The Effects of AMD Severities on Eye Movements in Virtual Environments

Jesse W Grootjen
LMU Munich
Munich, Germany
Munich Center for Machine Learning (MCML)
Munich, Germany
jesse.grootjen@um.ifi.lmu.de

Sairam Narsimha Reddy Yadla
LMU Munich
Munich, Germany
sairamnarasimhareddy@gmail.com

Sven Mayer
TU Dortmund University
Dortmund, Germany
LMU Munich
Munich, Germany
info@sven-mayer.com

Abstract

Age-related macular degeneration (AMD) is a visual impairment that poses a global challenge due to limited access to regular checks. In this work, we investigate AMD by creating a virtual reality simulation of central-field loss. In the first step, interviews (N=6) revealed that dark circles are not accurate in terms of the perception of those affected by AMD. Thus, we developed a novel visualization that simulates different AMD severities, which better matches the interviewer's explanations. In an evaluation user study (N=13), we focus on understanding AMD severities using our visualization in high-fidelity virtual reality scenes to preserve contextual cueing. In detail, we explore the impact of AMD on a visual search task and investigate the correlations between eye movement features and the severity of the simulation. We found significant differences in several eye movement characteristics as well as task performance. Our findings lay the groundwork for future simulation studies.

CCS Concepts

• **Human-centered computing → Empirical studies in accessibility**; *Human computer interaction (HCI).*

Keywords

Age-Related Macular Degeneration Simulation, VR, Eye Movement

ACM Reference Format:
Jesse W Grootjen, Sairam Narsimha Reddy Yadla, and Sven Mayer. 2025. The Effects of AMD Severities on Eye Movements in Virtual Environments. In *Mensch und Computer 2025 (MuC '25), August 31–September 03, 2025, Chemnitz, Germany*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3743049.3748561

1 Introduction & Background

Visual impairments, particularly age-related macular degeneration (AMD), are increasingly prevalent due to an aging global population, with approximately 300 million people expected to be affected by 2040 [1, 37]. AMD, the leading cause of central blindness among adults, progressively impairs central vision critical for tasks such as reading and face recognition. Despite effective treatments like anti-VEGF injections, slow symptom onset often delays awareness and timely intervention, highlighting the necessity for early detection and management strategies [15]. Variability in AMD progression speed further complicates early diagnosis, significantly impacting quality of life and daily functionality without consistent monitoring.

Previous studies utilized simulation techniques to investigate the effects of visual impairments on task performance, oculomotor behaviors, and accessibility [19, 26, 36, 38, 39]. Simulations, ranging from goggles to advanced VR systems, foster empathy, identify design flaws, and inform assistive technology development [20, 32]. AMD simulations effectively reproduce central-field loss (CFL) and its impact on fixation stability, saccadic behavior, and reading performance [4, 6, 9, 17, 24]. Additionally, simulations differentiate impairments, contrasting central vision loss (AMD) with peripheral vision loss (glaucoma), highlighting distinct adaptive eye-movement strategies [5]. Such simulations bridge theoretical knowledge and real-world experiences of visually impaired individuals.

We developed an improved VR-based AMD simulation informed by structured interviews with AMD patients, accurately modeling central-field loss and peripheral fading effects. Our method maintains contextual cues in realistic visual search tasks, enabling detailed eye-movement analyses under simulated impairments. Interviews provided essential insights into subjective AMD experiences, revealing overlooked perceptual and functional challenges. This qualitative approach enhances simulation authenticity, closely matching actual patient experiences and coping strategies.

Our study revealed significant differences in eye movements and task performance between control and simulated AMD conditions, consistent with clinical observations of AMD patients. Simulated AMD resulted in reduced fixation stability, longer saccadic reaction times, and altered search patterns, effectively mirroring clinical behaviors. These findings validate our realistic simulation as a valuable tool for early AMD detection research. The enhanced realism supports empathetic understanding and informs accessible design and interventions, potentially shaping future guidelines, diagnostics, and therapies to mitigate AMD's daily-life impacts [23, 27].

2 Structured Interviews

From the related work, AMD simulations typically represent central-field loss as a dark circle with gradient edges. To verify this visualization, we conducted semi-structured interviews with individuals diagnosed with AMD. Interviews comprised demographic inquiries followed by questions about their daily visual experiences.

MuC '25, Chemnitz, Germany

ACM ISBN 979-8-4007-1582-2/25/08
https://doi.org/10.1145/3743049.3748561

Procedure. Participants received detailed explanations and consent forms beforehand. Sessions began with addressing any participant questions, followed by demographic data collection and perception-related questions such as "How does AMD affect your daily life?" and "Do specific lighting conditions influence your perception?"

Participants. We interviewed six AMD-affected individuals, excluding one who had additional influential visual impairments. Of the five included, residual vision varied: P1 (female, 86) had 3 − 5% in the left eye and no vision in the right; P2 (female, 54) had 3% residual vision in her left eye and only light perception in her right; P3 (male, 24, Juvenile Macular Degeneration similar to AMD) had 3% vision in both eyes; P4 (male, 63) had 5% vision in both eyes; and P5 (female, 76) had 3% vision in her right eye and 10% in her left. All participants previously reported normal vision.

Results. Four of five participants did not perceive AMD as a dark spot with fading edges, describing it instead as similar to normal blind spots, where the brain infills visual information. Participant examples include: P3 stating, "I see a road continue as normal, but I cannot see if there is a bike standing in front," and P2 mentioning an empty visual area in her kitchen. However, P1 described her experience as "a heavy fog" with a grey tint obscuring her vision. (Non-English participant statements were translated by a native speaker with full professional proficiency in English).

3 AMD Simulation

In the following, we describe the implementation of our effects pipeline using two parameters: central-field loss and fading. It is important to note that we assume that the visualization is completely round.

We simulate the central-field loss using a scotoma with a spherical shape of size S (diameter of the sphere) at a fixed distance (d) while being gaze-contingent. SC is the degree of central vision to be obstructed by our AMD simulation. Using the following formula, we determine the size of the sphere: $S = 2 \times d \times tan(SC/2)$.

We implemented the fading on the edges using an adaptation of the `smoothstep` function (see, http://www.thebookofshaders.com/, last accessed: 2025–08–05). The `smoothstep` function uses three parameters, the lower edge (e_0), the upper edge (e_1), and the source variable for interpolation (x). If x is less than or equal to e_0, it outputs 0; if x is greater than or equal to e_1, it outputs 1; and if x is between e_0 and e_1, it interpolates between e_0 (start edge) and e_1 (end edge) according to the Hermite interpolation. The source variable for interpolation (x) is the normalized distance of the objects' texture fragment concerning the sphere's central position in the screen space. Finally, we use the output of this `smoothstep` function as alpha values of the objects' texture to control the objects' visualization.

$$f(x) = \begin{cases} 0 & \text{if } x \leq e_0 \\ 3(\frac{x-e_0}{e_1-e_0})^2 - 2(\frac{x-e_0}{e_1-e_0})^3 & \text{if } e_0 < x < e_1 \\ 1 & \text{if } x \geq e_1 \end{cases}$$

By applying the combination of the central field loss and the fading as a custom shader in Unity, we were able to simulate the loss of central vision, see Figure 1. We chose to have our fading dynamically adjust to the size of our CFL, namely being 20% of the CFL, if our AMD simulation is 30°, our fading ends at 30°, and the CFL encompasses 80% of the 30°, specifically 24°.

4 User Study

In the following section, we will discuss the user study performed with 17 participants, the virtual environment and hardware used for this user study, and the analysis. We ensured that luminance in all rooms was consistent. We chose to simulate eight conditions of AMD, all Latin Square balanced, of no visualization, 4.3°, 8.6°, 12.9°, 17.2°, 21.5°, 25.8°, and 30°. These were chosen to keep the interval between conditions equal. Furthermore, we decided not to go beyond 30° to keep the visualization lower than what has been reported in previous work to go unnoticed [15] and to stay inside the near periphery [34].

Apparatus. We employed a visual search task to evaluate how AMD simulations impact participant behavior. Such tasks are frequently used in studies involving actual and simulated visual impairments [10, 11, 21, 25, 27]. Emphasizing realistic scenes for contextual cueing [27], we created eight virtual household environments with relevant objects (e.g., kettle, phone; see Figure 2) [11]. We developed the environments in Unity3D and deployed them on a desktop (Ryzen 9 7900X3D, NVIDIA RTX 4080 Super GPU, HTC Vive Pro Eye headset with Tobii eye-tracking at 120 Hz via Vive SRanipal SDK). Head and eye movements, captured as 3D directional vectors, were converted into 2D Fick angles using the Fick-gimbal method [18]. Analysis was conducted at the trial level, given short durations (4.64 ± 3.41 seconds).

Procedure. Participants signed consent forms and completed demographic surveys before VR setup and eye-tracking calibration. After four practice trials without simulation, they performed visual searches for 15 items per virtual room across eight balanced AMD simulation conditions (from no scotoma to 30°). Drift corrections following each room maintained gaze accuracy despite participant movement [8, 33]. Participants received 10 EURO compensation.

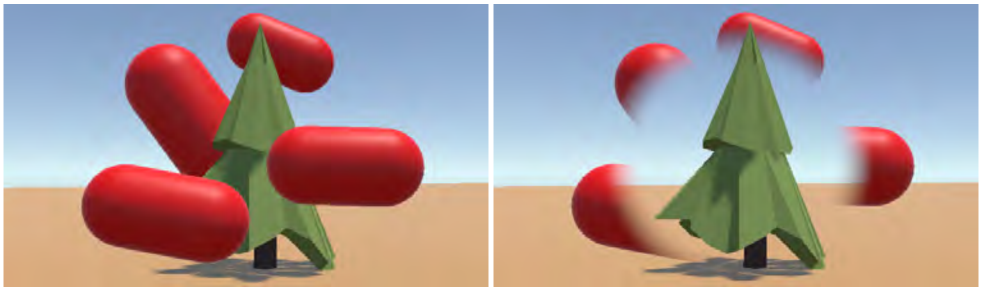
Participants. We recruited 17 participants. However, we had to exclude four participants (one for technical issues, one was too exhausted to participate in the study properly, and two did not follow the instructions). The remaining 13 participants had a mean age of 23.2 (SD = 2.2), 8 identifying as female and 5 as male. All participants had normal vision.

5 Results

In this section, we first present the results of our preprocessing. After which, we present the findings of how our simulation affects eye movements and task performance while being affected by different severities of our AMD simulation.

5.1 Preprocessing

We calculated fixations and saccades using pymovements [22] with the ID-T algorithm [29], applying thresholds of 83 ms minimum fixation duration and 1.8° maximum dispersion [3, 35]. Metrics included fixation duration, fixation rate, saccadic amplitude (degrees between onset and offset), and saccade frequency (number per trial minute), computed using the microsaccade algorithm [13].



(a) **(b)**

Figure 1: (a) A low-poly landscape without any of the AMD visualizations applied. (b) A low-poly landscape with the central-field loss and fading visualization applied. In this image, the red capsules have a custom material that hides these items in the central field if they are obscured by our visualizations. This simulation is gaze-contingent.

(a) Garage **(b) Bedroom** **(c) Dining Room** **(d) Bathroom**

(e) Kitchen **(f) Living Room** **(g) Meeting Room** **(h) Office**

Figure 2: All rooms used in the user study.

Table 1: Results of the GLMM analysis for the time per trial under different central-field loss conditions. A Gamma family with identity link was used.

CFL (deg)	Est.	t	p
0	1.37	13.48	< 0.001
4.3		0.19	0.852
8.6		0.68	0.497
12.9		1.97	0.049
17.2		2.35	0.019
21.5		3.13	0.002
25.8		2.14	0.033
30		2.72	0.007
	$R_c^2 = 0.70, R_m^2 = 0.56$		

Table 2: Results of the GLMM analysis for the index of pupillary activity (IPA) and pupil diameter under different central-field loss conditions. An inverse Gaussian family with identity link was used for IPA; a Gamma family with identity link for pupil diameter.

	IPA			Pupil Diameter		
CFL (deg)	Est.	t	p	Est.	t	p
0	0.66	16.29	< 0.001	4.39	15.58	< 0.001
4.3		−0.15	0.879		0.64	0.525
8.6		−0.30	0.767		0.71	0.481
12.9		−2.11	0.055		1.63	0.104
17.2		−1.51	0.131		2.20	0.028
21.5		−1.22	0.223		2.36	0.018
25.8		−0.88	0.379		2.72	0.007
30		−0.66	0.509		3.01	0.003
	$R_c^2 = 0.04, R_m^2 < 0.01$			$R_c^2 = 0.84, R_m^2 = 0.54$		

Pupil metrics comprised mean pupil size, standard deviation, and the Index of Pupillary Activity (IPA) via two-level discrete wavelet transforms [12]. Out of 1560 recorded trials, we excluded trials with excessive head movement (>15 cm deviation from average) and trials exceeding 20 seconds duration. Object location accuracy was verified using gaze angle comparisons to objects' angular diameter, calculated as $\delta = \arctan\left(\frac{d}{2D}\right)$. Trials were retained if more than

50% of the last ten gaze samples fell within 180% of δ. After filtering, 1356 trials remained: 178 (no CFL) and 182, 178, 172, 168, 169, 158, 151 for CFL of 4.3° to 30°. A Bayes repeated measures ANOVA (JASP, default priors) indicated no significant effect of filtering on trial counts ($BF_{10} = 0.169$).

5.2 General Linear Mixed Model Results

We used generalized linear mixed-effect models (GLMMs) to analyze the data from our complex experimental design. GLMMs account for random effects due to individual variability, room, object, spawning location, or learning effects and are well-suited for non-normal data and repeated measures [7, 31]. The model formula was $DV \sim condition + (1|Room) + (1|Object) + (1|Location) + (1|TrialNr) + (1|Pid)$, where DV represents the dependent variable. Analyses were conducted in R using lme4 [2]. We report conditional R^2 as R^2_c and marginal R^2 as R^2_m.

Table 3: GLMM results for fixation rate and mean fixation duration under different central-field loss conditions. Gamma family with identity link for fixation rate; inverse Gaussian family for mean fixation duration.

	Fixation Rate			Mean Fixation Duration		
CFL (deg)	**Est.**	**t**	**p**	**Est.**	**t**	**p**
0	25.93	19.78	< 0.001	0.16	18.77	< 0.001
4.3		0.45	0.650		−1.10	0.272
8.6		1.24	0.216		−0.97	0.335
12.9		3.03	0.003		−0.54	0.591
17.2		2.95	0.003		0.66	0.508
21.5		1.75	0.080		−1.28	0.200
25.8		4.52	< 0.001		0.70	0.485
30		3.04	0.002		−1.03	0.301
	$R^2_c = 0.69$, $R^2_m = 0.44$			$R^2_c = 0.08$, $R^2_m < 0.01$		

Table 4: GLMM results for saccade frequency and saccade amplitude under different central-field loss conditions. Gamma family with identity link for both models.

	Saccade Frequency			Saccade Amplitude		
CFL (deg)	**Est.**	**t**	**p**	**Est.**	**t**	**p**
0	2.60	32.08	< 0.001	25.93	13.55	< 0.001
4.3		−0.92	0.357		0.19	0.852
8.6		0.68	0.497		0.02	0.982
12.9		1.62	0.106		−1.83	0.067
17.2		−0.78	0.433		2.25	0.025
21.5		1.42	0.155		−4.89	< 0.001
25.8		−0.80	0.424		2.64	0.008
30		−2.31	0.021		−3.22	0.001
	$R^2_c = 0.34$, $R^2_m = 0.34$			$R^2_c = 0.79$, $R^2_m = 0.54$		

6 Discussion

This work involved semi-structured interviews with individuals living with AMD to better understand their visual experiences and assess the accuracy of existing visualizations. Participants described their vision as a blind spot rather than the darkened visualizations typically used, leading us to develop an AMD simulator in Unity. This simulator allows controlled adjustments of two parameters: central field loss and fading effect. Using this tool, we conducted a Latin square-balanced user study to evaluate the impact of central field loss on task performance and eye movements.

Our results indicate that there are differences in several eye movement characteristics when participants experience our simulation in different severities. Amongst these is saccade amplitude, which has been shown as a correlator in previous work with AMD patients [4, 28], as well as with simulated scotomas [14, 30]. These are attributed to inefficient saccadic eye movement (small forward saccades and often regressions) in previous work [28]. Fixation rate is another eye movement where we found significant differences when simulating AMD, which has been found in previous research with simulated scotomas [16]. Finally, we also found a significant increase in pupil diameter for all the conditions, including and above 17.2°. Pupil diameter is often associated with perceptual load, which we suspect to be the case in this study. Finding objects when your vision is obscured may be more demanding than when your vision is clear. We were unable to find studies with similar findings in AMD patients, which leads us to believe that this is an artifact from the simulation.

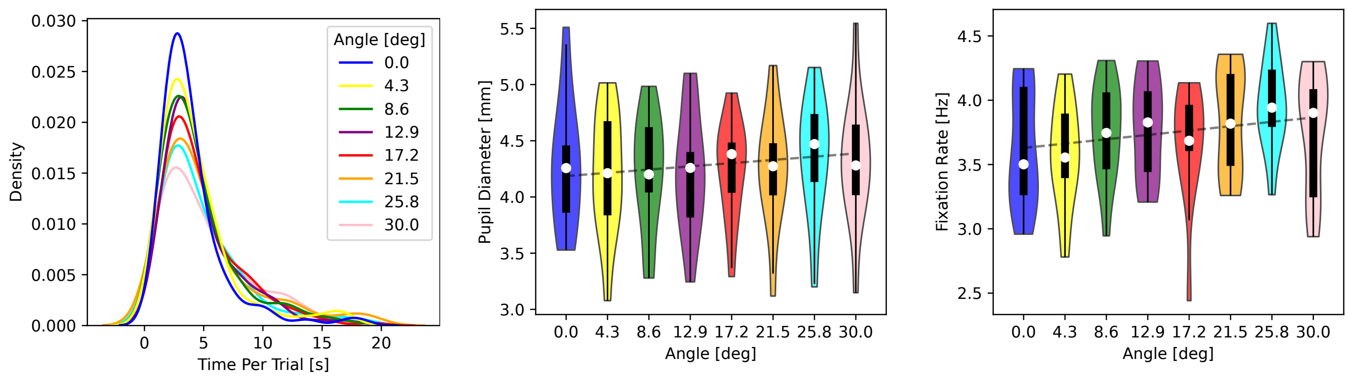
Future research should aim to enhance the AMD simulation by integrating additional variables, such as varied patterns of central vision loss, broadening the scope beyond the current visual search task, and including a larger sample size. Validating these simulations with AMD patients will be crucial to ensure their accuracy and relevance. Engaging directly with individuals affected by AMD will allow researchers to verify that the simulated visual impairments closely match their subjective experiences, increasing the realism and utility of the simulations.

7 Conclusion

Based on interviews with AMD patients, we systematically investigate how to implement an AMD simulation. In the following study, we used this simulation to simulate different severities of AMD in a realistic VR environment using a visual search paradigm. We have identified significant differences in eye movements and task performance between the control condition and several severities of the novel AMD simulation. Those affected by the more severe conditions of the AMD simulation took longer to complete the visual search task, had a higher fixation rate, and made smaller saccades and more frequent saccades.

8 Open Science

We encourage readers to reproduce and extend our results and analysis methods. Therefore, our simulation scripts, collected data, and analysis scripts are available at https://osf.io/5khxm/.



(a) (b) (c)

Figure 3: (a) Kernel Density Estimate of Time per Trial for each of the different central-field loss simulations. (b) Pupil diameter for each of the different central-field loss simulations. (c) Fixation rate for each central-field loss simulation.

Author Contributions

Jesse W. Grootjen: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **Sairam Narsimha Reddy Yadla**: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft; **Sven Mayer**: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing.

References

[1] Rajendra S. Apte. 2021. Age-Related Macular Degeneration. *New England Journal of Medicine* 385, 6 (Aug. 2021), 539–547. https://doi.org/10.1056/NEJMcp2102061

[2] Douglas Bates, Martin Mächler, Ben Bolker, and Steve Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* 67, 1 (2015), 1–48. https://doi.org/10.18637/jss.v067.i01

[3] Jaap A Beintema, Editha M van Loon, and Albert V van den Berg. 2005. Manipulating saccadic decision-rate distributions in visual search. *Journal of vision* 5, 3 (2005), 1–1. https://doi.org/10.1167/5.3.1

[4] Mark A Bullimore and Ian L Bailey. 1995. Reading and eye movements in age-related maculopathy. *Optometry and Vision Science* 72, 2 (1995), 125–138. https://doi.org/10.1097/00006324-199502000-00011

[5] Robyn Burton, Nicholas D Smith, and David P Crabb. 2014. Eye movements and reading in glaucoma: observations on patients with advanced visual field loss. *Graefe's Archive for Clinical and Experimental Ophthalmology* 252 (2014), 1621–1630. https://doi.org/10.1007/s00417-014-2752-x

[6] Aurélie Calabrèse, Jean-Baptiste Bernard, Géraldine Faure, Louis Hoffart, and Eric Castet. 2014. Eye movements and reading speed in macular disease: the shrinking perceptual span hypothesis requires and is supported by a mediation analysis. *Investigative ophthalmology & visual science* 55, 6 (2014), 3638–3645. https://doi.org/10.1167/iovs.13-13408

[7] Leen Catrysse, David Gijbels, Vincent Donche, Sven De Maeyer, Marije Lesterhuis, and Piet Van den Bossche. 2018. How are learning strategies reflected in the eyes? Combining results from self-reports and eye-tracking. *British Journal of Educational Psychology* 88, 1 (2018), 118–137. https://doi.org/10.1111/bjep.12181

[8] Viviane Clay, Peter König, and Sabine U. König. 2019. Eye tracking in virtual reality. *Journal of Eye Movement Research* 12, 1 (April 2019). https://doi.org/10.16910/jemr.12.1.3

[9] Michael D Crossland, Louise E Culham, and Gary S Rubin. 2004. Fixation stability and reading speed in patients with newly developed macular disease. *Ophthalmic and Physiological Optics* 24, 4 (2004), 327–333. https://doi.org/10.1111/j.1475-1313.2004.00213.x

[10] Louise E. Culham, Anthony Chabra, and Gary S. Rubin. 2004. Clinical performance of electronic, head-mounted, low-vision devices. *Ophthalmic and Physiological Optics* 24, 4 (2004), 281–290. https://doi.org/10.1111/j.1475-1313.2004.00193.x arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1475-1313.2004.00193.x

[11] Erwan David, Julia Beitner, and Melissa Le-Hoa Võ. 2020. Effects of Transient Loss of Vision on Head and Eye Movements during Visual Search in a Virtual Environment. *Brain Sciences* 10, 11 (2020), 26. https://doi.org/10.3390/brainsci10110841

[12] Andrew T Duchowski, Krzysztof Krejtz, Izabela Krejtz, Cezary Biele, Anna Niedzielska, Peter Kiefer, Martin Raubal, and Ioannis Giannopoulos. 2018. The index of pupillary activity: Measuring cognitive load vis-à-vis task difficulty with pupil oscillation. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–13.

[13] Ralf Engbert and Reinhold Kliegl. 2003. Microsaccades uncover the orientation of covert attention. *Vision research* 43, 9 (2003), 1035–1045. https://doi.org/10.1016/S0042-6989(03)00084-1

[14] Elisabeth M Fine and Gary S Rubin. 1999. Reading with simulated scotomas: attending to the right is better than attending to the left. *Vision Research* 39, 5 (1999), 1039–1048. https://doi.org/10.1016/S0042-6989(98)00208-9

[15] Donald C Fletcher, Ronald A Schuchard, and Laura Renninger. 2011. Patient awareness of binocular central visual field defects in age related macular degeneration (AMD). *Investigative Ophthalmology & Visual Science* 52, 14 (2011), 4236–4236.

[16] Franziska Geringswald, Anne Herbik, Michael B. Hoffmann, and Stefan Pollmann. 2013. Contextual Cueing Impairment in Patients with Age-Related Macular Degeneration. 13, 3 (2013), 28–28. https://doi.org/10.1167/13.3.28 arXiv:https://arvojournals.org/arvo/content_public/journal/jov/933551/i1534-7362-13-3-28.pdf

[17] Leslie Guadron, Samuel A Titchener, Carla J Abbott, Lauren N Ayton, John van Opstal, Matthew A Petoe, and Jeroen Goossens. 2023. The saccade main sequence in patients with retinitis pigmentosa and advanced age-related macular degeneration. *Investigative Ophthalmology & Visual Science* 64, 3 (2023), 1–1. https://doi.org/10.1167/iovs.64.3.1

[18] Thomas Haslwanter. 1995. Mathematics of three-dimensional eye rotations. *Vision Research* 35, 12 (1995), 1727–1739. https://doi.org/10.1016/0042-6989(94)00257-M

[19] Alex D. Hwang and Eli Peli. 2014. An Augmented-Reality Edge Enhancement Application for Google Glass. *Optometry and Vision Science* 91, 8 (Aug. 2014), 1021–1030. https://doi.org/10.1097/opx.0000000000000326

[20] J. Häkkilä, A. Colley, J. Väyrynen, and A.-J. Yliharju. 2018. Introducing Virtual Reality Technologies to Design Education. *Seminar. net* 14 (2018), 1–12.

[21] Pete R. Jones, Tamás Somoskeöy, Hugo Chow-Wing-Bom, and David P. Crabb. 2020. Seeing other perspectives: evaluating the use of virtual and augmented reality to simulate visual impairments (OpenVisSim). *npj Digital Medicine* 3, 1 (10 Mar 2020), 32. https://doi.org/10.1038/s41746-020-0242-6

[22] Daniel G. Krakowczyk, David R. Reich, Jakob Chwastek, Deborah N. Jakobi, Paul Prasse, Assunta Süss, Oleksii Turuta, Paweł Kasprowski, and Lena A. Jäger. 2023. Pymovements: A Python Package for Eye Movement Data Processing *(ETRA '23)*. ACM, New York, NY, USA, Article 53, 2 pages. https://doi.org/10.1145/3588015.3590134

[23] Arun Kumar Krishnan and Harold E. Bedell. 2018. Functional Changes at the Preferred Retinal Locus in Subjects with Bilateral Central Vision Loss. 256, 1 (2018), 29–37. https://doi.org/10.1007/s00417-017-3818-3

[24] Girish Kumar and Susana T. L. Chung. [n. d.]. Characteristics of Fixational Eye Movements in People with Macular Disease. 55, 8 ([n. d.]), 5125–5133. https://doi.org/10.1167/iovs.14-14608

arXiv:https://arvojournals.org/arvo/content_public/journal/iovs/932996/i1552-5783-55-8-5125.pdf

[25] Miyoung Kwon, Chaithanya Ramachandra, Premnandhini Satgunam, Bartlett W Mel, Eli Peli, and Bosco S Tjan. 2012. Contour enhancement benefits older adults with simulated central field loss. *Optom Vis Sci* 89, 9 (Sept. 2012), 1374–1384. https://doi.org/10.1097/OPX.0b013e3182678e52

[26] Christian Lehsing, Florian Ruch, Felix M. Kölsch, Georg N. Dyszak, Christian Haag, Ilja T. Feldstein, Steven W. Savage, and Alex R. Bowers. 2019. Effects of simulated mild vision loss on gaze, driving and interaction behaviors in pedestrian crossing situations. *Accident Analysis & Prevention* 125 (2019), 138–151. https://doi.org/10.1016/j.aap.2019.01.026

[27] Stefan Pollmann, Lisa Rosenblum, Stefanie Linnhoff, Eleonora Porracin, Franziska Geringswald, Anne Herbik, Katja Renner, and Michael B. Hoffmann. 2020. Preserved Contextual Cueing in Realistic Scenes in Patients with Age-Related Macular Degeneration. *Brain Sciences* 10, 12 (2020). https://doi.org/10.3390/brainsci10120941

[28] Gary S. Rubin and Mary Feely. 2009. The Role of Eye Movements During Reading in Patients with Age-Related Macular Degeneration (AMD). 33, 3 (2009), 120–126. https://doi.org/10.1080/01658100902998732

[29] Dario D Salvucci and Joseph H Goldberg. 2000. Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the 2000 symposium on Eye tracking research & applications*. 71–78. https://doi.org/10.1145/355017.355028

[30] Anne-Catherine Scherlen, Jean-Baptiste Bernard, Aurélie Calabrese, and Eric Castet. 2008. Page mode reading with simulated scotomas: Oculo-motor patterns. *Vision research* 48, 18 (2008), 1870–1878. https://doi.org/10.1016/j.visres.2008.06.005

[31] Breno B. Silva, David Orrego-Carmona, and Agnieszka Szarkowska. 2022. Using linear mixed models to analyze data from eye-tracking research on subtitling. *Translation Spaces* 11, 1 (2022), 60–88. https://doi.org/10.1075/ts.21013.sil

[32] Alexandra Sipatchin, Miguel García García, and Siegfried Wahl. 2022. Assistance for macular degeneration (MD): Different strategies for different augmentations. *Investigative Ophthalmology & Visual Science* 63, 7 (2022), 714–F0442.

[33] Alexandra Sipatchin, Miguel García García, and Siegfried Wahl. 2021. Target Maintenance in Gaming via Saliency Augmentation: An Early-Stage Scotoma Simulation Study Using Virtual Reality (VR). *Applied Sciences* 11, 15 (Aug. 2021), 7164. https://doi.org/10.3390/app11157164

[34] Hans Strasburger, Ingo Rentschler, and Martin Jüttner. 2011. Peripheral Vision and Pattern Recognition: A Review. 11, 5 (2011), 13–13. https://doi.org/10.1167/11.5.13

[35] AV Van den Berg and EM Van Loon. 2005. An invariant for timing of saccades during visual search. *Vision Research* 45, 12 (2005), 1543–1555. https://doi.org/10.1016/j.visres.2004.12.018

[36] Jani Väyrynen, Ashley Colley, and Jonna Häkkilä. 2016. Head mounted display design tool for simulating visual disabilities. In *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia*. Association for Computing Machinery, New York, NY, USA, 69–73. https://doi.org/10.1145/3012709.3012714

[37] Hrishikesh Vyawahare and Pranaykumar Shinde. 2022. Age-Related Macular Degeneration: Epidemiology, Pathophysiology, Diagnosis, and Treatment. *Cureus* (Sept. 2022). https://doi.org/10.7759/cureus.29583

[38] Joanne Wood, Alex Chaparro, Trent Carberry, and Byoung Sun Chu. 2010. Effect of simulated visual impairment on nighttime driving performance. *Optom Vis Sci* 87, 6 (June 2010), 379–386. https://doi.org/10.1097/OPX.0b013e3181d95b0d

[39] Joanne M. Wood and Rod Troutbeck. 1994. Effect of Visual Impairment on Driving. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 36, 3 (Sept. 1994), 476–487. https://doi.org/10.1177/001872089403600305