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Effects of virtual reality usage on kappa angle, accommodation, pupil, depth perception, and examination of the relationship of these parameters with discomfort perception

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ABSTRACT

Objective: This study aims to examine the effects of virtual reality (VR) usage on the eyes and investigate the parameters responsible for the subsequent discomfort sensation.

Materials and Methods: This prospective study enrolled 20 healthy volunteers who were engaged in a 10-minute VR game session. Refractive errors, kappa angles, phoria presence, accommodative responses, and scotopic, mesopic, and photopic pupillometry values were recorded before and after using VR. A Virtual Reality Sickness Questionnaire (VRSQ) was applied to assess discomfort, and the relation with evaluated parameters was investigated.

Results: Twenty volunteers (mean age 29.80±0.57 years) included 11 females (55%) and 9 males (45%). The mean spherical equivalent refractive error was – 1.94±0.28 diopters and 5 (25%) volunteers had phoria. Average kappa angles were 0.23±0.02 mm (x-axis) and 0.11±0.01 mm (y-axis). Post-VR, the median [(interquartile range (IQR)] stereopsis decreased from 30 (30-60) to 60 (60-60) arc seconds (P<0.001). Pupil sizes increased significantly across all lighting conditions (P<0.001). Accommodation did not significantly change post-VR (P>0.05). VRSQ scores correlated positively with phoria and kappa-x angle (r=0.458, P=0.003 and r=0.330, P=0.038) while negatively with stereopsis and kappa-y angle (r=-0.375, P=0.017 and r=-0.326, P=0.04).

Conclusion: Virtual reality use reduces depth perception and induces significant mydriasis across lighting conditions. Post-VR discomfort feeling may be related to phoria, kappa angle, and stereopsis.

Keywords: Virtual reality, Accommodation, Kappa, Stereopsis, Pupillometry

1. INTRODUCTION

As technology and internet usage continue to advance, the time spent looking at screens close has steadily increased. In parallel, utilizing virtual reality (VR) headsets has emerged as a promising trend. These headsets provide users with a more immersive experience by creating a sense of three-dimensional vision that separates the view of each eye. Consequently, the adoption of VR technology has increased, offering users an enhanced and realistic experience.

Virtual reality headsets position the screen only 15 cm away from the eyes. This proximity triggers various ocular responses, including pupillary constriction, ciliary muscle contraction, lens adjustment, and extraocular muscle convergence [1]. Accommodation, the mechanism by which the eyes adapt to focus on a near object's image onto the retina, is a complex reflex involving processes like convergence of the eyes inward, increased lens refractive power, and pupil constriction. Failure to achieve proper accommodation results in blurred vision, leading to a condition known as accommodative dysfunction. Individuals experiencing this dysfunction may report symptoms like blurred near vision, headaches, visual fatigue, and other asthenopic discomforts [2].

The angle between the anatomical axis of the eye and the visual axis is referred to as the kappa angle. A normal kappa angle indicates a slight outward deviation of the eyes, allowing each eye to slightly diverge outward [3]. However, this angle varies between individuals and can affect convergence and accommodation mechanisms. Increased kappa angles are associated with more significant outward eye divergence and potentially increased accommodation for convergence.

Virtual reality usage involves continuously changing focus due to dynamic visual stimuli. As a result, users need to constantly adjust their focus through near convergence and accommodation, leading to symptoms like discomfort, fatigue, headaches, blurred vision, and temporary dizziness when

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using VR. Scoring systems such as the Virtual Reality Sickness Questionnaire (VRSQ) have been developed to quantify this subjective discomfort [4].

Previous studies have investigated the effects of VR usage on visual parameters such as accommodation, vergence, stereopsis, refractive errors, pupil size, intraocular pressure, and choroidal thickness [5-8]. The central inquiry has been whether the increasing adoption of VR is linked to increased myopia progression and its implications for eye health. Additionally, the discomfort associated with VR usage and its correlation with these parameters remains an important research focus.

This study aims to assess the discomfort that can arise from a short-duration gameplay using VR headsets and investigate the relationship between this discomfort and various ocular parameters that could trigger it. To achieve this goal, volunteers engaged in a 10-minute VR game session, and parameters such as refractive errors, accommodation levels, horizontal and vertical kappa angles, stereopsis (depth perception) ratios, as well as static and dynamic pupillometry readings under scotopic, mesopic, and photopic conditions were evaluated both before and after gameplay. The primary objective is to examine the correlation between these parameters and the volunteers' VRSQ scores.

2. MATERIALS and METHODS

Study Design

This prospective study was conducted between January 2023 and February 2023 at the Neuro-Ophthalmology Division, Ophthalmology Department of Marmara University, School of Medicine. The study was designed in accordance with the principles of the Helsinki Declaration and received approval from the Marmara University Faculty of Medicine Clinical Research Ethics Committee under approval number 03.02.2023.336. Written informed consent was obtained from all the participants.

Participants

Residents attending the Ophthalmology Residency Program, aged 18 and above who volunteered for the study and consented to play a 10-minute game using a VR headset, were included. Participants with arrhythmias, tachycardia, bradycardia, hypertension, individuals over 45 years of age due to potential impact on accommodation, those with amblyopia, absence of stereopsis, history of corneal, uveitic, glaucomatous, retinal, or neuro-ophthalmological diseases, dry eye syndrome, epilepsy, migraine, history of motion sickness (car, ferry, airplane, etc.), vertigo, or vestibular dysfunction were excluded.

Procedure

All participants played the "Beat Blaster for Oculus" game for 10 minutes using the Oculus Quest 2 (Meta, USA) device. Prior to gameplay, demographic data, including age and gender, were collected. Additionally, pre-game measurements included refractive error measurements (spherical equivalent, diopters) using an auto-refractometer (TonoRef III, Nidek Co., Japan), accommodation measurements (diopters) using the same device, presence of esophoria or exophoria using the cover test, stereopsis values (arc seconds ["]) using the TNO Stereo Test, static and dynamic pupillometry readings (millimeters) under scotopic, mesopic, and photopic conditions using the Sirius corneal topography device CSO (Costruzione Strumenti Oftalmici, Florence, Italy), horizontal and vertical kappa angle values based on the pupil center using optical biometry device (Lenstar, Haag-Streit, USA). The participants who had refraction errors used contact lenses during VR gaming.

Post-Game Assessments

After the 10-minute gameplay, participants were surveyed using the VRSQ to assess discomfort levels with nine questions. This questionnaire included questions about general discomfort, fatigue, eyestrain, and difficulty focusing, which evaluated the "Oculomotor discomfort – C score". Additionally, it had questions about the level of headache, fullness of head, blurred vision, dizziness with eyes closed, and vertigo, which evaluated "Disorientation discomfort – D score" [4]. Participants' accommodation levels, stereopsis degrees, and static and dynamic pupillometry readings under scotopic, mesopic, and photopic conditions were measured again to assess changes in these parameters. Lastly, the relationships between initial and post-game parameter measurements, their differences, and VRSQ scores were examined.

Statistical Analysis

Statistical Package for Social Sciences (SPSS) version 24.0 was used for data analysis. Data distribution was assessed using the Shapiro-Wilks test. Categorical data were presented as numbers (percentages), parametric data as mean ± standard deviation, and non-parametric data as median and interquartile range (IQR). The Mann-Whitney *U* test was used for comparing non-parametric data. The Spearman correlation test was used to assess correlations between parameters. $P<0.05$ was considered statistically significant.

3. RESULTS

A total of 20 volunteers, contributing 40 eyes, were included in the study. The volunteers had a mean age of 29.80±0.57 years, with a female-to-male ratio of 11/9 (55%/45%). Exophoria was present in 5 individuals. The median spherical equivalent refractive error was – 1.50 D (IQR: – 2.44 to – 0.75 D). The median IQR horizontal and vertical kappa angle values, measured using Lenstar, were 0.25 mm (0.15 – 0.34 mm) and 0.10 mm (0.04 – 0.16 mm), respectively.

There was no significant difference observed between participants' accommodation levels measured before and after playing the game (3.39 D [IQR: 2.19 – 5.10 D] and 4.03 D [IQR: 1.82 – 5.87 D], P=0.121), respectively. However, the median IQR stereopsis value decreased significantly from 30 arc seconds (30 – 60 arc seconds) before gameplay to 60 arc seconds (60 – 60 arc seconds) after a 10-minute gameplay session (P<0.001) (Table I).

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Post-game measurements revealed a significant increase in median IQR pupil diameter compared to pre-game measurements under scotopic (6.30 mm [5.91 – 6.77 mm] and 5.99 mm [5.53 – 6.36 mm], P<0.001), mesopic (5.01 mm [4.56 – 5.38 mm] and 4.28 mm [3.90 – 4.79 mm], P<0.001), and photopic (4.08 mm [3.78 – 4.44 mm] and 3.67 mm [3.21 – 3.93 mm], P<0.001) conditions, respectively (Table I).

Table I. *Changes of evaluated parameters and statistical comparisons before and after 10 minutes of playing games using virtual reality (Oculus Quest 2)*

	Pre-VR usage Median (IQR)	Post-VR usage Median (IQR)	P value*
Accommodation, diopter	3.39 (2.19 – 5.10)	4.03 (1.82 – 5.87)	0.121
Stereopsis, arc/sec	30 (30 – 60)	60 (60 – 60)	**<0.001**
Scotopic Pupillometry, mm	5.99 (5.53 – 6.36)	6.30 (5.91 – 6.77)	**<0.001**
Mesopic Pupillometry, mm	4.28 (3.90 – 4.79)	5.01 (4.56 – 5.38)	**<0.001**
Photopic Pupillometry, mm	3.67 (3.21 – 3.93)	4.08 (3.78 – 4.44)	**<0.001**

VR: virtual reality, IQR: 25-75% Interquartile Range, Wilcoxon test was used for P values. P<0.05 values were considered significant and marked in bold.

The median IQR VRSQ score after gameplay was 51.67 (44.38 – 69.38) points. The "C score", assessing oculomotor discomfort, had a median (IQR) of 58.33 (43.75 – 66.67) points, and the "D score", evaluating disorientation discomfort, had a median (IQR) of 46.67 (40 – 71.67) points. A negative correlation was observed between C score and pre-game stereopsis (r=-0.438, P=0.005), and a positive correlation with pre-game accommodation (r=0.325, P=0.040) and vertical kappa angle (r=-0.316, P=0.047). D score correlated positively with the presence of exophoria (r=0.510, P=0.001) and post-game scotopic pupil measurement (r=-0.412, P=0.008). Total VRSQ score demonstrated positive correlations between exophoria and kappa-x angle (r=0.458, P=0.003 and r=0.330, P=0.038, respectively), and negative correlations between stereopsis and kappa-y angle (r=-0.375, P=0.017 and r=-0.326, P=0.04, respectively).

4. DISCUSSION

In this study, it was observed that there was no significant change in the accommodation following 10 minutes of VR gameplay, but pupil diameter increased, and depth perception decreased. Additionally, the VRSQ questionnaire revealed that participants experienced some level of discomfort, especially related to oculomotor and disorientation issues. This discomfort was found to be associated with horizontal and vertical kappa angles, as well as the presence of exophoria and stereopsis levels.

Virtual reality technology has rapidly advanced in recent years and is utilized in various fields. VR headsets offer users the opportunity to experience interactive 3D virtual worlds. However, prolonged VR usage can induce discomfort in some users, a phenomenon called "cybersickness." Cybersickness is believed to arise from a mismatch between what an individual perceives and feels. It has been proposed that discomfort occurs when there is a discrepancy between what one feels without seeing it or when there is a difference between what is seen and what is felt [9]. This sensation of discomfort following VR use is thought to stem from the perception of motion in the absence of corresponding physical action [10]. Researchers have been actively investigating factors that could contribute to this discomfort, aiming to reduce it and enhance the VR experience.

A recent study found that discomfort in individuals performing specific tasks without playing VR games decreased when anisometropia was induced to suppress stereopsis [11]. However, this reduction in discomfort was accompanied by worsened motion and spatial perception [11]. Another study showed that discomfort perception remained unchanged despite reducing stereopsis or motion parallax [12]. In the current study, it has been observed that when participants were engaged in a 10-minute gaming session, there was a significant reduction in the measured post-game stereopsis values. Additionally, contrary to the studies mentioned in the present work, it has been demonstrated that the introduction of gaming, in alignment with the literature, is associated with an inverse relationship between stereopsis and both the total scores on the VRSQ as well as the C score assessing oculomotor discomfort.

Previous studies have investigated the visual parameters and effects of 30 minutes of VR usage. In their study, Yoon et al. examined changes in refractive errors and accommodation after a 30-minute VR gaming session with 23 volunteers. While no significant alterations were observed in refractive errors following VR usage, they reported a noteworthy increase in near-point accommodation, near-point convergence, and subjective complaints [5]. Munsamy et al. investigated binocular accommodative and vergence changes in 42 individuals after playing VR games for 25 minutes while the control group watched a television film projected on a screen at 1 m. The study's findings indicated that binocular accommodative changes were significantly greater in the group using VR [8]. In the current study, no significant differences were observed in accommodation power following a shorter duration of gameplay (10 minutes). It was observed that significant pupil dilation occurred after gaming sessions across scotopic, mesopic, and photopic lighting conditions. Additionally, it has been demonstrated that VR usage is associated with decreased intraocular pressure [7] and increased choroidal thickness [5]. This increase in choroidal thickness has led to the suggestion that VR usage may not act as a myopogenic stimulus [5].

In the current study, in addition to the existing literature, the impact of horizontal and vertical kappa angles on the discomfort sensation following VR usage has been examined. Given that VR devices require the user to look at a close distance, such as 15 cm, during use, the eyes need to be converged. However, a larger horizontal kappa angle and a smaller vertical kappa angle define a position where the eyes are more divergent. Consistent with this proposition, the study has concluded that the magnitude of the horizontal kappa angle and the smallness of the vertical kappa angle are associated with increased discomfort sensation measured by the VRSQ. Building upon this outcome, it can be suggested that discomfort sensation can be reduced by measuring individualized kappa angles during device usage through simple techniques and implementing necessary automatic lens adjustments on the device. This approach could potentially contribute to the development of devices that offer an improved VR experience by addressing the unique kappa angle variations among different individuals.

One of the significant limitations of the study is the timing of measurements taken immediately after gameplay and the absence of consecutive measurements. As a result, the study's findings do not allow for an assessment of how long it takes for the parameters that exhibited significant changes to return to their baseline state. Another limitation of the study is the uniformity in both the duration of gameplay and the specific device used. The study did not investigate the effects of different lens and optic models on VR devices or varying durations of gameplay. In the future, addressing these limitations through more comprehensive research could lead to a better understanding of the impacts of VR goggles on the eyes and the evolving discomfort sensation. This might involve investigating the effects of different devices with varying lenses and durations of gameplay, thus providing a more nuanced perspective on the subject.

In conclusion, this study demonstrated that despite no changes in accommodation following a 10-minute motion-based gameplay session with VR, significant alterations in pupil size occurred across all lighting conditions. This change in pupil size could be particularly noteworthy for individuals who have undergone corneal refractive surgery. Moreover, the study indicated a potential relationship between stereopsis, fusion presence, and the horizontal and vertical kappa angles with the discomfort sensation experienced after VR usage. By evaluating individual differences in kappa angles prior to device usage and implementing necessary adjustments, devices that offer a more comfortable experience could be designed. Overall, these findings shed light on the multifaceted impacts of VR devices and provide insights for potential improvements in user comfort and experience.

Compliance with the Ethical Standards

Ethics Committee approval: This study was approved by the Marmara University Faculty of Medicine Clinical Research Ethics Committee (approval number 03.02.2023.336).

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