Influence of Virtual Reality on Visual Functions: Immersive Versus Non-Immersive Mode

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Abstract

Background To investigate differences in refraction, accommodative factors, ocular parameters, and subjective symptoms after using two types of virtual reality (VR) content with different perception depths.

Methods Twenty-three volunteers, who played VR games in two modes (immersive and non-immersive) for 30 min, were enrolled. Ocular parameters were examined before and after using VR. Accommodative factors were measured using static and dynamic methods, and subjective symptoms were assessed using a questionnaire. Differences according to VR content and correlations between each ocular parameter were analyzed.

Results There were no changes in refraction and accommodative factors after use of the VR. However, there was a significant increase in near point accommodation (NPA), near point convergence (NPC), and subjective symptom scores after using the immersive mode. Correlation analysis revealed that NPA and accommodative lag were increased in subjects with exophoria, and that subjects with high NPA or NPC were more likely to exhibit an increase in mean accommodative lag.

Conclusions The use of VR for 30 min reduced NPA and NPC especially after the immersive mode was used. In addition, using VR could further increase accommodation lag and reduce the amplitude of accommodation and convergence in subjects with exophoria.

Background

A virtual reality (VR) device is an immersive medium that uses a head-mounted display (HMD). It creates the sensation of being entirely transported into a virtual three dimensional (3D) world, and can provide a far more visceral experience than other video formats. Recently, VR devices from a variety of manufacturers have become available for purchase on the Internet, and have been widely used for gaming.

However, the proper use of VR has not yet been established. In health and safety warnings provided by manufacturers, VR is not recommended for use by children < 13 years of age, and continuous use for > 30 min is discouraged, although these warnings are based on weak evidence[1]. Many studies have reported that a significant proportion of VR device users experience a highly aversive sense of discomfort, disorientation, nausea, and motion sickness and that viewing stereoscopic images on 3D devices may induce visual asthenopia such as visual discomfort and fatigue [2–6]). It is essential to study the effects of VR devices on the eye because HMD images are presented to users at a short distance with a powerful convex lens to simulate 3D reality. Compared with older types of VR, many improvements have been made to reduce user discomfort including image resolution and corresponding processes for head movement. However, there are only a few ophthalmological studies investigating the effects of recent iterations of VR devices [7–11]

Ha et al. [7] investigated the clinical effects of the HMD on visual function, including the oculomotor system; they found no significant clinical changes, except for transient refractive error or binocular alignment. However, they adopted the method of watching movies using VR rather than immersive content such as games. In that case, the perceived depth was fixed at one distant point; therefore, it is
possible that ocular parameters change and the accommodation-convergence conflict are not fully induced, compared with immersive content, which has variable perceived depth. In addition, accommodative change was not evaluated. It is necessary to investigate accommodative change because it can be related to a user’s subjective symptoms, and transient or permanent myopia [12–14].

Turnbull et al. [15] reported that refraction and binocular status (e.g. gaze stability, stereopsis, and amplitude of accommodation) did not change after VR trials, while the choroid, which is a pigmented vascular tissue located outside of the eye, was thickened. In that study, investigators used virtual indoor and outdoor environmental content. They also examined accommodative amplitudes, but did not analyze their correlation with other ocular parameters.

In the present study, we examined changes in objective ocular parameters and subjective symptoms after subjects played two modes of VR content – immersive and non-immersive – each with a different perception depth. The change in accommodation was evaluated using static and dynamic methods. In addition, correlations between ophthalmological factors after playing VR content were evaluated.

**Methods**

**Participant selection**

Thirty-five healthy volunteers who had better than 16/20 uncorrected visual acuity with over 20/20 best-corrected visual acuity were recruited. The subjects had no ophthalmologic diseases, including strabismus, amblyopia, corneal or retinal disease, or a history of ocular surgery, except for refractive surgery. Twelve subjects with exophoric deviation > 10 prism diopters (PD) and/or esophoric deviation > 5 PD were excluded. Informed consent was obtained from all 23 volunteers who were eligible and ultimately enrolled in this study. Ethics committee approval was obtained from the Chonnam National University Hospital Institutional Review Board (Gwangju, Korea). The study protocol adhered to the guidelines of the Declaration of Helsinki.

**Display**

The Oculus Rift VR device (Oculus VR, LLC., Irvine, California, USA) was used in this study. The device comprised a lightweight (0.44 kg) headset that completely covered the field of view. The headset included separate displays for each eye, each with 960 × 1080 resolution, yielding a 100-degree-horizontal field of view. A fixed-degree convex lens located in front of each display rendered display content at optical infinity. The control key that enabled the user to adjust the inter-pupillary distance was located at the right side of the VR device.

Participants used the Oculus Rift device while seated on a freely rotating chair. They were asked to perform 30 min of game play (Minecraft, Mojang AB, Sweden) in two different modes (immersive and non-immersive), with a 1-week interval between two modes. In the immersive mode, the stereo head-
tracked head-mounted display presentation brings the player inside the 360-degree virtual reality environment to become a physical being in the game. The viewpoint moves in accordance with the player's head movements. In the non-immersive mode the player is placed in a static environment, a living room, while watching on a screen in the front, approximately 2 m away (a desktop view). He can look around the room; however, the area of game-play is fixed on a virtual screen in front of the player (Additional file 1).

**Measurements of accommodation**

Refraction and accommodation were measured using a binocular open-field refractor (Auto Ref/Keratometer WAM-5500, Grand Seiko Co Ltd, Hiroshima, Japan). The spherical equivalent (sphere + 1/2 of cylinder) was used for calculation. For static measurement, the accommodative amplitude was calculated by subtracting the refractions obtained under monocular condition while viewing a 1 cm × 1 cm E-shape target at 33 cm from those while viewing the target at 5 m.

To function in the dynamic mode, software verified by the manufacturer was installed on a computer. To initiate measurements, the instrument was aligned with the pupil of each eye, the joystick button was pushed and released once; the instrument then commenced recording dynamic measurements at approximately 5 samples/s. During dynamic measurements, the observer ensured that the instrument remained carefully aligned with the subject's right eye by observing the alignment target imaged within the pupillary center in the LCD monitor for the entire duration of the testing. The instrument wrote the data to a spreadsheet file (Excel, Microsoft Corporation, Redmond, WA, USA) that recorded the time of measurement, eye measured, spherical equivalent refraction, and pupil diameter approximately every 0.2 s and converted it to a sine graph form [16]. In dynamic measurement of accommodation, the velocity of accommodation, mean accommodative lag, and dynamic accommodative response was investigated. The velocity of accommodation was obtained by calculating the difference between the maximum and minimum refraction divided by the time taken. Mean accommodative lag was calculated by averaging the value that the participant's actual refraction differed from the target refraction. The dynamic accommodative response was calculated according to the dispersion between actual refraction and target refraction. A higher correlation coefficient was associated with better dynamic accommodative response (Fig. 1).

**Other ocular parameters**

Monocular near point accommodation (NPA) was obtained using Donder's push-up method. A 20/30 single letter on a fixation stick, approximately 50 cm from the subject, served as the target and was moved gradually closer to the subject at a rate of approximately 5.0 cm/s until the subject noticed the target starting to blur.
The near point of convergence (NPC) was also obtained. The fixation target, the starting point of examination, and the moving velocity of the fixation target were the same as those previously described for the NPA measurement. The first point at which the corneal reflex of the subjects began to extend outward was considered to be the endpoint. Near stereopsis was measured using a near stereopsis vision test (Stereo Fly SO-001 test; Stereo Optical Co., Chicago, IL, USA). The test stereogram was held 40 cm from the subject during the test. Threshold stereopsis level was recorded in seconds of arc.

Ocular dominance was determined by the hole-in-the-card test, in which the subject was asked to hold a card with a hole at arm's length and focus on an objective 3 m away with both eyes. The examiner then alternately occluded the eyes to determine which eye was viewing the object through the hole and that eye was determined to be the dominant eye.

The presence and magnitude of far (5 m) and near (33 cm) phoria were verified using the cover test and alternating cover test with prism. A standard set of loose plastic prisms was used for all measurements. The individual prisms increased in power from 1 PD to 10 PD in 1-PD increments, and from 10 to 20 PD in 2-PD increments. All measurements were repeated 3 times for each tested eye, with results reported as the mean value.

All measurements were performed before and immediately after playing the VR game in the order listed above. If ocular parameters were changed, it was measured repeatedly every 15 min until the initial value was obtained again. The criteria for re-examination were > 2-cm changes in NPA and NPC, over 20 arc of seconds change of stereopsis, and over 0.5 D change of refraction. Ocular phoric deviation was evaluated by the same pediatric ophthalmologist (H.H.). The other ocular parameters were examined by a single examiner (H.J.Y.).

Evaluation of subjective symptoms

Thirteen symptoms were included in the questionnaire. The questionnaire was based on a computer vision syndrome questionnaire previously described by Seguí del M et al. [17]. The symptom sensation questionnaire contained six identical analogue scales (0 = none, 6 = too severe to tolerate) on which the subject recorded the magnitude of each of the symptoms compared with baseline. After playing two modes of the VR game, the subjects completed the questionnaire.

Statistical analysis

Statistical analysis was performed using SPSS version 18.0 (IBM Corporation, Armonk, NY, USA) for Windows (Microsoft Corporation, Redmond, WA, USA). Data are presented as mean ± standard deviation (SD). The normal distribution for all variables was assessed using the Kolmogorov-Smirnov test. All variables were not normally distributed. A Wilcoxon signed rank test was used to compare changes in
variables before and after performing VR. Differences in subjective symptoms according to the contents were also compared using the Wilcoxon signed rank test. Spearman’s rho correlation test between each of the ocular parameters was used for correlation analysis. The variables for a single eye, including NPA and accommodative parameters, were solely correlated with the corresponding eye. For all tests, differences with p < 0.05 were considered statistically significant.

Results

Among the 23 participants, 11 were men and 12 were women, with a mean age of 23.9 ± 3.7 years (range, 20-35 years). The mean uncorrected visual acuity (logarithm of the minimum angle of resolution [logMAR]) was 0.03 ± 0.04 logMAR. Fifteen of the participants had previous temporary experience with VR within 1 hour. Eleven of the participants had a history of refractive surgery for myopia. There were no statistically significant variables in each case. One participant, who discontinued the immersive mode of VR because of severe headache and nausea, was excluded from the analysis.

In the immersive mode, the mean refractive error of both eyes did not change significantly (p = 0.935 in the dominant eye, p = 0.654 in the non-dominant eye). There was no significant change, but there was a relative increase in the angle of deviation for near distance after using the immersive mode of VR (p = 0.086). However, NPA was increased in both eyes (p = 0.005 in the dominant eye, p = 0.002 in the non-dominant eye). NPC was also increased in the immersive mode (p = 0.001). In the non-immersive mode, the mean refractive error did not change significantly for either eye (p = 0.261 in the dominant eye; p = 0.881 in the non-dominant eye). NPA in the non-dominant eye (p = 0.031) and NPC (p = 0.002) were increased after using VR. NPA in the dominant eye, near stereopsis, and phoria were not significantly different in the non-immersive mode (Table 1).

Table 2 summarizes the comparisons between subjective symptoms according to the 2 VR modes. Neurological symptoms, such as headache, dizziness and nausea, were more severe in the immersive mode than the non-immersive mode of VR (p < 0.05 for all 3 parameters). In addition, tearing, blurred vision, double vision and difficulty focusing for near vision were relatively increased in the immersive mode (p < 0.05 for all 4 parameters). Table 3 summarizes the changes in accommodation using static and dynamic measurements with the WAM-5500 binocular refractor after using 2 modes of VR content. There was no significant change in accommodative amplitude, velocity of accommodation, mean accommodative lag, or dynamic accommodative response.

Table 4 summarizes the correlations between the baseline data of ocular parameters (exophoria at far/near, NPA in the dominant/non-dominant eye and NPC) and changes in ocular and accommodative parameters, and the sum of subjective symptom scores after using VR. There was a positive correlation between baseline values of far exophoria and changes in NPA of the dominant eye after using VR (r =
In addition, near exophoria in baseline measurements demonstrated a positive correlation with changes in mean accommodative lag of the dominant eye \( r = 0.372, p = 0.014 \). Baseline values of NPA and NPC exhibited a negative correlation with changes in mean accommodative lag of the dominant eye \( r = -0.328, p = 0.032; r = -0.333, p = 0.027 \).

**Discussion**

VR is a technology that renders a proximal display to be perceived as a real-world experience at a distance using powerful convex lenses. In a VR environment, accommodation is fixed to a single depth of field at a distant point. However, convergence is constantly induced. This accommodation-convergence conflict and sustained eyeball movement are known to cause fatigue and 3D asthenopia \([8, 18–20]\)

In this study, NPA of the dominant eye was increased in the immersive mode, and the NPC was also relatively increased. In the immersive mode, more image disparity can occur than in the non-immersive mode. Image disparity activates an accommodative response, and convergence-accommodation to a change in accommodation \([21–23]\). However, the actual accommodative target was fixed; thus, there was a possibility of fatigue due to the excessive activation of accommodative adaptation \([22]\). As shown in Table 3, other accommodative factors did not change. It appears that ocular fatigue induced an increase in NPA and NPC, which is more of a subjective factor than actual accommodation.

Data presented in Table 2 demonstrate that in the immersive mode, neurological symptoms, such as headache, dizziness and nausea, were more severe than discomfort in the eyes such as dryness. In addition, blurred vision, double vision and defocusing symptoms were worse in the immersive mode, suggesting that ocular fatigue due to excessive accommodation-convergence response is more severe in the immersive mode.

In Table 4, correlation analysis revealed that NPA and accommodative lag were increased in subjects with exophoria. Vergence adaptation modulates fast response, and reduces error and fatigue by maintaining vergence stimulus \([21–23]\). Exophoric subjects may require more effort in accommodation and convergence due to reduced adaptation, which can cause more fatigue than in normal individuals \([4, 24–27]\)

In addition, subjects who had high NPA or NPC were more likely to exhibit an increase in mean accommodative lag. Sreenivasan et al. \([28]\) reported that retinal image quality is better when accommodative lag is greater, because, paradoxically, the depth of field is more structurally or functionally wider in individuals with higher accommodative lag. In this study, subjects with high baseline NPA and NPC exhibited a small change in accommodative lag. In addition, baseline NPA and NPC demonstrated a high positive correlation with accommodative lag (dominant eye, \( p = 0.010, \ p = 0.008 \); non-dominant eye, \( p = 0.026, \ p = 0.017 \), respectively). In individuals with high baseline NPA and NPC, retinal image quality was, paradoxically better, as with high accommodative lag. This may reduce ocular fatigue due to a rapid accommodation response. However, there is controversy regarding whether accommodative lag enhances accommodative stress by promoting a blurred retinal image \([29]\). Further
research is needed to support this hypothesis. Shiomi et al. [30] reported that actual accommodation can change depending on the perception depth of the 3D content, even when the 3D display is fixed. Unlike previous reports, the use of VR appears to affect accommodation, and further study is needed to resolve these issues.

Turnbull et al. [15] suggested that increased choroidal thickness caused by myopic retinal defocus could be associated with reduced myopia progression. In our study, myopic shift and hyperopic shift > 0.5 D was evident in each of 3 cases in the immersive mode. In the non-immersive mode, myopic shift and hyperopic shift were observed in 8 cases and 4 cases, respectively. These changes, however, fully recovered within 1 h. Our study showed that myopic and hyperopic shifts presented atypically, and did not correlate with other ocular factors and VR mode. In addition, Ha et al. [7] reported that transient myopia can occur after using VR. The hypothesis of increased or reduced myopic progression with using VR appears to require a more cautious approach.

One limitation of this study was the inclusion of a specific population (i.e., 23 subjects 20 to 39 years of age, with a corrected visual acuity of 0.8 or higher). Thus, it is difficult to judge the effect on users of different conditions. Notably, the actual refraction data were not analyzed, including those of subjects with a history of refractive surgery. Furthermore, there were no control groups that did not use VR. It is possible that VR use of only 30 min was insufficient to produce changes in ocular parameters. Additional larger-scale studies are needed to resolve these issues.

Conclusions

In conclusion, the use of VR for approximately 30 min did not affect refraction, regardless of the VR mode; however, it reduced NPA and NPC, especially after using the immersive mode. In addition, using VR could further increase accommodation lag and reduce the amplitude of accommodation and convergence in subjects with exophoria. This study was the first to evaluate VR influence, which was assessed using immersive, real 3D content, instead of non-immersive VR content, and accommodation was analyzed using dynamic techniques. It is meaningful that the effects of ocular visual functions differ depending on VR content, despite the use of the same VR device. Our results may form the basis for recommendations for users who should be more careful when using VR.

Abbreviations

VR: Virtual reality; NPA: near point accommodation; NPC: near point convergence; HMD: head-mounted display; PD: prism diopters; SD: standard deviation

Declarations

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Availability of data and materials

Data supporting our findings are contained in the manuscript. However, the raw data set on which the conclusion was made is available on request from Professor Hwan Heo (contact email: opheyeye@hanmail.net).

Author’s Contributors

Design of the study (H.H); Conduct of the study (H.J.Y, H.H); Collection and management of data (H.J.Y, S.W.P); Analysis and interpretation of data (H.J.Y, J.K, H.H); Preparation, review, or approval of the manuscript (H.J.Y, J.K, S.W.P, H.H)

All authors read and approved the final manuscript.

Competing interests

The authors report no conflicts of interest.

Consent for publication

Not applicable

Ethics approval and consent to participate
This study received ethical approval from the Institutional Review Board of the Chonnam National University Hospital. A written informed consent was obtained from all patients before study initiation.

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Tables

Table 1. Comparison of changes in ocular parameters after playing a virtual reality game according to content with different perception depths
| Variable                                      | Pre          | Post         | p-value |
|----------------------------------------------|--------------|--------------|---------|
| **Immersive mode**                           |              |              |         |
| NPA (dominant eye), cm                       | 9.27±2.23    | 10.4±1.97    | 0.005   |
| NPA (non-dominant eye), cm                   | 9.14±2.19    | 10.6±2.35    | 0.002   |
| NPC, cm                                      | 8.14±2.55    | 9.82±3.00    | 0.001   |
| Near stereopsis, sec                         | 64.6±76.5    | 65.9±76.6    | 0.180   |
| Phoria, PD (near)                            | 3.41±3.94    | 3.82±3.75    | 0.086   |
| Refraction (dominant eye), Diopter           | -0.36±0.47   | -0.37±0.59   | 0.935   |
| Refraction (non-dominant eye), Diopter       | -0.23±0.64   | -0.19±0.60   | 0.654   |
| **Non-immersive mode**                       |              |              |         |
| NPA (dominant eye), cm                       | 9.43±2.03    | 10.0±2.39    | 0.058   |
| NPA (non-dominant eye), cm                   | 9.38±1.93    | 10.0±2.30    | 0.031   |
| NPC, cm                                      | 8.00±2.20    | 9.00±2.25    | 0.002   |
| Near stereopsis, sec                         | 63.0±75.0    | 64.8±75.1    | 0.234   |
| Phoria, PD (near)                            | 4.23±3.75    | 4.45±3.95    | 0.257   |
| Refraction (dominant eye), diopter           | -0.41±0.64   | -0.49±0.73   | 0.261   |
| Refraction (non-dominant eye), diopter       | -0.24±0.61   | -0.23±0.65   | 0.881   |

Data presented as mean ± SD. NPA, near point accommodation; NPC, near point convergence; PD, prism diopter

**Table 2.** Comparison of subjective symptoms after playing a virtual reality game according to content
| Symptom                          | Immersive mode | Non-immersive mode | p-value |
|---------------------------------|----------------|-------------------|---------|
| Burning                         | 0.26±0.69      | 0.30±0.77         | 0.564   |
| Feeling of a foreign body       | 0.26±0.62      | 0.22±0.60         | 0.705   |
| Excessive blinking              | 1.26±1.36      | 1.13±1.32         | 0.554   |
| Tearing                         | 0.70±1.19      | 0.30±0.77         | 0.014   |
| Dryness                         | 1.22±1.62      | 1.17±1.40         | 0.942   |
| Burning                         | 0.78±1.28      | 0.39±0.78         | 0.084   |
| Blurred vision                  | 1.09±1.24      | 0.61±0.84         | 0.005   |
| Double vision                   | 0.26±0.62      | 0.09±0.29         | 0.046   |
| Difficulty focusing for near vision | 0.74±1.18   | 0.22±0.60         | 0.018   |
| Increased sensitivity to light  | 0.39±0.72      | 0.30±0.64         | 0.623   |
| Headache                        | 1.83±1.53      | 0.74±1.36         | 0.012   |
| Dizziness                       | 2.30±1.58      | 1.17±1.64         | 0.012   |
| Nausea                          | 2.74±1.76      | 1.04±1.87         | 0.004   |
| Total                           | 13.8±9.99      | 7.70±7.89         | 0.002   |

Data presented as mean ± SD.

**Table 3.** Changes in accommodation according to content using static and dynamic measurement after playing a virtual reality game
| Variable                        | Immersive mode | Non-immersive mode |
|--------------------------------|----------------|--------------------|
|                                | Pre | Post | p-value | Pre | Post | p-value |
| Static measurement – Accommodative amplitude, diopter |     |      |         |     |      |         |
| Dominant eye                   | 1.98±0.76 | 1.97±0.66 | 0.722 | 1.90±0.54 | 1.83±0.72 | 0.571 |
| Non-dominant eye               | 2.19±0.80 | 2.14±0.78 | 0.442 | 2.08±0.76 | 2.01±0.70 | 0.572 |
| Dynamic measurement            |     |      |         |     |      |         |
| Velocity of accommodation, diopter/s |     |      |         |     |      |         |
| Dominant eye                   | 0.346±0.080 | 0.366±0.113 | 0.095 | 0.380±0.071 | 0.376±0.090 | 0.910 |
| Non-dominant eye               | 0.397±0.068 | 0.391±0.106 | 0.664 | 0.355±0.079 | 0.368±0.086 | 0.362 |
| Mean accommodative lag, diopter|     |      |         |     |      |         |
| Dominant eye                   | 0.696±0.371 | 0.625±0.400 | 0.108 | 0.670±0.392 | 0.629±0.380 | 0.322 |
| Non-dominant eye               | 0.711±0.330 | 0.797±0.355 | 0.274 | 0.757±0.357 | 0.783±0.363 | 0.548 |
| Dynamic accommodative response |     |      |         |     |      |         |
| Dominant eye                   | 0.874±0.093 | 0.832±0.214 | 0.778 | 0.846±0.128 | 0.844±0.154 | 0.664 |
| Non-dominant eye               | 0.860±0.097 | 0.821±0.179 | 0.821 | 0.911±0.048 | 0.883±0.055 | 0.099 |

Data presented as mean ± SD.

**Table 4.** Correlations between the value of baseline and changes of ocular parameters
### Ocular parameters

|                          | Exophoria (far) | Exophoria (near) | NPA (dominant eye) | NPA (non-dominant eye) | NPC |
|--------------------------|----------------|-----------------|--------------------|------------------------|-----|
|                          | r   | P*  | r   | P*  | r   | P*  | r   | P*  | r   | P*  |
| Exophoria (far)          | -0.100 | 0.514 | 0.127 | 0.410 | -0.032 | 0.841 | -0.064 | 0.685 | -0.087 | 0.573 |
| Exophoria (near)         | -0.166 | 0.276 | -0.149 | 0.335 | -0.054 | 0.731 | -0.066 | 0.676 | -0.152 | 0.324 |
| NPA (dominant eye)       | 0.296 | **0.048** | -0.007 | 0.963 | -0.255 | 0.099 | 0.007 | 0.966 |       |     |
| NPA (non-dominant eye)   | 0.202 | 0.184 | -0.028 | 0.859 | -0.204 | 0.189 | 0.105 | 0.498 |       |     |
| NPC                      | 0.046 | 0.764 | 0.046 | 0.764 | 0.051 | 0.747 | 0.051 | 0.747 | -0.188 | 0.222 |

**Accommodative parameter (dominant eye)**

|                          | r   | P*  | r   | P*  | r   | P*  | r   | P*  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Accommodative amplitude  | -0.110 | 0.507 | 0.030 | 0.860 | -0.220 | 0.191 | -0.003 | 0.987 |
| Velocity of accommodation| 0.059 | 0.703 | -0.034 | 0.834 | 0.123 | 0.438 | 0.001 | 0.994 |
| Mean accommodative lag    | 0.165 | 0.285 | 0.372 | **0.014** | -0.175 | 0.266 | -0.159 | 0.309 |
| Dynamic accommodative response | 0.032 | 0.845 | 0.139 | 0.393 | 0.085 | 0.607 | 0.004 | 0.979 |

**Accommodative parameter (non-dominant eye)**

|                          | r   | P*  | r   | P*  | r   | P*  | r   | P*  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Accommodative amplitude  | -0.141 | 0.373 | -0.034 | 0.834 | -0.128 | 0.430 | -0.008 | 0.959 |
| Velocity of accommodation| -0.017 | 0.913 | 0.151 | 0.327 | -0.005 | 0.976 | 0.207 | 0.187 |
| Mean accommodative lag    | 0.111 | 0.468 | 0.076 | 0.624 | -0.328 | **0.032** | -0.333 | **0.027** |
| Dynamic accommodative response | -0.110 | 0.507 | 0.019 | 0.903 | 0.003 | 0.983 | -0.069 | 0.659 |
| Sum of symptom scores     | -0.110 | 0.471 | 0.173 | 0.261 | 0.198 | 0.202 | 0.222 | 0.152 | 0.084 | 0.587 |

NPA, near point accommodation; NPC, near point convergence *Spearman’s rho correlation

## Figures
Dynamic accommodative response was calculated according to the dispersion between actual refraction and target refraction ([A] demonstrates better dynamic accommodative response than [B]).

**Supplementary Files**

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- supplement1.avi