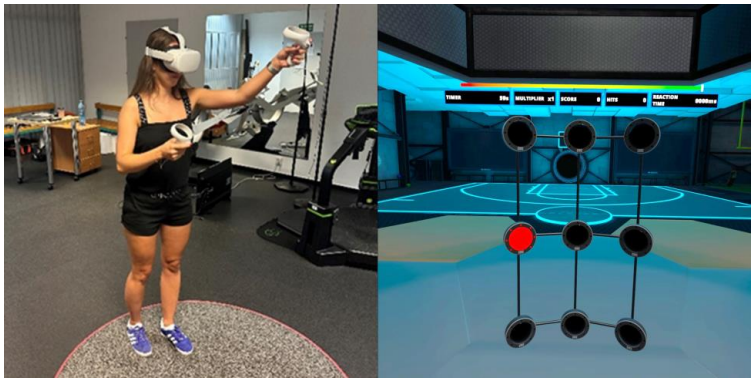

Figure 1. Participant during the test using the Rezzil Player application (Reaction module, "Reaction Wall" 3 × 3 option).

To assess the validity of the VR-based test, the obtained RS values were compared with those from a test performed in a real-world environment using the SMARTfit Mini device (model 1-30111, On-Wall Adjustable version). This interactive measurement system, produced by SMARTfit Inc. (Camarillo, CA, USA), includes nine multifunctional LED targets (diameter 11.5 cm, 16 × 16 pixels each) mounted on a 116.84 × 116.84 cm panel. The distance between the centers of the disks vertically and horizontally is 38 cm. It allows for measuring RS, movement accuracy, and analyzing motor patterns by recording target strikes. The "track the targets" mode, analogous to the VR test, was used. Participants struck illuminated targets randomly appearing on a 3 × 3 grid for 60 s (Figure 2). Unlike in VR, the RE test targets were represented as white emoji icons instead of red disks. Participants were positioned at a distance from the board such that they could touch each target with their right or left hand. The system recorded average RS (in milliseconds) and the number of target hits.

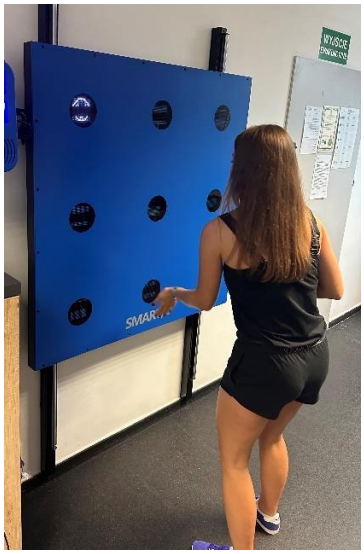

Figure 2. Participant during the test using the SMARTFit board.

Both tests were repeated three times. The final test result was the average of all trials. The averaged values from each trial were used to assess test reliability. A 5 min break was provided between measurements. Participants were allowed to stop the test in case of discomfort. After the VR test, they were verbally asked about symptoms of cybersickness, such as dizziness, nausea, eye strain, or headache. A short briefing and one trial test preceded the main measurement. A 10 min break was given between the VR and RE tests. To eliminate order effects, half of the participants completed the VR test first, followed by the RE test, and the other half completed the tests in the reverse order. Before each of the main measurements (VR and RE), participants completed one practice test to familiarize themselves with the measurement environment and procedure. All students declared that they had not previously used the SMARTFit device or the Rezzil Player app. All participants also reported familiarity with VR technology and had used it at least a few times.

Statistical analyses were conducted using Statistica (version 13.3) and SPSS (version 26.0) software. Basic descriptive statistics were calculated: arithmetic means and standard deviations. The Shapiro–Wilk test was used to verify the normality of data distribution. The convergent validity of the VR test was assessed by correlating its results with those from the SMARTFit device using Spearman's rank correlation, while agreement was estimated using the Bland–Altman method [54], reporting the bias (mean VR−RE difference) and the 95% limits of agreement (LOA = bias ± 1.96·SD of the differences) for both outcomes (reaction speed, number of hits). Interpretation of the results followed the scale proposed by Dancey and Reidy [45].

Measurement reliability for the VR and RE tests was estimated using the intraclass correlation coefficient (ICC) and its 95% confidence interval (CI), according to the procedures of Koo and Li [55]. A two-way mixed-effects model was used, with random effects for subjects and fixed effects for items. The ICC type was defined as absolute agreement. Reliability was evaluated based on a single measurement, incorporating three repeated measurements per participant, using the following formula:

$$\text{ICC}\ (3.1)\ = \ \frac{\text{MS}_\text{R} - \text{MS}_\text{E}}{\text{MS}_\text{R} + (\text{k} - 1)\text{MS}_\text{E} + \frac{\text{k}}{\text{n}}(\text{MS}_\text{C} - \text{MS}_\text{E})}$$

where

- MS_R—mean square for rows (subjects);
- MS_E—mean square error;
- MS_C—mean square for columns (trials);
- n—number of subjects;
- k—number of repeated measurements per subject.

The ICC values were interpreted as follows: poor (<0.5), moderate (0.5–0.75), good (0.75–0.9), and excellent (>0.9) reliability [55]. Statistical significance of ICC values was assessed using the F-test.

To verify differences between the results of the two tests, the nonparametric Wilcoxon test was applied. Effect sizes were calculated using the rank-biserial correlation coefficient (r_{rb}). A *p*-value < 0.05 was considered statistically significant.

3. Results

The results showed a strong ($r_S = 0.610$) and statistically significant ($p < 0.001$) correlation between the number of target hits in the VR and RE tests (Figure 3), according to the scale proposed by Dancey and Reidy [45]. A relatively high correlation ($r_S = 0.535$; $p < 0.001$) was also observed for the second analyzed parameter—average RS (Figure 4).

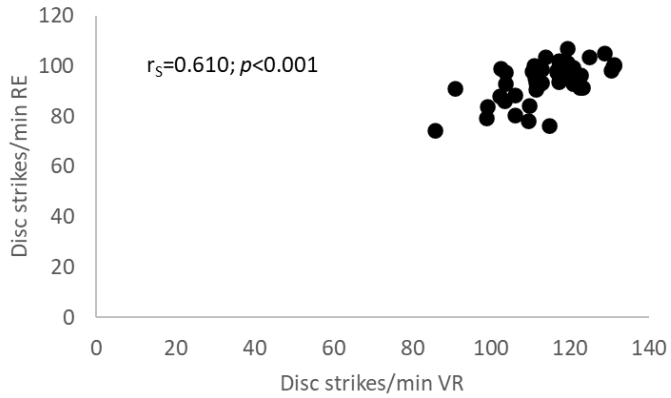

Figure 3. Correlation between the number of target hits in virtual reality (VR) and in real environment (RE); r_S, Spearman's rank correlation coefficient; *p*, *p* value; n = 43.

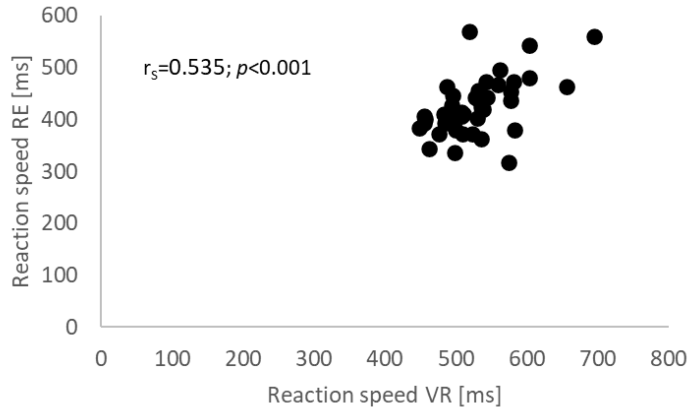

Figure 4. Correlation between mean reaction speed (RS) in virtual reality (VR) and in the real environment (RE); r_S, Spearman's rank correlation coefficient; *p*, *p*-value; n = 43.

Additionally, the relationship between the number of hits and RS was very strong and statistically significant in both environments: VR (r_S = 0.999; $p < 0.001$) and RE (r_S = 0.916; $p < 0.001$) (Figures 5 and 6). This suggests that both parameters can be used interchangeably to evaluate reaction performance.

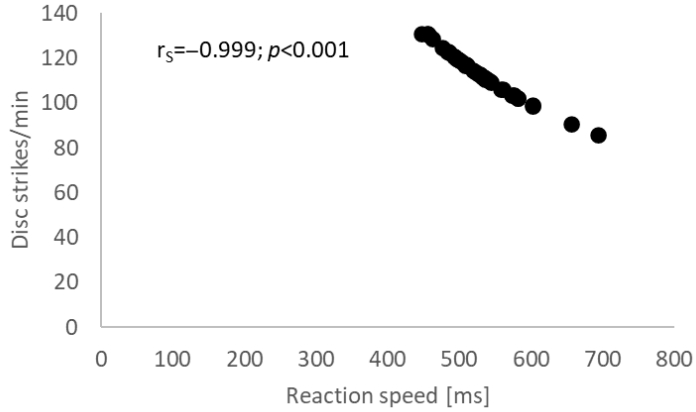

Figure 5. Correlation between the number of target hits and reaction speed (RS) in the virtual reality (VR) test; r_S, Spearman's rank correlation coefficient; *p*, *p*-value; n = 43.

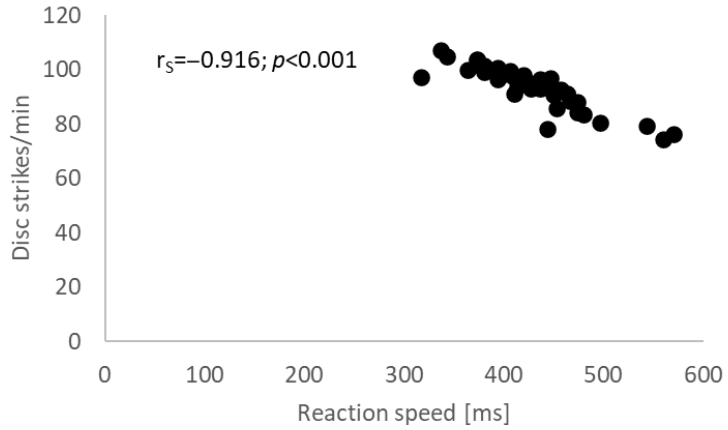

Figure 6. Correlation between the number of target hits and reaction speed (RS) in the real environment (RE) test; r_S, Spearman's rank correlation coefficient; *p*, *p*-value; n = 43.

The ICC values for the reaction tests in VR demonstrated high measurement reliability and were similar to the values observed in the RE tests. For the average RS parameter in VR, the ICC was 0.844, while in RE it was 0.878. For the number of hits per minute, the ICCs were 0.851 in VR and 0.881 in RE (Tables 1 and 2).

Table 1. Intraclass correlation coefficients (ICCs) for reaction tests in virtual reality (VR).

Parameter	ICC (95% CI)	F	*p*
Reaction Speed	0.844 (0.758–0.906)	17.120	0.001
Hits per Minute	0.851 (0.768–0.910)	18.036	0.001

Legend: ICC, intraclass correlation coefficient; CI, confidence interval; F, F-test value; *p*, *p*-value; n = 43.

Table 2. Intraclass correlation coefficients (ICCs) for reaction tests in the real environment (RE).

Parameter	ICC (95% CI)	F	*p*
Reaction Speed	0.878 (0.809–0.928)	23.373	0.001
Hits per Minute	0.881 (0.813–0.929)	22.956	0.001

Legend: ICC, intraclass correlation coefficient; CI, confidence interval; F, F-test value; *p*, *p*-value; n = 43.

The mean RS in VR was significantly ($p < 0.001$; $r_{rb} = 0.992$) higher (528.0 ms) than in the real environment (426.4 ms), with a difference of 101.6 ms (Figure 7).

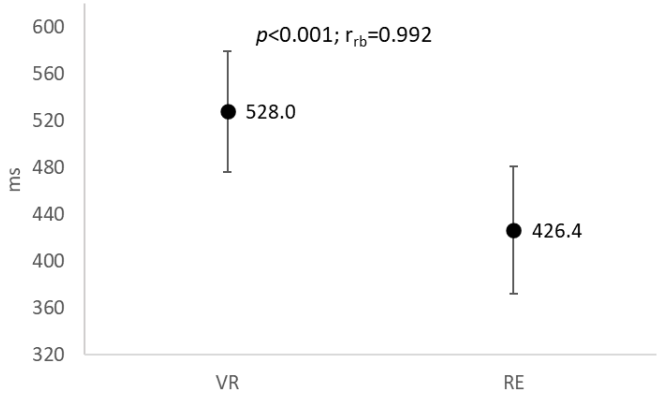

Figure 7. Mean reaction speed (RS) during tests in virtual reality (VR) and in the real environment (RE); r_{rb}, rank-biserial correlation coefficient; *p*, *p*-value; n = 43.

For the number of hits, Bland–Altman analysis indicated a positive bias (VR−RE) of +19.7, with 95% limits of agreement from 3.3 to 36.1 (n = 43) (Figure 8). For RS, Bland–

Altman analysis indicated a positive bias of +101.6, with 95% limits of agreement from 2.3 to 200.8 ms (n = 43) (Figure 9).

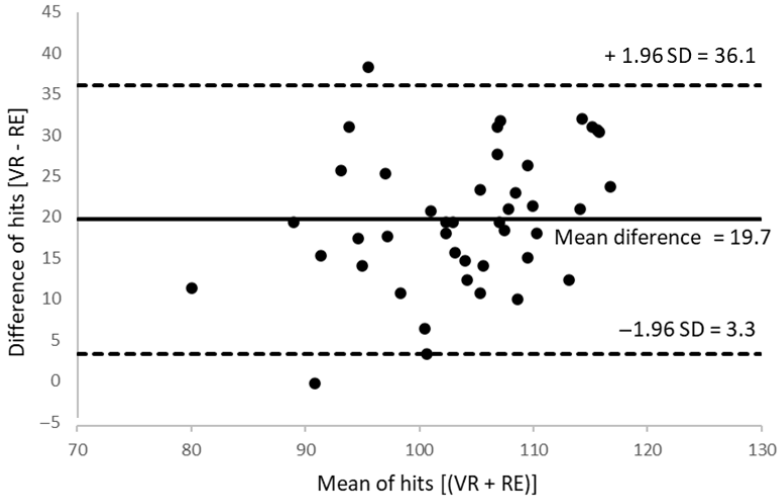

Figure 8. Bland–Altman plot for the number of hits in virtual reality (VR) and the real environment (RE) (n = 43). The solid line shows the mean difference (bias; VR−RE), and the dashed lines indicate the 95% limits of agreement (LOAs); n = 43.

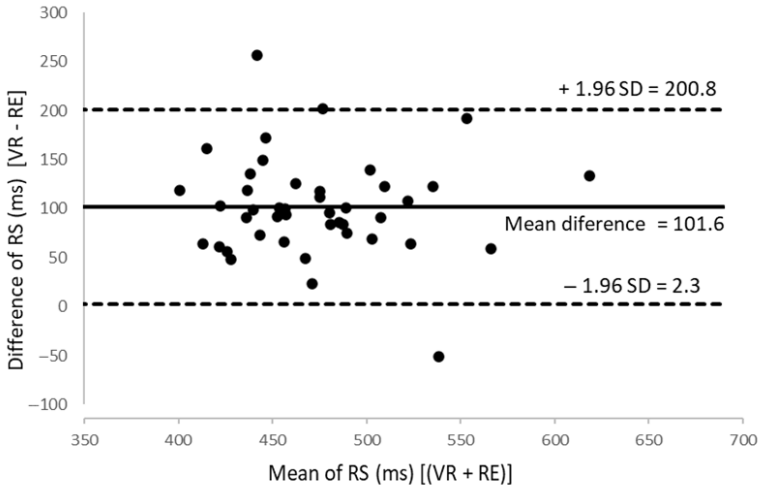

Figure 9. Bland–Altman plot for reaction speed (RS, ms) in virtual reality (VR) and the real environment (RE) (n = 43). The solid line shows the mean difference (bias; VR−RE), and the dashed lines indicate the 95% limits of agreement (LOAs); n = 43.

4. Discussion

The results of the present study provide significant evidence for the measurement validity of the Rezzil Player application as a tool for assessing reaction speed (RS) in a virtual reality (VR) environment. The obtained correlation coefficients (r_S = 0.610 for the number of target hits and r_S = 0.535 for mean RS) are consistent with findings from previous studies validating similar diagnostic tools in VR. Polechoński and Langer [21] reported comparable correlations (r = 0.564–0.744) when validating reaction tests in VR among combat sports athletes. The VR task involved pressing controller buttons with index fingers in response to the illumination of virtual disks, and results were compared with classical computer-based tests. In another validation study [19], significant correlations (r = 0.683–0.767) were found when comparing results from standard computer-based tests with a VR-implemented Ruler Drop test. The same authors also compared results from the VR version of the Ruler Drop test with its traditional real-world counterpart, yielding

slightly lower but still statistically significant correlations (r = 0.468–0.474). These studies were conducted among mixed martial arts athletes, which supports the consistency of results across different populations of physically fit young individuals. A very similar correlation (r = 0.445) between Drop-bar test results in VR and real environments was also reported by Pastel et al. [8], who tested a group of young adults. Much higher correlation values (r = 0.85–0.89) were found by Chen and Liang [42], who compared the results of similar VR and real-world reaction tests that involved quickly responding to visual stimuli by pressing a button with the index finger.

An important part of the present study was the assessment of the reliability of the Rezzil Player measurement tool in a VR environment. To this end, intraclass correlation coefficient (ICC) analysis was conducted. The obtained ICC values, ranging from 0.844 to 0.851, indicate good measurement reliability according to the classification by Koo and Li [55]. It should be noted that very similar results (ICC = 0.878–0.881) were obtained in the same test conducted in the real environment using the SMARTFit device. Our findings are in line with those of Pastel et al. [8], who demonstrated high reliability of the Drop-bar reaction test in both real (ICC = 0.858) and virtual (ICC = 0.888) environments. Chen and Liang [42] reported an ICC of 0.710 for a VR-based version of a classical reaction test involving index finger responses to visual stimuli. Comparable ICC values were obtained in other studies assessing reaction to a falling object in VR (Ruler Drop test; ICC = 0.710–0.783) [19], finger response to virtual lights (ICC = 0.730–0.805) [21], and hand strikes on illuminated virtual targets (ICC = 0.792–0.846) [20]. In the first two cases, parallel traditional computer tests were conducted, with ICC values ranging from 0.800 to 0.845 and 0.743–0.836, respectively. These converging results suggest that VR technology has reached a sufficient level of technological maturity to allow stable and repeatable measurements of reaction ability.

Another aspect of the present results was the correlation between two indicators of the examined coordination ability: the number of target hits and the mean RS to light stimuli. This analysis was conducted for tests performed in both virtual and real environments. In both cases, the correlation was very high: VR (r_s = 0.999), RE (r_s = 0.916). According to basic psychometric principles, a high correlation between different indicators of the same construct is evidence of convergent validity [56]. This result has important practical implications, as it allows both parameters to be used interchangeably depending on the specifics of the study or diagnostic preference. Although the redundancy found suggests that a single metric could suffice for future evaluations, it appears likely that both metrics will be used interchangeably as needed. The number of hits will be more intuitive in a practical context, while the average response speed provides greater precision in millisecond measurements and may be more useful for scientific comparisons.

The study also compared the reaction speed results obtained in virtual and real environments. A significant difference ($p < 0.001$; r_{rb} = 0.992) was observed between the mean RS in VR (528.0 ms) and RE (426.4 ms), which requires further analysis. One possible explanation is technological delay inherent in VR systems [57,58]. The motion-to-photon latency for systems similar to the Meta Quest 2 (HTC Vive, Oculus Rift, Oculus Rift S) is 21–42 ms [59]. The 101.6 ms difference between VR and RE cannot therefore be explained solely by technical latency. This indicates the involvement of additional factors. Reaction time differences between VR and real-world settings may also result from distinct perceptual and motor demands in virtual environments. For instance, depth and distance perception in VR may differ from natural perception, influencing motor decision-making time [60]. Technological delays may also affect user experience quality and measurement accuracy [61]. Another technical limitation is the risk of dropped or reprojected frames, which may compromise the accuracy of reaction time measurements. It should also be

noted that despite the high similarity between the tests and their procedures, the two measurement tools differed slightly (e.g., the shape of the 3 × 3 grid/wall, the color of the stimuli). Nonetheless, the results of the present study are consistent with findings from similar research comparing RS in VR and standard computer tests [19,21,42]. In all of these studies, reaction times were significantly slower in virtual environments.

Bland–Altman analysis confirms the presence of systematic but constant bias between VR and RE measurements. The absence of proportional bias indicates that differences between methods remain relatively constant across the full range of participant performance, which is favorable from a practical application perspective. The systematic bias of 101.6 ms for RS and 19.7 hits can be accounted for in result interpretation through the application of correction coefficients or the use of relative rather than absolute measurements. The 95% limits of agreement suggest that for individual measurements, differences between methods may range from 2.3 to 200.8 ms for RS and from 3.3 to 36.1 hits, which should be considered when making decisions about the interchangeable use of methods in clinical or sports applications.

One limitation of the present study is the use of a single VR headset (Meta Quest 2), which restricts the generalizability of the findings to other systems. Different VR headsets may vary in motion capture precision, latency, and tracking accuracy. Another limitation is the relatively small sample size (n = 43) and the homogeneity of the group (physically fit university students), which limits the possibility of generalizing the findings of the study to other populations. Therefore, future validation of the Rezzil Player application should include participants from diverse age groups and fitness levels (elderly people, patients, children, and athletes). The study also did not include a systematic assessment of cybersickness, which should be considered a limitation, as there are reports suggesting that cybersickness can affect cognitive and motor performance [62]. It should be noted, however, that none of the participants reported experiencing any discomfort during or after the tests that could indicate the occurrence of cybersickness.

5. Conclusions

The conducted study provides compelling evidence for the validity and reliability of the Rezzil Player application as a tool for measuring reaction speed in a VR environment. The obtained correlation coefficients with traditional measurement methods and high ICC values confirm the psychometric quality of the tool. The observed difference in reaction times between VR and the real world, although statistically significant, does not disqualify the tool but should be considered when interpreting results. These findings contribute to the growing body of research validating VR tools in sports and diagnostics, confirming the potential of this technology to complement traditional measurement methods.

Author Contributions: Conceptualization, J.P.; methodology, J.P.; validation, J.P. and A.H.; formal analysis, J.P. and A.H.; investigation, J.P.; resources, J.P.; data curation, J.P.; writing—original draft preparation, J.P.; writing—review and editing, J.P. and A.H.; visualization, J.P.; supervision, J.P.; project administration, J.P. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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

Abbreviations

The following abbreviations are used in this manuscript:

VR	Virtual reality
PA	Physical activity
RS	Reaction speed
RE	Real environment
r_S	Spearman's rank correlation coefficient
p	*p*-value
ICC	Intraclass correlation coefficient
RT	Reaction time
MT	Movement time
MS_R	Mean square for rows
MS_E	Mean square error
MS_C	Mean square for columns
n	Number of subjects
k	Number of repeated measurements per subject
Cl	Confidence interval
F	F-test value
r_{rb}	Rank-biserial correlation coefficient

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