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IMPACT OF POSITIVE AND NEGATIVE LENS-INDUCED DEFOCUS ON CONTRAST SENSITIVITY IN MYOPIC AND NON-MYOPIC ADULTS

Original Research

Mansoor Ahmed[1], Fariha Ambreen[2], Ummara Shafique[3], Sidra Saleem*[4], Sheeraz Bashir[5], Kinza Arif[6], Ayesha Mohsin[6]

[1]Optometrist at Al-Mansoor Eye Centre, Taunsa Sharif, Department of Rehabilitation Sciences Superior University, Lahore, Pakistan.
[2]Head of Speech-language pathology department, Superior University, Lahore, Pakistan.
[3]Assistant Professor, Superior University, Consultant Opthalmologist Cirns Rilway Hospital.
[4]Optometrist at Al-Noor Eye Centre, Taunsa Sharif, Department of Rehabilitation Sciences Superior University, Lahore, Pakistan.
[5]Optometrist at Dar ul Shifa Eye Hospital & Al Rehman Hospital, Sheikhupura, Department of Rehabilitation Sciences, Superior University, Lahore, Pakistan.
[6]Physiotherapist at Allah Yar Khan Hospital, Lahore, Department of Rehabilitation Sciences, Superior University, Lahore, Pakistan.

Corresponding Author: Sidra Saleem, Optometrist at Al-Noor Eye Centre, Taunsa Sharif, Department of Rehabilitation Sciences Superior University, Lahore, Pakistan. saleemsidra164@gmail.com

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ABSTRACT

Background: Lens-induced defocus (LID) alters contrast sensitivity (CS), a key determinant of visual performance, affecting both myopic and non-myopic individuals. Myopia, a prevalent refractive error, is associated with compromised CS, which may be further influenced by optical defocus. Positive defocus shifts the focal plane posteriorly, while negative defocus moves it anteriorly, leading to differential visual adaptations. Understanding these effects is essential for optimizing refractive correction strategies and mitigating potential visual impairments in clinical and rehabilitative settings.

Objective: This study evaluates the impact of positive and negative LID on CS in myopic and non-myopic adults, assessing adaptive responses over a four-week period to determine potential implications for long-term visual function.

Methods: A randomized controlled trial was conducted with 36 participants (mean age = 33.81 ± 9.17 years), allocated into four groups: myopic-positive defocus (n=9), myopic-negative defocus (n=9), non-myopic-positive defocus (n=9), and non-myopic-negative defocus (n=9). CS was assessed using the Pelli-Robson chart under standardized lighting conditions at baseline, two weeks, and four weeks. The Wilcoxon Signed Rank Test and Friedman Test were used for within-group comparisons, while the Mann-Whitney U test assessed between-group differences. Statistical significance was set at $p < 0.05$.

Results: At baseline, the mean Pelli-Robson CS score was 1.51 ± 0.37. After two weeks, CS declined to 1.40 ± 0.41, and at four weeks, it further decreased to 1.30 ± 0.44 ($p < 0.001$). Myopic participants with positive defocus exhibited the most significant decline (1.10 ± 0.42 at four weeks), whereas non-myopic participants with negative defocus showed the least reduction (1.40 ± 0.41). CVS-Q scores increased from 3.94 ± 2.47 at baseline to 8.25 ± 3.52 at four weeks ($p < 0.001$), indicating worsening visual strain. VFQ scores decreased from 60.56 ± 13.93 to 52.94 ± 17.99, reflecting reduced subjective visual function ($p < 0.01$).

Conclusion: Both positive and negative LID adversely affect CS, with greater impairment observed in myopic individuals exposed to positive defocus. The findings highlight the importance of refining refractive correction approaches to minimize defocus-induced visual deficits. Further research is needed to explore long-term adaptive mechanisms and potential interventions for optimizing visual performance.

Keywords: Contrast sensitivity, lens-induced defocus, myopia, non-myopia, optical blur, refractive errors, visual adaptation

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INTRODUCTION

Vision is a fundamental sense that enables individuals to interpret and navigate their surroundings through the processing of light stimuli. The human visual system perceives colors, shapes, distances, and movement through intricate neural mechanisms, allowing for effective interaction with the environment. Visual perception begins with light entering the eye, where photoreceptor cells in the retina, including rods and cones, process wavelengths ranging from 380 to 770 nm (1,2). These cells contain pigments such as rhodopsin and iodopsin, which facilitate color differentiation through additive color mixing. Depth perception relies on disparity, the difference in images received by each eye, which is initially processed in the primary visual cortex (V1) for absolute disparity and later refined in higher-order visual areas for relative disparity. The human visual system retains a short-term memory for binocular disparities, which gradually diminishes over time or when exposed to competing stimuli (3,4). Neurons in the visual cortex demonstrate selective responses to spatial frequencies, with higher frequencies encoding relative disparity and lower frequencies processing absolute disparity. This fundamental aspect of vision plays a pivotal role in various technologies, including three-dimensional (3D) displays, where excessive disparity can lead to visual discomfort (5). The prevalence of visual impairment is a significant global health concern, affecting approximately 596 million individuals, including 43 million who are blind and 510 million with uncorrected near vision impairment. More than 90% of these cases are preventable or correctable with cost-effective interventions. However, disparities in access to eye care persist, particularly among women, rural populations, and ethnic minorities, underscoring the urgent need for enhanced vision care strategies. As demographic shifts such as population aging and urbanization continue, the burden of distance vision impairment is projected to rise by 2050, necessitating comprehensive approaches to mitigate its impact (6,7).

Contrast sensitivity (CS) is a crucial component of visual function, representing the ability to discern objects from their background under varying contrast levels. Unlike visual acuity, which measures clarity under high contrast, CS is particularly relevant in real-world scenarios such as night driving and reading in dim lighting conditions. Reduced CS is often an early indicator of visual disorders, including age-related macular degeneration (AMD), where retinal ganglion cell (RGC) thickness correlates strongly with contrast perception. Given its clinical significance, CS is increasingly recognized as a superior predictor of vision-related quality of life compared to visual acuity alone. Luminance levels significantly influence CS, with brighter environments enhancing contrast perception, necessitating standardized testing conditions for accurate assessment. Emerging deep neural network models have demonstrated the ability to replicate human CS patterns, paving the way for more precise diagnostic tools in ophthalmology (8,9). Myopia, or nearsightedness, is the most prevalent refractive error worldwide, with projections indicating that over half of the global population will be affected by 2050. Characterized by excessive axial elongation of the eyeball, myopia leads to blurred distance vision and an elevated risk of complications such as myopic macular degeneration and glaucoma. Environmental factors, including prolonged near work and reduced outdoor activity, are key contributors to the rising prevalence of myopia. As a result, effective myopia management has become a critical public health priority. Optical interventions, such as lens-induced defocus, have emerged as a promising approach to modulating eye growth. Positive defocus shifts the focal point beyond the retina, inhibiting excessive elongation, whereas negative defocus places the focal point anterior to the retina, promoting elongation. These mechanisms form the basis of myopia control strategies, including orthokeratology and multifocal contact lenses (10,11).

While previous research has explored the influence of lens-induced defocus on visual acuity, its impact on contrast sensitivity remains less understood, particularly in individuals with and without myopia. Existing studies suggest that defocus may affect CS to a greater extent than visual acuity, particularly in low-contrast environments. However, a comprehensive comparison of positive and negative lens-induced defocus on CS across myopic and non-myopic populations remains limited. This study aims to address this knowledge gap by systematically investigating the effects of optical defocus on CS in these groups. By elucidating the relationship between refractive errors, defocus, and visual performance, the findings will contribute to optimizing myopia management strategies and enhancing the quality of life for individuals with refractive anomalies (12).

METHODS

This study employed a double-blinded, randomized controlled trial (RCT) design to assess the impact of lens-induced defocus on contrast sensitivity and visual fatigue in myopic and non-myopic individuals. Participants were randomly assigned to different groups using the fishbowl randomization method to ensure equal distribution. Blinding was maintained throughout the study, with both the

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optometrist conducting assessments and the statistician analyzing data unaware of group allocation. The primary outcome measure was contrast sensitivity, while visual fatigue was assessed as a secondary outcome. Both outcomes were measured at baseline, two weeks, and four weeks using standardized tools, including the Pelli-Robson contrast sensitivity chart, the Computer Vision Syndrome Questionnaire (CVS-Q), and the Visual Fatigue Questionnaire (VFQ) (13). The study was conducted at THQ Taunsa Sharif over a period of six months. The sample size was calculated using G*Power 3.1 software, based on a comparison of two independent means with an alpha level of 0.05. The effect size was derived from previous literature, and a noncentrality parameter of 5 was utilized to determine the critical t-value with appropriate degrees of freedom, resulting in a total sample size of 36 participants. Simple random sampling was employed to recruit eligible individuals aged 18 to 50 years. Inclusion criteria required participants to have either a confirmed diagnosis of myopia or no refractive error, a best-corrected visual acuity of 20/30 or better, no prior ocular surgery, no history of serious ocular conditions, and the ability to provide informed consent. Individuals were excluded if they had systemic disorders affecting vision, such as diabetes or hypertension, binocular vision anomalies like strabismus, a history of severe ophthalmic diseases including glaucoma, cataracts, or retinal disorders, were pregnant or breastfeeding, or were using medications known to affect visual function (14).

Ethical approval for the study was obtained from the Ethics Review Board (ERB) of the Faculty of Allied Health Sciences (FAHS), Superior University, Lahore Campus. The research protocol was reviewed for compliance with ethical guidelines, and approval was granted prior to participant recruitment. All participants provided written informed consent after receiving a comprehensive explanation of the study objectives, procedures, potential risks, and benefits. Consent forms were available in both English and Urdu to ensure full comprehension. Participant confidentiality was maintained throughout the study, with no identifiable information disclosed in publications or presentations (15). Data collection commenced following ethical approval. Each participant underwent an ophthalmic examination, followed by contrast sensitivity assessment using the Pelli-Robson chart. Participants wore either simple or blue glasses during testing. Visual fatigue was assessed using the CVS-Q and VFQ, which quantified symptoms related to prolonged screen exposure and general visual strain. The CVS-Q consists of 13 items, with total scores ranging from 0 to 18, categorizing symptoms as mild (0–5), moderate (6–12), or severe (13–18). The VFQ evaluates visual fatigue severity on a scale of 0 to 100, classifying symptoms as minimal (0–20), mild (21–50), moderate (51–75), or severe (76–100). The Pelli-Robson contrast sensitivity scores ranged from 0.00 to 2.25, with classifications as severe loss (0.00–1.00), moderate loss (1.00–1.50), mild loss (1.55–1.90), and normal contrast sensitivity (1.90–2.25) (16).

Statistical analysis was performed using IBM SPSS version 29. The Shapiro-Wilk test revealed that the data were not normally distributed; therefore, non-parametric tests were applied. The Mann-Whitney U test was used to compare differences between two independent groups, while the Wilcoxon Signed-Rank test assessed differences between related or paired samples. The Kruskal-Wallis test was employed to determine statistically significant differences among three or more independent groups, serving as a non-parametric alternative to one-way ANOVA. Additionally, the Friedman test was used to analyze variations across multiple related groups. All statistical analyses were conducted by a blinded statistician to ensure objectivity and minimize bias. There was no missing data, and all necessary precautions were taken to maintain the integrity and accuracy of the research findings (17).

RESULTS

The study included 36 participants aged between 19 and 50 years, with a mean age of 33.81 years (SD = 9.17). Gender distribution was equal, while variability in social status (mean = 2.0, SD = 0.828) and refractive status (mean = 1.5, SD = 0.507) remained low. The visual function, as assessed by VFQ, declined from a baseline mean score of 60.56 (SD = 13.93) to 52.94 (SD = 17.99) at four weeks. A similar trend was observed in contrast sensitivity (Pelli-Robson), which decreased from 1.51 (SD = 0.37) at baseline to 1.30 (SD = 0.44) at four weeks. In contrast, CVSQ scores increased over time, indicating worsening visual strain, from a baseline mean of 3.94 (SD = 2.47) to 8.25 (SD = 3.52) at four weeks. The Shapiro-Wilk test indicated that most variables, including the primary outcome measures, deviated significantly from normality ($p < 0.05$), confirming the necessity of non-parametric statistical analyses. The Wilcoxon Signed Rank Test revealed statistically significant differences in visual function and contrast sensitivity over time, with p-values < 0.001 across all comparisons. A significant decrease in Pelli-Robson contrast sensitivity and VFQ scores was observed from baseline to four weeks, while CVSQ scores demonstrated a marked increase, signifying a decline in visual comfort.

The Friedman test confirmed significant time-dependent variations in CVSQ, VFQ, and Pelli-Robson scores ($p < 0.01$), indicating progressive changes across the study period. The mean ranks for VFQ were highest at all time intervals (baseline: 8.63, two weeks: 8.10, four weeks: 7.28), while CVSQ scores increased over time (baseline: 4.25, two weeks: 4.92, four weeks: 5.83), and Pelli-Robson scores declined (baseline: 3.00, two weeks: 2.00, four weeks: 1.00). A Mann-Whitney U test comparing myopic participants with positive

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defocus against myopic participants with negative defocus demonstrated significantly better visual outcomes in the latter group across all metrics, with p-values < 0.05. Pairwise comparisons between myopic and non-myopic participants using different defocus types revealed substantial differences. Non-myopic participants with negative defocus lenses consistently performed better than their myopic counterparts with positive defocus. The statistical analysis demonstrated that negative defocus had a more significant impact on improving visual outcomes across both myopic and non-myopic groups.

Further analysis using across-group comparisons confirmed statistically significant differences across all study groups for CVSQ, VFQ, and Pelli-Robson scores at all time points ($p < 0.001$). The results showed that contrast sensitivity declined over time while visual fatigue worsened, particularly in myopic individuals subjected to positive defocus. Negative defocus had a more favorable impact on visual function and contrast sensitivity, particularly in non-myopic individuals.

Table 1: Descriptive Statistics

Variable	N	Mean	SD
Age	36	33.81	9.17
Gender	36	1.5	0.507
Social Status	36	2	0.828
Refractive Status	36	1.5	0.507
CVSQ Baseline	36	3.94	2.47
CVSQ 2 Weeks	36	5.72	3.34
CVSQ 4 Weeks	36	8.25	3.52
VFQ Baseline	36	60.56	13.93
VFQ 2 Weeks	36	56.55	13.75
VFQ 4 Weeks	36	52.94	17.99
Pelli-Robson Baseline	36	1.51	0.36
Pelli-Robson 2 Weeks	36	1.4	0.41
Pelli-Robson 4 Weeks	36	1.3	0.44

Table 2: Shapiro-Wilk Normality Test Results

Variable	Statistic	df	p-value
Age	0.943	36	0.062
Gender	0.638	36	0
Social Status	0.795	36	0
Refractive Status	0.638	36	0
CVSQ Baseline	0.768	36	0
CVSQ 2 Weeks	0.778	36	0
CVSQ 4 Weeks	0.873	36	0.001
VFQ Baseline	0.842	36	0
VFQ 2 Weeks	0.909	36	0.006
VFQ 4 Weeks	0.908	36	0.006
Pelli-Robson Baseline	0.71	36	0
Pelli-Robson 2 Weeks	0.758	36	0
Pelli-Robson 4 Weeks	0.782	36	0

Table 3: Wilcoxon Signed Rank Test Results

Comparison	Z-score	p-value
CVSQ 2 Weeks - Baseline	-4.011	< 0.001
CVSQ 4 Weeks - Baseline	-5.043	< 0.001
VFQ 2 Weeks - Baseline	-3.946	< 0.001
VFQ 4 Weeks - Baseline	-2.91	0.004
Pelli-Robson 2 Weeks - Baseline	-5.332	< 0.001
Pelli-Robson 4 Weeks - Baseline	-5.332	< 0.001

Table 4: Across Group Comparisons

Tool	Timepoint	Test Statistic	df	p-value
Pelli-Robson	Baseline	35	3	< 0.001
Pelli-Robson	2 Weeks	35	3	< 0.001
Pelli-Robson	4 Weeks	35	3	< 0.001
CVSQ	Baseline	29.333	3	< 0.001
CVSQ	2 Weeks	33.333	3	< 0.001
CVSQ	4 Weeks	31	3	< 0.001
VFQ	Baseline	26.183	3	< 0.001
VFQ	2 Weeks	29.622	3	< 0.001
VFQ	4 Weeks	19.839	3	< 0.001

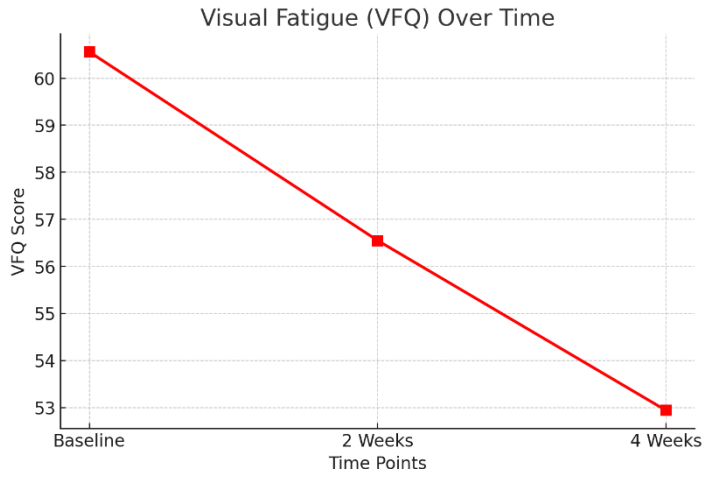

Figure 2 Visual Fatigue (VFQ) Over Time

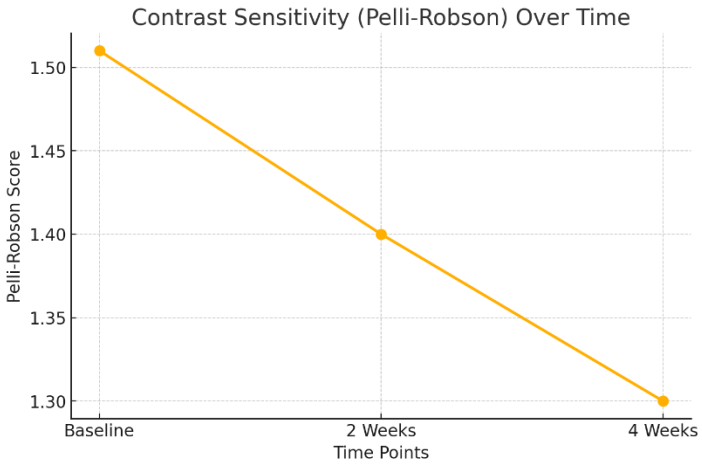

Figure 1 Contrast Sensitivity (Pelli-Robson) Over Time

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DISCUSSION

Lens-induced defocus has gained increasing attention for its impact on visual function, particularly in myopic and non-myopic individuals. Myopia, as a prevalent refractive error, has been linked to structural and functional visual abnormalities, including reduced contrast sensitivity. The ability of positive and negative defocus to modify optical blur offers an opportunity to understand how visual function adapts or deteriorates under controlled conditions. This study evaluated the influence of defocus on contrast sensitivity, visual function, and computer vision syndrome symptoms, providing insight into differential responses across refractive groups over time (18-20). Contrast sensitivity, assessed using the Pelli-Robson chart, demonstrated a significant decline over the study duration, particularly in individuals exposed to positive defocus. Computer vision syndrome symptoms, measured using the CVS-Q, progressively worsened, indicating increased visual strain with time. Visual function, assessed through VFQ, exhibited a decline, suggesting that defocus negatively influenced subjective visual performance. The findings align with previous studies highlighting the detrimental effects of optical defocus on contrast sensitivity and overall visual adaptation. Research investigating the impact of peripheral hyperopic defocus on myopia progression has demonstrated that external environmental factors play a role in refractive development. In contrast, this study provided controlled evidence that central defocus directly affects contrast sensitivity and visual function, supporting the hypothesis that induced defocus has a measurable impact on visual performance (21-24).

Previous findings have suggested that contrast sensitivity adapts differently to various optical manipulations. Studies investigating contrast reduction techniques, such as scattering and controlled defocus, have shown that contrast perception is influenced by both neuronal and optical factors. The current study found that contrast sensitivity progressively declined with defocus exposure, reinforcing the notion that central visual processing is sensitive to artificially induced optical blur. Experimental models examining positive defocus have indicated its potential role in reducing axial elongation, a factor critical in myopia control. However, negative defocus has been associated with increased axial length, supporting the hypothesis that excessive near focus contributes to myopic progression. The observed differences between myopic and non-myopic participants in the response to defocus further suggest that refractive status influences visual adaptation mechanisms (25-28). The clinical relevance of these findings extends to the use of optical interventions for refractive error management. Multifocal and defocus-modulating lens designs have been employed in myopia control strategies, with varying effects on contrast sensitivity. Studies assessing defocus-integrated lenses have reported reductions in contrast sensitivity in off-axis vision while maintaining central visual function. The current findings indicate that while defocus-induced blur can modulate contrast perception, the impact is more pronounced in myopic individuals. These observations support the refinement of optical correction strategies to minimize visual discomfort while preserving contrast sensitivity (29-31).

Despite the contributions of this study, certain limitations must be acknowledged. The sample size was relatively small, which may limit the generalizability of the findings to larger populations. Additionally, factors such as individual accommodative responses, environmental lighting, and screen-based variability during CVS-Q assessments may have influenced the results. Future research should include larger and more diverse populations to explore the long-term implications of defocus on contrast adaptation. Incorporating objective measures such as wavefront aberrometry and adaptive optics could provide further insights into the underlying mechanisms of visual adaptation to optical defocus. Longitudinal studies assessing the persistence of contrast sensitivity changes beyond the study period could further enhance understanding of the sustained effects of defocus on visual function (32-34). The findings highlight the significance of lens-induced defocus in modulating contrast sensitivity, visual function, and computer vision syndrome symptoms, emphasizing the need for tailored optical interventions. Understanding the impact of defocus on contrast adaptation is essential for optimizing myopia management strategies and minimizing visual discomfort associated with defocus-based refractive treatments. Further investigations into accommodative responses and neurophysiological adaptation to optical blur will be essential in refining vision correction methodologies.

CONCLUSION

This study demonstrates that both positive and negative lens-induced defocus significantly influence contrast sensitivity, visual function, and computer vision syndrome symptoms in myopic and non-myopic adults. The findings underscore the importance of understanding the effects of optical defocus in clinical and rehabilitative settings, providing valuable insights for optimizing vision correction strategies. By highlighting the differential impact of defocus on visual performance, this research supports the development of tailored interventions to enhance visual quality and mitigate discomfort associated with refractive errors. These results contribute to the growing body of evidence informing the design of myopia management approaches and other optical treatments aimed at preserving functional vision and improving overall visual well-being.

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AUTHOR CONTRIBUTIONS

Author	Contribution
Sidra Saleem*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Fariha Ambreen	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Ummara Shafique	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Mansoor Ahmed	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Sheeraz Bashir	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Kinza Arif	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Ayesha Mohsin	Contributed to study concept and Data collection Has given Final Approval of the version to be published

REFERENCES

1. Lobar, K. (2023). History of Retinal Implants. Texas Journal of Medical Science. https://doi.org/10.62480/tjms.2023.vol18.pp142-143.

2. Yang, J., Wang, C., Jiang, B., Song, H., & Meng, Q. (2021). Visual Perception Enabled Industry Intelligence: State of the Art, Challenges and Prospects. IEEE Transactions on Industrial Informatics, 17, 2204-2219. https://doi.org/10.1109/TII.2020.2998818.

3. Ignatov, I., & Vanlyan, K. (2020). Electromagnetic Conception of Color Vision in Additive Mixing of Colors. Application in the Photography. Art and Psychology. Journal of Medicine, Physiology and Biophysics. https://doi.org/10.7176/jmpb/64-02.

4. Ignatov, I., & Vanlyan, K. (2020). Electromagnetic Conception of Color Vision in Additive Mixing of Colors. Application in the Photography. Art and Psychology. Journal of Medicine, Physiology and Biophysics. https://doi.org/10.7176/jmpb/64-02.

5. Elam AR, Tseng VL, Rodriguez TM, Mike EV, Warren AK, Coleman AL, Aguwa U, Alabiad C, Briceno C, Capo H, Contreras M. Disparities in vision health and eye care. Ophthalmology. 2022 Oct 1;129(10):e89-113.

6. Kaestner, M., Evans, M., Chen, Y., & Norcia, A. (2021). Dynamics of absolute and relative disparity processing in human visual cortex. NeuroImage, 255, 119186 - 119186. https://doi.org/10.1016/j.neuroimage.2022.119186.

7. Chen, Y., Kaestner, M., & Norcia, A. (2022). Cognitive penetrability of scene representations based on horizontal image disparities. Scientific Reports, 12. https://doi.org/10.1038/s41598-022-22670-7.

8. Nemes, V., Radó, J., Fülöp, D., Mikó-Baráth, E., Hamvas, I., Jandó, G., & Buzás, P. (2024). Visual short-term memory for crossed and uncrossed binocular disparities. PLOS ONE, 19. https://doi.org/10.1371/journal.pone.0312202.

9. Kaestner, M., Chen, Y., Clement, C., Hodges, A., & Norcia, A. (2024). Two Disparity Channels in Human Visual Cortex With Different Contrast and Blur Sensitivity. Translational Vision Science & Technology, 13. https://doi.org/10.1167/tvst.13.2.21.

10. Karimi, M., Nejati, M., & Lin, W. (2021). Bi-disparity sparse feature learning for 3D visual discomfort prediction. Signal Process., 188, 108179. https://doi.org/10.1016/J.SIGPRO.2021.108179.

11. Burton MJ, Ramke J, Marques AP, Bourne RR, Congdon N, Jones I, Tong BA, Arunga S, Bachani D, Bascaran C, Bastawrous A. The lancet global health commission on global eye health: vision beyond 2020. The Lancet Global Health. 2021 Apr 1;9(4):e489-551.

12. Contrast sensitivity is an important feature of visual function that represents the ability to distinguish brightness changes between an object and its background. It is a more comprehensive measure of visual performance than visual acuity because it takes into account the quality of vision in different lighting settings and is sensitive to changes in visual health.

13. Ou, W., Lesmes, L., Christie, A., Denlar, R., & Csaky, K. (2021). Normal and Low Luminance Automated Quantitative Contrast Sensitivity Assessment in Eyes with Age-Related Macular Degeneration.. American journal of ophthalmology. https://doi.org/10.1016/j.ajo.2021.01.017.

14. Shamsi, F., Liu, R., Owsley, C., & Kwon, M. (2022). Identifying the Retinal Layers Linked to Human Contrast Sensitivity Via Deep Learning. Investigative Ophthalmology & Visual Science, 63. https://doi.org/10.1167/iovs.63.2.27.

15. Silva-Viguera, M., García-Romera, M., López-Izquierdo, I., De-Hita-Cantalejo, C., Sánchez-González, M., & Bautista-Llamas, M. (2022). Contrast Sensitivity Assessment in Early Diagnosis of Diabetic Retinopathy: A Systematic Review. Seminars in Ophthalmology, 38, 319 - 332. https://doi.org/10.1080/08820538.2022.2116289.

16. Silva-Viguera, M., García-Romera, M., López-Izquierdo, I., De-Hita-Cantalejo, C., Sánchez-González, M., & Bautista-Llamas, M. (2022). Contrast Sensitivity Assessment in Early Diagnosis of Diabetic Retinopathy: A Systematic Review. Seminars in Ophthalmology, 38, 319 - 332. https://doi.org/10.1080/08820538.2022.2116289.

17. Vingopoulos, F., Wai, K., Katz, R., Vavvas, D., Kim, L., & Miller, J. (2021). Measuring the Contrast Sensitivity Function in Non-Neovascular and Neovascular Age-Related Macular Degeneration: The Quantitative Contrast Sensitivity Function Test. Journal of Clinical Medicine, 10. https://doi.org/10.3390/jcm10132768.

18. Sankaridurg, P., Tahhan, N., Kandel, H., Naduvilath, T., Zou, H., Frick, K., Marmamula, S., Friedman, D., Lamoureux, E., Keeffe, J., Walline, J., Fricke, T., Kovai, V., & Resnikoff, S. (2021). IMI Impact of Myopia. Investigative Ophthalmology & Visual Science, 62. https://doi.org/10.1167/iovs.62.5.2.

19. Houser, K., Heschong, L., & Lang, R. (2022). Buildings, Lighting, and the Myopia Epidemic. LEUKOS, 19, 1 - 3. https://doi.org/10.1080/15502724.2022.2141503.

20. Khanal, S. (2023). Is myopia a disease or just a dis-ease?. Ophthalmic and Physiological Optics, 43. https://doi.org/10.1111/opo.13145.

21. Martínez-Albert, N., Bueno-Gimeno, I., & Gené-Sampedro, A. (2023). Risk Factors for Myopia: A Review. Journal of Clinical Medicine, 12. https://doi.org/10.3390/jcm12186062.

22. Dutheil, F., Oueslati, T., Delamarre, L., Castanon, J., Maurin, C., Chiambaretta, F., Baker, J., Ugbolue, U., Żak, M., Lakbar, I., Pereira, B., & Navel, V. (2023). Myopia and Near Work: A Systematic Review and Meta-Analysis. International Journal of Environmental Research and Public Health, 20. https://doi.org/10.3390/ijerph20010875.

23. Pärssinen, O. (2024). Myopia, what causes it and can it be avoided?. Acta Ophthalmologica. https://doi.org/10.1111/aos.16409.

24. Zhu, X., Kang, P., Troilo, D., & Benavente-Perez, A. (2021). Temporal properties of positive and negative defocus on emmetropization. Scientific Reports, 12. https://doi.org/10.1038/s41598-022-07621-6.

25. Swiatczak, B., & Schaeffel, F. (2021). Emmetropic, But Not Myopic Human Eyes Distinguish Positive Defocus From Calculated Blur. Investigative Ophthalmology & Visual Science, 62. https://doi.org/10.1167/iovs.62.3.14.

26. Swiatczak, B., & Schaeffel, F. (2021). Emmetropic, But Not Myopic Human Eyes Distinguish Positive Defocus From Calculated Blur. Investigative Ophthalmology & Visual Science, 62. https://doi.org/10.1167/iovs.62.3.14.

27. García-Pedreño, C., Tabernero, J., Benito, A., & Artal, P. (2024). Impact of Peripheral Refractive Errors in Mobility Performance. Investigative Ophthalmology & Visual Science, 65. https://doi.org/10.1167/iovs.65.6.42.

28. Choi KY. Effect of optical defocus characteristics in the living environment and interaction with peripheral refractive error on myopia progression.

29. Roth, A., Breher, K., Domdei, N., & Wahl, S. (2024). Foveal neural adaptation to optically induced contrast reduction. Journal of Vision, 24. https://doi.org/10.1167/jov.24.9.13.

30. Zhu, X., Kang, P., Troilo, D., & Benavente-Perez, A. (2021). Temporal properties of positive and negative defocus on emmetropization. Scientific Reports, 12. https://doi.org/10.1038/s41598-022-07621-6.

31. Ortiz-Peregrina, S., Casares-López, M., Castro-Torres, J., Anera, R., & Artal, P. (2022). Effect of peripheral refractive errors on driving performance.. Biomedical optics express, 13 10, 5533-5550 . https://doi.org/10.1364/boe.468032.

32. Ghoushchi, V., Mompeán, J., Prieto, P., & Artal, P. (2024). Contrast sensitivity is resilient to induced fast periodic defocus oscillations. Biomedical Optics Express, 15, 3848 - 3858. https://doi.org/10.1364/BOE.521340.

33. Kaymak, H., Neller, K., Schütz, S., Graff, B., Sickenberger, W., Langenbucher, A., Seitz, B., & Schwahn, H. (2022). Vision tests on spectacle lenses and contact lenses for optical myopia correction: a pilot study. BMJ Open Ophthalmology, 7. https://doi.org/10.1136/bmjophth-2022-000971.

34. Silva-Leite, S., Amorim-De-Sousa, A., Queirós, A., González-Méijome, J., & Fernandes, P. (2023). Peripheral Refraction and Visual Function of Novel Perifocal Ophthalmic Lens for the Control of Myopia Progression. Journal of Clinical Medicine, 12. https://doi.org/10.3390/jcm12041435.