Original Article

JHSMR Journal of Health Science and Medical Research

Influence of Watching 3D Video on Accommodation, Vergence Function, and Visual Fatigue

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Received 13 May 2025 ● Revised 23 September 2025 ● Accepted 16 October 2025 ● Published online 22 June 2026

Abstract:

Objective: 3D video consumption has become increasingly popular these days. This study aimed to evaluate the effect of different 3D video-watching techniques: Virtual reality (VR), polarised filter (PR), and red/green filter(R/G) on accommodation, vergence parameters, and associated subjective symptoms.

Material and Methods: This cross-sectional study included 25 young adults with refractive error ±0.50D and stereo acuity better than 60 arc seconds. Participants with binocular vision anomalies and ocular pathologies were excluded. Baseline binocular vision parameters were measured, followed by a 30-minute 3D video watching session under each condition (VR, PR, and R/G) in dim illumination. Post-task binocular vision assessment was performed for each condition, and the ODAS (Ocular Discomfort Analog Scale) questionnaire was administered to assess the subjective symptoms.

Results: A significant reduction in median distance negative fusional vergence (NFV) was observed with R/G (6±4 PD, p-value=0.002) and PR (6±4 PD, p-value=0.04) compared to the baseline (10±4 PD). Compared to baseline, negative relative accommodation (NRA), accommodative facility (AF), and vergence facility (VF) were significantly impaired across all three viewing conditions. ODAS scores indicated higher eye fatigue with VR (4±4), followed by PR (3±2) and R/G (2±3).

Conclusion: All three 3D video-watching techniques caused significant deterioration in accommodation and vergence functions. Subjective symptoms, including dryness, burning, blurred vision, and visual fatigue, were the most pronounced with VR, followed by PR and R/G filter.

Keywords: 3D Video, Accommodation, Binocular Vision, Filters, Vergence, Virtual Reality

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J Health Sci Med Res 2026;44(5):e20261369
doi: 10.31584/jhsmr.20261369
www.jhsmr.org

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Introduction

The display market has seen a surge in new technologies and equipment, with stereoscopic displays taking centre stage[1]. 3D content, from games and animations to movies and sports broadcasts, has become increasingly popular[2]. However, a significant concern with stereoscopic displays is visual fatigue. Conventional 3D displays create a conflict between the eye's vergence and accommodation systems. Vergence refers to the relatively slow, disjunctive, non-conjugate movement of both eyes, initiated to track and fuse stationary or moving objects located at different distances, while accommodation refers to visual responses for focusing on near objects[3,4]. Binocular disparity is the difference between the position of an image feature in one eye and that of the corresponding image feature in the other eye, which cues the vergence system to converge on a near-point object on the display[5]. However, the accommodation system must focus on the actual display surface, which is typically fixed at a far distance. This mismatch between the two systems can disrupt binocular fusion and lead to visual fatigue. Several models based on accommodation and vergence (DAVI model, 3D-AVM model) have also demonstrated the ability to predict visual discomfort while watching stereoscopic videos[6,7]. Studies have shown that prolonged viewing (around 30 minutes) of stereoscopic displays can induce asthenopia, a general feeling of eye strain and discomfort[8–10]. A study also reported that participants with no clinically measurable stereo acuity can still experience 'pop-out' effects while viewing 3D videos[11].

While research on visual discomfort caused by stereoscopic and auto-stereoscopic displays is ongoing, the methods used to deliver 3D experiences have evolved. Early 3D movies utilized red/green filters, requiring viewers to wear coloured glasses to separate the parallax-shifted images for each eye[12]. Modern advancements include polarizing filters, allowing for colour viewing in 3D films[13]. Virtual reality has emerged as another prominent platform for stereoscopic visuals[14]. Despite these advancements, the issue of eyestrain associated with 3D displays remains a critical discussion point. Amenos et al. found that Projected VR systems are less likely to induce uncomfortable ocular symptoms than head-mounted VR devices due to the difference in visual system demand that they produce[15]. It was also found that when compared to static disparity information, our human visual system can utilize dynamic disparity information more effectively[16].

This study aimed to evaluate the impact of different 3D video-watching techniques on accommodation and vergence parameters. Here, we have compared three popular methods: Virtual reality (VR), red/green (R/G) filters, and polarised (PR) filters. By analysing accommodation and vergence changes during 3D video viewing with these techniques, we hope to gain insights into which method creates the least strain on the visual system, potentially contributing to a more comfortable and immersive 3D experience.

Material and Methods

Participants:

Twenty-five college students (19 females, 6 males) aged 18–25 years (mean ± S.D.: 20.3±0.9) participated in the experiment. After providing informed consent, participants underwent a comprehensive eye examination. Those with normal or corrected-to-normal visual acuity and normal stereo acuity (assessed using the Randot stereo test) were included. Additionally, baseline binocular vision assessments were conducted, including Near Point of Convergence (NPC), Near Point of Accommodation (NPA), Negative Fusional Vergence (NFV), Positive Fusional Vergence (PFV), Vergence Facility (VF), Accommodative Facility (AF), Negative Relative Accommodation (NRA), and

Positive Relative Accommodation (PRA). Participants with any ocular pathology or binocular vision anomalies were excluded from the study. The study was approved by the Institutional Ethics Committee of SRM Medical College Hospital and Research Centre (Ethics clearance number: SRMIEC-ST0323-363) and followed the Declaration of Helsinki.

To assess individual susceptibility to motion sickness, participants completed the Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ) (Keshavarz, Murovec, & Golding, 2021) before the experiment.

Experimental setup:

Three different 3D video viewing conditions were tested. Each participant was randomly assigned to one of the three following conditions per session.

Condition 1 (VR Headset): Participants watched a 3D animated video using a virtual reality (VR) device for 30 minutes while seated comfortably in a dimly lit room (2–5 lux) (Figure 1). The video was displayed on a smartphone (1080p resolution, brightness: 230–250 lux) placed inside a head-mounted VR box.

Condition 2 (Red-Green (R/G) Filter): Participants watched the same 3D video for 30 minutes using an R/G filter system. They were seated at a viewing distance of 40 cm (Figure 2), wearing goggles with a red lens over the right eye and a green lens over the left eye. The room illumination, video resolution, and smartphone size were identical to Condition 1.

Condition 3 (Polarized (PR) Glasses): Participants watched the 3D video for 30 minutes using polarized (PR) glasses at a viewing distance of 40 cm. The lighting conditions, video resolution (Figure 3), and smartphone dimensions were the same as in Condition 1.

Procedures

After a comprehensive eye examination and baseline assessment of binocular vision parameters, each participant watched a 3D video for 30 minutes using one of the three viewing techniques (VR, R/G, or PR) in a randomized order across three different sessions. Post-task binocular vision assessments were conducted immediately after watching the 3D video in each session. To prevent carryover effects, a minimum 1-week washout period was maintained between sessions. To ensure consistency, all assessments were conducted under identical lighting conditions, viewing distances, and examiner instructions across sessions. Additionally, participants completed the Ocular Discomfort Analog Scale (ODAS) questionnaire after each session to assess subjective visual discomfort, including symptoms such as photophobia, burning, blurred vision, tightness or pressure around the eyes, dry eyes, foreign body sensation, and onset of symptoms.

Statistical analysis:

Statistical analyses were conducted using SPSS software. The Shapiro-Wilk test was applied to assess the normality of data distribution. All data were presented as median ± interquartile range. Pre- and post-video viewing values were compared using the Wilcoxon signed-rank test. A p-value<0.05 was considered statistically significant.

Results

After 30 minutes of watching a 3D video, post-task NPC break and recovery distances significantly increased across all conditions compared to baseline. The largest increase was observed with VR (p-value=0.039 for break, p-value=0.047 for recovery), followed by PR (p-value=0.02 for break, p-value=0.014 for recovery) and R/G (p-value=0.056 for break, p-value=0.014 for recovery). This suggests that 3D video exposure leads to a temporary reduction in convergence ability, with VR having the most

pronounced effect. No significant differences were observed in objective NPC break and recovery across conditions.

NFV at distance showed a significant reduction with R/G (6±4 PD; p-value=0.002) and PR (6±4 PD; p-value=0.046) compared to baseline (10±4 PD), as shown in Figure 4a. However, no statistically significant difference was observed between baseline and VR (8±4 PD; p-value=0.077). At near, the median baseline NFV (16±6 PD) was significantly higher than post-task values with R/G (14±4 PD; p-value=0.004) and PR (12±6 PD; p-value=0.002) (Figure 4b). No significant difference was found between baseline NFV and VR (14±4 PD; p-value=0.018).

The Negative Relative Accommodation (NRA) significantly decreased across all conditions. The baseline NRA (+3.50±0.75 D) was significantly higher than post-task values in VR (+2.75±0.5 D, p-value<0.01), R/G (+2.75±0.75 D, p-value<0.01), and PR (3.00±1.00 D, p-value<0.01).

Vergence and Accommodative Facility were also found to decline post-task. When compared to the baseline accommodative facility (13±4 cpm), significant reductions were observed in VR (10±7.5 cpm; p-value=0.004), R/G (9.5±4 cpm; p-value=0.002), and PR (10±6.5 cpm; p-value=0.018). Similarly, vergence facility significantly decreased from baseline (14±2 cpm) in VR (12±2.5 cpm; p-value=0.005), R/G (13±2 cpm; p-value=0.005), and PR (12.5±2.5 cpm; p-value=0.003) (Figure 5).

No significant changes were observed in Near Point of Accommodation (NPA), Positive Relative Accommodation (PRA), or Positive Fusional Vergence (PFV) between baseline and all three conditions (Table 1).

The ODAS questionnaire revealed that eye fatigue was most pronounced in VR (4±4), followed by PR (3±2) and R/G (2±3). Other symptoms, including eye dryness, burning/stinging, and blurred vision, were reported more frequently in VR than in R/G and PR (Figure 6).

Figure 1 Image showing participant watching 3D video with virtual reality device

Figure 2 Image showing participant watching 3D video with red-green filter

Figure 3 Image showing participant watching 3D video with polaroid filter

Table 1 Comparison of the accommodation and vergence parameters between the baseline and post-task measurements after watching a 3D video with VR, R/G, and PR

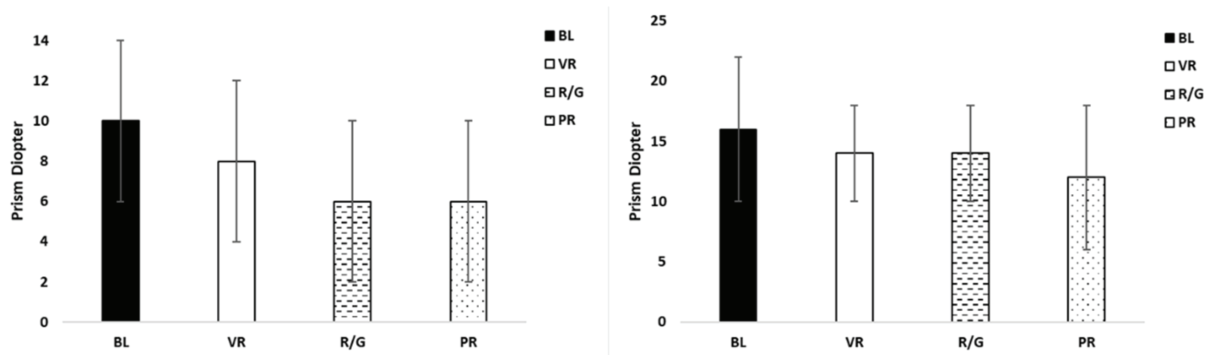
Parameters		Baseline [Median (IQR)]	Post-task VR [Median (IQR)]	p-value (Baseline vs VR)	Post-task R/G [Median (IQR)]	p-value (Baseline vs R/G)	Post-task PR [Median (IQR)]	p-value (Baseline vs PR)
NPC Subjective (cm)	Break	6 (4)	8 (4)	0.05	7 (2)	0.056	8 (5)	0.02
	Recovery	8.5 (5)	10 (5)	0.039	9 (4)	0.047	9 (6)	0.018
NPC Objective (cm)	Break	7 (4)	8 (5)	0.076	8 (3)	0.033	8 (4)	0.016
	Recovery	8 (4)	10 (7)	0.035	9 (4)	0.017	10 (4)	0.014
NFV Distance Prism Dioptre (PD)	Blur	0 (0)	0 (0)	1	0 (0)	1	0 (0)	1
	Break	10 (4)	8 (4)	0.077	6 (4)	0.002	6 (4)	0.046
	Recovery	10 (6)	6 (4)	0.126	6 (4)	0.007	6 (4)	0.002
NFV Near (PD)	Blur	0 (0)	0 (0)	0.317	0 (0)	0.317	0 (0)	0.317
	Break	16 (6)	14 (4)	0.404	14 (4)	0.009	12 (6)	0.001
	Recovery	14 (4)	12 (4)	0.419	12 (4)	0.002	10 (6)	0.004
PFV Distance (PD)	Blur	0 (0)	0 (0)	0.068	0 (0)	0.109	0 (0)	0.157
	Break	16 (8)	16 (10)	0.727	16 (10)	0.337	14 (10)	0.627
	Recovery	14 (8)	14 (10)	0.561	14 (8)	0.432	12 (10)	0.959
PFV Near (PD)	Blur	0 (0)	0 (0)	0.317	0 (0)	1	0 (0)	0.18
	Break	20 (9)	18 (9)	0.226	18 (13)	0.19	18 (11)	0.067
	Recovery	18 (6)	16 (6)	0.558	16 (10)	0.421	16 (8)	0.207
VF (CPM)		14 (2)	12 (2.5)	0.005	13 (2)	0.005	12.5 (2.5)	0.003
NPA (in mm)	Right eye	7.5 (2.5)	8.8 (2.5)	0.152	8 (2.5)	0.391	8 (3)	0.158
	Left eye	8 (2.5)	8 (2)	0.227	8 (2.5)	0.468	8.5 (2.5)	0.124
	Both eyes	7 (2.5)	7 (2.5)	0.972	7 (2)	0.343	7 (3.5)	0.83
NRA (D)		3.5 (0.75)	2.75 (0.5)	0	2.75 (0.75)	0	3 (1)	0.001
PRA (D)		3.75 (1.25)	3.5 (1)	0.189	3.25 (1.5)	0.538	3.5 (1.5)	0.222
AF (CPM)	Right eye	12 (3)	11 (3.5)	0	10.5 (5)	0.004	10.5 (6)	0.024
	Left eye	13 (3.5)	9 (5.5)	0	8.5 (5)	0.001	10 (6)	0.009
	Both eyes	13 (4)	10 (7.5)	0.004	9.5 (4)	0.002	10 (6.5)	0.018

NPC=Near Point of Convergence, NFV=Negative Fusional Vergence, PFV=Positive Fusional Vergence, VF=Vergence Facility, NPA=Near Point of Accommodation, NRA=Negative Relative Accommodation, PRA=Positive Relative Accommodation, AF=Accommodative Facility, CPM=Cycles Per Minute, PD=Prism Dioptre, IQR=Inter Quartile Range, VR=Virtual Reality, R/G=Red/Green filters, PR=Polarised filters

Discussion

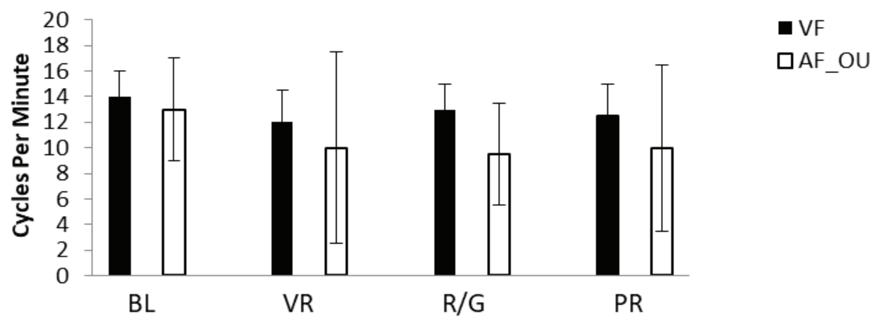
The present study aimed to evaluate the impact of 3D video watching on binocular vision parameters and ocular symptoms in healthy young adults. Our findings suggest that certain binocular vision parameters, particularly NFV and AF, were significantly influenced by watching 3D video. The results were similar to Zang et al., who also found a significant increase in accommodation and vergence while viewing a 3D stimulus[17]. In particular, a significant deterioration was observed in NFV and accommodative function.

The significant reduction in NFV at distance with R/G and PR suggests that these viewing conditions may pose greater challenges to the binocular fusion system. This



BL=Baseline, VR=Virtual Reality, R/G=Red/Green filters, PR=Polarised filters

Figure 4 Changes in Negative Fusional Vergence (NFV) at distance (4a) and near (4b) pre- and post- watching 3D video with three different devices



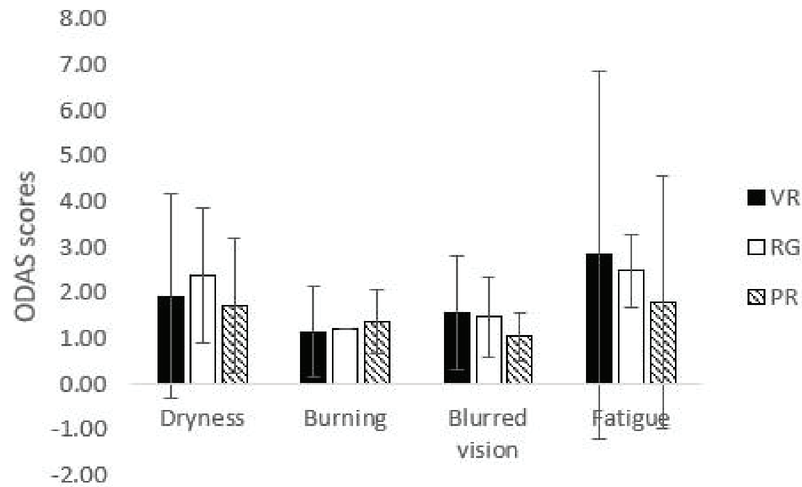
BL=Baseline, VR=Virtual Reality, R/G=Red/Green filters, PR=Polarised filters, VF=Vergence Facility, AF_OU=Binocular Accommodative Facility

Figure 5 Changes in accommodative facility and vergence facility while watching 3D video with three different devices

could be attributed to the stereoscopic depth cues provided by these display methods, requiring increased vergence effort to maintain binocular fusion. However, the lack of a significant NFV reduction in VR at distance is noteworthy. Unlike R/G and PR, VR incorporates additional visual cues, such as head tracking and motion parallax, which might mitigate the vergence load and contribute to a different binocular fusion response.

At near, the baseline NFV was significantly higher than post-task NFV with R/G and PR, indicating that the near binocular fusion system is relatively resilient to the effects of 3D video exposure. However, the significant deterioration in NFV with VR at near suggests that near binocular fusion may also be susceptible to VR-induced vergence stress.

The significant reduction in NRA and accommodative facility across all three 3D video conditions highlights the impact of 3D video exposure on accommodative function. This could be due to the increased accommodative demand required to maintain focus on stereoscopic images,



VR=Virtual Reality, R/G=Red/Green filters, PR=Polarised filters

Figure 6 Average scores of the Ocular Discomfort Analog Scale (ODAS) questionnaire

leading to accommodative fatigue and reduced efficiency[18]. Prolonged exposure to 3D stimuli may disrupt normal accommodation-vergence interactions, resulting in visual discomfort and reduced visual performance[19].

The higher prevalence of ocular symptoms, particularly eye fatigue, in VR compared to R/G and PR aligns with previous findings[20]. Several factors could contribute to this, including the immersive nature of VR, which leads to prolonged and intense visual stimulation and greater accommodation-vergence conflicts. Induced by head movement and latency issues in VR headsets, VR places unique demands on the visual system and can potentially cause motion sickness. These factors suggest that VR may impose a greater strain on the visual system than other 3D viewing methods, making it less comfortable for prolonged use. Additionally, ocular symptoms, particularly eye fatigue, were more prevalent with VR compared to R/G and PR. This could be due to VR devices inducing greater accommodation-vergence conflicts, leading to increased eye strain and fatigue[21].

Our study demonstrates that 3D video watching can significantly impact binocular vision parameters and ocular symptoms in healthy young adults. While further research is needed to fully understand the underlying mechanisms and long-term consequences of prolonged 3D video exposure, these findings highlight the potential risks associated with 3D viewing, particularly for individuals with pre-existing binocular vision problems or ocular sensitivities. Future studies could explore the effects of 3D video exposure in individuals with different refractive errors and across various age groups, providing deeper insights into how visual factors influence binocular function and discomfort in diverse populations.

Conclusion

Our study concluded that the binocular vision parameters were significantly affected, with notable changes observed in NPC, NFV, NRA, and vergence facility across all three viewing conditions. However, NPA, PRA, and PFV remained unaffected. Additionally, our findings suggest

that R/G and PR filters induced significant changes in accommodation and vergence parameters compared to VR. However, ocular symptoms, particularly eye fatigue, were more prevalent with VR than with R/G and PR filters, highlighting the potential for greater visual discomfort with immersive 3D experiences.

Acknowledgement

We would like to thank Dr Aiswaryah Radhakrishnan for providing her valuable input throughout the study.

Conflict of interest

The authors have no competing interests to declare.

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