

Effect of Virtual Reality–Based oculomotor training on Saccadic Eye movements and Smooth Pursuit Function in Young Adults with Convergence Insufficiency - A Prospective Pre–Post Study

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ABSTRACT

Background: Convergence insufficiency (CI) is a binocular vision disorder in which the eyes struggle to converge during near work, giving rise to headaches, eye strain, blurred or double vision and poor concentration. Office-based vergence therapy works, but its cost, time demands and the difficulty of keeping patients engaged limit how widely it is used. We tested whether a virtual reality (VR) programme built around saccadic and pursuit eye-movement tasks could improve binocular function and symptoms in young adults with CI.

Methods: Thirty adults aged 18–35 years with symptomatic CI (Convergence Insufficiency Symptom Survey [CISS] score ≥ 21) were recruited by convenience sampling at Bhaarith medical college and hospital, Chennai. Each completed 12 VR sessions of 20 minutes (twice weekly for six weeks) using a head-mounted viewer, playing a fast-paced game (Temple Run) and a slow-paced game (Mr. Cat's Adventure). Near point of convergence (NPC), King–Devick (K-D) test time and CISS score were recorded at baseline and after six weeks and compared with paired t-tests.

Results: Mean age was 21.56 ± 2.5 years and 18 participants (60%) were female. The NPC break point moved 1.82 cm closer ($t = 6.17$), K-D time fell by 4.64 s ($t = 8.71$) and CISS scores fell by 5.00 points ($t = 18.43$); $p < 0.001$ for each. Near positive fusional vergence and vergence facility also improved. The mean post-training CISS score (about 21) remained close to the entry threshold.

Conclusions: Six weeks of VR-based saccade and pursuit training was followed by significant gains in convergence, saccadic performance and symptoms. With no control group, the results are preliminary. Randomised trials with longer follow-up are needed before VR training can be recommended in place of established therapy.

Keywords: convergence insufficiency; virtual reality; saccades; smooth pursuit; near point of convergence; King–Devick test; CISS

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1. INTRODUCTION

Convergence insufficiency (CI) is one of the most frequently diagnosed disorders of binocular vision. People with CI cannot comfortably keep both eyes aligned on a near target, and they typically report headaches, eye strain, intermittent blur or diplopia, and a tendency to lose their place while reading [1]. Reported prevalence ranges widely, from about 2% to 33% depending on the population and the diagnostic criteria applied. The long hours many people now spend on computers, phones and tablets add to the demand placed on near vision and may worsen symptoms [2].

Treatment usually involves vergence exercises, delivered in the clinic, at home (for example pencil push-ups) or on a computer. These approaches can work, but each has practical drawbacks. Clinic-based therapy needs repeated visits and is costly, and home programmes depend on patients practising correctly and regularly, which many do not [2].

Virtual reality (VR) offers a different way of delivering the same kind of training. A head-mounted display can present controlled binocular stimuli inside an interactive game, adjust task difficulty, and keep the patient's attention in a way that repetitive exercises often cannot. In one

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comparison, VR-based training produced higher compliance and better convergence outcomes than anaglyph-based training in people with CI [3]. A pilot randomised trial in young adults found VR therapy to be comparable to office-based vergence and accommodative therapy [4]. The idea of using games for vergence training is not new: a stereoscopic computer game was tested for CI as early as 2008 and was reported to be well accepted by participants [5]. More recent work has shown that brief periods of immersive VR play can change vergence and accommodative facility and fusional vergence [6–8].

Most of this literature concentrates on vergence. Yet reading and many everyday tasks also depend on rapid saccades and smooth pursuit, and these two systems interact closely [9]. VR headsets are able to present and record both kinds of eye movement [10–12], which suggests that a programme combining fast and slow tasks could address saccadic and pursuit control alongside vergence. Neural imaging work on CI also points to changes in the brain's oculomotor networks after therapy [13], and serious games combined with eye tracking have been explored as vision-training tools [14]. VR has been discussed more broadly as a rehabilitation platform, with engagement as one of its main attractions and cost and technical limitations among its drawbacks [15].

To our knowledge, there is little evidence on VR programmes built specifically around saccadic and pursuit training in CI. The aim of this study was to measure changes in near point of convergence, King–Devick performance and symptom score after six weeks of such training in young adults with symptomatic CI.

2. METHODS

2.1 Study design and ethics

This was a prospective, single-group, pre–post interventional study carried out at bhaarith medical college and hospital, Chennai, during the 2025–2026 academic year. Participants were selected by convenience sampling. The study followed the tenets of the Declaration of Helsinki. All participants gave written informed consent before any study procedure.

2.2 Participants

Thirty adults aged 18 to 35 years took part. To be included, participants had to meet all of the following: best-corrected visual acuity of 6/6 at distance and near; a CISS score of 21 or more; near exophoria at least 4 prism dioptres (Δ) greater than at distance; a receded NPC with a break point of 6 cm or more; reduced positive fusional vergence at near; and at least two weeks of wear of an appropriate refractive correction. The diagnosis followed the criteria used in the Binocular Vision Anomalies and Normative Data (BAND) study, report 1 [16].

Exclusion criteria were: under-correction of 0.75 D or more in myopia, 1.00 D or more in hyperopia or 1.00 D cylinder or more in astigmatism; distance esophoria of 2Δ or more; strabismus, amblyopia, or manifest or latent nystagmus; any previous vision therapy; organic ocular disease or ocular

surgery; head trauma or known brain disease; systemic or psychiatric conditions, such as diabetes or anxiety, that could affect accommodation, vergence or ocular motility; use of atropine, pirenzepine or antiepileptic medication in the preceding three months; and any other binocular vision disorder.

2.3 Baseline and follow-up assessment

Each participant had a full history, objective and subjective refraction, pupil size measurement and a binocular vision examination. The sensory and motor assessment included stereopsis, Worth's four-dot test at distance and near, extraocular movements, and the cover test at both distances. The King–Devick (K-D) test and the CISS questionnaire were also completed. All measurements were repeated after the six-week training period, under best-corrected refraction.

NPC was recorded as the mean of three consecutive measurements of the break point, using an accommodative target (a single optotype, 0.8 M) and a red–green filter with a penlight. Fusional vergence was measured with rotary prisms, using a single column of 20/30 letters at 5 m and at 40 cm, and blur, break and recovery points were noted. Base-in and base-out prisms were used for negative and positive fusional vergence respectively. Near vergence facility was assessed at 40 cm with a 3Δ base-in/ 12Δ base-out flipper for 60 seconds and expressed in cycles per minute (cpm) [16,17].

Amplitude of accommodation was calculated with the formula derived from the BAND study for the Indian population [16]. Accommodative accuracy was assessed by dynamic retinoscopy using the monocular estimation method (MEM). Negative and positive relative accommodation were measured at 40 cm. Monocular and binocular accommodative facility was measured for 60 seconds using ± 2.00 D flippers and a 1.0 M word card and expressed in cpm.

The primary outcomes were NPC break point, K-D test time and CISS score. All other measures were treated as secondary outcomes.

2.4 VR training

Training was delivered through a ZEISS VR ONE head-mounted viewer (100° field of view, convex lenses, 62 mm inter-pupillary distance). Two gamified applications were used: *Temple Run*, a fast-paced game that demands rapid shifts of fixation and was used to emphasise saccadic control, and *Mr. Cat's Adventure*, a slow-paced game that requires following moving targets and was used to emphasise pursuit. Each session lasted 20 minutes without a break. Participants trained twice a week for six weeks, giving 12 sessions in total.

2.5 Statistical analysis

Data were analysed with IBM SPSS Statistics version 20. Descriptive statistics were calculated for all variables. The Shapiro–Wilk test indicated that the data were normally distributed ($p > 0.05$), so pre- and post-training means were compared with paired t-tests. A p value below 0.05 was

taken as statistically significant. For the primary outcomes, 95% confidence intervals for the mean change and the paired effect size (Cohen's *dz*) were derived from the reported mean change and *t* value (standard error = mean change ÷ *t*; *dz* = *t* ÷ √*n*). No adjustment was made for multiple comparisons.

3. RESULTS

3.1 Participants

All 30 participants completed the 12-session programme and the post-training assessment. Their mean age was 21.56 ± 2.5 years; 12 (40%) were male and 18 (60%) were female. Baseline characteristics are shown in Table 1.

Table 1. Baseline characteristics of the participants (*n* = 30)

Characteristic	Value
Age, years (mean ± SD)	21.56 ± 2.5
Sex, <i>n</i> (%)	Male 12 (40%); female 18 (60%)
King–Devick time, seconds (mean ± SD)	44.13 ± 6.75
CISS score (mean ± SD)	26.26 ± 4.07

SD, standard deviation; CISS, Convergence Insufficiency Symptom Survey.

3.2 Primary outcomes

All three primary outcomes improved after training (Table 2, Figure 1). The NPC break point moved 1.82 cm closer (*t*

= 6.17), K-D test time fell by 4.64 seconds (*t* = 8.71), and the CISS score fell by 5.00 points (*t* = 18.43). Each change was significant at *p* < 0.001 (*df* = 29). Effect sizes were large for all three measures. Using the baseline means, the average CISS score after training works out at about 21.3, and the average K-D time at about 39.5 seconds.

Table 2. Change in primary outcomes after six weeks of VR training (*n* = 30)

Outcome	Mean improvement	95% CI	<i>t</i> (<i>df</i> = 29)	<i>p</i>	Cohen's <i>dz</i>
NPC break (cm)	1.82	1.22 to 2.42	6.17	<0.001	1.13
K-D time (s)	4.64	3.55 to 5.73	8.71	<0.001	1.59
CISS score (points)	5.00	4.45 to 5.55	18.43	<0.001	3.36

Improvement means a nearer NPC, a shorter K-D time and a lower CISS score. Confidence intervals and Cohen's *dz* were derived from the mean change and *t* value. NPC, near

point of convergence; K-D, King–Devick; CISS, Convergence Insufficiency Symptom Survey.

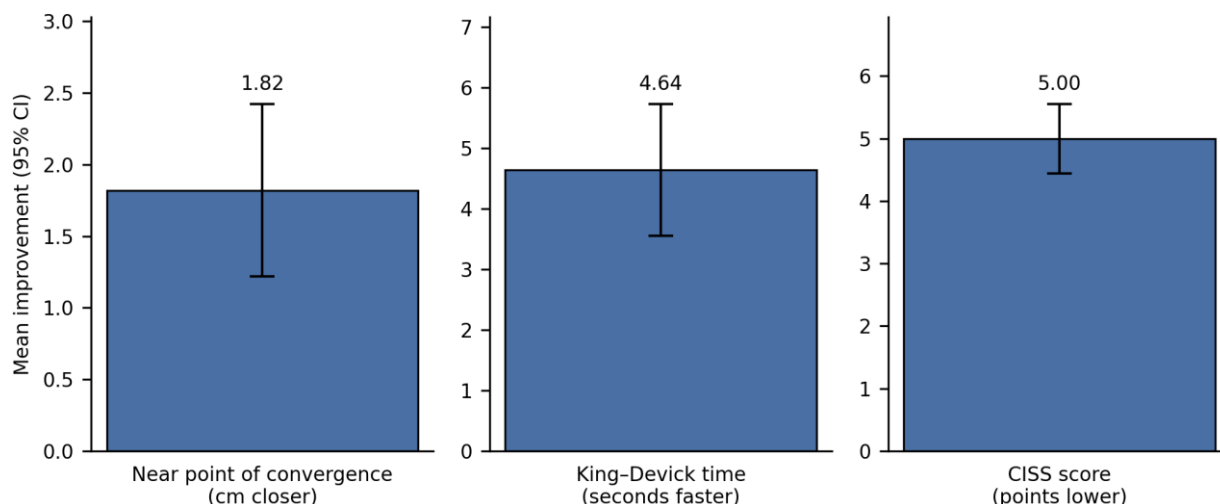


Figure 1. Mean improvement (with 95% confidence interval) in near point of convergence, King–Devick time and CISS score after six weeks of VR training. Each panel uses its own units.

3.3 Secondary outcomes

Results for the secondary outcomes are summarised in Table 3. Objective NPC break and recovery values improved (*p* < 0.001), as did the subjective break and recovery values. For the NPC measured with the accommodative target, the break point improved while the recovery point did not change significantly (*p* = 0.676).

Among fusional vergence measures, positive fusional vergence showed the clearest gains: distance blur (*p* = 0.006), near blur (*p* < 0.001), and near break and recovery (both *p* < 0.05) all improved. For negative fusional vergence, the distance break point (*p* = 0.017) and the near blur point (*p* = 0.011) improved, but distance recovery and near break and recovery did not. Vergence facility increased by 1.67 cpm (*p* < 0.001).

In the accommodative measures, the near point of accommodation and amplitude of accommodation improved in each eye separately but not binocularly. MEM retinoscopy values fell significantly, and monocular accommodative facility improved.

Table 3. Secondary outcomes after VR training

Measure	Significant change?	p value
NPC, objective break and recovery	Yes	<0.001
NPC, subjective break and recovery	Yes	Not reported
NPC (accommodative target), break	Yes	<0.001
NPC (accommodative target), recovery	No	0.676
NFV, distance break	Yes	0.017
NFV, distance recovery	No	Not reported
NFV, near blur	Yes	0.011
NFV, near break and recovery	No	Not reported
PFV, distance blur	Yes	0.006
PFV, near blur	Yes	<0.001
PFV, near break and recovery	Yes	<0.05
Vergence facility	Yes (+1.67 cpm)	<0.001
NPA and amplitude of accommodation, monocular	Yes	Not reported
NPA and amplitude of accommodation, binocular	No	Not reported
MEM retinoscopy	Yes (reduced)	Not reported
Accommodative facility, monocular	Yes	Not reported

NPC, near point of convergence; NFV, negative fusional vergence; PFV, positive fusional vergence; NPA, near point of accommodation; MEM, monocular estimation method; cpm, cycles per minute. No correction for multiple comparisons was applied; secondary results should be read as exploratory.

4. DISCUSSION

In this group of young adults with symptomatic CI, six weeks of VR training built around saccadic and pursuit tasks was followed by a nearer NPC, faster King–Devick performance, better fusional vergence at near and lower symptom scores. These findings fit with earlier reports that VR can serve as a vehicle for vergence training [3,4,6–8], and they extend that work by adding eye-movement tasks to the training.

The NPC improvement and the gain in near positive fusional vergence are the findings most closely tied to the definition of CI, since a receded near point and reduced near fusional reserve are its hallmark signs [1]. Playing a game in a headset keeps the eyes working binocularly for an extended period, and repeated exposure of this kind may have strengthened convergence responses. Earlier imaging work has linked vergence therapy to changes in brain activity in adults with CI [20], which would be consistent with a neural adaptation, although our study did not measure this. The gain in vergence facility points the same way, indicating that responses became faster as well as larger. Because accommodation and convergence are tightly coupled [18,19], the improvements in some accommodative measures may be a secondary effect of better vergence control rather than a direct effect of training.

The pattern of change in negative fusional vergence was uneven. Blur and break points improved in some

conditions, while recovery values mostly did not. One possible reading is that training improved the early part of the fusional response more than the final motor limit, but with these data and without correction for multiple testing, this should be treated as a suggestion rather than a conclusion.

The reduction in K-D time indicates faster performance on a task that requires rapid number reading and scanning, a task that depends on saccades. This agrees with the rationale for including a fast-paced game that demands frequent shifts of gaze. VR systems have been used to assess and train eye movements with eye tracking [10–12,21], but we did not record eye movements directly. The K-D test is a clinical proxy, and part of the improvement could reflect practice with the test rather than a change in saccadic control. The study design cannot separate these explanations.

The CISS fell by an average of 5 points. That change was highly consistent across participants, as the large effect size shows, but its size deserves careful interpretation. Mean scores after training were still about 21, which was the threshold used to enter the study. For many participants, symptoms were therefore reduced but not resolved after six weeks. A longer programme, a higher training dose or a combination with conventional exercises might be needed to achieve fuller symptom relief, and this is a question for future trials. Engagement and adherence were not formally measured, so the commonly stated advantage of games in this respect [2,3,15] could not be tested here, although every participant completed all sessions.

4.1 Limitations

This study has several limitations. The sample was small and recruited by convenience from a single institution, so

the findings may not generalise. There was no control or comparison group, so the improvements cannot be attributed to the VR training with certainty; test–retest learning, regression to the mean and placebo effects may have contributed, particularly for the CISS and K-D scores. The two games were not compared with each other or with conventional vergence therapy, and the individual contribution of the saccadic and pursuit components could not be separated from the vergence demand inherent in VR viewing. Eye movements were not recorded objectively. Many outcomes were tested without adjustment for multiple comparisons, so isolated secondary findings may be due to chance. Participants were not followed after the programme ended, so the durability of the effects is unknown.

5. CONCLUSION

In young adults with symptomatic convergence insufficiency, a six-week VR programme of saccade and pursuit training was followed by significant improvements in near point of convergence, King–Devick performance, fusional vergence at near and symptom score. The symptom reduction was modest, and the single-group design means a causal effect cannot be confirmed. Randomised controlled trials with a comparison group, larger samples, objective eye tracking and long-term follow-up are needed to establish whether VR training can be recommended as part of CI management.

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