

# Toward a Virtual-Reality Diagnostic Suite for Cerebral Visual Impairment

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## Abstract

*This paper reports progress towards a novel system intended to diagnose Cerebral Visual Impairments, a class of conditions where the brain is unable to correctly process visual information. Designed for use in Virtual Reality, it hosts tests created to diagnose several distinct Cerebral Visual Impairments. The implementation reported here measures visual acuity, visual fields, visual inattention/neglect, and contrast sensitivity. This project is ongoing, with future efforts prioritizing validation and refinement.*

## Author Keywords

Virtual Reality; Cerebral Visual Impairments; Virtual Reality Diagnostic Tools

## 1. Background and Context

Cerebral Visual Impairments (CVIs) are a class of visual impairment resulting from brain damage or dysfunction affecting the parts of the brain associated with processing and understanding vision [1]. CVIs most commonly arise through complications before or during birth, however they can also be acquired later in life through stroke, head trauma, or degenerative brain disease [2].

In developed nations, CVI is the most common cause of visual impairment in children [3]. In adults, especially older adults, it can be then frequently acquired when a person has a stroke, with a prevalence of up to 70% in stroke survivors [4].

It is important for patients to be given an accurate diagnosis and be supported to understand the consequences of their condition in order to optimise both their care and their quality of life [5,6]. Some types of CVI can be partially rehabilitated [7], with a correct diagnosis essential to maximal rehabilitation.

Due to the number and diversity of possible Cerebral Visual Impairments, accurately diagnosing and distinguishing them can be challenging. This is compounded because the associated visual impairments can vary in severity and several distinct CVIs can exist simultaneously. There is no international standardised diagnostic process for CVI thus making particular diagnoses more difficult [6,8].

It is not completely new to propose to use VR headsets and tools to attempt to diagnose CVIs. Multiple tests have previously been implemented, such as cancellation tasks [9], a field of perception and regard test [10], and a navigation task [11], but all of these tests, and others, most often focus specifically on forms of visual neglect [12,13]. Following a thorough online search only a couple of other VR CVI diagnostic tools could be found. These included visual search tests for other Cerebral visual impairments [14] (including one that used a visual search task to diagnose an associated condition called Multisystemic Smooth Muscle Dysfunction Syndrome [15]),

The fact that all the above diagnostic tools primarily test for only one type of CVI (visual neglect) highlights the need for a more

comprehensive, adaptable, and precise diagnostic tool suite, in which many different CVIs may be diagnosed. This has driven the development of innovative solutions such as the *Virtual Reality CVI Diagnostic Suite* reported here.

## 2. Aim and Objectives

The *Virtual Reality Diagnostic Suite* aims to enhance and streamline the diagnostic process by offering a unified platform capable of hosting a diverse set of diagnostic tests. The aim is to provide a comprehensive, "one-stop-shop" test suite that can accommodate tests for a large number of forms of cerebral visual impairments. The suite is built off a large custom-made base framework, designed with continuous expansion and adaptability in mind, allowing for more tests to be added and the suite, as a whole, to be updated as clinical understanding of cerebral visual impairments evolves.

Creating this test suite in Virtual Reality (VR) gives the included tests several advantages over more traditional testing methods such as those found in high street optometry or routine clinical ophthalmology. A first significant advantage of implementing these tests in virtual reality is the ability to provide standardized tests in a controlled environment, where factors such as ambient light levels and background clutter can be eliminated, precisely controlled, standardized, made repeatable, and accounted for. The ability to identically reproduce the visual environment can be crucial as some cerebral visual impairments, such as simultanagnosia, are influenced by the user's surroundings. A second advantage is that the spatial positioning of each test can be locked in place relative to the orientation of the user's head. This feature eliminates the need for users to remain perfectly still, as is sometimes required by traditional non-VR tests, thereby improving comfort and accessibility as some brain disorders make this extremely difficult. A third advantage is the potential to carry out the tests in the comfortable and familiar environment of the patient's home; this is particularly relevant for patients who may be physically frail, have limited mobility, live remotely from an optometrist, are bed bound in hospital, or require repeated testing to track changing symptoms. A fourth advantage is the ability for earlier tests to inform and tailor the format and presentation of later tests, which can be important when a user has more than one cerebral visual impairment, as it offers the opportunity to minimize or avoid one symptom masking or adversely affecting the measurement of another symptom. This could avoid, for example, instances where you are attempting to test a person's visual acuity in a part of their visual field which they cannot see.

The most significant potential disadvantage of the VR approach is that it may not be suitable for all patients. Some patients may be uneasy or uncomfortable wearing the headset while others, in extreme cases, may be altogether unable to wear the headset. Despite the headset being adjustable this is still a disadvantage to be aware of in that there will likely always be those in the patient population for whom this system will never be practical.

In summary, CVI testing using VR has the potential to make the testing and the diagnosis faster, easier, more comfortable, more efficient, more reproducible and objective, and less resource intensive, for the vast majority of patients thus benefiting both clinician and patient.

### 3. Results

The Virtual Reality CVI Diagnostic Suite has currently been developed to the proof-of-concept stage.

The system is designed to operate on the Varjo XR-3 headset system which provides extremely high screen resolution (2880 x 2720 pixels per eye) [16] plus accurate, built-in eye-tracking, thus ensuring precise visual presentations and measurements necessary for diagnostic accuracy. While it has been designed initially for this headset, it is simple to adapt to other headsets of suitable capability and upgradable in future for more advanced headsets as VR technology continues to advance.

The test suite itself has been built using the Unity engine [17] and consists of a large custom underlying framework into which the set of individual tests is integrated and can be easily built upon. Patient interaction with the tests is achieved entirely using the integrated eye-tracking functionality, enabling intuitive and non-invasive data collection. As operation of the eye-tracking may not be feasible in all situations with all patients, alternative input methods (such as button presses) are available to address different accessibility needs, ensuring that all the tests can accommodate the widest possible range of patients' frailty and capabilities.

Four tests have already been developed at the proof-of-concept level.

1. **Visual Acuity Test:** Visual acuity is a measure of the level of fine detail that a person can perceive. To a person with a high visual acuity the world will appear sharper and well defined, compared to a person with a lower visual acuity to whom the world will appear fuzzier or blurrier. This test presents Landolt C symbols [18] to the user, with a focus on quick responses thus facilitating fast, efficient testing. A measure of the visual acuity of the individual is given using the LogMAR scale [19].
2. **Visual Field Test:** Visual fields are a measure of the extent of the world that a person can see. When that person has visual field impairments (attributable to CVI) they will not be able to see portions of their visual world. Stimuli are presented at specific locations within the virtual environment to evaluate and map out the user's visual fields.
3. **Visual Inattention/Neglect Test:** Visual attention is a measure of how much attention a person gives to one part of their field of vision. A person suffering from visual inattention may not immediately notice items in part of their field of vision and, in the more extreme case of visual neglect, can never become aware of the items. This test presents asymmetric stimuli to detect and quantify the level of inattention. A screenshot of this test can be seen in Figure 1, which shows a moment in time that is part way through the test when the user has already been flagged for potential inattention on their left side. In this screenshot the user is focussed on the central larger stimuli, and after a small, randomised delay the two smaller upper stimuli are allowed to slowly fade from the grey background colour to white. In

this case the stimuli on the left (the side with the potential inattention) will have been revealed first. The user as soon as they become aware of the upper stimuli should look at the first one they see, and this will be captured by the headset's integrated eye tracking. After each time the stimuli are presented, the amount of time between the stimuli in the side with potential inattention being presented compared to the favoured side will be adjusted in a deliberate attempt identify the threshold at which the user is equally as likely to look at the left or right stimuli despite their inattention. This threshold, which provides a measure of visual inattention, is found through use of the Psychtoolbox-3 Quest algorithm to help identify this threshold as quickly as possible [20–22].

4. **Contrast Sensitivity Test:** In order to assess the ability of an individual to differentiate between (similar) shades of grey, this test presents stimuli at different differential contrast levels on a background. The measure of contrast sensitivity is achieved by determining the point at which the user becomes aware of the stimulus as it "fades in" from different background shades.

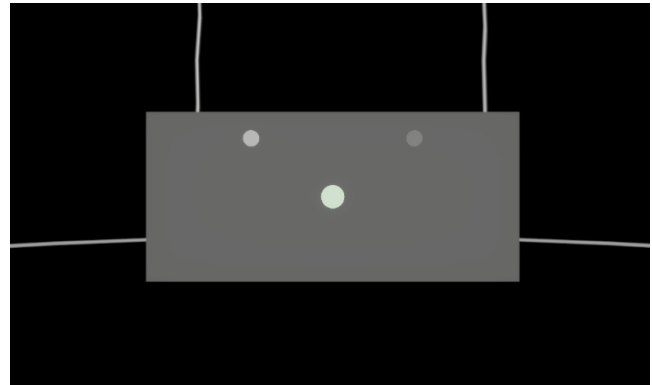


Figure 1: Screenshot of the Visual Inattention test

The multi-disciplinary team contributing to this research recognises the importance of learning about the needs and experiences of patients, the public and other stakeholders such as family, healthcare professionals, and clinicians. Thus, in the conception, and throughout the development, of the tests Patient and Public Involvement and Engagement (PPIE) [23] activity has been conducted to assess their views. Feedback on the experience of wearing the headset, plus the experience and understandability of taking the tests, has been gathered and utilized to inform the ongoing design of the testing suite.

In working towards assessing the viability and accuracy of the tests, we are currently part way through the process of obtaining medical ethical approval to run a study on the accuracy of the visual inattention test. This represents the first stage in determining the viability of the underlying framework and therefore overall test suite.

### 4. Impact

VR has recently been used more and more as a tool to measure and detect various different visual impairments, both ocular (such as glaucoma [24]) and cerebral. There are some reports in which teams have created virtual reality tools to target specific cerebral

visual impairments including visual neglect [9] and visual search [25]. But, to the best of the authors' knowledge, there is no existing system that contains a comprehensive suite of tests. Having multiple tests within the same diagnostic suite offers several advantages. A first advantage is that the diagnostic process becomes significantly more streamlined, as clinicians and patients need only interact with a single system, reducing setup time and complexity. A second is that multiple tests within one system allow results from earlier tests to dynamically influence the presentation of later ones. Furthermore, this can assist in isolating overlapping symptoms, thus improving the discrimination of the system in diagnosing multiple distinct conditions.

The tests are currently in the proof-of-concept stage. Nevertheless, they are already serving as a foundation for assessing their accuracy and reliability in upcoming studies.

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## 6. References

- Chokron S, Dutton GN. Impact of Cerebral Visual Impairments on Motor Skills: Implications for Developmental Coordination Disorders. *Front Psychol*. 2016 Oct 4;7:1471.
- McDowell N, Dutton GN. Hemianopia and Features of Bálint Syndrome following Occipital Lobe Hemorrhage: Identification and Patient Understanding Have Aided Functional Improvement Years after Onset. *Case Rep Ophthalmol Med*. 2019;2019:3864572.
- Lehman SS, Yin L, Chang MY, Section on Ophthalmology, Council on Children With Disabilities; American Association for Pediatric Ophthalmology and Strabismus, American Academy of Ophthalmology; American Association of Certified Orthoptists. Diagnosis and Care of Children With Cerebral/Cortical Visual Impairment: Clinical Report. *Pediatrics*. 2024 Nov 19;154[6]:e2024068465.
- Rowe FJ. The importance of accurate visual assessment after stroke. *Expert Rev Ophthalmol*. 2011 Apr;6[2]:133–6.
- Trauzettel-Klosinski S. Current Methods of Visual Rehabilitation. *Dtsch Arztebl Int*. 2011 Dec 26;108 [51–52]:871–8.
- Pilling RF, Allen L, Bowman R, Ravenscroft J, Saunders KJ, Williams C. Clinical assessment, investigation, diagnosis and initial management of cerebral visual impairment: a consensus practice guide. *Eye*. 2023 Jul;37[10]:1958–65.
- Perez C, Chokron S. Rehabilitation of homonymous hemianopia: insight into blindsight. *Front Integr Neurosci*. 2014;8:82.
- Dale N. Cerebral visual impairment-related vision problems in the classroom. *Dev Med Child Neurol*. 2021;63[6]:632–632.
- Knobel SEJ, Kaufmann BC, Gerber SM, Cazzoli D, Müri RM, Nyffeler T, et al. Immersive 3D Virtual Reality Cancellation Task for Visual Neglect Assessment: A Pilot Study. *Front Hum Neurosci*. 2020 May 25;14.
- Kim TL, Kim K, Choi C, Lee JY, Shin JH. FOPR test: a virtual reality-based technique to assess field of perception and field of regard in hemispatial neglect. *J NeuroEngineering Rehabil*. 2021 Feb 18;18[1]:39.
- Morganti F, Gaggioli A, Rusconi ML, Cantagallo A, Mondin E, Riva G. Virtual reality contexts for the situated assessment of spatial neglect. *Cyberpsychol Behav*. 2006 Dec 1;9:703–4.
- Ansuini C, Pierno AC, Lusher D, Castiello U. Virtual reality applications for the remapping of space in neglect patients. *Restor Neurol Neurosci*. 2006;24[4–6]:431–41.
- Sauvage C, Chaulet P, Lopez LR, Garbusinski J, Cabaraux P, Duvigneaud Z, et al. Immersive Virtual Reality to Assess Unilateral Spatial Neglect in Stroke Patients: a Preliminary Study. *J Rehabil Med*. 2025 Jan 3;57:41195.
- Manley CE, Bennett CR, Merabet LB. Assessing Higher-Order Visual Processing in Cerebral Visual Impairment Using Naturalistic Virtual-Reality-Based Visual Search Tasks. *Children*. 2022 Jul 26;9[8]:1114.
- Tambala D, Da Cruz E, Lynch A, Manley C, Bambery M, Kelly D, et al. Abstract WP223: Cerebral Visual Impairment in ACTA2 Patients Assessed by Virtual Reality Testing. *Stroke*. 2024 Feb;55[Suppl\_1]:AWP223–AWP223.
- Varjo Technologies. Varjo XR-3 - The industry's highest resolution XR headset | Varjo [Internet]. *Varjo.com*. 2024 [cited 2024 Dec 10]. Available from: <https://varjo.com/products/xr-3/>
- Unity [Internet]. [cited 2024 Dec 20]. Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine. Available from: <https://unity.com>
- Recommended standard procedures for the clinical measurement and specification of visual acuity. Report of working group 39. Committee on vision. Assembly of Behavioral and Social Sciences, National Research Council, National Academy of Sciences, Washington, D.C. *Adv Ophthalmol*. 1980;41:103–48.
- Bailey IL, Lovie JE. New Design Principles for Visual Acuity Letter Charts. *Optom Vis Sci*. 1976 Nov;53[11]:740–5.
- Brainard DH. The Psychophysics Toolbox. *Spat Vis*. 1997;10[4]:433–6.
- Pelli DG. The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spat Vis*. 1997;10[4]:437–42.
- Kleiner M, Brainard DH, Pelli D, Ingling A, Murray R, Broussard C. What's new in Psychtoolbox-3. *Perception*. 2007 Jan 1;36:1–16.
- Ede J, Clarete M, Taylor I, Taylor C, Kent B, Watkinson P, et al. Patient and public involvement and engagement (PPIE) in research: The Golden Thread. *Nurs Crit Care*. 2024;29[1]:10–3.

24. Shetty V, Sankhe P, Haldipurkar SS, Haldipurkar T, Dhamankar R, Kashelkar P, et al. Diagnostic Performance of the PalmScan VF2000 Virtual Reality Visual Field Analyzer for Identification and Classification of Glaucoma. *J Ophthalmic Vis Res.* 2022 Jan 21;17[1]:33–41.
25. Figueroa JCM, Arellano RAB, Calinisan JME. A Comparative Study of Virtual Reality and 2D Display Methods in Visual Search in Real Scenes. In: Cassenti DN, editor. *Advances in Human Factors in Simulation and Modeling (AHFE 2017)*. Cham: Springer International Publishing Ag; 2018. p. 366–77. [Advances in Intelligent Systems and Computing; vol. 591].