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ORIGINAL ARTICLE

The effect of gaming on accommodative and vergence facilities after exposure to virtual reality head-mounted display

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KEYWORDS
Virtual Reality;
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Abstract
Background: To investigate the change between accommodative and vergence facilities before and after exposure to gaming in a virtual reality (VR) device amongst participants with normal binocular visual function.
Methods: 62 participants between the ages of 18–30 years with normal binocular visual function and inter-pupillary distances between 51 and 70 mm were selected for the study. Spectacle and contact lenses users were excluded. The experimental group (n = 42) was exposed to gaming using Samsung Gear VR(SM -R323) whilst the control group (n = 20) watched a television film projected on a two-dimensional screen at 1 m. Pre-test and post-test binocular amplitude-scaled facilities and vergence facilities were obtained for both groups after exposures of 25 min.
Results: Binocular accommodative facilities for the experimental group had a mean pre-test and post-test facility of 11.14 $\pm$ 3.67 cpm and 13.38 $\pm$ 3.63 cpm, respectively, after gaming using VR device. The vergence facilities for the experimental group had a mean pre-test and post-test facility of 11.41 $\pm$ 3.86 cpm and 15.28 $\pm$ 4.93 cpm, respectively, after gaming using a VR device. Binocular accommodative facilities for the control group had a mean pre-test and post-test facility of 11.70 $\pm$ 3.2 cpm and 11.95 $\pm$ 3.4 cpm, respectively. Vergence facilities for the control group had a mean pre-test and post-test facility of 11.55 $\pm$ 6.4 cpm and 11.70 $\pm$ 4.9 cpm, respectively. The mean change for binocular accommodative facilities was 2.24 $\pm$ 3.43 cpm and 0.25 $\pm$ 1.25 cpm for the experimental and control group, respectively. The mean change for vergence facilities was 3.81 $\pm$ 3.09 cpm and 0.15 $\pm$ 2.72 cpm for the experimental and control group, respectively. Binocular accommodative facilities and vergence facility showed a statistically significant mean increase greater than the control group after gaming using a VR device using an independent t-test ($p < 0.05$).

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Conclusion: The results showed that binocular accommodative facilities and vergence facilities increased after 25 min of VR gaming in emmetropic participants under 30 years of age with inter-pupillary distances between 51 mm and 70 mm.

PALABRAS CLAVE
Realidad virtual;
Facilidad de acomodación;
Facilidad de vergencia;
Juego

Efecto del juego en la flexibilidad de acomodación y vergencia tras la exposición a un dispositivo de realidad virtual acoplado a la cabeza

Resumen
Antecedentes: Investigar el cambio en la flexibilidad de acomodación y vergencia antes y después de la exposición al juego en un dispositivo de realidad virtual (RV) entre participantes con función visual binocular normal.
Métodos: Para el estudio se seleccionó a 62 participantes de edades comprendidas entre 18 y 30 años, con función visual binocular normal y distancias inter-pupilares comprendidas entre 51 y 70 mm. Se excluyó a los usuarios de gafas y lentillas. El grupo experimental (n = 42) se expuso al juego utilizando Samsung Gear VR (SM-R323), mientras el grupo control (n = 20) visionó una película de televisión proyectada en una pantalla de dos dimensiones a una distancia de 1 m. Se obtuvieron en ambos grupos los valores de flexibilidad de amplitud escalada binocular y de vergencia pre-test y post-test, tras una exposición de 25 minutos.
Resultados: Los valores medios de flexibilidad de acomodación binocular pre-test y post-test para el grupo experimental fueron de 11,14 $\pm$ 3,67 cpm y 13,38 $\pm$ 3,63 cpm, respectivamente, tras el juego con el dispositivo de RV. Los valores medios de flexibilidad de vergencia para el grupo experimental fueron de 11,41 $\pm$ 3,86 cpm y 15,28 $\pm$ 4,93 cpm, respectivamente, tras el juego con el dispositivo de RV. Los valores medios de flexibilidad de acomodación binocular pre-test y post-test para el grupo control fueron de 11,7 $\pm$ 3,2 cpm y 11,95 $\pm$ 3,4 cpm, respectivamente. Los valores medios de flexibilidad de vergencia pre-test y post-test para el grupo control fueron de 11,55 $\pm$ 6,4 cpm y 11,7 $\pm$ 4,9 cpm, respectivamente. Los valores del cambio medio para la flexibilidad de acomodación binocular fueron de 2,24 $\pm$ 3,43 cpm y 0,25 $\pm$ 1,25 cpm para los grupos experimental y control, respectivamente. Los valores del cambio medio para la flexibilidad de vergencia fueron de 3,81 $\pm$ 3,09 cpm y 0,15 $\pm$ 2,72 cpm para los grupos experimental y control, respectivamente. La flexibilidad binocular de acomodación y vergencia reflejó un incremento medio estadísticamente significativo superior con respecto al grupo control tras el juego con un dispositivo de RV, utilizando una prueba t independiente $p < 0,05$.
Conclusión: Los resultados reflejaron que la flexibilidad de acomodación binocular y la flexibilidad de vergencia se incrementaron tras 25 minutos de juego con RV en los participantes emetrópicos menores de 30 años, con distancias inter-pupilares comprendidas entre 51 y 70 mm.

Introduction

The World Economic Forum, has included Virtual Reality (VR) as part of the fourth industrial revolution.[1] VR is becoming increasingly accessible, giving thousands of users' access to an immersive experience. VR gaming arcades has become increasingly popular in China, Japan, Taiwan, and Australia.[2] Approximately 7 million of VR devices were sold globally in 2016, and sales are predicted to quadruple by 2020.[3] Today, VR head-mounted displays (HMD) feature in the gaming, medicine, education and tourism sectors. It is estimated that the VR gaming market worth would reach 22.9 billion U.S dollars in 2020,[3] with claims by the International Data Corporation (IDC) of approximately 53.1 million VR headsets shipped by the year 2021.[4]

The arrival of VR allows for an era where a giant space battle in a living room is a possibility. Virtual reality devices (VRD) are designed to simulate an alternate reality, allowing for an exhilarating experience in which the user feels a ''sense of presence'' in an interactive three-dimensional environment.[5] The immersion experience provided by VR sets it apart from augmented reality which is an enhanced version of reality, created to escalate one's perception of reality through the use of computer generated images.[5,6]

Common short-term side effects such as cyber-sickness, motion sickness, nausea and headaches have been listed among VR users.[7–9]

The HMD functions by engaging the ability of depth perception by creating disparity in images seen by each eye by assuming that the average near point of an individual is 25 cm and an eye-lens separation of the HMD of 7-cm infers the user will have to compensate by accommodating three times more than they would at their near point.[10] The images are depicted at varying distances, thus the convergence is not constant throughout, hence creating a conflict between the coupled accommodation and convergence systems manifesting in the resulting aforementioned symptoms.[11–13] The viewing distance of head mounted displays are considerably small, and leads us to believe that this prolonged exposure may lead to changes in accommodative and vergence facility. Schieman and Wick[14] discusses accommodative and vergence facilities is a measure of the stamina and dynamics of vergence and accommodative response.

According to Kooi et al.,[15] visual strain can be quantified by measuring accommodative facilities. Studies conducted on both virtual and augmented reality revealed a reduction in accommodative facilities after at least twenty minutes of VR use using a *Vision Sport HMD Vision IO*, which inferred a potential source of eyestrain.[15,16] After ten minutes of VR exposure, Mon-Williams et al[17] found an esophoric shift at distance using an *Eyephone LX HMD*, and this implies that there is significant stress placed on the accommodative-convergence system. Turnbull et al.[18] in 2017, studied the effects of VR in four different environments after 40 min and concluded it had no effect on amplitude of accommodation, fixation disparity, heterophoria, stereopsis and choriodal thickening. Likewise, they concluded the VR HMD had no influence on myopic progression despite its near viewing distance. Previous studies have showed that this uncoupling of accommodation and vergence causes symptoms, such as headaches, sore eyes, blurred vision and difficulty concentrating.[11–13] The potential effect that gaming in a VRD could have on our accommodative-convergence system is a factor that informed our investigation due to the accommodative-convergence conflict. However, no evidence regarding its effects on vergence facility exists.

Backus et al.[19] found that the use of VR devices could treat conditions such as suppression, amblyopia and convergence insufficiency using the Oculus Rift Development Kit as a binocular vision therapy device. It was found that the accommodative-convergence conflict served as a benefit to the treatment of convergence insufficiency.[19]

The future of VR in various sectors is undeniable, with the gaming sector appealing to the techno savvy generation of today. The prolonged exposure and accommodation-convergence conflict motivated us to evaluate the endurance of the visual system by investigating the dynamics and stamina of the accommodative response known as accommodative facility and the ability of the fusional vergence system to rapidly and accurately respond to varying vergence demands over-time termed vergence facility. It is important to note that during accommodative facility testing, accommodation changes whilst vergence remains constant and similarly with vergence facility testing accommodation remains constant.

Therefore, by evaluating these two aspects before and after virtual reality exposure, the study aims to investigate the effect of playing a game in VR using a HMD on accommodative and vergence facilities to help suppliers; optometrists and VR users better understand the effects of HMD use on the binocular visual system with the rise in its popularity in the present day fourth industrial revolution and the rise in gaming today. The research question for the study is, does gaming in a VR HMD effect binocular accommodative and vergence facilities?

Methodology

The study is a quasi-experimental design. Participants were recruited using a convenient sampling technique. The total sample size comprised 62 university students with 42 comprising the experimental and 20 comprising the control group between the ages of 18–30 years. The sample size was determined using Cochran's formula: $n = \frac{z^2 s}{d^2}^2$ where $\boldsymbol{s} = \frac{(n_1 - s_1^2) + (n_2 - s_2^2)}{\bigcap_1 + \bigcap_2 - 2}$; z = standard value from normal distribution: 1.96, s (values from pilot study) where: n1 and n2=sample size (11) and s1 and s2 3.698 and 3.443 respectively, with d = margin of error of 0.05.

The study was conducted at the eye clinic of an optometry department located on the campus of South African university. All participants whose visual acuities were 6/6 and 1 M at distance and near respectively, refractive error of (<0.50DS/DC),[20] with an inter-pupillary-distance between 55 mm and 70 mm, and a near point of convergence of less than 10 cm were included in the study. Spectacle and contact lenses users and students with a history of ocular and or systemic disease and binocular vision disorders were excluded from the study.

Both experimental and control group participants were recruited irrespective of their pass/fail criteria for both accommodative and vergence facilities, as the purpose of the study was to determine if the accommodative and vergence facilities improved or declined, irrespective of participants passing the baseline normal for the respective tests. Experimental data was collected first followed by control data in order to age and sex match participants. Baseline characteristics and test procedures were kept constant for both experimental and control group and the same fieldworkers gathered data for both groups. The pass/fail criterion for facility testing was not consider as the focus of the study was to investigate the effects of VR on facilities irrespective of reduced or normal baseline measurements.

Procedure

A Samsung Gear VR(SM -R323) head mounted device powered by Oculus Rift was utilized to elicit the VR exposure. The field of view elicited by the device was 101 degrees with convex lenses in the HMD with an inter-pupillary distance of 62 mm. Data collection consisted of pre- and post-test binocular accommodative and vergence facility measurements.

Binocular accommodative facilities (BAF) were measured using binocular amplitude-scaled facilities[21] where probe lenses were determined using 30 percent of the individual participant's binocular push-up amplitude of accommodation. Thus, probe lenses were customised according to the participant's binocular amplitude of accommodation. Participants fixated a 20/30 target on an accommodative rock card which was held at a test distance which was calculated using 45 percent of the participant's binocular push up amplitude of accommodation. Participants were to fixate on a word until letters were visible after interposition of the probe lens.[21] Vergence facility was measured using 12^{Δ}BO and 3^{Δ}BI flipper prisms with participants fixating a vertical row of 20/30 letters at a standard test distance of 40 cm until fusion was regained.[14] Accommodative facility using binocular amplitude-scaled facilities was regarded normal at greater than or equal to 10 cpm whilst normal vergence facility using 12^{Δ}BO/3^{Δ}BI prisms was defined as greater than or equal to 15 cpm.[14]

Pilot study

A pilot study consisting of 11 participants was conducted in order to obtain the appropriate gaming time to elicit a change in accommodative and vergence facilities. A fast-paced game, ''Temple run'' and a slow-paced game, ''Mr Cat's adventure'' were piloted. The results determined that the average time of twenty-five minutes using the fast-paced game, ''Temple Run'' showed a change in accommodative and vergence facilities thus informing the choice of a fast-paced game with a minimum of 25 min of VR exposure for data collection. Participants who did not pass pre-test facilities were still admitted into the study as the results from the pilot study showed a statistically significant increase in post-test accommodative facility. P-values from the pilot study were used to calculate the sample size using Cochran's formula.

Data collection

Pre-test binocular amplitude-scaled facilities and vergence facilities were obtained before VR exposure. Participants were then given 25 min to play a fast-paced game on the Samsung VR display. Thereafter post-test accommodative and vergence facility measurements were obtained. Testing was alternated for each participant to guard against the influence of the procedure on results. A control group consisting of 20 participants (obtained using Cochran's formula) who met the inclusion criteria were made to watch a fast-paced film on a two dimensional projection screen for a period of 25 min at 1 m to reduce the effects of accommodation. Examiners were unmasked during exposure to VR for the experimental group and the non-VR exposure for the control group. This was to ensure the same examiners performs the same facility test for the age-matched control. Pre-test and post-test facilities as described for the experimental group was measured in an identical manner for the control group. 35 participants of the experimental group self-administered the convergence insufficiency symptom survey (CISS) as an aid to gauge any level of symptomology before and after VR exposure.

Data analysis

The Statistical Package for Social Sciences (SPSS) version 24 was utilized to analyse data. Descriptive statistics included means, standard deviations and medians. Distributions of variables were presented using tables at a statistical significance of $p < 0.05$.

Ethical considerations

Ethical permission was obtained from the Biomedical Research and Ethics Committee (ethical clearance reference number: BE 234/18) at the University of KwaZulu-Natal. All participants signed an informed consent prior to commencement of the study. All researchers ensured that participant information was kept confidential. The conduct of the study complied with the Declaration of Helsinki regarding research on human subjects.

Results

42 participants comprised the experimental group; 27 were female and 15 were male, with a mean age of 21.07 ± 2.00 years. 20 participants comprised the control group; 11 were female and 9 were male with a mean age of 20 ± 1.47 years. The Kolmogorov–Smirnov Test revealed that distribution of the data was normal thus informing the use of means and standard deviations to represent the data as the data was not skewed.

A sub-sample of 35 participants from the experimental group had self-administered the convergence insufficiency symptom survey (CISS) to gauge for binocular vision symptomology. A mean CISS score of 12.26 which increased to 14.49 after VR exposure however, the change was not statistically significant for the paired *t*-test ($p = 0.20$). The expected score for the experimental group's age of 21 years was less than 16 which implied the group was not symptomatic.

Binocular Amplitude-scaled facility after gaming using a VR device

Fig. 1 and Table 1 shows for binocular amplitude-scaled facilities the experimental group had a mean pre-test facility of 11.14 ± 3.67 cpm and after gaming using VRD the mean post-test facility was 13.38 ± 3.63 cpm. The mean increase for binocular accommodative facilities was 2.24 ± 3.43 cpm and 0.25 ± 1.25 cpm for the experimental and control group, respectively. A paired t-test showed that there is a mean change between pre-test and post-test accommodative facilities was statistically significant for the experimental group ($p < 0.001$). The mean binocular accommodative facility change for the experimental group is more than the mean binocular accommodative facility change for the control group which was statistically significant on the independent *t*-test as shown in Table 1 ($p = 0.002$). Binocular accommodative facilities for the control group had a mean pre-test and post-test facility of 11.70 ± 3.2 cpm and 11.95 ± 3.4 cpm, respectively.

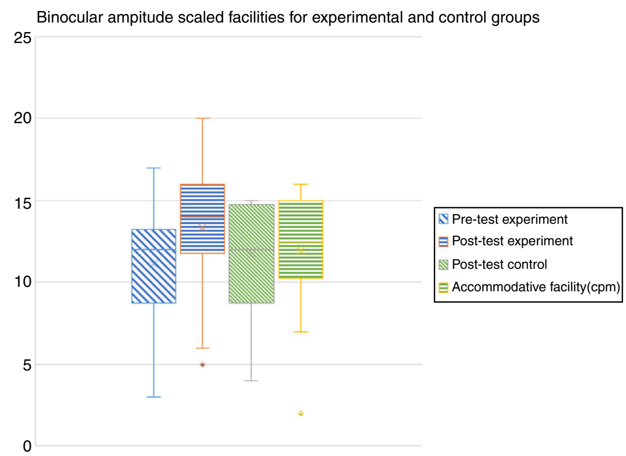

Figure 1 Box and Whisker plot showing changes in mean pre and post-test binocular accommodative facilities for the control and experimental group after 25 min of gaming using a VRD.

Figure 2 Box and Whisker plot showing mean changes (cpm) in vergence facilities in the experimental and control groups after 25 min of gaming using VRD.

Vergence facility after gaming using a VR device

Fig. 2 and Table 1 shows for vergence facilities the experimental group had a mean pre-test facility of 11.47 ± 3.86 cpm and after gaming using a VRD the mean post-test facility was 15.28 ± 4.93 cpm. The mean change for vergence facilities was 3.81 ± 3.09 cpm and 0.15 ± 2.72 cpm for the experimental and control group, respectively. A paired t-test showed a significant mean change between pre-test and post-test vergence facilities for the experimental group ($p < 0.001$). The mean change in vergence facility for the experimental group is more than the mean change in vergence facility for the control group which was statistically significant on the independent t-test as shown in Table 1 ($p < 0.001$). Vergence facilities for the control group had a mean pre-test and post test facility of 11.55 ± 6.4 cpm and 11.70 ± 4.9 cpm, respectively.

Discussion

The study set out to determine the effects of gaming in a VRD on binocular accommodative and vergence facilities. The fixed accommodative demand in a HMD, and the associated accommodative-convergence disconnect did not cause the visual system to fatigue[13] after 25 min of gaming using VRD. Results showed an increase in the dynamics and stamina of the accommodative system by 2.24 cpm which was measured using binocular amplitude-scaled facilities. The fusional vergence system rapidly responded to the varying vergence demand and increased by 3.81 cpm which was measured using vergence facility. Turnbull et al.[18] found no effect on binocular vision and although facilities increased, this finding may agree with Turnbull et al. in that there was no deterioration.

The study findings disagrees with the results of Kooi et al.[15] and Kang et al.[16] who showed a reduction in accommodative facilities after 24 min and 20 min of VR exposure respectively. Exposure times were very similar thus this may not serve basis for disagreement in results. However, Kooi et al.[15] attributed the results of reduced accommodative facilities to binocular rivalry. Possible reasons for the disagreement with this study could be attributed to the use of different VR devices and variation in the activity participants were required to engage in. Kooi et al.[15] subjected participants to a dynamic reading task and thereafter measured visual strain whilst Kang et al.[16] used a Google cardboard type VR in which participants were made to watch a movie and thereafter play a game. Despite advancement in technology the basic principles still remain the same and

Table 1 Pre and post test scores and mean changes in accommodative and vergence facilities after 25 min of gaming using a VRD.

Variable (CPM)	Group	N	Pre-test	Post-test	Mean change				Independent T-testP-value
					Mean change	Min.	Max.	Paired t -testp-value	
Binocular accommodative facility	Experimental	42	11.14 ± 3.67	13.38 ± 3.63	2.24 ± 3,43	1.42	1.12	<0.001	0.002*
	Control	20	11.70 ± 3.20	11.95 ± 3.43	0.25±1.25	3.08	3.09	0.383	
Vergence faCILITY	Experimental	42	11.47 ± 3.86	15.28 ± 4.93	3.81 ± 3.09	4.77	2.85	<0.001	<0.00*
	Control	20	11.55 ± 6.44	11.70 ± 4.86	0.15±2.72	1.42	1.13	0.808	

Mean change: Pre-test minus Post-test.
*Equal variance not assumed.

the studies are comparable. The medium of the activity (dynamic reading task) to create the visual strain was different compared to the medium (a video game) that was used in this study, however HMD's were used in all these studies and the present study.

The present study also used amplitude-scaled facilities which customised probe lenses and test distances for each participant's binocular amplitude of accommodation whilst the previous studies used a fixed test distance and a single set of probe lenses for all participants. This allows for older participants in the group to not be unfairly disadvantaged because of an age-reduced amplitude of accommodation and thus facilitates a level playing field with younger participants. Binocular accommodative facilities was chosen for this study due to the binocular medium of VR which includes accommodative convergence. This should be a consideration when considering the lack of decay in binocular accommodative and vergence facilities after VR gaming. Future studies should consider are superior to monocular accommodative facility testing as well. The vergence facilities findings is novel to this study and could serve as seminal evidence for other studies to confirm or refute as no previous study investigated the impact of VR use on vergence facilities.

The 25 min duration was influenced by the results of the pilot study, and participants in this study were not gamers. In reality, some users are likely to spend much longer periods than 25 min gaming using a VRD however with the findings of this study, practitioners and suppliers can be informed to suggest a duration of 25 min of VR exposure to guard against any decay in stamina of vergence and binocular accommodative facilities. Furthermore, this prompts a new research question of whether the changes elicited is time-based or from VR exposure or a combination of both.

During VR use, as one converges on objects, a higher convergence demand is created in comparison to natural vision, and thus the present findings may not directly be extended to users with convergence disorders. Secondly, the findings showed no significant effects of gaming using a VRD on vergence and accommodative facilities in our adult sample, however there may still be concerns if children utilised VR headsets which have been calibrated for adults, as children tend to have smaller inter-pupillary distances. Some VR headsets allow the lens centration distance to be adjusted, but many mobile phone-based headsets, which may be more accessible to children, do not currently allow lens separation adjustment. The VRD in this study did not allow for inter-pupillary distance less than 55 mm.

Both binocular amplitude-scaled facilities and vergence facilities showed a statistically significant mean increase greater than the control group after gaming using a VRD. The research question was directed to the safety of the VRD but these findings showed that for accommodative facilities, this increased by 2 cpm, and for vergence facilities this increased by 3.5 cpm. This shows that gaming using a VRD is proved satisfactory but may also improve the stamina of the vision after 25 min, prompting further research on its therapeutic use. Vivid vision supports the use of VRD adjusted for children's inter-pupillary distance to train vergences similar to vectographic therapy to treat convergence insufficiency [19] These may appear appealing to paediatric patients requiring orthoptics as it is more engaging and novel.

Considering the exposure time made use of in this study, it is recommend that future studies to explore the effect of repeated exposures to VR on facilities. Despite facility testing's routine use in clinical practice, the influence of the testing as trainer and a tester is limitation of this study. However in the control group did not show the same improvement as the experimental group and this helps with the reliability of the study findings. A binocular head mounted VR device is similar to a stereoscope, where accommodative demand is kept constant whilst the vergence demand is varied. Eadie et al.[22] suggests that vergence adaptation is a process that improves vergence dynamics, subsequently minimizing vergence error and reducing visual fatigue as the vergence system adapts to the stereoscopic demand. It is believed this may help inform the improvement in binocular accommodative facilities and vergence facilities after 25 min of gaming using a VR device.

A recommendation of the study is to inform the supplier that a time use of 25 min may guard against visual fatigue in people with normal binocular function. The short exposure time may also prompt further studies to consider the effect of repeated exposures on the impact of facilities, as well a longer duration of exposure to determine if facilities decay. Future studies should consider a randomised control trial utilising gaming in a VRD to treat vergence or binocular accommodative infacilities with masked examiners. Traditional therapy is cost effective as opposed to this consideration however the novelty incentive for patients may help encourage therapy. Further recommendations include repeating the study on gamers to qualify the results of this study and including ametropes using spectacles and contact lenses to establish if a similar outcome is achieved.

Limitations

Participant dropout failed to satisfy the recommended sample size of the experiment group of 46. The control group sample size was not identical to the experiment group which may interfere with the power and effect size of the findings or introduce type 1 or 2 errors. The inclusion of pre-test failures of participants for both accommodative and vergence facilities may have influenced the outcome of the study findings. A more equitable gender representation within the sample was lacking. The larger standard deviations of some findings suggest variations between participants within the sample. Examiners were not blinded during data collection therefore one cannot rule out any undue influence on outcomes.

Conclusion

The study focus was to assess the effect of gaming using a virtual reality device by evaluating the stamina of the binocular accommodative and vergence system. This was done by comparing binocular accommodative and vergence facilities after 25 min of gaming in a VRD to inform eye care practitioners as well as virtual reality device users and gamers on the fatigue status of vision. The results showed that this exposure does not decrease facilities because the stamina of accommodation and vergence did not deteriorate after 25 min. The findings of this study enhances current knowledge by providing information on the effect of gaming using a VR device on the stamina of accommodative and vergence system. However the robustness of the findings still requires further investigations and the findings of this study may serve as pilot results and cautions its generalisations to the public at large.

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