Gamified virtual reality training and ocular vergence: evidence from a randomized controlled study with rehabilitation perspectives

Entrenamiento en realidad virtual gamificada y vergencia ocular: evidencia de un estudio controlado aleatorio con perspectivas de rehabilitación

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Abstract

Background: Alterations in ocular vergence are linked to balance and visual coordination; few studies have examined the role of gamified virtual reality (VR) in modulating these functions in healthy adults.
Objective: To assess the effects of a VR-based game on ocular vergence through a randomized controlled trial and explore its potential for rehabilitation.
Methods: 32 university students were randomly assigned to an intervention group (24 sessions of VR training) or a control group. Near Point of Convergence (NPC) and Near Point of Break (NPB) were measured at baseline, after one session, and after 12 weeks. Finally, 27 participants completed the protocol and were included in the final analysis
Results: Participants in the program saw noticeable improvements quickly, with their NPC distance decreasing by about 1.01 cm early on (p=0.001). At the same time, their NPB distance also improved, decreasing by around 1.29 cm (p=0.002). After 12 weeks, these changes became even more noticeable, with NPC decreasing by 1.92 cm (p=0.014) and NPB dropping by about 1.86 cm (p=0.040). The study also found strong links between NPC and NPB measurements, with correlation coefficients over 0.6. Interestingly, it showed differences in how men and women responded to the program.
Conclusions: Playing engaging VR training games can help improve eye coordination in the short and medium term. This promising early evidence suggests that they could be useful additions to rehabilitation or performance routines. Bigger studies are needed to back up these findings and to understand what factors might influence how well they work.

Keywords

Gamification; ocular vergence; randomized controlled trial; rehabilitation; virtual reality.

Resumen

Introducción: Las alteraciones en la vergencia ocular afectan el equilibrio y la coordinación visual; existen pocos estudios sobre el papel de la realidad virtual (RV) gamificada en su modulación en adultos sanos.
Objetivo: Evaluar los efectos de la RV sobre la vergencia ocular mediante un ensayo controlado aleatorio y explorar su potencial para la rehabilitación.
Métodos: 32 estudiantes universitarios fueron asignados aleatoriamente a un grupo de intervención (24 sesiones de entrenamiento de RV) o a un grupo de control. Se evaluaron el punto próximo de convergencia (PPC) y el punto próximo de ruptura (PPR) al inicio, después de una sesión y tras 12 semanas. En el análisis final se incluyeron 27 participantes.
Resultados: Se observaron mejoras tempranas significativas. Disminuyendo el PPC en 1,01 cm al principio (p = 0,001). Su distancia PPR también mejoró, disminuyendo en 1,29 cm (p = 0,002). 12 semanas después, la reducción fue mayor, el PPC disminuyó en 1,92 cm (p = 0,014) y PPR en 1,86 cm (p = 0,040). El estudio encontró fuertes vínculos entre las mediciones de PPC y PPR, con coeficientes de correlación superiores a 0,6. Curiosamente, mostró diferencias en la forma en que los hombres y las mujeres respondieron al programa.
Conclusiones: El entrenamiento con juegos de RV mostró efectos positivos en la coordinación ocular a corto y medio plazo. Estos resultados preliminares respaldan su potencial como herramienta complementaria en programas de rehabilitación o entrenamiento visual. Se requieren estudios con mayor tamaño muestral para confirmar su eficacia y determinar factores moduladores.

Palabras clave

Ensayo controlado aleatorio; gamificación; rehabilitación; realidad virtual; vergencia ocular.

Introduction

Alterations in the coordination of the oculomotor muscles can affect balance and increase the risk of falls, especially in geriatric populations with neurological and balance involvement. Ocular vergence can be clinically assessed through the Near Point of Convergence (NPC) and Near Point of Break (NPB), which are commonly used as indicators of convergence quality. NPC is determined by stressing the muscles while the individual fixes their eyes on a point and measures the distance at which diplopia occurs. The NPB is the distance at which normal vision is re-established from the NPC (Mestre et al., 2021).

Virtual reality (VR) is a technology that allows real-time interaction between users and hardware, thereby generating a realistic and safe environment. VR is used for the rehabilitation of balance and motor control (Prasertsakul et al., 2018; Ramírez-Moran et al., 2025; Damasceno da Rocha et al., 2025) and in chronic pain management, anxiety, and other mental health disorders (Cornwell et al., 2013).

VR is used to rehabilitate mobility, muscle coordination, and ocular vergence. It trains focus, eye tracking, and convergence, aiding patients with strabismus or amblyopia in improving visual acuity. VR also serves as a dissociative test for eye muscle rehabilitation (Nesaratnam et al., 2017). It is a motivating and playful therapy, allowing greater adherence and therapeutic results (Chan et al., 2023), even in children after surgery for concomitant strabismus (Yang et al., 2025).

Although there is growing evidence for the use of VR in balance, motor control and neurological rehabilitation, its direct impact on ocular vergence in healthy adults is still largely unexplored. This is an important gap, since ocular vergence is central to postural stability, coordination and many everyday visual tasks.

VR creates more engaging treatment experiences (Rutkowski et al., 2021) and motivation through gamification (Campo-Prieto et al., 2025), proving to be more effective than conventional methods (Erhardsson et al., 2020; Molina Heredia et al, 2025) by providing visual, auditory, and tactile feedback that influences the brain reward mechanisms and potentially modifies brain plasticity.

In patients with Parkinson's disease, VR rehabilitation improves gait, is more effective for returning to work (Mangone et al., 2022), improves balance, and reduces falls (Zhang et al., 2023). In geriatric syndromes, motivation and cognitive abilities increase (Amorim et al., 2018) by acting on the alpha band of electroencephalograms (Qu et al., 2022). Neurophysiological evidence also supports this idea: Qu et al. (2022) showed that VR exposure increases alpha EEG rhythms, which are associated with visual attention and oculomotor control. VR is similarly effective in vestibular rehabilitation in terms of functional balance, gait, and quality of life (Alahmari et al., 2014).

Patients with stroke prefer motivating and easy-to-use games to traditional rehabilitation (Seo et al., 2016). Early use in the chronic stages is beneficial because it increases strength, decreases depression and anxiety, and improves physical function, balance and gait, upper limb function, and activities of daily living (ADLs) (Aramaki et al., 2019; Lin et al., 2020). VR combined with physical therapy presents superior results in lower-extremity functional improvement compared to isolated physical therapy (Yaman et al., 2022).

In other nervous system-related conditions, VR can be helpful for training motor imagination (Micarelli et al., 2019). It can also improve movement, strength, and increase independence in everyday activities for people recovering from traumatic brain injuries (Aoyagi et al., 2019). Besides, VR is used in neurorehabilitation to help reduce pain caused by missing sensory input (Sano et al., 2016). In healthy adolescents, VR is safe to use for short periods because it is related to refractive errors and the oculomotor system (Ha et al., 2016).

Exploring VR-based interventions in healthy adults may provide baseline evidence to design rehabilitation strategies for populations with oculomotor or balance disorders."

Therefore, this study aimed to analyze whether a structured VR gaming program can modulate ocular vergence parameters in young adults and explore the potential translational applications of these findings in rehabilitation contexts.

Method

This prospective, controlled, randomized, open-label, longitudinal clinical study had a mixed quantitative and qualitative design. This study was registered in Clinical Trials with the Identifier NCT05649566. Documented information and informed consent were obtained from each participant during the initial interviews.

The sample calculation (GRANMO calculator) anticipated the need for 30 participants (alpha risk of 0.05, beta risk <0.2, standard deviation 4.08 according to the literature (Minooners et al., 2019), expected follow-up losses: 10%). The sample size calculation was based on the NPB variable, which was expected to show the greatest change with VR training. We anticipated a moderate effect size, requiring a minimum of 30 participants to achieve 80% power at $\alpha = 0.05$. A post-hoc power analysis was performed using the collected data, obtaining a power of 79.8% ($\alpha = 0.01$, ClinCalc calculator, Post-hoc Power Calculator).

Randomization was simple (1:1 ratio) and automatically generated (random.org) in two groups (control and intervention, CG and IG, respectively) using the identification number (ID) assigned in the first survey. Stratification was not performed according to sex or age groups. The nature of the intervention prevented blinding of the allocation between the CG and IG groups. Although allocation was not blinded for participants and outcome assessment physiotherapists due to the nature of the intervention, statistical analyses were conducted without knowledge of group assignments to ensure objectivity.

The inclusion criteria were as follows: young adult university students aged 18 to 25 years, both sexes, and physically active (affirmative and greater answers of three days and three hours, respectively, to the first two questions of the International Physical Activity Questionnaire (IPAQ) (Hagströmer et al., 2006), without visual pathology or history of vertigo or other pathologies that compromised balance. The exclusion criteria were smoking, alcohol consumption, use of illicit drugs, and use of medications that were neurologically active or could affect the nervous or motor systems. Withdrawal criteria: appearance of vertigo in any of the interventions or non-attendance at > 15% of the scheduled sessions (IG).

The anthropometric variables describing the sample included the IPAQ test results and sex of the participants. Ocular vergence was assessed using the Near Point of Convergence (NPC) and Near Point of Break (NPB) using the RAF Rule method, and qualitative interviews were conducted to explore participants' subjective experiences.

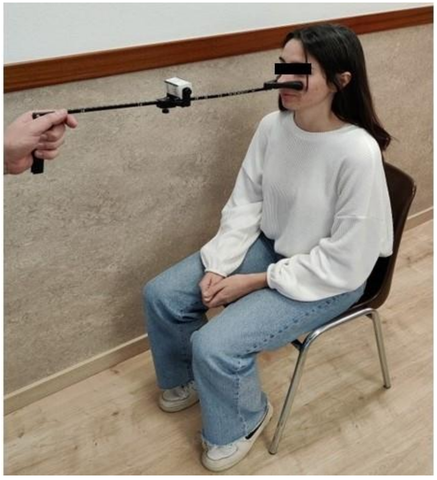
A visual stimulus was positioned 40 cm from the participants at eye level and gradually advanced until diplopia was observed. This process established the distance for NPC measurement. The value of the NPB, starting from the NPC point, moves the stimulus away until diplopia disappears. The "RAF rule" was used for the calculation (Pétursdóttir et al., 2022) (Figure 1). The environmental conditions were in an open-planned room, two-by-two meters, without elements or artefacts that could alter the concentration of participants.

The action protocol lasted 12 weeks. The intervention group completed 24 virtual reality training sessions (two per week, 30 minutes each). Ocular vergence was measured at baseline, before and after the 12th session to assess immediate effects, and seven days post-program for medium-term effects. The control group followed the same measurement schedule but received no intervention.

Regarding qualitative variables, unstructured interviews were conducted with the IG participants before and after the program to analyze the sensations and additional effects of the VR program.

The CG performed their usual activities without taking any additional steps to participate in the study. In the IG, the program consisted of 24 sessions of 30 min (2 sessions per week for 3 months). Wireless VR headsets (Oculus Quest 2) were used to deliver the intervention, and the Beat Saber game was selected for its validated capacity to induce immersive visuomotor activity. (Lai et al., 2020).

Figure 1: Image of the NPC/NPB measurement procedure using the Raf Rule.



Source: Own elaboration.

The NPC and NPB variables were measured before the first session and seven days after the last session in the IG (or at 13 weeks in the CG) to analyze medium-term changes. The IG participants underwent two more measurements before and 30 min after the 12th VR play session to analyze the influence of this activity before and after a single session (immediate effect of the intervention). The 12th session was chosen because it was the central session of the entire program and because the participants had already been familiarized with VR glasses and were unlikely to experience fatigue or overexposure to the intervention.

All the findings were recorded in a dedicated data collection notebook. Statistical analyses were carried out with IBM SPSS v.27. We first checked the distributions for normality using the Kolmogorov–Smirnov test and for homoscedasticity using Levene's test. Depending on the results, either parametric or non-parametric techniques were applied to compare baseline and post-program values, to examine differences between groups, and to explore correlations between variables. The significance level was set at $p < 0.05$ (two-tailed), and 95% confidence intervals were reported when appropriate. Qualitative data from unstructured interviews were examined with thematic content analysis, and two researchers coded the material independently to improve credibility. No corrections for multiple comparisons were applied, as this was an exploratory study.

The study was approved by the Ethics Committee of the Universitat Autònoma de Barcelona (ref. #5884). All participants gave written informed consent in line with the Declaration of Helsinki.

Results

Thirty-two participants were enrolled, 16 women and 16 men. They were randomly assigned to the IG: 10 males, 7 females) or to the CG: 6 males, 9 females. Age and sex distribution did not differ significantly between groups, which indicates that they were comparable at baseline. All participants in the IG completed follow-up. Five control group participants (three men, two women) missed the final data collection and were lost to follow-up after not attending the second measurement. Despite multiple contact attempts, they could not be reached or rescheduled and were excluded from analysis. The intervention group had no dropouts or related incidents. As a result, the per-protocol analysis included 27 participants (17 in the IG and 10 in the CG).

Overall changes in NPC and NPB: At baseline, the IG had a mean NPC of 2.61 cm (SD = 5.74). After the 12-week program this decreased to 1.86 cm (SD = 3.81), a reduction of –1.92 cm (SD = 2.86; $p = 0.014$; 95% CI: 0.45–3.39). The CG did not show significant changes. When comparing groups while assuming unequal variances (Levene's test, $p = 0.026$), the difference was not statistically significant, although the IG showed a moderate effect size (Cohen's $d = -0.64$; 95% CI: –1.44 to 0.16).

For NPB, the IG had a baseline mean of 8.99 cm (SD = 2.97), which decreased to 7.12 cm (SD = 2.30) after the intervention (Δ = −1.86 cm; SD = 3.44; p = 0.040). The CG again showed no significant change. Between-group comparisons (Levene's test, p = 0.009) indicated a significant effect in favor of the IG (p = 0.038; 95% CI: −3.87 to −0.12). The corresponding effect size was moderate to large (Cohen's d = −0.71; 95% CI: −1.50 to −0.71).

Sex-specific analyses and correlations: Among males (IG: n = 10; CG: n = 3), the IG showed significant reductions in both NPC (Δ = −2.23 cm; SD = 2.14; p = 0.009) and NPB (Δ = −2.18 cm; SD = 2.86; p = 0.039). The CG did not show meaningful changes, and the differences between groups were not statistically significant. Effect sizes were moderate for NPC (Cohen's d = −0.45; 95% CI: −1.74 to 0.87) and for NPB (Cohen's d = −0.47; 95% CI: −1.77 to 0.84).

In females (IG: n = 7; CG: n = 7), neither NPC nor NPB changes reached significance, though both groups tended to show lower scores at follow-up. The high variability in this subgroup indicates that larger samples will be needed to clarify sex-specific effects (Table 1).

Across the whole study, NPC and NPB values declined progressively, with a consistent slope from baseline to the final assessment (Figures 2 and 3). When all participants were considered together (n = 27), changes in NPC and NPB were strongly correlated (r = 0.875; p < 0.0001). Within the IG, correlations were significant in both men (r = 0.671; p = 0.034) and women (r = 0.972; p < 0.0001). In the CG, a significant correlation appeared in men (r = 1.000; p = 0.011) but not in women. A significant between-group difference was observed for NPB variation (p = 0.008).

Table 1. Tests of related samples of the initial and final NPB by sex: male (IG: n=10; CG: n=3) and female (IG: n=7; CG: n=7).

		Related differences					P-Value
		Mean	St. Dev.	Typical Mean Error	95% Confidence Interval for Difference		
					Inferior	Superior	
IG Male	Initial NPC - Final NPC	-2,2300	2,1354	,6753	,7024	3,7576	,009
CG Male	Initial NPC - Final NPC	-1,3333	1,3317	,7688	-1,9747	4,6414	,225
IG Male	Initial NPB - Final NPB	-2,180	2,860	,904	,134	4,226	,039
CG Male	Initial NPB - Final NPB	-,933	1,234	,713	-2,133	3,999	,321
IG Female	Initial NPC - Final NPC	-1,486	3,816	1,442	-2,044	5,015	,343
CG Female	Initial NPC - Final NPC	,0143	,8194	,310	-,772	,743	,965
IG Female	Initial NPB - Final NPB	-1,414	4,357	1,647	-2,615	5,444	,423
CG Female	Initial NPB - Final NPB	,586	,570	,215	-1,113	-,059	,035

Figure 2. Evolution of NPC by sex throughout the study. Source: Own elaboration.

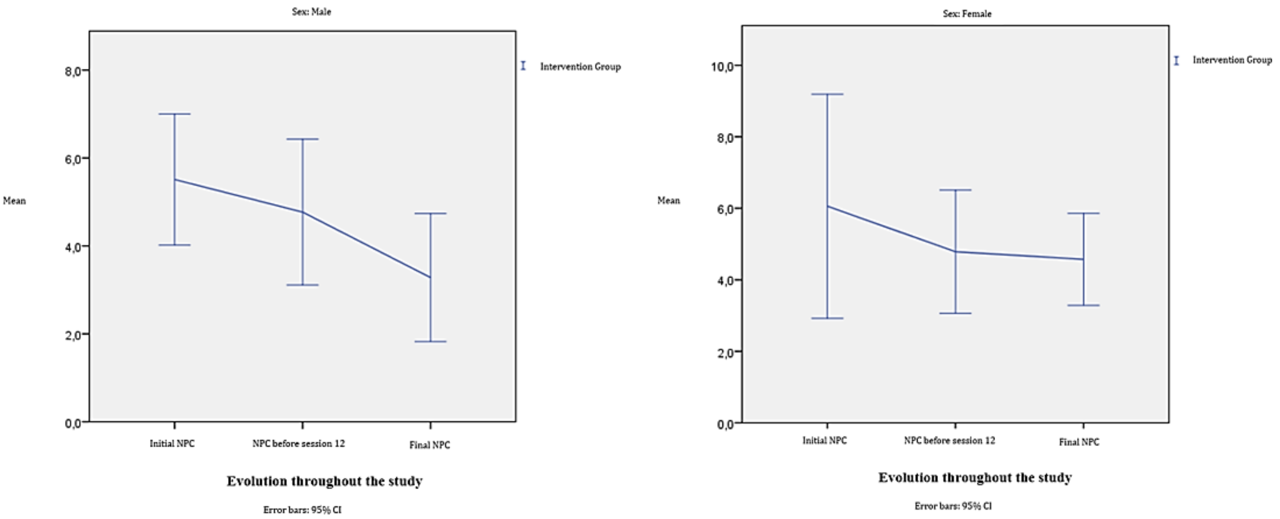
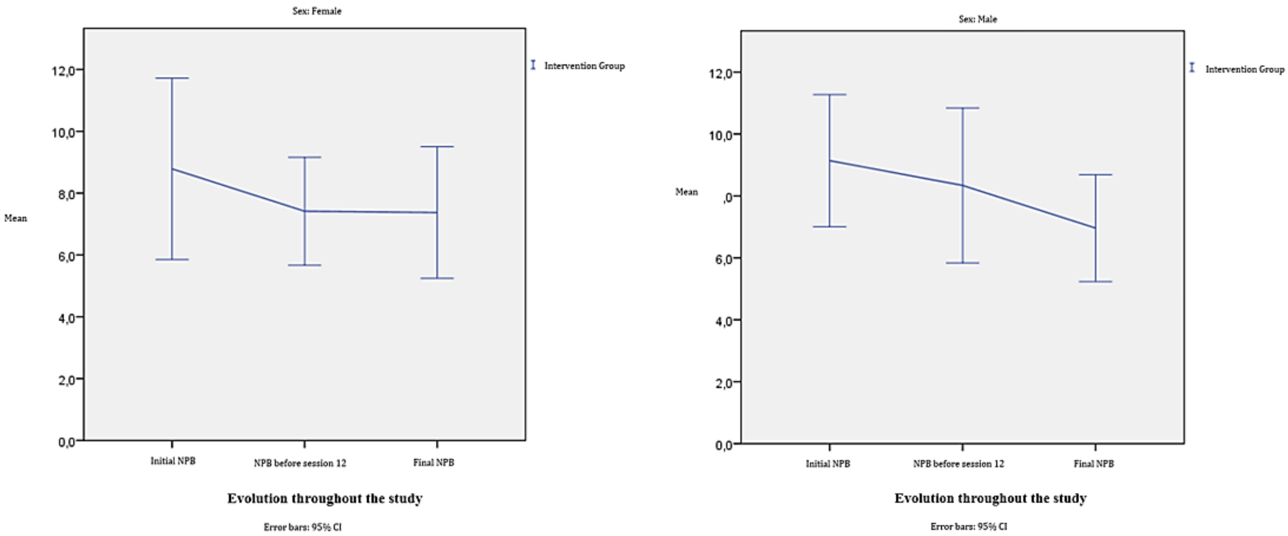


Figure 3. Evolution of NPB by sex throughout the study. Source: Own elaboration.



Immediate single-session effects: Seventeen participants (10 men and 7 women) completed the mid-program assessment at Session 12. Short-term improvements were clear. NPC fell from 4.78 cm (SD = 2.08) to 3.77 cm (SD = 2.28) (Δ = –1.01 cm; SD = 1.06; p = 0.001; 95% CI: 0.47–1.56). NPB also decreased, from 7.96 cm (SD = 2.91) to 6.67 cm (SD = 2.57) (Δ = –1.29 cm; SD = 1.43; p = 0.002; 95% CI: 0.56–2.03). These changes were strongly correlated (r = 0.602; p = 0.011).

Sex-specific results: In men, reductions in NPC (4.77 to 4.14 cm; p = 0.089) and NPB (8.34 to 7.26 cm; p = 0.069) did not reach significance. In women, both NPC (4.79 to 3.23 cm; p = 0.003) and NPB (7.41 to 5.81 cm; p = 0.008) improved significantly. Correlation analyses showed that NPC and NPB changes were linked in men (r = 0.632; p = 0.050) but not in women (r = 0.488; p = 0.266).

Discussion

This study offers preliminary evidence that gamified VR training can improve ocular vergence in the short and medium term, as indicated by reductions in NPC and NPB. Our results are consistent with the findings of Szpak et al. (2020), who reported positive physiological effects of immersive VR, and they add to the existing literature by showing that the improvements were present after both a single session and a structured 12-week program.

From a methodological standpoint, application of the RAF Rule minimized postural bias and enhanced internal validity, thereby likely increasing the protocol's reproducibility (Pétursdóttir et al., 2022). The intervention was also practical and portable, since it relied on commercially available headsets and a popular game. This simplifies replication in both research and clinical contexts.

In our data, the short-term benefits appeared rapidly. Our results suggest that VR training may be especially useful in situations where rapid functional gains are needed, for example in sports preparation or intensive rehabilitation (MPT et al., 2025). Benefits were still present after several weeks, which means that repeated exposure could help these improvements become more stable over time. This pattern points to a role for VR-based protocols in longer rehabilitation programs.

Sex-specific analyses highlighted the divergent response patterns. In our data, men tended to improve in a more consistent way, while the results for women were mixed and only reached significance in a few outcomes. The cause of these differences is unclear, partly because the CG group included only three men. Physiological, hormonal, or psychosocial factors may play a role, but larger and more balanced studies are needed to clarify this.

We observed a strong link between NPC and NPB, both across all participants as a group and when analyzing the data separately by sex. Seeing both measures change in parallel suggests that they may be driven by common mechanisms. For that reason, assessing them jointly could give a fuller picture of convergence control and add value for both clinical practice and future research.

The qualitative observations were consistent with the statistical results. Participants often said the VR sessions were motivating and not difficult to follow.

This appeared to keep them engaged as the weeks went by. Their feedback also matched the playful and interactive character of VR, a point already noted in studies of musculoskeletal, ocular and neurological rehabilitation (Maranesi et al., 2022; Truijen et al., 2022). From these observations we can infer that gamified VR not only supports functional progress but also makes the intervention a more positive experience for participants.

This study has some limitations. The sample size was limited, and the subgroup analyses were not strong enough to identify certain sex-related effects, which makes it harder to apply these findings broadly. We also observed considerable variability between individuals, making it clear that larger and more controlled trials are needed. Sex-specific analyses should be interpreted with caution, particularly in the male control group where only three participants completed the study, making the statistical power very low and limiting the reliability of subgroup comparisons. One further issue is that the nature of VR made blinding impossible, so both allocation and participation were open, which might have introduced some performance or expectation bias.

Future studies should apply this approach to larger and more varied groups. Future studies should also look at whether physiological, hormonal or psychosocial factors explain the variability we observed. Extended follow-up beyond 12 weeks is necessary to determine whether the effects persist in the long term.

Conclusions

Our study indicates that gamified VR training could improve ocular vergence with promising but not definitive results. NPC and NPB both improved after a single session, and the reduction was even stronger at 12 weeks. Their parallel change points to shared physiological mechanisms that might be addressed through integrated interventions. Men and women did not respond in the same way, yet all subgroups benefited to some degree. What we saw here hints that the approach with VR could be relevant across different populations.

The sample was small and the responses were different in men and women, so conclusions should be read carefully. Stronger evidence will require studies with more participants, blinding and longer follow-up.

Overall, our findings point to a role for VR-based programs in clinical and sports settings to improve visual function and physical performance. Future work should also ask whether physiological, hormonal or psychosocial factors explain the differences we observed between individuals and sexes.

Key Conclusions

- Gamified VR training significantly reduced NPC and NPB after both a single session and a 12-week program.
- The effects were consistent across sexes, although with different response patterns, and NPC–NPB changes were strongly correlated.
- VR-based protocols show promise for clinical and sports applications; however, larger studies are needed to confirm and extend these findings.

Practical Implications

- Gamified VR can be integrated into rehabilitation programs as a motivating tool for improving ocular vergence and visual coordination.
- Even brief sessions may yield immediate benefits, making VR suitable for intensive or short-term intervention.

- Its portability and engagement potential support long-term adherence, especially in populations with low compliance with traditional therapies.

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