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Enhancing adaptations to peripheral distractors during basketball throwing in real world through virtual reality application

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Introduction: The role of sensory distractors has been understudied, particularly in the context of training the sensory system to filter essential information during motor performances. In sports, many distracting peripheral stimuli can disturb an athlete's optimal performance, such as an opponent attempting to block a throw or disrupt walking paths. This study investigated whether Virtual Reality (VR) technology could mitigate such influences by creating a virtual training scenario involving a basketball throwing task.

Methods: 54 participants were divided into three groups who underwent different training: one group trained in the real world (RW_G), another that trained in a virtual environment (VR_G), both with an opponent, and a third group (RW_WO) trained in the real world (RE) without an opponent. The RW_WO group was excluded from the main analysis, as it did not fulfill the necessary prerequisites, which are described later. Pre- and post-tests were conducted to assess whether the participants improved performance by reducing the disturbance effect of the opponent. A self-defined scoring system was used to quantify the participants' performances, which was compared across different throwing conditions (with and without opponent's impact). A three-way ANOVA with repeated measurements with Bonferroni-corrected *post hoc* tests was conducted, including the between-subject factor group [RW_G, VR_G] and the within-subject factors Time [Pretest, Posttest] and Condition [with and without opponent].

Results: No significant interaction of Time*Condition*Group was found between the groups RW_G and VR_G (p = 0.552), indicating similar habituation to the opponent after VR and RW sensory training. In the posttest, no significant differences existed between conditions (with and without opponent) were observed in either group.

Discussion: VR training can match the effectiveness of training in real-world conditions. However, its benefits appear to be limited to participants who were genuinely affected by an opponent attempting to block the throw (beginners). The role of distractive stimuli is discussed, and possible future implementations are suggested.

KEYWORDS

virtual reality, peripheral distractors, head-mounted display, basketball, throwing, virtual opponent

1 Introduction

In recent years, Virtual Reality (VR) has significantly streamlined working processes and expanded applications across various fields (Zhang et al., 2020). Continuous technological advancements and the plethora of applicable tools have enabled researchers from diverse domains to utilize VR for their specific needs. Numerous studies are now exploring how VR can be leveraged in sports (Bürger et al., 2022; Faure et al., 2020; Neumann et al., 2018; Liu et al., 2020). In this domain, physical resistance provided by opponents, sports equipment, is crucial for achieving physical adaptations, which depend on the duration or intensity of the load. Despite its potential, certain limitations remain, notably the lack of haptic feedback in most VR systems (Wang et al., 2019), which makes them unsuitable for many sporting disciplines in terms of physical adaptations. Consequently, it is vital to propose and test alternative solutions before fully integrating VR into athletes' training.

In the realm of sports, numerous factors contribute to differentiating athletes' performance levels beyond physical conditioning. The ability to develop effective strategies in dynamic situations (Natsuhara et al., 2020), perceive relevant stimuli for the completion of motor tasks despite higher anxiety in competitive situations (Tremayne and Barry, 1988), anticipate opponents' actions (Müller et al., 2019) and master fundamental movement patterns are all essential for successful performance. Differences between novices and experts are often rooted in visual-perceptual and visual-cognitive abilities (Ericsson and Starks, 2003). Consequently, training perceptual-cognitive skills such as attention, anticipation, and decision-making, has become a major focus of sports science research (Williams and Jackson, 2019; Raab et al., 2019; Limballe et al., 2021).

With the gradual advancement of head-mounted display technology, research has focused on visual perception, particularly central or peripheral vision (Schumacher et al., 2019; Zwierko, 2008). The importance of both types of vision has been extensively discussed in relation to athletic performance (Schumacher et al., 2019; Chen and Treisman, 2008). Accordingly, peripheral vision (PV), in particular, plays a crucial role in a wide range of tasks essential for seamless functioning in daily life and, especially, in sports (Vater et al., 2022). It is used to detect objects outside the direct line of sight (Ringer et al., 2021), guide visual search and self-positioning, plan saccades, and track or recognize multiple objects (Vater et al., 2022). For a comprehensive explanation of PV and its significance in sports, we refer to the review of Vater et al. (2022). Nonetheless, a few key points need to be revisited to clarify the motivation for this study.

PV enables us to more easily perceive static or moving objects without moving the head or eyes. Its spatial range can be divided into far-peripheral (between 60 and 110°), mid-peripheral vision (between 30 and 60°), and near-peripheral vision (between 18 and 30°) (Badau et al., 2023). The ability to detect peripheral stimuli can enhance reaction times and facilitate the initiation of appropriate actions. However, it can also limit performance efficiency, particularly when distractors interfere the focus (Sigitov et al., 2016; Wallace and Vodanovich, 2003; Murray et al., 2018). This is particularly true even in sports-related scenarios, where movement patterns must be retrieved amid potential distractions. For instance, in competitive sports or situations involving interactions with teammates or opponents, distractions, primary visual, auditive, haptic, can affect athletes, requiring sustained focus on essential elements such as movement execution, for example, landing stability (Wilke et al., 2021), or ankle stability (Chan et al., 2024). A study demonstrated that optimal gaze control and focus relative to the single target location, referred as the Quiet Eye, led to improved performance in basketball field goal shooting (Vickers et al., 2017). The authors also examined transfer effects by having participants shoot while defensive pressure, which, as expected, led to decreased performance (Vickers et al., 2017). Naturally, expert athletes tend to be more resilient to frequent unexpected distractions than novices in sports contexts.

Hereby, we see great potential of VR to train such sports scenarios where distractive stimuli occur repeatedly, thereby helping to minimize performance loss. VR allows precise programming of elements within a scenario, such as opponent's appearance, speed, and location, enabling the development of unprecedented study designs that would not be feasible in real-world (RW) settings. For instance, interindividual differences can be investigated as athletes of varying performance levels are exposed to identical same sportive situations under standardized experimental conditions, allowing researchers to assess and classify variables such as decision-making, reaction times, and attentional focus. A recent study examined whether vision training in VR could enhance athletes' ability to identify wide-open opportunities for passing the ball to a better-positioned teammate (Liu et al., 2023). The authors reported satisfactory participant acceptance of the four-week vision training program. However, further investigations are necessary to confirm transfer effects on RW performances. Using the passing example, it is important to consider additional factors, beyond quick and accurate teammate identification, when initiating the next move.

Further VR basketball studies have been reported from findings which examined whether specialized throwing scenarios in VR can match with RE throwing. These studies assessed the success rate of throws, kinematic data such as wrist, ankle, and shoulder angles between novices and experts (Chan et al., 2024), and systems that provide feedback of ball trajectory and angle of incidence (Sumiya et al., 2022). Comparison between novices and experts indicated that the VR throwing applications were realistic: in VR, experts outperformed novices similarly to RW settings and showed comparable differences in kinematic data, smaller hand and ankle angles, and larger shoulder angles (Chan et al., 2024). Moreover, VR-based throwing training has shown significant improvements in performance, including smaller deviations from the center of the basket and reduced standard deviation, indicating enhanced stability (Jiang et al., 2022). However, most training studies involved throwing with a real basketball to compensate for the lack of haptic feedback and focused primarily on improving kinematics rather than sensory input.

To achieve an acceptable level of sports performance, a variety of visual abilities must to be trained, as previous studies have already described in basketball (Vera et al., 2020; Chan et al., 2024; Tsai et al., 2022). In real game situations, opponents are likely to attempt to intercept passes or block shots. VR may serve as a valuable tool to mitigate the previously described impact of such distracting stimuli, potentially enhancing athletes' performances and yielding improvements in RW scenarios as well. This could be, for example, directing the user's attention to the key points required to perform successfully. Attention plays a crucial role in motor learning and performance, and previous studies have already shown its importance for basketball players and their shooting accuracy (Netolitzchi et al., 2019). The impact of the distractors appearing in sports scenarios was already proven since the attention drives directly to them, and the performance level suffers (Lewthwaite and Wulf, 2017; Wulf and Lewthwaite, 2016). In this context, we focus on visual attention cues, although others may impact athletes' performances, such as auditive (Venkatakrishnan et al., 2024), emotions (Vast et al., 2010) and further. Experts are better at isolating essential cues from unnecessary ones (Mann et al., 2007), and VR appears to be a valid tool for enhancing such habituation abilities (Lachowicz et al., 2025). Considering the current state of research, there is a gap in understanding how VR can be actively integrated into athletes' training and which athletes this training may be relevant for. A wider range of sports scenarios should undergo such habituation training to further clarify the requirements for this type of intervention, as well as to determine key training variables such as duration, repetition, and frequency.

Therefore, our aim is to create a virtual training scenario that improves the transfer of VR-adapted skills to real-world performance, particularly about sensory processing and habituation processes. We investigated whether habituation to a distractive opponent could occur in RW basketball shooting after training in VR. Three groups were formed, each undergoing different interventions: two trained in RW settings and one in a virtual environment. Pre- and post-tests were conducted in the university gymnasium, where participants attempted to score basketball hoops from a fixed position, both with and without a distracting opponent. Given previous findings on different stimulus perception concerning higher eccentricities (DeCouto et al., 2023), we varied the opponent's position to asses habituation to the distraction. The scores from pre- and post-test suggest a discernible habituation effect.

Several scientific objectives are addressed in this study. Due to the lack of comparable prior research focusing on adaptation to sensory distractors, the first objective is to evaluate the hypothesis that participants perform worse, i.e., achieve fewer successful hits, when facing an opponent attempting to block them, compared to conditions without any distractors. Second, we hypothesize that when training takes place without the presence of a distracting opponent, no adaptation or habituation to such distractors will occur. The third and primary focus of this study is the hypothesis that VR training can lead to adaptation to peripheral visual distractors, based on previous findings suggesting that visual cues can be authentically replicated in VR. Furthermore, given the known differences in motor performance between real and virtual scenarios, particularly the absence of haptic feedback from the ball, we expect the VR group to perform worse overall in terms of total posttest scores. However, when comparing performance under conditions with and without a virtual opponent, we expected no significant difference in performance for the VR group's performance. Such a result would support the notion that habituation to visual peripheral distractors has occurred through VR training.

2 Materials and methods

Three groups were tested and went through different types of interventions. A pre-test was carried out to establish the participants' baseline levels and to reveal possible influences regarding the disruptive opponent. Following the intervention, a posttest was conducted to evaluate any changes in participants' performance due to training.

2.1 Experimental apparatus

2.1.1 Software

The virtual environment was built with Blender (version 3.1.2) by modeling and texturing each virtual asset. Here, the original order of magnitude (height, length, width) corresponding to the standard was considered. The virtual scene was then imported to Unity 3D (version 2021.3.16f1), and SteamVR (version 1.27.1) was integrated to include VR interactions. The functionality within the scene was realized via self-written C# scripts. The humanoid avatar (used for the virtual opponent) was downloaded from the Unity Asset Store and was developed by Code this Lab (Italy, 2009). The basketball animations were self-captured using Vicon Shogun (version 1.6.3) and then transferred to the humanoid avatar's skeleton. Python (version 3.10.8) and its library Pygame (version 2.3.0) were used to guarantee a standardized pre-and post-test process by instructing the experimenter where to go next (randomly assigned opponent's position) and giving the participants the auditive start signal in a standardized sequence (procedure later described). The data were processed and visualized with Python, and further statistical analysis was conducted using SPSS (version 29).

2.1.2 Hardware

The Pimax Vision 5K Super (developed in 2020, Shanghai, China) with a 200° field of view (depending on the chosen sampling rate) and up to 180 Hz was selected for the VR training group. The resolution of 2,560 × 1,440 per eye and the built-in Fresnel lenses ensure a clear view without pixelation. Since the focus was to examine the influence of peripheral distractors (the storming virtual opponent), a broad view must be prioritized. This means reducing the sampling rate to 90 Hz, getting the most possible field of view of approximately 200°. The connection to the computer was made via cable (5 m). In this case, no problem arises since the participant should not move from the original throwing position. A computer equipped with Intel i7 CPU, 16 GB memory, 512 GB SSD, and NVIDIA GTX 1080 8 GB graphic card was used to run the VR application. For the interaction (throwing the ball), the HTC VIVE Controller version from 2018 (equipped with 24 sensors, HTC, Taiwan) was used. It is compatible with the Pimax Vision 5K Super since both systems run over SteamVR. To start the Python application for the pre-and post-test (to ensure a standardized process), a computer consisting of an 11th generation Intel Core i5, 8 GB memory, and 256 GB SSD was used. The participant was also captured via a GoPro 8, Full HD resolution, being able to track the hits each participant made.

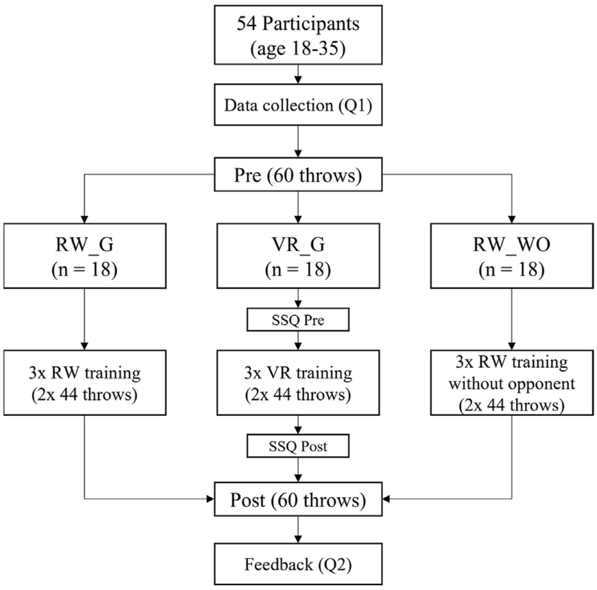

FIGURE 1
The test design of the current study. SSQ stands for the Simulator Sickness Questionnaire (Kennedy et al., 1993). RW_WO stands for real world conditions without a distractor. The distractor involves an opponent attempting to block the participants' throw. RW_G denotes the group trained in the real world with an opponent, while VR_G trained with an opponent in the virtual environment. Q1 and Q2 for the self-made questionnaires.

2.2 Participants and experimental setup

In total, 54 participants (20 females, 34 males, mean age 24.19 ± 2.69) were recruited primarily from a university context and completed the pre-and post-tests, and the interventions. To ensure an equal starting level across the groups, all participants should have no professional basketball experience. Before starting the experiment, the participants were demanded to fill out a self-created questionnaire in which pre-experiences in basketball exist. This also concerns VR pre-experiences that could influence participants' performances in the VR scenario itself. The participants had little experience in both VR and basketball, as they primarily reported participating in the university's sport courses (approximately 40% in each group), which do not reflect a high level of basketball ability. Approximately 18% of each group stated that they had already experienced VR, mostly through participation in previous studies. No one owned an HMD at home.

2.3 Procedure

The following figure shows the procedure of the current study (see Figure 1).

Before starting the experiment, the participants completed a self-created questionnaire. Including the pre-experiences regarding the usage of VR training tools and basketball training sessions. The participants were randomly assigned to one of the three groups. Regardless of group assignment, all participants first underwent a pre-test in the RW setting. Pre-analyses were conducted to ensure group homogeneity regarding equal performance levels before beginning the intervention. Additionally, the VR-group completed a pretest in VR to assess potential improvements within the virtual training sessions. Since the motor task in VR differed from that in RW due to controller handling, we did not anticipate any learning effects solely from the test itself.

In VR, the participants had to hold the controller at an approximately 45° angle and press a button that allowed them to manipulate the force input to the ball. The longer they pressed the button, the more force was transmitted to the ball.

The pre- and post-test consisted of 60 throws, divided into four conditions with 15 throws each. Participants conducted the throws from a fixed throwing position (see Figure 2, TP). TP was chosen because we have tested beginners, and the position is located in the area of the basketball court with the highest scoring potential. In one condition, no storming opponent attempt to block the throws (WO). In the remaining ones, the opponent started randomly from one of the three designated positions (see Figure 2, WL, WM, WR). Since the participants should not have known from which position the opponent tried to reach them, they stood to the basket with their backs. When the starting signal sounded, they initiated an approximately 180° rotation on the longitudinal axis before throwing. This also applies to the group that later trained without distracting an opponent to ensure similar movement patterns during training. Generally, the participants had less than 1.5 s to complete the throw in the pre-and post-test condition, as well as during the VR interventions. If they hesitated for too long, the opponent blocked the throw. Therefore, they were instructed to throw the ball upon hearing the sound.

All groups underwent three training sessions, each consisting of 88 trials. After 44 trials, the participants took a short break (5 minutes) to rest. We had to reduce the number of training sessions compared to other studies due to practical constraints. For RW_G and VR_G, during the first training session, no opponent appeared. In the second session, the opponent appeared in 44 trials. By the final training, the opponent appeared for all throws. In VR, a virtual opponent was used to simulate the storming opponent (see Figure 2, bottom row B). We captured the opponent's movements from the same person who performed the attempts in a real environment to enhance the similarity between the movement patterns in the real and virtual environments. The distance between the opponent and the participant was approximately 3.5 m, and the opponent took about 1.1 s (around 11.5 km/h) to complete their defense, which is noticeably slower than in natural game conditions due to the participants' beginner skill level). The group without distractor trained without any disruptive influences, as the effect of such distractions would be analyzed later. The remaining groups performed their throws with the opponent present to acclimate to its appearance. In the following, the group that trained in RW with the opponent's appearance is described as RW_G, the group that trained in RW without the opponent's influence as RW_WO, and the group that trained in VR with virtualized opponent as VR_G. Therefore, the group descriptions are based on the training form, whereas both the pre- and post-tests required real throwing, with and without an opponent. As shown in previous studies, feedback should be integrated in training sessions (Pastel et al., 2023). Therefore, we decided to include a report of the hits (the score, see Figure 2, A in

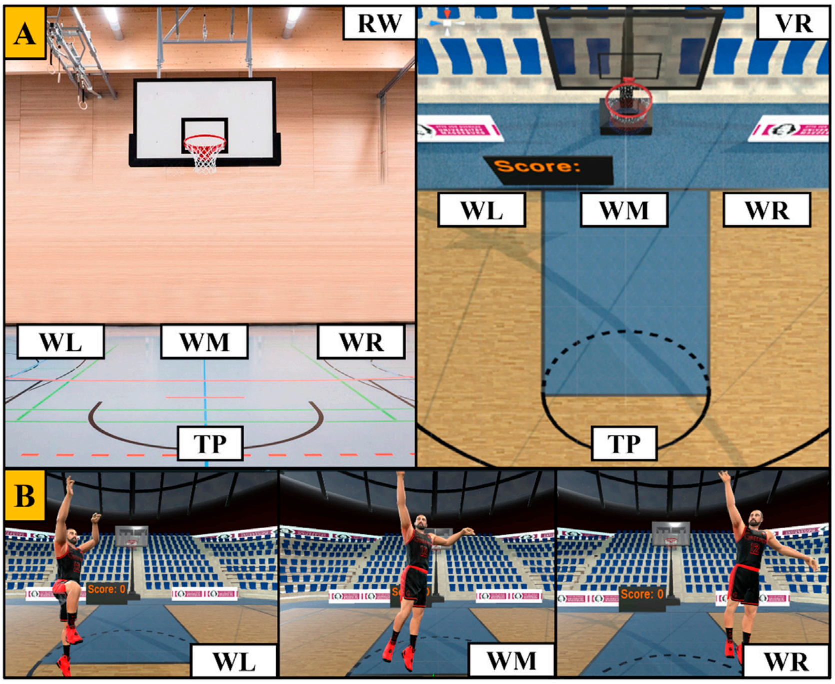

FIGURE 2
Experimental setup. In **(A)**, the RW scenario is depicted. TP illustrates the participants' throwing position. The opponent attacked the participant from three different positions: from the left (WL), from the mid (WM), and from the right (WR) (see in the bottom row, **(B)**). The condition in which no opponent appeared (WOO) is not illustrated. The upper picture illustrates the scene from the bird's perspective, whereas the lower picture shows the participants' view while the virtual opponent is trying to block the throw from each direction. Of course, the pre-and post-test took place in a real-world scenario. This virtual illustration serves as an overview of the setup and gives insight into the visualization within the VR scenario.

the virtual scenario). After the intervention, the participants went through the post-test, which was equal to the pre-test. After completion, they filled out a self-made questionnaire that contained questions about the subjective perception of, for example, the impression of the realism of the virtual opponent (in VR_G) and whether they felt more uncomfortable when the opponent tried to block them. To those who experienced the virtual training condition, the Simulator Sickness Questionnaire (Kennedy et al., 1993), SSQ) was handed out before and after the training sessions. To quantify participants' responses, Likert scales were used as elevation procedure based on already established questionnaires measuring subjective impressions (Hausler et al., 2017).

2.4 Data analysis and statistics

Participants' performances were evaluated using a scoring system: zero points if the ball touched only the backboard or missing entirely, one point if it hit the hoop, and two points for a successful basket. This point system was used to quantify participants' throws without relying on motion capture, although this would certainly offer more detailed information about movement execution (Chan et al., 2024). One within-subject factor, condition, was defined with four levels: without opponent (WOO), with opponent coming from the left side (WL), with opponent coming from the mid (WM), and with opponent coming from the right (WR). The total points achieved were then divided by the number of throws (15) for each condition. Additionally, a new variable was computed to represent overall performance in the presence of a distracting opponent by averaging the scores from all three opponent positions (WL, WM, WR).

All prerequisites for data analysis were carefully assessed. Normal distribution was tested using Kolmogorov-Smirnov test. Statistically significant outliers were excluded based on the median absolute deviation (MAD), calculated for each participant's relative performance in the opponent conditions, normalized by their performance in the non-opponent condition. Each participant who did not show a significant impact from WOO to WO_{Mean} was excluded from the analysis.

Before examining the outcomes of each training condition, it was necessary to verify whether the distracting opponent had a significant impact on participants' performance within each group. To assess this, normal distribution was confirmed for both WOO and the average of the opponent conditions (WL, WM, WR), referred to as WO_{Mean}. A two-way analysis of variance (ANOVA) for repeated measurements was conducted with one between-subject factor, group [RW_WO, RW_G, VR_G], and one within-subject factor, condition [WOO, WO_{Mean}] for the pre-test. Bonferroni-corrected *post hoc* tests were subsequently performed to determine whether a significant performance difference existed between conditions (with and without an opponent) within each group.

For the main analysis, relative performance was calculated by dividing the scores in the opponent conditions by the score in WOO, to gain a clearer understanding of adaptation effects. Unfortunately, in one group (RW_WO), too many participants were unaffected by the opponent's presence, making group comparisons unreliable.

Therefore, the main analysis was conducted using a three-way ANOVA with repeated measurement, with the between-subjects factor group [RW_G, VR_G], and the within-subjects factors Time [Pretest, Posttest] and Condition [WL, WM, WR], to interpret main effects and interactions. Bonferroni-corrected *post hoc* tests were used to further explore pairwise differences. The statistical power of the analysis was precalculated in advance using G*Power (version 3.1), yielding a 1-β error probability of 0.89, based on the assumption of a small effect size between the two groups. Special attention was given to the interaction effects, as different training types were expected to yield different levels of improvement, for example, due to the lack of haptic feedback.

Further group-specific analyses were conducted to gain more detailed insights into performance changes. The alpha level for all analyses was set at 0.05. When the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Effect sizes were reported using Cohen's eta squared (η^2), with thresholds of ≥0.01 for small, ≥0.06 for moderate, and ≥0.14 for large effects (Cohen, 2013).

For the VR_G group, participants' perceptions of how realistic the opponent appeared during training were assessed by converting responses from the Likert scale in the feedback form. The median was used to identify possible trends in perceived realism.

3 Results

3.1 Effect of opponent on group performance

In this chapter, the first and the second objective were analyzed. The first part of the results section presents the outcomes of the two-way repeated-measures ANOVA and the Bonferroni-corrected *post hoc* comparisons, with Condition [WOO, WO_{Mean}] as the within-subject factor. All groups were included in this analysis to assess whether the presence of an opponent had a negative impact on participants' performance. The dependent variable was the participants' performance scores, calculated using the scoring system described in the data analysis section.

A significant difference with a strong effect size was found between conditions, $F(1, 51) = 71.108$, $p < 0.001$, $\eta^2 = 0.582$. Participants scored significantly higher in the WOO condition compared to WO_{Mean} ($p < 0.05$). However, a significant interaction between Condition and Group was also observed, $F(2, 51) = 13.377$, $p < 0.001$, $\eta^2 = 0.344$, indicating a smaller but notable effect that required further examination.

Upon reviewing the raw data, it was found that in the RW_G and VR_G groups, only a small percentage of participants were unaffected by the opponent's presence. In contrast, 66% of participants in the RW_WO group showed no performance decline when the opponent attempted to block their throws. As a result, this group was excluded from the main analysis, as the remaining eight participants did not provide a sufficient sample size for meaningful interpretation. Although we applied our exclusion criteria, we examined the ratio of individual to team sport athletes by comparing the combined groups RW_G and VR_G with RW_WO, and found a moderately significant difference in the distribution of individual versus team sports ($\chi^2(1) = 8.91$, $p = 0.003$, $\varphi = 0.39$). This difference may be partly explained by the higher proportion of team sport athletes in the RW_WO group, who are generally more accustomed to reacting to peripheral distracting cues (Heinen, 2011). Such a potential influence should be taken into account in future studies.

For the RW_G and VR_G groups, the effect of a storming opponent on performance was clearly observable. This was confirmed by a one-way repeated-measures ANOVA on scores from all four opponent positions (WOO, WL, WM, WR) ($p < 0.05$), conducted separately for each group due to the significant interaction with the group factor. In contrast, only eight participants in the RW_WO group were affected by the opponent's presence, as indicated by higher scores in the absence of the storming opponent, resulting in no significant difference between the throwing positions ($p > 0.05$); therefore, the first hypothesis cannot be confirmed for this group and must be rejected.

Due to the failure to verify the first hypothesis for the third group, it is not possible to assess whether training without an opponent also leads to no improvement in the opponent conditions (WL, WM, WR). Therefore, we decided to proceed with the main analysis to determine whether VR training can match RW training.

3.2 Group comparisons across conditions over time

The main goal was to analyze whether habituation to the opponent occurred similarly across the RW_G and VR_G groups. A three-way repeated-measures ANOVA, with particular focus on the interaction between Time and Condition, was conducted to reveal statistically significant differences in the observations. Performance was measured based on the points from the defined scoring system (see Table 1). For further analysis, values were standardized relative to the condition without an attacking opponent, meaning there is no separate WOO condition.

Sphericity was met for Condition ($p = 0.871$) and Time × Condition ($p = 0.369$), as well as for the equality of the covariance matrix (Box's M test: $p = 0.385$) and error variances (Levene's test: $p > 0.05$).

All effects are summarized in Table 1. A large effect for the Time factor was observed in both groups, indicating performance improvement after training under conditions where the opponent attempted to block the ball. No significant interactions were found between the groups, suggesting similar adaptations across both groups. Therefore, we can confirm the third hypothesis at this stage.

When including the third group (RW_WO), without considering their sensitivity to the opponent's presence, significant differences were found for Time (moderate effect, as this group showed no impact in the pretest), as well as large effects for Condition and Time × Condition. A moderate effect was also observed for the Time × Condition × Group interaction, reflecting that the RW_WO group did not experience the same level of adaptation.

The adaptations of the RW_G and VR_G groups are illustrated in Figure 3, where the relative performance for each condition (WL, WM, WR) is normalized to the WOO condition. Each percentage

TABLE 1 Descriptive and inferential statistics of the participants' throwing performance are presented. RW_G represents the real-world group that trained with an opponent (n = 17), RW_WO represents the group that trained without an opponent (n = 18), and VR_G represents the group that trained within the virtual environment with a virtualized opponent (n = 16). The RW_WO group is grayed out because they were excluded from the main analysis.

Group	Pretest								Posttest							
	WOO		WL		WM		WR		WOO		WL		WM		WR	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
RW_G	1.27	0.15	1.09	0.16	1.12	0.16	1.14	0.19	1.16	0.26	1.16	0.24	1.11	0.24	1.19	0.16
RW_WO	1.16	0.23	1.11	0.22	1.14	0.25	1.14	0.21	1.25	0.21	1.17	0.21	1.16	0.23	1.23	0.23
VR_G	1.34	0.13	1.09	0.14	1.12	0.22	1.10	0.21	1.20	0.18	1.24	0.19	1.22	0.17	1.21	0.17

Three-way ANOVA with repeated measurements and calculated effect sizes (n = 33)

Factor	Significance	Effect
Within-subject effects		
Time	$F(1, 31) = 54.599$, $p < 0.001$, partial $\eta^2 = 0.638$	large
Condition	$F(2, 62) = 0.430$, $p = 0.652$, partial $\eta^2 = 0.014$	no significant effect
Time*Group	$F(2, 30) = 2.398$, $p = 0.132$, partial $\eta^2 = 0.072$	no significant effect
Time*Condition	$F(2, 30) = 1.145$, $p = 0.325$, partial $\eta^2 = 0.036$	no significant effect
Condition*Group	$F(2, 30) = 1.200$, $p = 0.308$, partial $\eta^2 = 0.037$	no significant effect
Time*Condition*Group	$F(2, 62) = 0.599$, $p = 0.552$, partial $\eta^2 = 0.019$	no significant effect
Between-subject effects		
Group	$F(1, 31) = 0.883$, $p = 0.355$, partial $\eta^2 = 0.028$	no significant effect

deviation was subtracted from zero to indicate how much performance differed from the baseline (WOO). The RW_G group showed a greater improvement than the VR_G group, which had started at a slightly higher baseline.

The evaluation of the SSQ showed a significant difference from the pretest to the posttest in the category disorientation (pretest: M = 4.34 ± 8.38, posttest: M = 15.66 ± 18.93, p = 0.016), but not in the other domains, such as nausea (pretest: M = 2.98 ± 5.74, posttest: M = 4.17 ± 6.94, p = 0.414) and oculomotor functions (pretest: M = 7.58 ± 11.07, posttest: M = 14.69 ± 18.25, p = 0.153).

Participants' responses to the self-created questionnaire indicated that the storming opponent was perceived by all participants in both the pretest and posttest. However, for most participants, it was noted that the storming opponent played a neutral role in terms of its disturbing effect. For the VR_G group, the virtual opponent was rated as realistic, as it was based on real animations that translated into virtual opponent's movements. The participants' self-assessment of the effectiveness of this intervention was that it was "effective," which supports the statement that they felt more secure when no opponent tried to interrupt them.

4 Discussion

The role of sensory distractors in sports-specific scenarios has rarely been examined. With newer technologies, this research gap could be addressed. The main goal of the current study is to examine whether VR can be used as an additional training tool to reduce the impact of a peripheral distractor during a sports-specific task. To achieve this, a basketball throwing scenario was used, in which the participants were instructed to throw the ball 60 times during both the pretest and posttest. They threw 15 times without being disturbed by an opponent and 15 times in each of three conditions, with an opponent approaching from the left, middle, and right sides. To quantify the participants' performances, a scoring system was developed to evaluate them, considering that none of the participants had any prior basketball experience. Three groups underwent different interventions: one trained in RW with an opponent (RW_G), another trained in the RW without a disturbing opponent (RW_WO), and the third group trained in a virtual environment (VR_G).

The first objective was to verify that the impact of a storming opponent was spread across all groups in the pretest. Unfortunately, the negative effect of the opponent was not statistically significant for all of them, preventing full verification of the first hypothesis. For RW_WO, only tendencies of performance decreases were observed from the descriptive data for at least eight participants. Therefore, it was not possible to illustrate habituation to the storming opponent by comparing the outcomes of all groups, nor to include this group in the main analysis. RW_WO was included to show that, when no training with a distracting opponent was completed, significant differences between the WOO condition and the other groups still remained. Since RW_WO had trained without an opponent, a significant interaction of Time*Condition*Group would have demonstrated the different outcomes of the interventions. For RW_G and VR_G, the impact of the opponent was significant, with strong effect sizes in the pretest. This indicates the importance of clarifying the target group, as the current VR tool might not be

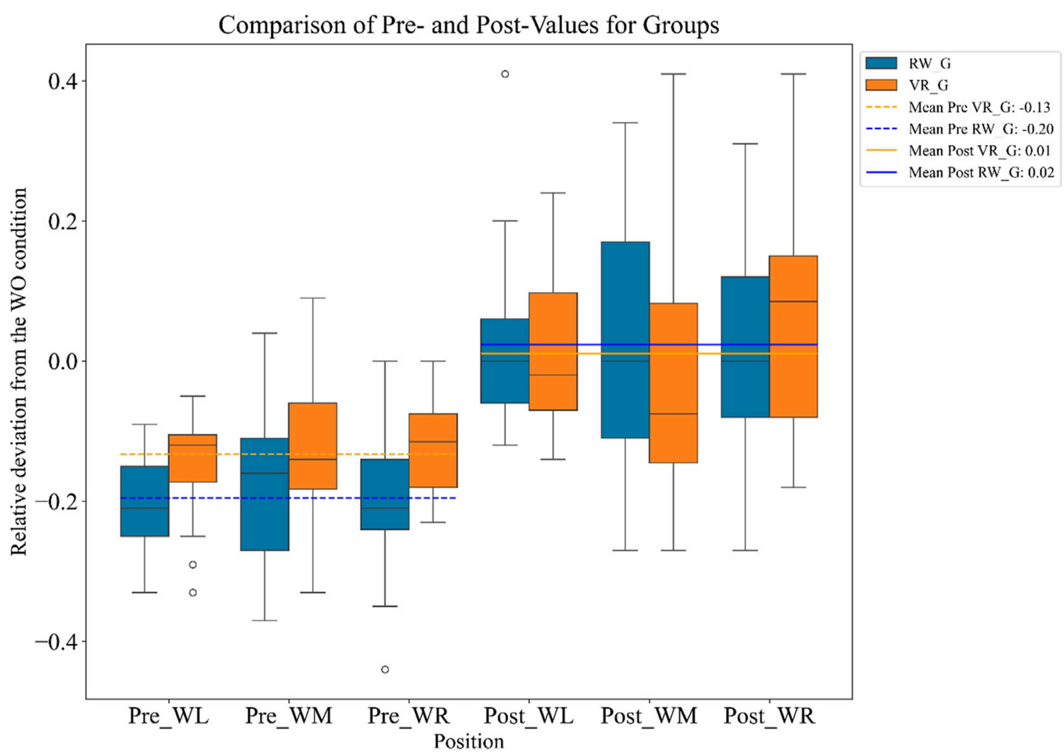

FIGURE 3
The graph illustrates training adaptation in both groups. The values on the y-axis represent the deviation of participants' performance in all opponent conditions (WL, WM, WR) from the base line (WOO), which is set to zero. In the posttest, small positive values indicate slight improvements relative to the WOO condition, suggesting successful adaptation to the opponent.

useful for all individuals, particularly those who have already had extensive experience confronting an opponent in a ball sport scenario. At the end of the study, 33% of participants in RW_WO reported participating in team sports, which was 10% higher than in the other groups. This could have consequences for their sensitivity to the opponent. Regarding the exclusion criteria, other team sports might also have been excluded in this context. However, habituation to the storming opponent occurred in the remaining groups, as no significant effect between the conditions (WL, WM, WR) was found in the posttest. This was not the case in the pretest conditions for both groups, and no significant interaction between Group*Condition was observed.

RW_WO was expected to demonstrate the negative impact of the opponent more clearly. However, since this group did not suffer from the opponent in the pretest, the posttest results were not surprising. In this group, a different opponent was included due to organizational issues. Nevertheless, the new opponent was instructed in the same manner as the first, and video analysis revealed a similar level of motivation and commitment. This group could have demonstrated that reduced performance persists in the posttest after training without a distracting opponent. This would have served as additional evidence for the effectiveness of the interventions conducted in RW_G and VR_G with disturbing opponents. By considering other factors, such as the scoring systems used, uncertainties might have been revealed, possible also though the use of additional parameters, such as kinematic data, as in previous studies determining the performance level (Chan et al., 2024).

Previous studies suggest that basketball players with higher performance levels exhibit distinct behaviors in response to peripheral stimuli, such as having shorter reaction times (Chaliburda et al., 2023). Additionally, the anticipation of an opponent's movements depends on the athletes' peripheral perception (Ghasemi et al., 2009). This is particularly evident when athletes are under time pressure, as was the case in the current study (Williams and Jackson, 2019).

In general, the use of newer computer-based methods is becoming increasingly apparent, including in tactics for handball, football, and basketball (Lisenchuck et al., 2019). Regarding sports vision training, a critical review of emerging approaches and technologies to facilitate visual perceptual and oculomotor tasks—aiming to enhance sensory processing speed or improve motion accuracy—illustrates the current trend. The review highlighted the key assumptions of vision training philosophies, aspects of vision itself, training visual functionality, and the translation to RW performance (Appelbaum and Erickson, 2018). In the current study, this transfer was observable by comparing the pre- and posttest performances of the VR_G group to the others, as training occurred solely within a virtual environment. Although the haptics of the ball were missing, learning in VR was still possible, as significant improvement was also observed in this group.

The ability to actively inhibit distracting stimuli (such as a storming opponent) was important for successfully performing the field goal task. This filtering of relevant versus non-relevant information is well-documented in visual perception (Chen and Treisman, 2008). The authors noted that an incompatible distractor in the periphery causes more interference compared to a foveal one. Nevertheless, they also discussed the nature of stimuli that are task-relevant or irrelevant. A task-irrelevant foveal distractor causes more interference than a peripheral one, and the subjects' attention more strongly suppresses the foveal area (Chen and Treisman, 2008). To provoke this kind of suppression, more variations of the opponent should have been implemented, indicated by a higher number of different positions, body postures or even body types. These variations could also be achieved by adding different speeds for the opponent during the training, which is challenging in the RW, thus provoking greater variation in fixation time on the target. Previous studies have reported longer fixation durations for experts compared to novices (Brams et al., 2019). This represents a significant challenge in quantifying differences among athletes based on their PV (Vater, 2024).

During the VR session, the virtual opponent appeared only in the peripheral view, while in the RW, the arms of an opponent vary in many ways when it comes to defensive blocks. Therefore, it is important to implement a function in which the opponent's arms try to block the ball's trajectory to make the experience more realistic. When the participants hesitated too much, their throws were blocked by the virtual opponent's arm collider. Both groups, which had individuals who struggled with the oncoming opponent in the pretest (RW_G, VR_G), did not exhibit this effect in the posttest, as there was no significant difference between the conditions (WO, WL, WM, WR). Despite the absence of this effect, the comparison between the groups (RW_G, VR_G) did not show a statistical interaction, indicating similar adaptation over time. This adaptation is reflected in the absence of significant differences between the conditions (WO, WL, WM, WR). However, there were no differences in performance between the groups in the posttest. Improvement in sensory system performance may not be evident in this static task. Nevertheless, differences might emerge if participants trained in more dynamic situations, such as varying throwing distances or facing different opponents. The final hypothesis could therefore be verified, encouraging further development of more flexible devices and applications.

It is quite difficult to find similar training applications at present, as their effectiveness has yet to be proven. Previous studies have explored how sensory input can improve learning and its transfer to RW performance, even in non-sporting contexts, such as tire-changing tasks (Cooper et al., 2021) or air attack training (Clifford et al., 2020). The authors suggested that VR tools could be used to measure actual performance improvement, emphasizing the potential to quantify the relative performance gains of different training paradigms and the time required to acquire such skills. Even though peripheral interference stimuli are not actively incorporated for learning in the current study, adaptation, such as habituation to the perceived blocking opponent, should still occur. This indicates that more research is needed to determine the optimal timing, nature, and frequency of exposure to certain stimuli to facilitate effective learning or sensory training.

In this study, visually focusing on the basket was crucial. Research has shown that maintaining focus on the basket significantly increases the success rate, especially during basketball free throws (Ayaz Kanat and Şimşek, 2021). In this context, eye tracking was used to determine visual attention, acknowledging that it can only be inferred indirectly from eye fixations and the field of view. If this data had been applied, it would have been possible to compare the duration of eye fixations between the groups (RW_G, VR_G, RW_WO), which could explain why RW_WO did not suffer significantly from the peripheral distractor.

The training intervention consisted of three 20-minute sessions. These sessions could also have a synergistic effect on training visual abilities such as depth perception, visual convergence or pursuit eye movements toward visual targets, as demonstrated in other studies (Balasaheb et al., 2008). However, such interventions often require a duration of over 6 weeks to achieve significant skill improvements. Studies have shown that a minimum number of sessions is necessary to make learning effects apparent, and these studies involved longer and more numerous training sessions than ours (O'Grady et al., 2020), especially those including executive functions (Xu et al., 2022). Furthermore, to expand the realism of training, one should vary the throwing positions, include more players, and introduce different opponent speeds, as is the case in real situations. Such an advanced training scenario could simultaneously be used to test athletes' behavior in response to peripheral distractors, as well as their tactics and decision-making processes.

Interestingly, VR_G showed no significant differences in the hit ratio despite lacking feedback from the ball (they only held the controller and pressed the trigger button), unlike the other groups. This improvement could further indicate habituation to the storming opponent, as evidenced by their performance improvement under these conditions in the posttest. Considering its motor component, it was still necessary to raise the arm about 45° toward (direction adjustment) the basket to score successfully, which is a major part of the actual throwing movement, aside from the bending motion of the elbow, wrist or the lower body. The visual adjustment to the storming opponent may have led to a stronger focus on the target motion components, which might explain the performance improvements observed in this group (Burleson et al., 2025; van Moorselaar and Slagter, 2020). In the future, motor analysis of the throws might provide insight into whether participants in the RW_G truly improved their throwing posture compared to the VR_G.

The participants' performances were compared using the self-defined scoring system. In future assessments of training effectiveness, it may be beneficial to consider the trajectories of the throws (Przednowek et al., 2018) to determine whether individuals achieve their individual stable condition, regardless of the presence of an opponent. However, the assessment of successful sports performance in team sports is always determined by whether the ball hits the goal or not. What could be more important is to create a scenario in which the throwing positions (TP) vary, allowing for greater transferability from VR to RW settings. To increase comparability, the opponent's properties, such as speed and size, should be kept consistent. Additional measurement systems could be used to examine the influence of these factors on participants' throwing performance. In this study, the virtual opponent was approximately 15 cm taller than the real-world opponent, which enhanced realism but reduced comparability.

It must be emphasized that this study addresses only the sensory training of a specific basketball scenario, and motor learning within virtual reality environments was not comparable due to the handling of the VR controller. Although newer HMDs, such as the Meta Quest 3 with advanced hand tracking, offer alternative options, there may still be no adequate solution to simulate the ball's physics. For this, a different setup, such as those used in other settings (Ueyama and Harada, 2024), would be required to maintain the motor component as well.

5 Conclusion

In general, the group that trained in a virtual environment exhibited adaptation to the negative performance impacts, similar to the group that trained in the RW under the same conditions (with an opponent). This demonstrates that VR can effectively expose beginners to specific situations and help them acclimate to disruptive stimuli appearing in their peripheral view. It could improve athletes' visual perception, specifically by directing their attention to essential stimuli. However, it is important to note that this study addresses only one specific scenario, and not all participants experienced issues with the peripheral distractor, in this case, the storming opponent. Therefore, this training scenario may not be universally applicable, especially for individuals who already engage in this sport intensively. For these individuals, it is crucial to identify their specific distracting stimuli and develop tailored VR training to address their unique challenges.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by The approval of the Ethics Committee of the Otto-von-Guericke University at the Medical Faculty and University of Hospital Magdeburg was obtained under the number 139/22. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SP: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. MS: Data curation, Investigation, Writing – review and editing. AS: Data curation, Investigation, Writing – review and editing. LB: Data curation, Investigation, Writing – review and editing. DB: Conceptualization, Methodology, Writing – review and editing. KW: Conceptualization, Funding acquisition, Project administration, Writing – review and editing.

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