DOI 10.26773/smj.240719

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ORIGINAL SCIENTIFIC PAPER

Enhancing Elementary School Students' Visual Perceptual Skills: A Comparative Study of Oculus Quest 2 Exergames and Conventional Activities

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Abstract

The purpose of this study was to investigate potential differences between two exercise training programs among elementary school students: one based on Oculus Quest 2 exergames and the other on conventional activities, focusing on the Visual Pursuit (VP) skills of visual tracking and selective attention. The study comprised two cohorts: the Oculus Quest (OQ) group and the Typical Activity (TA) group. Engaged a total of forty (n=40) students, specifically selected from the fifth and sixth grades of two public elementary schools situated in the northern region of Greece. The participants, aged 10 to 12 years, consisted of 17 boys and 23 girls. Evaluation of the children's VP abilities occurred through a Visual Pursuit Test administered prior to the interventions (pre-test), after the intervention sessions (post-test), and one month after the interventions (1-month retention test). This program spanned a duration of 6 weeks, with sessions held twice per week, each session lasting 30 minutes. Two-way analyses of variance with repeated measures, were conducted to determine effect of training program groups (TA, OQ) and measurements (pre-test, post-test, 1-month retention test) across time on VP performance. Analysis of the data illustrated that the post-test and 1-month retention test VP scores were remarkably greater than pre-test VP scores in both groups. In conclusion, the findings indicate that both utilizing Oculus Quest 2 VR and conventional activities as interventions show promise in enhancing the VP abilities of elementary school children. This suggests that VR technology, alongside typical methods, could be a valuable tool in Physical Education settings for improving cognitive skills among young learners.

Keywords: *visual pursuit, virtual reality, elementary education, perceptual abilities, children*

Introduction

Visual perceptual skills play a pivotal role in achieving success across a myriad of sports endeavors. Whether it's striking a baseball, blocking a soccer ball, or sinking a basketball shot, the execution of precise and intricate motor actions heavily relies on the faculty of vision. This intricate interplay between perception and action stands as a cornerstone for excellence in physical education and sports, with the visual senses serving as the fundamental catalyst (Klostermann & Mann, 2019).

The process of transducing light into neural signals relies on the intricate mechanisms of optics and retinal sampling to achieve heightened spatial acuity (Hejtmancik & Shiels, 2015). Moreover, the dynamic nature of ocular movements enables athletes to sustain focus amidst swift bodily motions and changes in the field of view (Kozik & Enns, 2021).

Following transduction, visual information traverses through the intricate pathways of the visual system to the cerebral cortex, where it amalgamates to form three-dimen-

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sional representations (Mahabadi & Al Khalili, 2023). These representations undergo a complex interplay with attentional mechanisms, cognitive control, memory, and motor systems, facilitating seamless perception and action. This symbiotic relationship ultimately culminates in the awe-inspiring displays of athleticism witnessed on the field (Kozik & Enns, 2021).

Different sports necessitate distinct visual aptitudes. For instance, the visual demands placed on a tennis player vastly differ from those placed on a hockey goaltender. A tennis player must swiftly anticipate the trajectory of a fast-moving ball to execute a precise shot, while a hockey goaltender must vigilantly track the puck amidst the flurry of activity in the rink. The ramifications of success or failure in these tasks extend far beyond the realm of sports, encompassing profound physical and psychological repercussions.

Past research endeavors have underscored the divergence in visual skills required across various sports disciplines. Studies examining Olympic athletes and participants in interceptive versus strategic sports have illuminated the nuanced intricacies of visual acuity and perceptual processing (Burris, Liu & Appelbaum, 2020; Laby, Kirschen & Pantall, 2011). The burgeoning field of "sports vision" posits that heightened visual abilities underpin superior athletic performance. Previous investigations have elucidated disparities in visual acuity, contrast sensitivity, and tracking abilities among athletes at different levels of proficiency (Uchida, Kudoh, Higuchi, Honda & Kanosue, 2013; Williams, Ford, Eccles, Ward & Library, 2011). Meta-analyses of physical education and sports expertise literature have further corroborated these findings, elucidating the superior perceptual prowess and attentional processing exhibited by high-achieving athletes in comparison to their counterparts (Mann, Williams, Ward & Janelle, 2007; Voss, Kramer, Basak, Prakash & Roberts, 2010).

Early methods of training for visual skills in physical education and sports primarily consisted of analog drills that placed significant demands on oculomotor skills. Trainees were tasked with rapidly adjusting visual focus and alignment, as well as tracking moving or spatially separated targets through saccadic and smooth pursuit eye movements. Despite initial enthusiasm, empirical studies and consensus reviews have raised doubts about the efficacy of such analog training techniques (Smeeton et al., 2013).

However, recent years have witnessed the emergence of a diverse array of new technologies aimed at revolutionizing sports visual skills training. Digital innovations, including stroboscopic eyewear and mobile tablet-based devices, now facilitate training within the natural context of sporting activities (Appelbaum & Erickson, 2018; Poltavski, Biberdorf, & Poltavski, 2021). Augmented and virtual reality simulations further expand the possibilities by offering realistic and immersive environments for sports-specific training (Akbaş et al., 2019).

The effectiveness of these modern approaches, as outlined in the "Modified Perceptual Training Framework," hinges on various factors. These include the specific perceptual functions targeted for training, the alignment of training stimuli with desired competitive skills, and the congruence between elicited responses and competitive demands. Thus, successful sports visual skills training strategies entail a nuanced interplay of multiple factors within a program that is both feasible and manageable for athletes who contend with demanding schedules (Hadlow, Panchuk, Mann, Portus, & Abernethy, 2018).

Specifically, Tirp, Steingröver, Wattie, Baker & Schorer (2015) examined the transferability of throwing accuracy and quiet eye duration between virtual and real learning environments, specifically in dart throwing. Participants were divided into virtual training, real training, and control groups. They completed pre- and post-tests on both real and virtual dartboards. The real training group showed superior throwing accuracy compared to the control group, while throwing accuracy was better in the virtual group. Both training groups improved between tests, with the control group performing the worst. Quiet eye duration increased significantly between tests, particularly in the virtual group. Overall, our results indicate the effectiveness of both training methods and suggest a degree of transferability between tasks.

Rauter et al. (2013) examined how well technical skills learned on a scull rowing simulator could transfer to actual sculling on water. Two groups, each consisting of four recreational rowers, were involved, with one group training on water and the other using the simulator. Both groups had four training sessions across two weeks under the guidance of the same licensed rowing instructor. Both groups demonstrated enhanced performance on water. In conclusion, realistic simulator training facilitated skill gains similar to real-world training, suggesting potential for further motor learning enhancement with augmented feedback.

Finally, Gray (2017) examined the transfer of training from virtual to real-world baseball batting among athletes with intermediate experience levels. The study compared a group undergoing adaptive training in a virtual environment with groups undergoing repetitive batting practice, where balls of consistent speed and trajectory were hit, both in the real world and virtual environment. In the adaptive training group, factors like pitch speed and spin would adjust based on performance, either increasing with success or decreasing with failure. Gray (2017) discovered that adaptive training led to significantly greater enhancements in real-world performance compared to both repetitive practice groups.

However, within the domain of sports visual skills, there exists a notable gap in research regarding the reliability and efficacy of Virtual Reality (VR) approaches. Despite advancements in VR technology, studies investigating its utility in enhancing perceptual motor skills performance remain scarce. This underscores the necessity for further exploration and evaluation of VR applications within the realm of sports visual skills to better understand their potential benefits and limitations. Such research endeavors could provide valuable insights into optimizing training methodologies and improving perceptual motor skills performance across various sports disciplines. Therefore, the purpose of this study was to investigate potential differences in the Visual Pursuit (VP) skills of visual tracking and selective attention between two exercise training programs among elementary school students: one based on Oculus Quest 2 exergames and the other on conventional activities. The study comprised two cohorts: the Oculus Quest (OQ) group and the Typical Activity (TA) group. Evaluation of the children's VP abilities occurred through a Visual Pursuit Test administered prior to the interventions (pre-test), after the intervention sessions (post-test), and one month after the interventions (1-month retention test). Specifically, the re-

search addressed the following hypotheses: (H1) There will be no significant difference in VP performance measures between the two groups of children (TA, OQ) at the pre-test stage, and (H2) children in both experimental groups (TA, OQ) will demonstrate improvement in their VP abilities, which will be sustained over time. These findings could inform the development of guidelines regarding the utilization of such devices among children.

Methods

Participants

This study engaged a total of forty (n=40) students, specifically selected from the fifth and sixth grades of two public elementary schools situated in the northern region of Greece. Their ages ranged between 10 and 12 years old, with an average age of 10.35 years and a standard deviation of 0.71. Among these participants, there were 17 boys (constituting 42.5% of the sample) and 23 girls (comprising 57.5%).

The sampling approach employed in this research was self-selected sampling, where individuals volunteered to participate. Subsequently, the participants were randomly divided into two distinct groups, each consisting of 16 children: the TA group, comprising 5 boys and 15 girls, and the OG group, comprising 12 boys and 8 girls.

Before the assignment to groups, a screening process was conducted for children whose parents had expressed interest in their involvement. This screening aimed to confirm the participants' willingness to participate and ensure they met the study's requirements. These requirements were clarified to the children, and they were assessed against specific inclusion and exclusion criteria.

The inclusion criteria specified that participants must be between the ages of 10 and 12 years at the commencement of the study, possess proficiency in using exergames, and commit to attending all intervention program sessions. Conversely, the exclusion criterion encompassed the presence of any clinically severe illness or disorder that would impede the participant's ability to engage in the intervention program effectively.

Furthermore, prior to the voluntary participation of each child in the study, informed consent was diligently obtained from their respective parents or legal guardians. This comprehensive process ensured that all ethical considerations were meticulously addressed before the commencement of the research.

The Ethics Committee of the Faculty of Physical Education and Sport Sciences at Democritus University of Thrace approved (decision number: 39936/277; date: 29.03.2023) that this experimental study complied with all ethical guidelines for research involving human subjects, as stipulated by the Helsinki Declaration (World Medical Association, 2023).

Procedures

Prior to the data collection, meticulous efforts were undertaken to ensure full compliance with ethical standards and procedures. Comprehensive parent permission forms and child assent forms were distributed and collected, affirming participants' voluntary consent to take part in the study. These documents outlined the nature of the research, including its objectives, procedures, and potential risks and benefits, providing parents and children with a clear understanding of their roles and responsibilities.

Upon securing all necessary permissions and assents, the data collection phase began with the administration of pre-tests. These pre-tests were conducted diligently between January 23rd and February 3rd, allowing for the initial assessment of participants' baseline visual pursuit skills prior to any intervention.

Following the completion of pre-testing, a rigorous random assignment process was implemented to ensure the formation of two distinct experimental groups: the TA group and the OQ group. This random assignment method helped to minimize biases and ensure the comparability of the two groups, thereby enhancing the internal validity of the study.

Both experimental groups participated in a structured visual perceptual (VP) training program focused on enhancing visual tracking abilities. The program lasted 6 weeks, with sessions held twice a week for 30 minutes each.

As the 6-week intervention period drew to a close on March 17th, participants underwent post-test assessments to evaluate the immediate effects of the VP training program on their visual pursuit abilities. These post-test assessments provided valuable insights into the efficacy of the intervention in promoting skill acquisition and improvement.

Furthermore, to assess the durability of acquired skills over time, retention test assessments were scheduled one month after the conclusion of the intervention period. This extended assessment timeline allowed researchers to examine the retention and transferability of skills acquired during the VP training program, providing critical insights into the long-term impact of the intervention on participants' visual pursuit abilities.

In summary, the meticulously structured timeline of the study, encompassing pre-tests, intervention sessions, post-tests, and retention tests, facilitated a comprehensive examination of the effectiveness and sustainability of the VP training program in enhancing participants' visual pursuit skills.

Experimental treatments

As mentioned before, both experimental groups embarked on a structured VP training program, meticulously designed to target and enhance visual tracking abilities. The carefully structured nature of the VP training program aimed to optimize learning outcomes while accommodating the participants' schedules and minimizing potential fatigue or burnout.

The VP training program officially launched on February 6th, marking the beginning of an intensive and immersive learning experience for participants. Over the ensuing weeks, participants engaged in a series of engaging and interactive activities tailored to enhance their visual pursuit skills, leveraging both traditional activities (e.g., change directions, changing reactions, you pass, badminton, dodge ball, etc.) and innovative Oculus Quest exergames (e.g., REAKT performance trainer, eleven table tennis, beat saber, holofit, etc.). The traditional activities were designed based on established physical education practices (e.g., Logan, Robinson, Wilson & Lucas, 2012; Payne & Isaacs, 2011), while the Oculus Quest exergames were selected for their proven effectiveness in enhancing visual and motor skills in previous research (e.g., Amprasi, Vernadakis, Zetou & Antoniou, 2022; Hashemi, Khodaverdi & Zamani, 2022).

A typical lesson for the intervention groups began with children transitioning from their classrooms to engage in Visual Pursuit (VP) abilities instruction. The session started

with warm-up activities and games designed to prepare the children for the tasks ahead, with each child having their own space for these activities, which lasted 2 to 3 minutes. The children were then randomly divided into two VP abilities stations, where they participated in specific VP games. Each half of the class spent 12 minutes on one VP game before switching to the other station, allowing each child to spend a total of 24 minutes actively participating in two distinct VP games. The session concluded with closing activities, including 2 to 3 minutes of stretching exercises. During this time, the importance of critical elements for the development of VP abilities was highlighted through interactive discussions, encouraging the children to engage and reflect on the key concepts of the session.

Measures

The present study utilized the Visual Pursuit test, a component of the Vienna Test System developed by Schuhfried GmbH in Austria. Widely recognized in psychological diagnostics (Schmid, Sauter, Stepansky, Lobentanz & Zeitlhofer, 2005), this computerized assessment tool is specifically designed to gauge concentrated targeted perception and selective attention within the visual domain. Consequently, successful performance on this test necessitates both selective and sustained attention abilities.

Comprising a short form of 40 items, the test presents participants with arrays of nine intricately intertwined dark lines leading to nine distinct endpoints against a light background computer screen. Each item begins with a marked starting point on one of the lines, prompting participants to visually track this line to its corresponding endpoint as swiftly as possible. Participants are required to respond by pressing one of nine number buttons on a response panel within a four-second time frame before the screen disappears. Any items not responded to correctly or within the designated time limit are marked as incorrect responses.

Automated scoring of participant performance considered the number of correct responses and the mean Reaction Time (RT) for correct answers. The mean Reaction Time for correct answers (in seconds) was standardized, with all norms provided as percentile ranks. Scores on the Visual Pursuit test ranged from 0 to 24, indicating below-average visual perception; scores from 25 to 75 showed average visual perception; and scores from 76 to 100 represented above-average visual perception. A higher score signifies better selective attention and orientation performance. Each test run typically lasts approximately 6 minutes per participant. The Visual Pursuit test's reliability and validity have been well-established through extensive research efforts. For example, a study conducted by Biehl, Wagner, Karner & Bernd (2005) reported high internal consistency for the short form of the test, with Cronbach's alpha coefficients reaching .92, indicating excellent reliability.

Statistical analysis

The research design utilized in this study followed a pre-test/post-test control group structure with a 1-month retention test, wherein participants were assigned to groups through randomization. This random assignment process was executed using computer-generated random student numbers, which determined the allocation of students to respective groups. Prior to data analysis, thorough screening was conducted to ensure adherence to statistical assumptions, revealing no detected violations (Green & Salkind, 2013).

To evaluate the impact of the training programs and the progression of measurements over time on Visual Pursuit (VP) performance, a two-way analysis of variance (ANOVA) with repeated measures was employed. The dependent variable under scrutiny was VP test scores. The within-individual factors included training program groups (TA, OQ) and time points (pre-test, post-test, 1-month retention test). Significance of mean differences across time points was determined at the 0.05 alpha level. Additionally, effect size calculations were conducted using the partial eta-squared statistic (partial η2) to gauge the practical significance of the findings, with interpretation based on Cohen's guidelines: 0.01=small, 0.06=medium, and 0.14=large (Cohen, 1988).

Results

An independent samples t-test was conducted to evaluate the hypothesis that both experimental groups (TA and OQ) would not differ significantly on measure of VP performance at pre-test. Indeed, there were no significant initial differences between the two intervention groups in the mean VP scores, $t(38)=1.12$, $p=.27$.

Two-way analysis of variance (ANOVA) with repeated measures was conducted to evaluate the Hypothesis II (that children in both the TA and the OQ groups would improve and retain their VP abilities). As demonstrated in what follows, this hypothesis was corroborated.

Table 1. Results of two-way analysis of variance (ANOVA) with repeated measures.

Factors' effects	Sum of Squares	df	Mean Square	F	p	η^2p
Time	4241.0	2	2120.48	31.944	<0.001	0.457
Time * Group	14.1	2	7.06	0.106	0.899	0.003
Group	267	1	267	2.24	0.143	0.056

A significant main effect was noted for Time, $F(2, 38)=31.94$, $p<0.001$, partial $\eta2=0.457$, while the Training programs x Time interaction effect was not significant, $F(2, 38)=0.106$, $p=0.899$, partial $\eta2=0.003$. The univariate test associated with the Group's main effect was also not significant, $F(1, 38)=2.24$, $p=0.143$, partial $\eta2=0.056$.

Pairwise comparisons using t-test with a Bonferroni adjustment were used to analyzing the main effect of Time. The results revealed significant mean differences in VP scores between pre-test and post-test (MD=-13.12; 95% CI: 62.2 to 78.8, $p<0.001$) and between pre-test and 1-month retention test (MD=11.13; 95% CI: 62.2 to 76.6, $p<0.001$) in both experimental groups (TA, OQ). As shown in Figure 1, the post-test and 1-month retention test VP scores were remarkably greater than pre-test VP scores for both experimental groups.

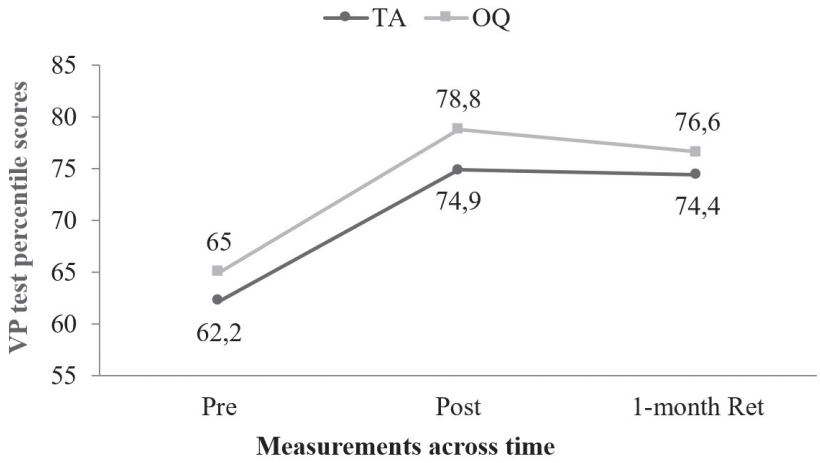

FIGURE 1. VP performance of the three groups on all measurements across time

Discussion

In recent years, there has been a growing body of research focusing on the physical and cognitive advantages of visual pursuit (VP) exercises for children (Dalziell, Booth, Boyle & Mutrie, 2019). VP exercises involve engaging multiple body parts and/or manipulating objects to accomplish goal-directed actions, necessitating precise timing, temporal, and spatial estimation, which in turn requires perceptual and high-level cognitive information processing (Pesce, 2012). For instance, activities such as kicking, throwing, catching, dribbling, volleying, or striking a ball exemplify coordinative exercises, where children must coordinate visual input with manual actions.

Considering the existing body of knowledge, our research sought to explore potential differences between two Visual Pursuit (VP) exercise training programs for elementary school students: one utilizing Oculus Quest 2 exergames and the other involving conventional activities. In order to achieve this goal, researchers established specific hypotheses to direct our investigation. The following sections detail the findings and conclusions derived from our study.

The first research hypothesis, which posited that there would be no significant differences in Visual Pursuit (VP) skills between the two experimental groups during the pre-test phase, was substantiated by our findings. This outcome can be interpreted in several ways. One possibility is that the VP tasks administered during the pre-test phase were inherently familiar and accessible to all participants, regardless of their group assignment. Consequently, the lack of significant differences in VP skills at the pre-test stage highlights the importance of considering contextual factors and task familiarity when interpreting research findings in educational settings.

The confirmation of the second research hypothesis further strengthens the validity of our study. It suggested that both the OQ and TA groups experienced improvements in their VP skills and were able to maintain these improvements over time. This finding was supported by the significant increase observed in the VP scores at both the post-test and the 1-month retention test, compared to the pre-test scores, across both experimental groups.

These outcomes are consistent with previous research findings that emphasize the effectiveness of early instruction in visual perceptual skills in enhancing children's perceptual development (Amprasi et al., 2022; Hashemi et al., 2022). The positive outcomes observed in our study align with the existing body of literature, providing further evidence of the beneficial effects of targeted interventions aimed at improving VP skills among elementary school children.

The results of the post-test were anticipated, given the documented effectiveness of visual perceptual skill instruction in facilitating immediate changes in children's perceptual abilities (Logan et al., 2012; Payne & Isaacs, 2011). However, the findings from the 1-month retention test are particularly noteworthy, as they demonstrate that participants in both the OQ and TA groups were able to sustain their improved VP skills over the course of one month following the completion of the intervention. This suggests that the interventions were not only effective in the short term but also led to enduring improvements in VP skill development.

These retention results are significant in the context of visual perceptual skill development literature, as they provide evidence of long-term retention, which is less commonly reported in existing studies (Hashemi, Khodaverdi & Zamani, 2022; Robinson & Goodway, 2009). The retention test results highlight the distinction between immediate perceptual learning observed in post-test assessments and the more enduring effects of perceptual skill development demonstrated in retention tests. This differentiation is crucial for understanding how initial gains in perceptual skills can be solidified and maintained over time, a topic that warrants further exploration in future research.

Moreover, the effectiveness of the Oculus Quest-based intervention in enhancing students' perceptual abilities can be attributed to several factors. The immersive and interactive nature of Oculus Quest exergames likely played a critical role in this regard. Previous research has shown that VR environments can enhance cognitive and motor skills by engaging multiple sensory modalities and providing real-time feedback, which promotes deeper learning and skill acquisition (Brown et al., 2020; Grosprêtre, Marcel-Millet, Eon & Wollesen, 2023). VR environments have been found to facilitate experiential learning, which is critical for the development of perceptual skills (Kolb, 1984; Merchant et al., 2014).

The adaptive and personalized nature of Oculus Quest technology allowed for tailored learning experiences that cater to individual learning styles and preferences. This adaptability is consistent with findings from previous studies that highlight the benefits of adaptive learning technologies in

optimizing educational outcomes (Clark & Feldon, 2014; Johnson & Mayer, 2009). Personalized learning experiences have been shown to significantly enhance engagement and motivation, which are essential for sustained learning and skill retention (Schunk & Zimmerman, 2012; Wang, Woo, Quek, Yang & Liu, 2014).

Furthermore, the active engagement and intrinsic motivation elicited by the VR exergames likely contributed to the sustained improvements observed in VP skills. Research indicates that interactive and engaging learning environments can lead to higher levels of motivation and, consequently, better learning outcomes (Deci & Ryan, 2000; Ryan & Deci, 2018). The motivational aspects of VR exergames, which combine elements of gamification and immersive experiences, have been shown to enhance both cognitive and physical engagement in learning activities (Hamari & Keronen, 2017; Lister, West, Cannon, Sax, & Brodegard, 2014).

The traditional activities, which were based on established physical education practices, also proved effective in enhancing VP skills. These activities, such as those involving changes in direction, reaction exercises, and sports like badminton and dodge ball, have been shown to improve motor and perceptual skills through repetitive practice and feedback (Gabbard, 2012; Vernadakis et al., 2012). These activities require children to process visual information quickly and accurately, enhancing their visual perceptual skills and selective attention.

Research has consistently demonstrated that physical activities involving coordinated movement and perceptual tasks can significantly improve visual perceptual skills in children (Payne & Isaacs, 2011). For example, activities that require children to track moving objects, such as catching or striking a ball, help develop their ability to anticipate and respond to visual stimuli (Logan et al., 2012). These tasks not only improve visual tracking but also enhance hand-eye coordination, spatial awareness, and reaction times, all of which are critical components of visual perceptual skills (Robinson & Goodway, 2009).

Moreover, traditional activities that incorporate dynamic and varied movements can stimulate cognitive processes related to attention, memory, and executive functions. For instance, research by Alesi, Bianco, Luppina, Palma & Pepi (2016) demonstrated that participation in complex physical activities, such as a football exercise program, which demand rapid decision-making and problem-solving, can effectively improve cognitive flexibility and executive control in children. This is supported by findings from Best (2010), who noted that physical activities requiring rapid shifts in attention and control, such as those found in sports and team games, can improve cognitive functions related to attention and inhibitory control.

Thus, it appears that the findings of this study highlight the potential of both traditional activities and the innovative Oculus Quest educational games to enhance and maintain visual perceptual skills in elementary school children. Traditional activities, which have long been valued for their role in cognitive and sensory development, continue to demonstrate their effectiveness in fostering visual perception. Meanwhile, the integration of Oculus Quest educational games introduces a modern, interactive approach that not only engages children through immersive experiences but also aligns with the technological advancements and digital fluency of today's youth. Together, these methods provide a comprehensive strategy to support the visual perceptual development of elementary school students, offering a balanced blend of conventional and cutting-edge educational tools.

Limitation

Upon assessing the findings of the current research, it's imperative to acknowledge several limitations. Firstly, one significant challenge was the practicality of conducting scientific investigations within a live school environment. The testing conditions were inherently non-clinical, subject to regular fluctuations, which may have impacted the consistency of data collection.

Furthermore, it's important to recognize that the results reported in this study were based on the utilization of four specific interactive gaming software platforms (REAKT performance trainer, Eleven Table Tennis, Beat Saber, & Holofit). This specificity introduces a potential limitation, as different gaming software covering alternative games and exercises may yield varied outcomes.

Lastly, the interventions targeting Visual Pursuit (VP) skills were implemented exclusively in two public elementary schools located in northern Greece. The characteristics of these specific schools may have influenced the results, thereby limiting the generalizability of findings to broader populations.

Despite these acknowledged limitations, it is hoped that this study contributes to the existing body of knowledge surrounding Physical Education practices, particularly regarding the utilization of exergames to enhance children's perceptual development. By identifying these constraints, future research endeavors can aim to address and overcome these challenges, further advancing our understanding of the potential benefits and limitations associated with exergaming in educational contexts.

Conclusion

This study represents a significant contribution to the field of educational research and physical education by exploring the efficacy of VP skill interventions using Oculus Quest 2 exergames among elementary school students. The findings of this research highlight several key insights.

Firstly, the results confirm the effectiveness of both Oculus Quest-based interventions and conventional activity-based interventions in improving VP skills among elementary school children. The significant improvements observed in VP scores at both post-test and 1-month retention test sessions underscore the potential of these interventions to enhance perceptual abilities over time.

Secondly, the study identifies various factors contributing to the success of the interventions. The immersive and interactive nature of the Oculus Quest 2 environment engages multiple sensory modalities, facilitating experiential learning and skill acquisition. Additionally, the personalized and adaptive nature of Oculus Quest 2 technology enables tailored learning experiences, catering to individual needs and preferences.

Moving forward, future research could explore the long-term effects of Oculus Quest-based interventions on perceptual development and academic performance among elementary school students. Additionally, investigating the optimal duration and frequency of exergaming interventions, as well as their potential effects on other aspects of children's health

and well-being, could further enhance our understanding of the role of exergaming in education.

Overall, this research contributes valuable insights into the potential of exergaming interventions to improve perceptual development among elementary school students. By elucidating the effectiveness of these interventions and identifying key factors influencing their success, this study informs future educational practices and research endeavors aimed at enhancing children's perceptual abilities through innovative technological interventions.

Acknowledgments
There are no acknowledgments.

Conflict of interest
The authors declare that there are no conflict of interest.

Received: 19 April 2024 | **Accepted:** 30 May 2024 | **Published:** 01 June 2024

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