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The Effect of Virtual Reality-Based Applications on the Agility and Balance Performance of Female Volleyball Players*

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Abstract

Virtual reality (VR)-supported applications may provide an alternative context for motor-skill practice in sports science. This study examined the immediate effects of a single VR session on agility and balance in 51 female volleyball players aged 11-14 years. Participants were allocated sequentially to an agility experimental group (n=19), a balance experimental group (n=15), or a control group (n=17). Each participant completed one VR session lasting approximately four minutes and no longer than five minutes. The illinois agility test, T-test, Y-Balance test, and flamingo balance test were administered before and after the session. Because parametric assumptions were not met, within-group changes were examined with the Wilcoxon signed-rank test and change scores were compared across groups with the Kruskal-Wallis H test; effect sizes were also reported. Within-group improvements were found in the T-test and illinois agility test for the agility group, in the illinois agility and Y-Balance tests for the balance group, and in the illinois agility test for the control group. The between-group difference was significant only for the T-test ($H=12.26$, $p=.002$, $\varepsilon^2=.214$). Pairwise comparisons showed that the agility group differed from the balance group, but neither experimental group demonstrated superiority over the control group. No between-group differences were found for illinois agility, Y-Balance, or flamingo change scores. These findings indicate test-specific, short-term changes after a single VR exposure; they do not establish that the experimental VR applications were superior to the control application.

Keywords: Balance, virtual reality, volleyball, agility, VR glasses

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INTRODUCTION

Volleyball is a dynamic team sport that requires high levels of agility, balance, reaction speed, and motor coordination. Owing to the nature of the game, volleyball players must rapidly perform sudden and repetitive movements such as jumping, changing direction, falling and recovering, and reacting instantly to the ball. These physical demands make the systematic development of balance and agility essential, particularly for athletes in developmental stages. Childhood and early adolescence are critical periods for acquiring and improving these motor skills (Tomaç et al., 2024).

Balance, one of these motor skills, is the ability to maintain and control the body's center of mass over its base of support. Static balance refers to the ability to maintain equilibrium in stationary positions, whereas dynamic balance is the ability to preserve stability during movement. For athletes in particular, balance is a fundamental prerequisite for performing movements efficiently and safely. Because postural control systems continue to develop throughout childhood and adolescence, balance training during these periods is critically important for motor development (Gebel et al., 2020). Agility, another motor skill, is the ability to change direction rapidly, stop, start, or suddenly perform different motor tasks. In addition to physical speed, this skill is associated with neuromuscular coordination, balance, and reaction time. In many sports-particularly volleyball, in which rapid positional changes occur frequently-agility is a key determinant of high performance. Agility-based training during adolescence provides substantial benefits in terms of movement economy, injury prevention, and the acquisition of sport-specific skills (Chaouachi et al., 2014). In addition to improving these motor skills, virtual reality (VR) exercises stimulate cognitive and neuromotor systems in an integrated manner. Recent advances in VR technologies within sports science suggest that real-time audiovisual feedback can improve athletes' movement quality and their capacity to respond to environmental stimuli (Mohammadi et al., 2023). The literature reports that VR-supported exercises have positive effects on fundamental motor skills such as agility and balance in children and young people (Liu et al., 2022). VR technology strengthens mental imagery and supports motor learning by providing realistic audiovisual stimuli. In volleyball, virtual scenarios can be used systematically to improve players' in-game decision-making, positioning, and ability to maintain balance during sudden movements. Furthermore, VR training has been reported to significantly improve agility and jumping performance and shorten in-game decision-making time in young volleyball players (Bujang & Hidayat, 2025).

Experimental studies have generally focused on physical exercise modalities such as plyometric, core, and balance training, which have produced improvements in agility and balance across different youth samples (Chaouachi et al., 2017; Arazzadeh et al., 2019; Çakır & Ergin, 2022; Sitti & Köroğlu, 2023). VR studies, by contrast, suggest that enriched audiovisual feedback, repeated perception-action coupling, and task-specific interaction may support motor learning and neuromotor adaptation; however, reported effects vary according to the task, outcome, and intervention duration (Liu et al., 2022; Richlan et al., 2023). Thus, evidence from clinical or other sporting populations cannot be directly generalized to volleyball-specific agility and balance. Female volleyball players aged 11-14 years were selected because early adolescence is a period of continuing neuromuscular and postural-

control development and because agility and balance are central to repeated changes of direction and stabilization in volleyball. Evidence concerning the immediate effects of task-specific VR applications in this population remains limited. The present study therefore examined whether a single exposure to agility-oriented or balance-oriented VR content produced different pre-post changes from a control VR application.

Accordingly, the study addressed the following research questions:

1- Do agility, dynamic balance, and static balance scores change from pre-test to post-test within the agility, balance, and control groups?

2- Do the magnitudes of these changes differ among the three groups?

3- Are VR-related dizziness and nausea distributed differently across groups or associated with performance-change scores?

METHOD

Research Model

This quantitative study employed a quasi-experimental pre-post test control-group design. Participants were recruited through convenience sampling and allocated to the three study groups by sequential distribution. Because the allocation sequence was not generated by a random mechanism and allocation concealment was not used, the design was not classified as a true randomized experiment.

Research Group

The study included 51 healthy volunteer female volleyball players aged 11-14 years (mean age:12.45±1.1 years) who played for clubs and school teams in Şanlıurfa and were selected through convenience sampling.

The sample consisted of students from Nesibe Hatun Imam Hatip High School, affiliated with the Şanlıurfa Provincial Directorate of National Education, and athletes from Karaköprü Volleyball Academy Sports Club. The target sample was 60 participants. Fifty-nine volunteers who returned the participation and parental-consent forms completed the pre-tests. Participants were placed into the agility experimental, balance experimental, and control groups in sequence, with successive participants assigned to successive groups. Eight participants did not attend the post-tests; therefore, the final analysis included 51 participants: agility experimental group (AEG, n=19), balance experimental group (BEG, n=15), and control group (CG, n=17). The final unequal group sizes resulted from post-test nonattendance. A sensitivity analysis in G*Power 3.1, based on a one-way fixed-effects omnibus framework with three groups, $\alpha = .05$, power $(1-\beta)=.80$, and n=51, yielded a minimum detectable effect of approximately Cohen's $f=.45$. Thus, the achieved sample was capable primarily of detecting large between-group effects; small-to-moderate effects may have remained undetected (Cohen, 1988; Faul et al., 2009; Lakens, 2022). Because the primary analysis was nonparametric, this value was interpreted as an approximation rather than a direct power estimate for the Kruskal-Wallis test.

Ethical approval was granted by the Harran University Social and Human Sciences Ethics Committee (Decision No. 2025/114; 16 April 2025). Before participation, the athletes received

information about the study, voluntary assent was obtained, and written informed consent was obtained from their parents or legal guardians.

Data Collection Tools

Participants were allocated sequentially to the agility experimental group, balance experimental group, or control group. Before testing, every group completed a five-minute warm-up run followed by stretching exercises. The illinois agility test and T-test completion times were measured in seconds using a photocell timing system. Each performance test was conducted in three trials, and the best result was used in the analysis. Y-Balance scores were normalized as (reach distance/leg length)×100. Flamingo balance test performance was recorded as the number of balance errors made within one minute. All groups completed the same tests at pre-test and post-test. After the VR session, participants answered yes or no to questions concerning nausea and dizziness, and their responses were recorded.

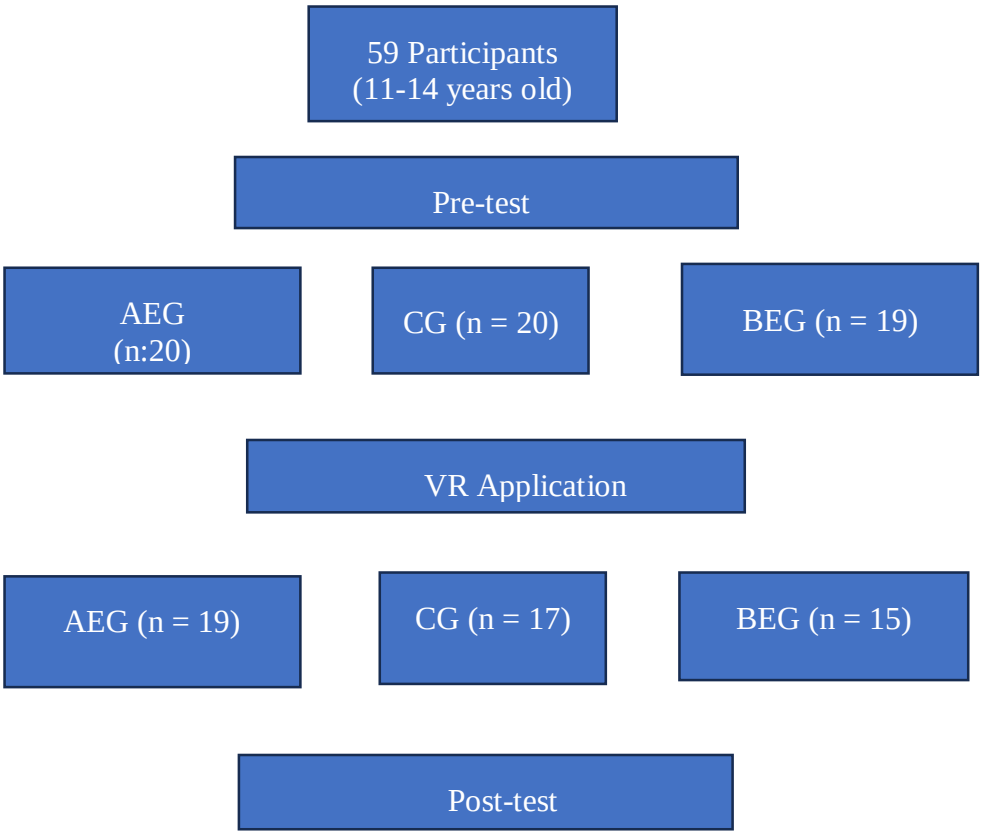

Figure 1. Research design

Data Procedure

The virtual intervention was delivered in a single session on an Oculus Quest 2 headset through specialist-developed interactive VR applications in APK format. The session lasted approximately four minutes per participant and did not exceed five minutes. In the agility condition, athletes actively avoided approaching objects while monitoring their performance on a scoreboard. As the number of objects increased, the application became progressively more difficult and exposed participants to faster movement and more intensive visual stimulation.

The balance experimental group used an interactive VR application that required participants to maintain stability while crossing a suspension bridge that gradually narrowed and began to sway, thereby moving the task from static to dynamic conditions. The control group explored an entertaining, nature-themed interactive VR application in which participants could move freely; this application was unrelated to the motor outcomes examined in the study.

The applications provided an immersive experience in which participants used an athlete avatar and handheld controllers to avoid objects, move within the virtual environment, and walk on a balance board.

Before the applications began, participants were shown in detail how to use the device, wear the headset correctly, and adjust its settings. During each session, participants fitted and adjusted the headset individually to ensure an ergonomic fit for their head shape.

Data Analysis

The data were analyzed using SPSS version 25.0 (Statistical Package for the Social Sciences). Demographic variables, performance-test scores, and VR-related dizziness and nausea (yes/no) were coded. Shapiro-Wilk tests and examination of distributional assumptions indicated that parametric assumptions were not met; therefore, nonparametric analyses were used. Within-group pre-post differences were examined with the Wilcoxon signed-rank test. For each outcome, a change score was calculated so that positive values indicated improvement, and change scores were compared across AEG, BEG, and CG with the Kruskal-Wallis H test. When the omnibus comparison was significant, pairwise Mann-Whitney U tests were conducted. Wilcoxon effect sizes (r), Kruskal-Wallis effect sizes (ε^2), and rank-biserial correlations (r_rb) for pairwise comparisons were reported. Dizziness and nausea frequencies were summarized by group and their distributions were compared with the Fisher-Freeman-Halton exact test. Mann-Whitney U tests were used to examine whether performance-change scores differed according to symptom status. Kruskal-Wallis tests were also used for exploratory comparisons by age, height, and body-mass categories. Statistical significance was set at $p<.05$.

FINDINGS

Table 1. Wilcoxon Signed-Rank test results for pre- and post-test scores in the agility experimental group

Group	Variable	n	Negative Ranks	Positive Ranks	Ties	Z	p	r
Agility Experimental	t-test (Pre-Post)	19	15	3	1	-3.37	**.00***	.77
Agility Experimental	Agility (Pre-Post)	19	15	3	1	-3.42	**.00***	.78
Agility Experimental	Y-Balance (Pre-Post)	19	4	14	1	-1.72	.08	.39
Agility Experimental	Flamingo (Pre-Post)	19	11	6	2	-.76	.44	.17

*p<.05

Table 1 presents the Wilcoxon signed-rank test results for the pre- and post-test measurements of the agility experimental group. Significant differences favoring the post-test were found for the t-test and illinois agility test (Z=-3.37, p<.05; Z=-3.42, p<.05, respectively). Although the Y-Balance test results favored the post-test, the difference was not statistically significant (Z=-1.72, p>.05). Similarly, the flamingo balance test showed no significant change (Z=-.76, p>.05).

Table 2. Wilcoxon Signed-Rank test results for pre- and post-test scores in the balance experimental group

Group	Variable	n	Negative Ranks	Positive Ranks	Ties	Z	p	r
Balance Experimental	t-test (Pre-Post)	15	7	8		-1.65	.10	.43
Balance Experimental	Agility (Pre-Post)	15	12	3		-2.61	**.01***	.67
Balance Experimental	Y-Balance (Pre-Post)	15	3	12		-2.67	**.00***	.69
Balance Experimental	Flamingo (Pre-Post)	15	8	6	1	-.73	.47	.19

*p<.05

Table 2 presents the Wilcoxon signed-rank test results for the pre- and post-test measurements of the balance experimental group. Significant differences favoring the post-test were found for the illinois agility test and Y-Balance test (Z=-2.61, p<.05; Z=-2.67, p<.05, respectively). Although improvement favoring the post-test was observed in the t-test, the difference was not statistically significant (Z=-1.65, p>.05). Similarly, the flamingo balance test showed no significant change (Z=-0.73, p>.05).

Table 3. Wilcoxon Signed-Rank test results for pre- and post-test scores in the control group

Group	Variable	n	Negative Ranks	Positive Ranks	Ties	Z	p	r
Control Group	t-test (Pre-Post)	17	9	8		-1.40	.16	,34
Control Group	Agility (Pre-Post)	17	15	2		-3.22	**.00***	.78
Control Group	Y-Balance (Pre-Post)	17	7	9	1	-.54	.59	.13
Control Group	Flamingo (Pre-Post)	17	10	7		-.86	.39	.21

*p<.05

Table 3 presents the Wilcoxon signed-rank test results for the pre- and post-test measurements of the control group. A significant difference favoring the post-test was found for the İllinois agility test (Z=-3.22, p<.05). No statistically significant pre-test to post-test differences were found for the t-test (Z=-1.40, p>.05), Y-Balance test (Z=-.54, p>.05), or flamingo balance test (Z=-.86, p>.05).

Table 4. Kruskal-Wallis results for performance tests by height group in the agility experimental group

Variable	Height Range (cm)	n	Mean Rank	H	p	ε²
T-test Pre-test	139-152	5	11.40	1.13	.56	.00
	153-161	9	10.44			
	162-169	5	7.80			
T-test Post-test	139-152	5	11.50	.62	.73	.00
	153-161	9	9.89			
	162-169	5	8.70			
Agility Pre-test	139-152	5	11.90	4.17	.12	.14
	153-161	9	11.39			
	162-169	5	5.60			
Agility Post-test	139-152	5	10.60	.22	.89	.00
	153-161	9	10.22			
	162-169	5	9.00			
Y-Balance Pre-test	139-152	5	7.20	6.46	**.03***	.28
	153-161	9	8.56			
	162-169	5	15.40			
Y-Balance Post-test	139-152	5	6.70	3.24	.19	.08
	153-161	9	10.11			
	162-169	5	13.10			

Variable	Height Range (cm)	n	Mean Rank	H	p	ε²
Flamingo Pre-test	139-152	5	10.30	.03	.98	.00
	153-161	9	9.78			
	162-169	5	10.10			
Flamingo Post-test	139-152	5	7.00	2.08	.35	.01
	153-161	9	11.50			
	162-169	5	10.30			

*p<.05

The Kruskal-Wallis results indicated that the height groups (139-152 cm, 153-161 cm, and 162-169 cm) in the agility experimental group generally had similar performance-test outcomes. No statistically significant differences were found among groups in the t-test (pre-test and post-test), İllinois agility test (pre-test and post-test), Y-Balance post-test, or flamingo balance test (pre-test and post-test) (p>.05). In contrast, the Y-Balance pre-test results differed significantly among height groups (H=6.46, p=.03).

Table 5. Kruskal-Wallis results for performance tests by age group in the balance experimental group

Variable	Age	n	Mean Rank	H	p	ε²
T-test Pre-test	11	5	9.20	1.19	.75	.00
	12	3	8.33			
	13	3	5.67			
	14	4	8.00			
T-test Post-test	11	5	10.60	3.17	.36	.02
	12	3	5.33			
	13	3	6.33			
	14	4	8.00			
Agility Pre-test	11	5	9.60	2.36	.49	.00
	12	3	6.00			
	13	3	5.67			
	14	4	9.25			
Agility Post-test	11	5	9.40	1.21	.75	.00
	12	3	5.83			
	13	3	8.17			
	14	4	7.75			
Y-Balance Pre-test	11	5	3.60	9.97	**.01***	.63
	12	3	8.67			
	13	3	8.00			
	14	4	13.00			
Y-Balance Post-test	11	5	5.50	4.51	.21	.14
	12	3	6.50			
	13	3	9.00			
	14	4	11.50			
Flamingo Pre-test	11	5	7.90	4.07	.25	.10
	12	3	4.50			
	13	3	7.33			
	14	4	11.25			
Flamingo Post-test	11	5	8.30	5.56	.13	.23
	12	3	5.50			
	13	3	4.83			
	14	4	11.88			

*p<.05

Performance differences among age groups in the balance experimental group were evaluated using the Kruskal-Wallis test. No statistically significant differences were found among age groups in the pre- or post-test scores for the T-test, illinois agility test, or flamingo balance test

(p>.05). In contrast, a significant difference was observed among age groups in the Y-Balance pre-test (H=9.97, p=.01). Examination of mean ranks showed that athletes aged 14 years had the highest Y-Balance pre-test scores, whereas those aged 11 years had the lowest.

Table 6. Kruskal-Wallis results for performance tests by body-mass group in the balance experimental group

Variable	Body-Mass Range (kg)	n	Mean Rank	H	p	ε²
T-test Pre-test	34-45	6	8.83	4.35	.11	.20
	46-60	6	5.33			
	61-85	3	11.67			
T-test Post-test	34-45	6	8.17	3.81	.14	.15
	46-60	6	5.83			
	61-85	3	12.00			
Agility Pre-test	34-45	6	9.17	5.12	.07	.26
	46-60	6	5.00			
	61-85	3	11.67			
Agility Post-test	34-45	6	7.83	6.16	**.04***	.35
	46-60	6	5.50			
	61-85	3	13.33			
Y-Balance Pre-test	34-45	6	5.33	3.62	.16	.14
	46-60	6	10.00			
	61-85	3	9.33			
Y-Balance Post-test	34-45	6	5.25	3.85	.14	.15
	46-60	6	9.58			
	61-85	3	10.33			
Flamingo Pre-test	34-45	6	8.50	.13	.93	.00
	46-60	6	7.75			
	61-85	3	7.50			
Flamingo Post-test	34-45	6	10.08	3.34	.18	.11
	46-60	6	5.50			
	61-85	3	8.83			

*p<.05

The Kruskal-Wallis analyses by body-mass category in the balance experimental group showed no statistically significant differences in the pre- or post-test scores for the T-test, Y-Balance test, or flamingo balance test (p>.05). In contrast, a significant difference among body-mass groups was found in the illinois agility post-test (H=6.16, p=.04). Examination of mean ranks showed that athletes in the 61-85 kg group had higher illinois agility post-test scores, whereas those in the 46-60 kg group had lower scores.

Table 7. Kruskal-Wallis results for performance tests by age group in the control group

Variable	Age	n	Mean Rank	H	p	ε²
T-test Pre-test	11	7	10.86	7.38	**.02***	.38
	12	6	10.83			
	13	4	3.00			
T-test Post-test	11	7	11.43	5.59	.06	.26
	12	6	9.50			
	13	4	4.00			
Agility Pre-test	11	7	10.43	2.93	.23	.07
	12	6	9.83			
	13	4	5.25			
Agility Post-test	11	7	11.29	5.03	.08	.22
	12	6	9.50			
	13	4	4.25			
Y-Balance Pre-test	11	7	7.00	1.97	.37	.00
	12	6	10.00			
	13	4	11.00			
Y-Balance Post-test	11	7	7.36	1.66	.43	.00
	12	6	9.33			
	13	4	11.38			
Flamingo Pre-test	11	7	9.50	2.28	.31	.02
	12	6	6.75			
	13	4	11.50			
Flamingo Post-test	11	7	11.36	2.80	.24	.06
	12	6	7.92			
	13	4	6.50			

*p<.05

The Kruskal-Wallis analyses by age group in the control group revealed a significant difference in the T-test pre-test (H(2)=7.38, p=.02). Examination of mean ranks indicated lower performance among athletes aged 11 and 12 years and higher performance among those aged 13 years. The T-test post-test showed a trend toward significance (p=.06), but the difference was not statistically significant. No statistically significant differences among age groups were found in the pre- or post-test scores for the illinois agility test, Y-Balance test, or flamingo balance test (p>.05).

Table 8. Between-group comparison of performance change scores

Variable	AEG Median (IQR)	BEG Median (IQR)	CG Median (IQR)	H	p	ε²
T-test	.38 (.13-.71)	-.28 (-.60-.12)	.01 (-.14-.60)	12.26	**.002***	.21
Illinois Agility	.91 (.15-1.93)	1.24 (.71-2.05)	.40 (.17-1.14)	2.99	.224	.02
Y-Balance	2.66 (.33-4.50)	3.00 (1.67-4.83)	.33 (-1.66-4.00)	3.80	.150	.04
Flamingo	1.00 (-1.50-4.00)	2.00 (-2.00-3.00)	2.00 (-6.00-2.00)	.95	.622	.00

*p<.05

The between-group difference was significant only for the T-test (H=12.26, p=.002, ε^2=.214). No significant group differences were found for the illinois agility, Y-Balance, or flamingo change scores.

Table 9. Pairwise Mann-Whitney U comparisons for T-Test change scores

Comparison (n)	Group 1 Median	Group 2 Median	U	p	r_rb
AEG vs BEG (19 vs 15)	.38	-.28	242.5	**.001***	.702
AEG vs CG (19 vs 17)	.38	.01	202	.205	.251
BEG vs CG (15 vs 17)	-.28	.01	70	**.031***	-.451

Note: Pairwise Mann-Whitney U tests were performed only for the significant omnibus t-test result. Unadjusted p values are reported; r_rb =rank-biserial correlation. *p<.05.

Pairwise testing showed a significant difference between the agility and balance experimental groups (p<.001, r_rb=.702). The agility experimental group did not differ significantly from the control group (p=.205). The balance experimental group had a significantly lower T-test improvement score than the control group (p=.031, r_rb=-.451). Thus, the direct comparison did not establish superiority of either experimental group over the control group.

Table 10. Frequency and between-group distribution of VR-Related adverse effects

Symptom	AEG n (%)	BEG n (%)	CG n (%)	p (Exact)	Cramér's V
Dizziness	4 (21.1%)	4 (26.7%)	2 (11.8%)	.613	.151
Nausea	3 (15.8%)	0 (.0%)	0 (.0%)	.102	.324

Note. p values are from the Fisher-Freeman-Halton exact test estimated with 200.000 Monte Carlo samples. AEG=agility experimental group; BEG=balance experimental group; CG=control group.

Dizziness was reported by 10 of 51 participants and nausea by 3 of 51 participants. Symptom frequencies did not differ significantly across groups (dizziness p=.613; nausea p=.102).

Table 11. Performance change scores according to dizziness and nausea status

Symptom	Variable	Yes: n; Median (IQR)	No: n; Median (IQR)	U	p	r_rb
Dizziness	T-test	10; .08 (-.33-.30)	41; .21 (-.14-.50)	155.5	.245	-.24
Dizziness	Illinois Agility	10; 1.16 (.06-1.87)	41; .86 (.19-1.82)	206.5	.981	.01
Dizziness	Y- Balance	10; 3.17 (.17-4.75)	41; 2.00 (-.33-4.33)	227.5	.601	.11
Dizziness	Flamingo	10; 2.00 (.25-4.50)	41; 1.00 (-5.00-3.00)	273	.108	.33
Nausea	T-test	3; .50 (.17-1.02)	48; .12 (-.19-.45)	97.5	.317	.35
Nausea	Illinois Agility	3; .00 (-.3-1.15)	48; .88 (.24-1.83)	54.5	.496	-.24
Nausea	Y-Balance	3; 1.67 (-1.50-2.17)	48; 2.83 (-.33-4.33)	48.5	.357	-.33
Nausea	Flamingo	3; -1.00 (-1.50-1.00)	48; 1.50 (-3.25-3.00)	66.5	.841	-.08

Note. Positive change scores indicate improvement. Unadjusted p values are reported; r_rb=rank-biserial correlation.

Table 11 presents the performance-change comparisons according to symptom status. Neither dizziness nor nausea was associated with a statistically significant difference in any performance-change score (p>.05).

DISCUSSION AND CONCLUSION

This study examined immediate changes in agility and balance after a single VR session in female volleyball players aged 11-14 years. Although several significant pre-post changes occurred within individual groups, direct comparison of change scores showed a group difference only for the t-test. The agility group differed from the balance group, but neither experimental group was superior to the control group. No group differences were found for illinois agility, Y-Balance, or flamingo changes. The findings therefore indicate test-specific short-term responses rather than a general experimental VR effect.

Previous research has reported possible benefits of VR-supported motor practice for agility, reaction time, coordination, and balance (Liu et al., 2022; Mohammadi et al., 2023; Richlan et al., 2023; Tomaç et al., 2024). However, those studies vary in population, task content, and intervention duration. In the present study, the lack of superiority over the control application for the primary change scores limits causal interpretation. Audiovisual feedback and perception-action coupling may be plausible mechanisms, but these mechanisms were not measured directly and should be examined in future studies.

The within-group increase in Y-Balance performance in the balance experimental group is compatible with the possibility that interactive VR tasks engage dynamic postural control. Novak et al. (2023) reported improved Y-Balance scores after a short VR balance application, and Ranjbarzadeh-Yamchi et al. (2021) reported improvements following a longer intervention. Nevertheless, the present between-group analysis did not show a significant difference in Y-Balance change, and the flamingo balance test did not change significantly. Accordingly, the present findings cannot establish a specific balance benefit of the experimental application after a single session.

The control group also showed a significant within-group improvement in the illinois agility test. Together with the absence of a between-group difference in illinois agility change scores, this pattern is compatible with a practice, motivation, or test-retest effect and prevents the improvement from being attributed specifically to the experimental VR applications.

Dizziness was reported by 10 participants and nausea by 3 participants. Symptom frequencies did not differ significantly across groups, and neither symptom was associated with a significant difference in performance-change scores. These findings describe short-term tolerability during the single exposure; they do not demonstrate physiological adaptation. Dizziness and nausea are consistent with cybersickness arising from visual-vestibular sensory conflict (Reason & Brand, 1975; Stanney et al., 2020). Significant differences were observed in some performance parameters according to age, height, and body mass. Height and body mass, in particular, produced significant differences in tests assessing balance performance (Y-Balance and flamingo). In contrast, demographic differences were more limited in the agility tests (illinois agility test and T-test). Previous research has linked excess body mass in children with poorer postural stability. McGraw et al. (2000) reported differences in gait and postural stability between obese and nonobese prepubertal boys. This evidence supports interpreting body-mass-related balance differences cautiously, although the present subgroup findings do not establish a causal mechanism. Balance performance continues to develop across childhood and adolescence (Schedler et al., 2019; Payne & Isaacs, 2024). Age-related performance differences in the present study may reflect this natural developmental process. The better agility-test performance observed among participants aged 13-14 years may be explained by increased motor-learning capacity with age (Lloyd et al., 2014).

Regarding body mass, athletes with greater body mass demonstrated lower agility-test performance than lighter participants. This subgroup result should be interpreted cautiously because body mass was categorized into small groups and body composition was not assessed directly. The comparatively balanced performance of athletes in the middle body-mass category across balance and agility tests may warrant further investigation in larger samples. Finally, the

sample was limited to female volleyball players. Studies of male athletes have reported greater performance gains (Wang et al., 2025). This difference may reflect the effects of hormonal and morphological characteristics on motor performance. Taken together, the results show several within-group, test-specific changes after one brief VR exposure, but they do not demonstrate that the agility or balance-oriented application was superior to the control application. The single-session design, post-test attrition, unequal group sizes, and small demographic subgroups require cautious interpretation.

In conclusion, a single brief VR session was followed by some immediate changes in agility and dynamic-balance measures, but direct group comparisons did not establish a general advantage of the experimental applications. VR may offer an engaging setting for motor practice; however, its effectiveness as a training method should be tested in larger studies using repeated sessions, stronger allocation procedures, and longer follow-up periods.

Recommendations

The study was conducted with female volleyball players aged 11-14 years. Future studies involving different age groups, male athletes, or other sports could strengthen the generalizability of the findings.

Future studies could combine VR applications with biomechanical analyses, such as motion capture and muscle-activation measurements, to provide a more detailed explanation of the neuromuscular effects of VR training.

The effects of VR technologies on psychological components such as motivation, attention, and self-confidence could also be examined to evaluate the role of VR in psychomotor integration.

Athlete training centers and sports clubs could develop hybrid training programs that integrate VR-supported activities with conventional training routines.

Limitations

The study was limited to one short VR session and two measurements conducted during the testing period: the pre-test and post-test. Consequently, the findings reflect immediate change and do not demonstrate lasting training adaptation.

The 51 athletes who participated in the study represented a limited sample; therefore, the generalizability of the findings is restricted. In addition, some age, height, and body-mass subgroups contained only three to five participants, making the exploratory subgroup estimates unstable and underpowered.

The study was limited to female volleyball players aged 11-14 years, which makes it difficult to generalize the findings to athletes of different ages and sexes.

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Statement of Ethics Committee	
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An artificial intelligence tool was not used for data analysis, interpretation of results, or creation of scientific content.	

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