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Effects of Six Months of Virtual Reality Exergaming Combined with Basketball Training on Visuomotor Stepping Reaction Time in Children Aged 10–12 Years: A Quasi-Experimental Study

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Abstract: *Background: Virtual reality (VR) has become increasingly integrated into education, rehabilitation, and performance training, largely due to its improved accessibility and affordability. Beyond providing sensory stimulation, VR offers immersive and interactive environments capable of engaging cognitive processes and facilitating motor learning and reaction speed across both pediatric and adult populations. Within sport and movement science, agility and reaction time are widely recognized as key indicators of neuromuscular coordination and cognitive-motor integration. The emergence of light-based assessment systems, such as BlazePod™, has enabled these capacities to be evaluated in a dynamic and engaging manner. However, despite the growing interest in VR-based exercise, the long-term effects of combining virtual exergaming with structured sport training on reaction-related performance in children remain insufficiently explored. In the present study, BlazePod performance was defined as the number of correct responses completed within a 30-second trial, with higher scores reflecting superior visuomotor performance. Purpose: To investigate the effects of a six-month VR exergaming program combined with basketball training on visuomotor reaction time in children aged 10–12 years, compared with basketball training alone and a no intervention control group. Methods: Sixty-four healthy children were allocated into three groups: VR + Basketball (n = 22), Basketball-Only (n = 22), and Control (n = 20). The intervention lasted six months (three sessions per week). The VR group completed 30 minutes of Beat Saber VR training plus 60 minutes of basketball per session; the basketball group completed 60 minutes of basketball only. Reaction time was assessed pre and post-intervention using the BlazePod system. Repeated-measures ANOVA, Bayesian ANOVA, and paired-samples t-tests were used to evaluate changes over time. Results: A significant improvement in reaction time was observed only in the VR + Basketball group,* $t(21) = -3.069$, $p = .006$, *with mean scores increasing from 17.50 to 19.27. In the BlazePod assessment used in this study, higher scores indicate better performance. Bayesian analysis provided strong evidence for a pre–post effect in this group* ($BF_{10} = 14.40$)*. No significant changes were observed in the Basketball-only* ($p = .204$) *or Control groups* ($p = .330$)*. Variability decreased notably in the VR group, indicating more consistent performance following training. Conclusion: Six months of VR exergaming combined with basketball training produced significant improvements in visuomotor reaction time in children, outperforming traditional sport training alone. VR-based exercise may serve as an effective, engaging tool for enhancing cognitive-motor performance in youth.*

Keywords: *virtual reality; exergaming; reaction time; motor learning; BlazePod; sports; motor performance.*

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Introduction

In recent decades, the rapid rise in childhood obesity and sedentary lifestyles has become a major global health challenge (Wang et al., 2016; Zhang et al., 2024). According to recent epidemiological reports, the prevalence of overweight and obesity in children aged 5–19 has more than quadrupled since 1975, with approximately 340 million children and adolescents now classified as overweight or obese (World Health Organization, 2025; Tomasi & Volkow, 2024). This trend not only increases cardiometabolic risk but also correlates with impairments in cognitive function, executive processing, and psychomotor performance (Mansoor et al., 2025). Consequently, early interventions that enhance both physical activity and cognitive engagement are of significant public health and neuroscientific interest.

Physical activity during childhood is a key modulator of neuroplasticity, synaptic efficiency, and cortical maturation, especially within the prefrontal and parietal networks that underpin attention, executive control, and reaction speed (Ferrer-Uris et al., 2022; Lachowicz et al., 2025; Mansoor et al., 2025). Exercise-induced neuroplastic changes have been linked to increased brain derived neurotrophic factor (BDNF) expression, enhanced dopaminergic signaling, and improved sensorimotor integration (Mansoor et al., 2025; Ji et al., 2023; Massah et al., 2025). However, adherence to conventional exercise programs in pediatric populations remains a major obstacle, often due to low motivation and reduced engagement (Chen et al., 2023).

In this context, virtual reality (VR)-based exergaming interactive physical activity delivered through immersive digital platforms has emerged as a promising alternative. (Mohd Jai et al., 2021). By combining sensorimotor stimulation with cognitive challenge and intrinsic motivation, VR-based exercise can potentially amplify neurocognitive outcomes compared to traditional training (Ji et al., 2023; Kou et al., 2024). Previous studies suggest that exergaming may improve reaction time, visuomotor coordination, and attentional processing, particularly in developing brains (Wang et al., 2016). Furthermore, the integration of playful, game-based paradigms can enhance adherence, making VR a socially relevant solution to the growing inactivity crisis among youth. (Lachowicz et al., 2024; Rutkowski et al., 2024).

The present study investigates the effects of VR-based exergaming on reaction time in children aged 10-12 years, as compared with traditional physical activity and a no intervention control condition. We hypothesized that VR exergaming would maintain significant greater improvements in reaction time as a result of the combined sensorimotor and cognitive demands of the virtual environment, thus providing a potentially superior tool for enhancing neurocognitive performance during childhood development.

Materials and methods

Participants

Sixty-four healthy children within the ages of 10 and 12 were chosen from neighborhood sports programs and elementary schools. Participants were cleared by their general practitioner to take part in the study and had no neurological, cognitive, or musculoskeletal conditions. Prior to enrolment, verbal assent was gathered from each participant and written informed consent was obtained from parents or legal guardians. Those who had health problems or were unable to attend for a long time were not allowed to participate. Furthermore, parents who declined to let their children participate in the study were not included. Additionally, a few children were unable to fully participate in the experiment due to injuries from incidents like fractures, which required time off.

Although randomization was initially planned, it could not be implemented due to logistical constraints related to school organization and sustained participation of the children. The quasi-experimental design enabled delivery of the intervention under routine training conditions, supporting consistent implementation and improving the applicability of the findings to comparable youth sport and educational settings.

Participants were allocated into three groups:

VR + Basketball group (n = 22). Participated in combined virtual reality exergaming and basketball training sessions.

Basketball-only group (n = 22). Participated exclusively in structured basketball training sessions.

Control group (n = 20). Did not engage in any structured physical activity beyond their regular daily routines.

All participants completed the study protocol in full, and no adverse events were reported.

Research design

Several clinical tests assess stepping performance in older adults, including the Four-Square-Step-Test (Whitney et al., 2007), Alternate-Step-Test, Side-Step-Test (Fujisawa & Takeda, 2006) Maximum-Step-Length-Test (Medell & Alexander, 2000), and Star-Excursion-Balance-Test (Munro & Herrington, 2010). While these tests demonstrate strong psychometric properties, they have a key limitation: participants receive step direction instructions beforehand, allowing pre-planned responses. This reduces cognitive and sensorimotor demands, potentially overestimating functional ability and underestimating fall risk. In contrast, randomized stepping tests better reflect real-world conditions by assessing reaction time, motor planning, and adaptability to sudden, multidirectional demands (Ilin & Kalron, 2025).

Visuomotor stepping reaction performance is a relevant variable in areas such as sports, academics, and other tasks of daily life. It can be defined as the time that elapses from when a stimulus appears until a response is given and is considered a good measure to assess the capacity of the cognitive system to process information. (Wang et al., 2016) From a physiological point of view, visuomotor stepping reaction performance is a complex phenomenon whose functioning has been studied by numerous researchers. The visuomotor stepping reaction performance depends on the speed of the sensorimotor cycle, composed by the detection of the initial stimulus, transfer of the information through the afferent nerves, generation of the response from the central nervous system, and final response (Reigal et al., 2019).

BSRT has a strong-to-moderate convergent validity with functional mobility (TUG test) and clinical dynamic balance measures, including stepping reaction time (Ilin & Kalron, 2025).

Throughout the six-month intervention period, all participants allocated to basketball training (VR + Basketball and Basketball-only groups) followed the same standardized basketball program. Each training session included approximately 30–40 minutes of structured instruction focused on fundamental basketball skills (e.g., dribbling, passing, shooting, and basic tactical concepts). Training intensity was intended to range from moderate to vigorous and was adapted to each participant's ability to maintain task engagement and correct execution, consistent with standard youth basketball practice. Followed by approximately 20 minutes of supervised game-based play. Training content, session structure, and duration were held constant across participants and across the intervention period. All sessions were conducted in the same facility and delivered by the same coaching staff, ensuring uniform exposure to basketball training

The VR intervention consisted exclusively of 30 minutes of Beat Saber gameplay per session, performed under supervision using commercially available virtual reality equipment. Difficulty levels were progressively adjusted to match individual performance and to sustain task challenge. Particular emphasis was placed on ensuring that participants remained fully immersed and actively engaged with the virtual environment throughout each session, as effective interaction with the game was considered essential to the intended cognitive–motor demands of the intervention. The timing of the VR exergaming component relative to basketball training was not fixed. Participants were allowed to complete the VR sessions before or after basketball practice, depending on scheduling and availability, provided that the prescribed weekly exposure was achieved. We opted for this implementation to maximize adherence across the six-month intervention period.

Visuomotor reaction time was evaluated using a square stepping reaction test implemented with the BlazePod™ system (González-Fernández et al., 2025; Polechoński et al., 2025). Four pods were positioned on the floor in a square configuration surrounding a central standing point. Participants began each trial from the central position (Wilk et al., 2023). As it was previously used in different studies participants will have 3 tries and the highest score will be the one later used. Participants completed three trials, and the highest score was used for analysis.

During the assessment, a pod illuminated at random, and participants were required to respond as rapidly as possible by stepping toward and deactivating the illuminated pod with their foot by tapping the BlazePod surface. Following each successful response, another pod illuminated immediately, creating a continuous sequence of unpredictable stimuli. The test lasted 30 seconds, and performance was quantified as the total number of correct responses completed within the time limit. Higher scores indicated superior visuomotor reaction speed, motor planning, and sensorimotor integration.

In this study, we chose to report both frequentist and Bayesian analyses because each approach answered a slightly different question relevant to our data. The frequentist repeated-measures ANOVA allowed us to test for pre and post differences using widely accepted criteria and to present results in a format familiar to the existing literature. The Bayesian analysis was added to better understand the strength of evidence for both change and no change across the three groups. This was particularly helpful given the sample size and the presence of non-significant results in the basketball-only and control groups. Rather than interpreting these findings as simply inconclusive, the Bayesian approach allowed us to determine whether the data actually supported the absence of an effect. Together, these analyses provided a more complete and transparent interpretation of the intervention outcomes.

Although Group × Time interaction models are commonly applied in randomized controlled trials, this approach was not considered optimal for the present quasi-experimental design. Group allocation was determined by logistical and organizational constraints rather than randomization; therefore, baseline equivalence across groups could not be fully assumed.

Although this approach limits direct between-group inference, it reduces bias due to non-random allocation.

Under these conditions, interaction effects may conflate intervention-related change with pre-existing between-group differences, potentially resulting in biased inference. Accordingly, analyses focused on within-group pre and post changes, allowing each group to serve as its own control and providing a more conservative and interpretable assessment of change over time.

Baseline characteristics (sex and baseline visuomotor stepping reaction performance) were summarized descriptively for each group. All participants were male; therefore, sex was not included as a covariate in the analyses.

Statistical analysis

All statistical analyses were performed using JASP (Version 0.95.3.0; University of Amsterdam, The Netherlands). Data were assessed for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test.

Pre–post changes in visuomotor reaction time were examined using repeated-measures ANOVA conducted separately for each group (VR + Basketball, Basketball-only, and Control). In addition, paired-samples t-tests were performed within each group to further evaluate pre- to post-intervention differences.

To complement frequentist analyses, Bayesian repeated-measures ANOVAs were conducted to quantify the strength of evidence for both the presence and absence of pre–post effects within each group. This approach was used to aid interpretation of non-significant findings, particularly in the Basketball-only and Control groups.

Effect sizes were calculated as generalized eta squared (η^2_G) and omega squared (ω^2) for ANOVA, and Cohen's d for paired comparisons. Statistical significance was set at $p < 0.05$.

Results

The Bayesian repeated-measures ANOVA provided strong evidence for an effect of the intervention on reaction time in one of the measured outcomes. Specifically, in the VR + Basketball condition, the model including a time effect (pre–post difference) was strongly supported over the null model (BF_{10} = 14.40, posterior model probability P(M | data) = 0.935), indicating that participants' reaction times significantly improved following the intervention with VR. Because group allocation was non-randomized and baseline equivalence could not be fully assumed, within-group pre- and post-analyses were conducted to focus on changes over time within each condition.

Paired-samples *t*-tests were conducted to examine pre- to post-intervention changes within each group. There was a significant improvement for the VR + Basketball group, $t(21) = -3.069$, $p = .006$, where the average score increased from 17.50 to 19.27. For the Basketball-only group, no significant difference was observed, $t(21) = 1.312$, $p = .204$, and similarly for the Control group, $t(19) = 1.000$, $p = .330$, indicating that the intervention did not yield any measurable effect within these groups.

Descriptive statistics supported these results. The VR + Basketball group showed a higher post-test mean and reduced variability, indicating both improved performance and greater consistency. The Basketball-only group demonstrated a small decrease in mean values but a marked reduction in variance, suggesting that although average performance did not change, participants became more uniform in their responses. The Control group showed minimal changes in both mean and variability, reflecting stable performance across the two testing points.

Table 1. Baseline characteristics of participants

Variable	VR + Basketball (n = 22)	Basketball- only (n = 22)	Control (n = 20)
Sex, male n (%)	22 (100%)	22 (100%)	20 (100%)
BlazePod score (pre), mean ± SD	17.50 ± 2.32	17.05 ± 2.75	16.40 ± 2.14

Baseline BlazePod performance was comparable across groups and is reported descriptively in Table 1.

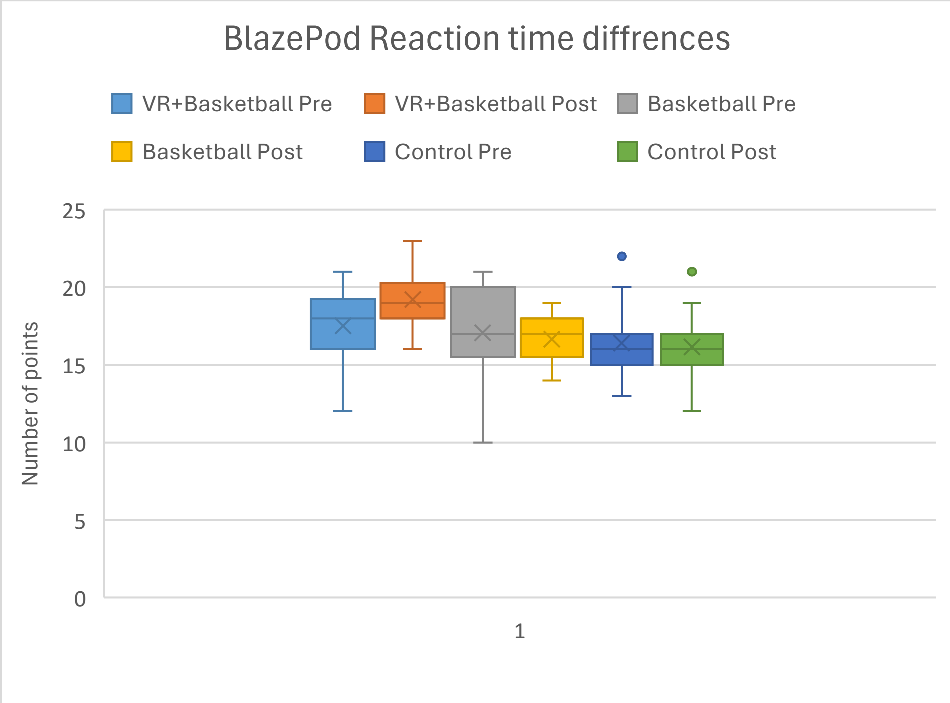
Table 2. Within-group pre–post effects on visuomotor stepping performance

Group	Frequentist test	F (1, df)	p value	Bayesian evidence (BF_{10})	Interpretation
VR+Basketball	RM-ANOVA (Time)	F(1, 21) = 9.42	.006	14.40	Significant improvement; strong evidence for change
Basketball Only	RM-ANOVA (Time)	F(1, 21) = 1.72	.204	0.56	No significant change; anecdotal evidence for no effect
Control	RM-ANOVA (Time)	F(1, 19) = 1.00	.330	0.51	No significant change; anecdotal evidence for no effect

Table 3. Results of Paired T-Test

Measure 1	Measure 2	t	df	p	Cohen's d	SE Cohen's d	Lower	Upper
VR+Basetball Pre	VR+Basketball Post	3.069	21	.006	-0.654	0.291	-1.110	-0.186
Basketball Pre	Basketball Post	1.312	21	.204	0.280	0.095	-0.150	0.703
Control group pre	Control Group post	1.000	19	.330	0.224	0.122	-0.223	0.665

Figure 1. Pre–post differences in BlazePod reaction test performance across groups



Box-and-whisker plots illustrate the distribution of visuomotor stepping reaction performance reaction test scores (number of points achieved in 30 seconds) before and after the intervention for the VR + Basketball, Basketball-only, and Control groups. Boxes represent the interquartile range, the horizontal line indicates the median, and whiskers denote the minimum and maximum values. Individual points represent outliers. An increase in post-intervention scores is evident only in the VR + Basketball group, whereas the Basketball-only and Control groups show largely stable distributions across time points.

Table 4. Descriptive statistics

Group	*N*	*Mean*	*SD*	*SE*	*Coefficient of variation*
VR+Basketball Pre	22	17.50	2.325	0.496	0.133
VR+Basketball Post	22	19.27	1.751	0.373	0.091
Basketball Pre	22	17.23	2.810	0.599	0.163
Basketball Post	22	16.77	1.445	0.308	0.086
Control group Pre	20	16.40	2.137	0.478	0.130
Control group post	20	16.15	1.954	0.437	0.121

Note. N = sample size; SD = standard deviation; SE = standard error

Overall summary

The present findings indicate that a six-month intervention combining virtual reality exergaming with basketball training elicited meaningful improvements in visuomotor stepping reaction performance in children aged 10–12 years. Improvements were observed exclusively in the VR + Basketball group, whereas no significant changes were detected in either the Basketball-only or Control groups.

In addition to increased performance scores, participants in the VR-based intervention demonstrated reduced variability at post-test, suggesting more consistent visuomotor responses following training. Together, these results suggest that the addition of cognitively engaging, interactive VR exercise may enhance reaction-related performance beyond what is achieved through traditional sport training alone.

The absence of improvement in the Basketball-only and Control groups indicates that repeated testing or general sport participation alone was insufficient to produce measurable gains in this outcome over the study period. These findings support the potential value of VR exergaming as a complementary training modality for improving cognitive–motor performance in youth.

Discussion

Stepping reaction tests have been extensively used in older adult populations to assess visuomotor reaction time and its association with fall risk. Beyond geriatric assessment, these tests have also been applied in post-surgical rehabilitation research to evaluate recovery of functional mobility and sensorimotor control. More recently, stepping-based reaction paradigms have been adopted in sport science contexts, where rapid response speed and task-specific motor performance are critical determinants of athletic performance (Rutkowski et al., 2024).

An interesting observation was that, although color specificity was not required by the task, participants consistently showed a preference for responding to the same color (most commonly blue). This suggests that color perception and salience may influence engagement or response behavior, potentially affecting motivation and performance during testing.

While randomized controlled trials are needed to fully elucidate these effects and to draw robust causal conclusions, the portability and flexibility of light-based devices such as the BlazePod system make them well suited for both training and assessment purposes. Their ease of implementation supports their potential integration into future rehabilitation and sport training programs, where they may contribute to the development of sustainable habits for recovery and performance enhancement.

Given that reaction time is widely used as an indicator of information processing speed and cognitive function, the observed reductions in reaction time across intervention phases may reflect improvements in both cognitive processing and motor performance. While these findings should be interpreted with caution, they are consistent with previous evidence suggesting that exergaming can positively influence executive functions in school-aged children, including working memory, cognitive flexibility, and inhibitory control, which are essential for learning and behavioral regulation (Pourazar et al., 2018; Zeng et al., 2023).

Similar benefits have also been reported following traditional sport-based training, such as tennis, indicating that both exergaming and conventional physical activity may support cognitive-motor development (Flôres et al., 2024).

Collectively, these findings suggest that interactive, movement-based digital games may represent a promising approach for enhancing cognitive performance, challenging the notion that computer-based games are exclusively sedentary in nature. Nevertheless, further research using randomized controlled designs and longer follow-up periods is required to clarify the magnitude, specificity, and durability of these effects (Mohd Jai et al., 2021; Resende & Flôres, 2023).

Limitations of the study

Although the present study provided premises about the influence of the VR-based activities and traditional basketball training on the reaction time in children, several limitations must be considered while interpreting the results of this study.

Sample size is modest, which limits the statistical power to detect smaller but possibly meaningful effects, and constrains the generalisability of results beyond participants studied. Future studies with larger samples and greater diversity are needed to confirm findings and validity.

Any learning or practice effect contamination cannot be excluded completely. Whereas this design tried to minimize such influences, the use of reaction time tasks repeatedly may contribute to improvement in performance regardless of the type of intervention.

The control for external factors is poor: sleeping habits, physical activity outside the intervention, nutritional habits, and screen exposure.

These are variables known to affect cognitive performance and introduced uncontrolled variability into the data.

Future research directions

Future research should build on the present findings by implementing longer-duration interventions accompanied by multiple long-term follow-up assessments to determine whether the observed improvements in visuomotor reaction time persist beyond the active training period or diminish once the intervention ceases. Given the quasi-experimental design and modest sample size of the current study, future investigations should recruit larger, more heterogeneous samples across different age ranges, developmental stages, and activity backgrounds to enhance statistical power and improve the external validity of the findings. Additionally, randomized controlled designs would strengthen causal inference and reduce potential allocation bias.

Further refinement of assessment tasks is also warranted, including the use of multiple reaction time paradigms that systematically manipulate perceptual load, response complexity, and decision-making demands. Such approaches would help clarify whether the observed gains are specific to visuomotor stepping responses elicited by light-based stimuli or reflect broader enhancements in cognitive processing speed, attentional control, and sensorimotor integration. Finally, incorporating complementary neurocognitive or neurophysiological measures may provide deeper insight into the mechanisms underpinning VR-induced performance changes, thereby ensuring that observed improvements are both sustainable and generalizable across contexts and populations.

Conclusions

This study suggests that VR-augmented sport training may enhance visuomotor stepping reaction performance, whether in the form of conventional basketball training or VR-based exercise, can elicit improvements in selected aspects of reaction time among 10 to 12 year-old children. Notably, a higher score within the BlazePod assessment used in this study reflects faster and more efficient reaction performance. However, the improvements observed were not consistent across all groups or outcome measures, suggesting that any benefits from these interventions may be task-specific rather than universal. Altogether, findings emphasize the potential benefits derived from incorporating novel, engaging, movement-based training modalities into youth physical education and sport programs to foster cognitive-motor development. Simultaneously, they identify a need for further research into the underlying mechanisms, long-term retention, and broader applicability of such improvements.

Conflict of Interest | *The authors declare no conflict of interests.*

Research Ethics Compliance | *All procedures were performed in accordance with the ethical standards of the Declaration of Helsinki and were approved by the Institutional Ethics Committee of Pegaso Telematic University (protocol PROT/E 002466, approved on 29 March 2024).*

Statement on the Use of AI Tools | *(AI) tools, specifically ChatGPT (OpenAI), were used in a limited and supervised manner during manuscript preparation to assist with language clarity and stylistic refinement. All outputs were reviewed, edited, and approved by the authors. The AI tool was not used to generate scientific content, analyze or interpret data, or draw conclusions. Responsibility for all intellectual content, data interpretation, and final editorial decisions lies solely with the authors.*

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